Port of Gladstone
Gatcombe and Golding Cutting
Channel Duplication Project

Environmental Impact Statement

Appendix K2
Underwater Noise Impact Assessment

PORT OF GLADSTONE GATCOMBE AND GOLDING CUTTING CHANNEL DUPLICATION PROJECT

Underwater Noise Impact Assessment

Prepared for:

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BASIS OF REPORT

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EXECUTIVE SUMMARY

The Port of Gladstone is a deep water natural port located on the Central Queensland coast approximately 525km north of Brisbane and 100km south of Rockhampton. The Port of Gladstone is located within Port Curtis and is bounded by the mainland to the west and south, Facing Island to the east and The Narrows and Curtis Island to the north.

Gladstone Ports Corporation Limited (GPC), as the governing port authority of the Port of Gladstone, proposes to duplicate the existing Gatcombe and Golding Cutting Channels, providing a two-way passage from the open coastal waters, around East Banks, to the western side of Facing Island (the Project). The proposed Channel Duplication area to be dredged is located west of the existing Gatcombe and Golding Cutting Channels. The total length of the proposed duplicate channel is approximately 15km.

This report provides an assessment of underwater noise impacts associated with the construction and operational phases of the Project. The assessment process involves the identification of noise sensitive marine fauna species potentially occurring within the Project area and their assessment criteria, characterisation of existing underwater noise environment based on baseline noise monitoring at representative locations, the identification of major noise sources and their noise emission characteristics, detailed modelling prediction of underwater noise propagations, the assessment of consequent impacts and relevant monitoring and mitigation measures to be implemented.

A number of marine fauna species of environmental significance, including megafauna species (i.e. whales, dolphins and dugongs), marine turtles and other fish species (e.g. Great white shark, Green sawfish etc.) occurring or potentially occurring in proximity to the project area have been identified. The noise impact criteria in terms of physiological and behavioural impacts for these marine fauna species have also been established via a review of the most relevant guidelines or literature.

The long term baseline underwater noise monitoring demonstrates that within the inner harbour area, anthropogenic noises associated with marine operations are the prevailing sources, dominating the low-frequency component below a few kilohertz (kHz). Biological noise, particularly noise from snapping shrimp, is another major noise source covering the mid to high frequency ranges from a few kHz up to 10kHz. The outer harbour area, however, has much lower baseline noise environment which strongly correlates with weather and sea-state variations, and with dominant frequency components ranging approximately from 100 hertz (Hz) to 2 kHz.

The detailed noise modelling prediction and assessment results show that impact piling events during the installation of the navigation aids are predicted to result in the highest noise impacts on the assessed marine fauna species, due to the high piling source noise emissions and the impulsive characteristics of piling noise. Piling noise is predicted to potentially cause physical injuries for marine fauna species in close proximity to the piling location. Due to their relatively low noise emissions, the non-impulsive characteristics, and relatively higher baseline underwater noise environment within the inner harbour area, other development activities such as vibratory sheet pile installation, rock dumping, dredging and barge noise are unlikely to result in significant adverse underwater noise impacts to assessed marine fauna species.

The acoustic monitoring and relevant mitigation measures will be implemented to minimise the piling noise impact on assessed marine fauna species.

Acronyms and Abbreviations

The acronyms below are commonly applied throughout this report, a glossary of acoustic terminology is provided in **Appendix A**.

Acronym	Definition
AHD	Australian Height Datum
BUF	barge unloading facility
cm	Centimetre (s)
CSD	cutter suction dredger
dB	decibel
DC	direct current
DEHP	Department of Environment and Heritage Protection
DEM	Digital Elevation Model
DES	Department of Environment and Science
DMPA	dredged material placement area
DTMR	Department of Transport and Main Roads
EIS	Environmental Impact Statement
EP Act	*Environmental Protection Act 1994* (Qld)
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Cth)
GBRMPA	Great Barrier Reef Marine Park Authority
GBRWHA	Great Barrier Reef World Heritage Area
GPC	Gladstone Ports Corporation Limited
GSDA	Gladstone State Development Area
HAT	highest astronomical tide
Hz	hertz
kg	kilogram
kHz	kilohertz
km	kilometre(s)
kNm	kilonewton meter
kW	kilowatt
LAT	lowest astronomical tide
LCD	liquid-crystal display
LNG	liquefied natural gas
M	metre
MNES	Matters of National Environmental Significance

Acronym	Definition
µPa	micropascal
MSQ	Maritime Safety Queensland
ML	Mining Lease
PSD	power spectral density
PTS	permanent hearing threshold shift
PVC	polyvinyl chloride
QER	Queensland Energy Resources
RGTCT	RG Tanna Coal Terminal
RL	received level
RMS	root-mean-square
SDPWO Act	*State Development and Public Works Organisation Act 1971* (Qld)
SEL	sound exposure level
SF	scale factor
SL	source level
SM3M	Song Meter SM3 Marine
SPL	sound pressure level
TL	transmission loss
ToR	terms of reference
TSHD	trailing suction hopper dredger
TTS	temporary hearing threshold shift
V DC	Voltage in direct current
WAC	WAV Compressed
WB	Western Basin
WBDDP	Western Basin Dredging and Disposal Project
WBE	Western Basin Expansion

CONTENTS

CONTENTS

CONTENTS

DOCUMENT REFERENCES

TABLES

FIGURES

CONTENTS

APPENDICES

1 Introduction

1.1 Port of Gladstone Channel Duplication Project

The Port of Gladstone is a deep water natural port located on the Central Queensland coast approximately 525km north of Brisbane and 100km south of Rockhampton. The Port of Gladstone is located within Port Curtis and is bounded by the mainland to the west and south, Facing Island to the east and The Narrows and Curtis Island to the north.

Gladstone Ports Corporation Limited (GPC), as the governing port authority of the Port of Gladstone, proposes to duplicate the existing Gatcombe and Golding Cutting Channels, providing a two-way passage from the open coastal waters, around East Banks, to the western side of Facing Island (the Project).

The proposed Channel Duplication area to be dredged is predominantly located west of the existing Gatcombe and Golding Cutting Channels. The total length of the proposed duplicate channel is approximately 15km.

The key features of the Project include:

- Establishing bund walls for the Western Basin Expansion (WBE) reclamation area;
- Construction of a barge unloading facility (BUF) adjacent to the existing Western Basin (WB) reclamation area;
- Initial dredging works of approximately 0.25 Mm^3 of seabed material to establish an access channel to -7m lowest astronomical tide (LAT) to allow barges to transport dredged material from the Gatcombe and Golding Cutting shipping channels to the BUF;
- Dredging approximately 12.6Mm^3 of seabed material with a trailing suction hopper dredger (TSHD) to permanently duplicate the Gatcombe and Golding Cutting Channels;
- The proposed dredging methodology involves utilising a TSHD which loads the dredged material from the Gatcombe and Golding Cutting shipping channels into barges (four barges will be working in cycles for the entire dredging operations) which will transport the material to the BUF to be unloaded using large excavators into trucks for placement within the existing WB and WBE reclamation areas;
- Provision of services to the Project activities;
- Removal, relocation and installation of new navigation aids;
- Demobilisation of dredging operation; and
- Project operational phase activities, including:
  - Reclaimed land surface stabilisation and operational management;
  - Final land uses on reclaimed land and future wharf usage of the BUF;
  - Maritime operation within duplicated channels; and
  - Maintenance dredging within duplicated channels and barge access channel.

The general extent of the existing Gatcombe and Golding Cutting shipping channels, the proposed channel duplication, the barge access channel, BUF and WBE reclamation area are shown in **Figure 1**.

The key stages and activities associated with the Project are discussed in further detail in **Section 2** of this report.

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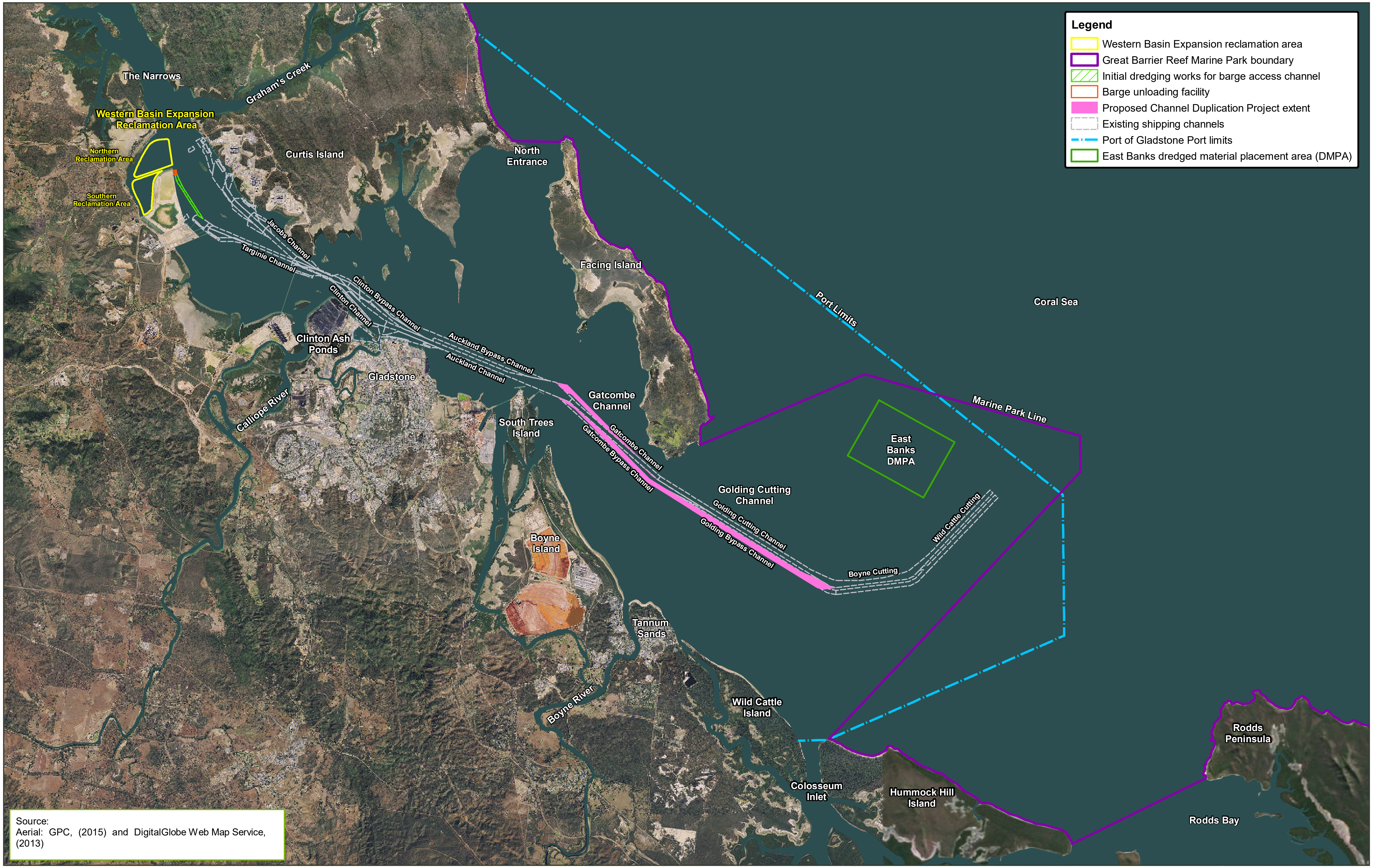

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Coordinate system: GDA_1994_MGA_Zone_56

Gatcombe and Golding Cutting Channel Duplication Project

Figure 1: Existing maintained shipping channels within the Port of Gladstone

1.2 Environmental Impact Statement

The Queensland Coordinator-General has declared the Project as a 'coordinated project' under the *State Development and Public Works Organisation Act 1971* (Qld) (SDPWO Act). The declaration initiated the statutory environmental impact assessment procedure of Part 4 of the SDPWO Act, which requires the preparation of an Environmental Impact Statement (EIS). The Project was also determined to be a 'controlled action' requiring an EIS under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act).

The EIS is required to provide an assessment of potential impacts to environmental values and detail the environmental protection and mitigation measures incorporated in the planning, construction and delivery of the Project.

The Queensland Coordinator-General has issued the Terms of Reference (ToR) for the EIS, and the Commonwealth Minister for the Environment has issued the EIS Guidelines for the Project which advises the content and format for the EIS, the legislation and regulatory guidelines relevant to the Project and the environmental values to be assessed.

The EIS Guidelines do not contain specific underwater noise assessment requirements; however the potential underwater noise impacts on the Matters of National Environmental Significance (MNES) (Australian Government, 2013) and the Great Barrier Reef World Heritage Area (GBRWHA) values have been addressed in the EIS outside the scope of this report.

The ToR requirements for potential noise impacts are primarily focused on the terrestrial environment but have been broadly applied in this assessment of potential noise impacts to aquatic fauna, as summarised in **Table 1**.

Table 1 Terms of Reference – Underwater Noise

ToR Section	Requirement	Addressed in this Report
5.8.1	Description of environmental values	Section 3
	Describe existing noise environment	Section 5
	Identify sensitive receptors (species of aquatic fauna)	Section 4
	Nominate performance indicators and standards	Section 4
5.8.2	Potential impacts and mitigation measures	Sections 7 and 8
	Describe the impacts of underwater noise generated during each phase of the Project	Section 2

1.3 Assessment of Underwater Noise Impacts - Methodology

The ToR requires the EIS to consider the potential noise impacts of the Project on aquatic fauna.

There is no national legislation or regulatory guidelines in Australia for the assessment of noise impacts to aquatic fauna. Until recently, the Great Barrier Reef Marine Park Authority (GBRMPA) has released a discussion and options paper (McPherson et al, 2017) in relation to underwater noise guideline development. The purpose of the paper, however, is to inform the process of developing an underwater noise guideline, rather than to set out the guideline itself, for considering and managing the impacts of anthropogenic underwater noise on the Great Barrier Reef's marine fauna specifically.

The assessment therefore has been undertaken with consideration of current best practice applied internationally, consistent with other similar major development projects around Australia, in relation to the comprehensive assessment methodology which comprises a number of components as detailed in the report structure below.

- **Section 2** provides an overview of the Project and the associated activities;
- **Section 3** discusses the environmental values to be met by the Project;
- **Section 4** identifies the aquatic fauna potentially sensitive to noise levels from the Project, and the assessment criteria derived from the relevant guidelines and similar studies;
- **Section 5** details the characterisation of the existing acoustic environment, based on the monitoring of existing underwater noise levels within the local environment, as well as in-depth temporal and spectral analysis of the noise data;
- **Section 6** provides the methodologies applied in the prediction of potential underwater noise levels and the estimated zones of impacts upon aquatic fauna for major noise generating activities associated with the construction of the BUF, WBE reclamation area bund walls, dredging activities, navigation aid installation, the operational phase of the reclamation area, and maintenance dredging;
- **Sections 7** details the assessment of potential underwater noise impacts on aquatic fauna during the construction and operation of the Project, as well as the implication of the baseline noise environment in relation to the noise impacts;
- **Section 8** details the measures to be implemented to mitigate potential noise impacts on aquatic fauna.

Supplemental assessment information is contained within the Appendices, including an explanation of commonly used acoustic terms in **Appendix A**.

2 Project Description

A detailed Project description is provided in the Port of Gladstone Gatcombe and Golding Cutting Channel Duplication Project EIS. A summary of the key Project stages applied in the assessment of underwater noise impacts is provided below.

2.1 Barge Unloading Facility

The construction of a BUF is required to allow for dredged material from the Gatcombe and Golding Cutting shipping channels to be unloaded. Dredged material will be loaded onto barges which will transport the material to the BUF to be unloaded using large excavators into trucks for placement within the existing WB and WBE reclamation areas.

The construction of the BUF will involve the installation of sheet piles or similar earth retaining structure to form a 'U shaped' barge dock adjacent to the existing WB reclamation area (refer **Figure 1**). Two short rock bunds comprising core material and protected with armour sourced from the Targinnie/Yarwun quarry location will be installed between the sheet pile or similar earth retaining structure dock and the existing WB reclamation area bund wall. The footprint within the enclosed sheet pile structure will be filled with material to allow excavators (i.e. six in total with three each side of the dock) and trucks (in the order of 32 trucks) to transport dredged material from the barges into the existing WB and WBE reclamation areas.

The construction of the BUF will take approximately 12 months and will be constructed as part of the reclamation bund wall construction program. The sheet piling works required for the BUF construction will be 2 to 3 months in duration.

2.2 Initial dredging works

Initial dredging works of approximately 0.25 Mm^3 of seabed material is required prior to dredging works associated with the Gatcombe and Golding Cutting Channels to establish an access channel to allow barges to access the BUF (refer **Figure 1**). The initial dredging works will be 6.5 weeks in duration.

A small cutter suction dredger (CSD) and a TSHD are proposed for the barge access channel dredging works. The CSD is a hydraulic dredger which operates by swinging about a central spud using anchors and winches. The CSD clears an arc of cut by winching on alternative sides and moving forward by pushing against the central spud.

The principal sources of noise for the CSD would be the mechanical plant on the main deck which power the dredging plant, the hydraulics and provide suction and pumping to transfer the dredged material.

The TSHD is described in Section 3.4.

2.3 Western Basin Expansion Reclamation Area

The WBE reclamation area will require the construction works summarised below to establish the northern and southern reclamation areas.

The outer seaward bund walls of the reclamation areas will be constructed of rock sourced from the Yarwun/Targinnie quarry area located off Landing Road at Targinnie. The rock armour material will be transported by haul truck on the existing road network to the WBE reclamation area where it will be installed by construction plant to create the footprint of the reclamation area.

The bund walls will be topped off with earth material to bring the walls to the final design levels (i.e. minimum +7m lowest astronomical tide (LAT)). Once complete a geotextile will be placed on the inner face of the outer bund walls to minimise migration of dredged material fines through the bund wall. An example cross section of the concept bund wall, armour, core and geotextile construction is shown in **Figure 2**.

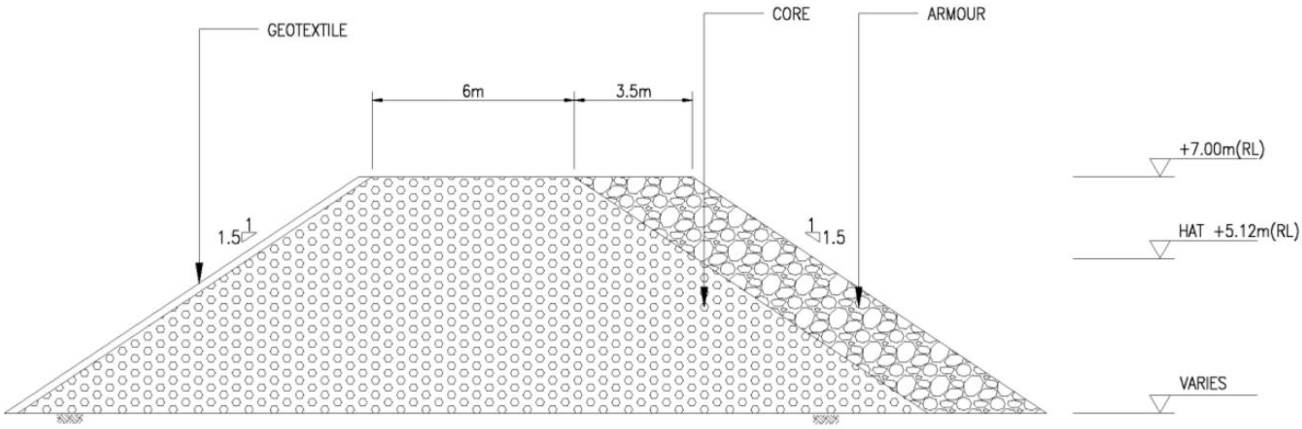

Figure 2 Western Basin Expansion Typical Bund Wall Cross Section

The dredged material will be transported into the existing WB and proposed WBE reclamation areas (i.e. northern and southern reclamation areas) and spread into primary internal cells to be filled out in turn. A secondary cell and final polishing cell will be utilised to ensure the decant water flow and facilitate discrete settling of suspended particles.

2.4 Dredging of the Gatcombe and Golding Cutting Shipping Channels

The existing Gatcombe and Golding Cutting shipping channel will be dredged to provide a permanent duplicated channel parallel to the main shipping channel (Channel Duplication). The proposed duplicate channel will be approximately 15km long and dredging is proposed to be undertaken to an ultimate depth of -16.1m LAT, with a channel width of 200m. The channel will be of sufficient depth to allow an improved two-way passage into the Port under all weather and tidal conditions.

Two dredging campaign options are proposed and will be selected upon predicted throughput and associated vessel movements. At this stage it is envisaged that the Project dredging will be undertaken over two stages. However, should the need and/or growth for Port trade justify the need for the final design channel depth, the two stages will be combined into a singular campaign. Stage 1 is proposed to commence in 2023 or later with a duration of 33 weeks and with dredging to a depth of -13.5 m LAT. Stage 2 would follow in 2026 or later and be a further 25 weeks of dredging, resulting in an ultimate dredging depth of -16.1 m LAT. It is expected that combining Stage 1 and Stage 2 would result in a 58 week dredging campaign.

The proposed Stage 1 and Stage 2 dredging areas are shown in **Figure 3** and **Figure 4**.

A number of dredging equipment and methodology options were investigated as part of the EIS. The feasibility study identified that the TSHD is the preferred dredger for undertaking the Channel Duplication dredging. The dredged material from the TSHD would be pumped into non-motorised barges. The barges will be propelled by pushbusters to the BUF where the barges will be unloaded using excavators. The dredged material will be placed into haulage trucks which will take the material to the WB and WBE reclamation areas for placement.

The TSHD is a self-propelled, highly manoeuvrable vessel which navigates pre-planned tracks with the drag arms lowered onto the sea floor. The dredged material is loaded into a hopper, contained within the ship structure, which separates the dredged material and returns the low density mixture back into the sea (overflow). The Project dredging methodology involves utilising a TSHD which loads the dredged material from the Channel Duplication area to be dredged into barges (four barges will be working in cycles for the entire dredging operations) which will transport the material to the BUF to unloaded using large excavators into trucks for placement with the WB and WBE reclamation areas.

The TSHD has the capacity to operate 24 hours a day, 7 days a week using multiple crews which are accommodated on board. At fortnightly intervals the TSHD would cease operations and berth for up to 24 hours to facilitate crew changes, bunkering and provisioning.

The principal sources of noise for the TSHD would be the mechanical plant on the main deck which power the dredging plant, the hydraulics and provide suction and pumping to transfer the dredged material.

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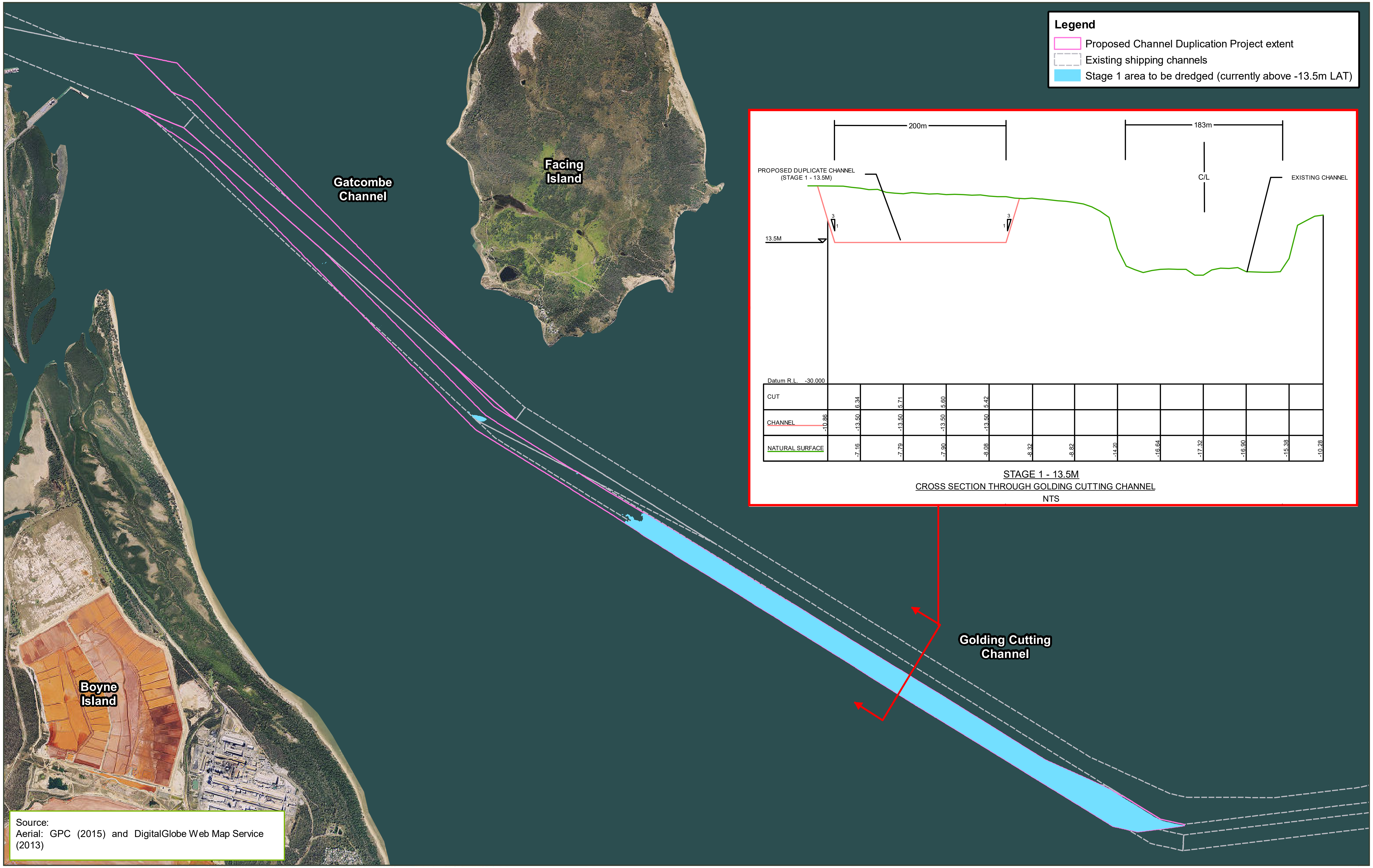

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Coordinate system: GDA_1994_MGA_Zone_56

Gatcombe and Golding Cutting Channel Duplication Project

Figure 3: Proposed area to be dredged - Stage 1 (-13.5m LAT)

2.5 Navigational Aids

For safe passage within the Gatcombe and Golding Cutting Channels, the Project will require two of the existing navigational aids in the channel to be removed, five navigational aids to be relocated and a further five new navigational aids installed. The relocation and installation of the navigational aids will be undertaken by a pile extractor and piling hammer located on a barge. The pile will be moved into a vertical position by crane then the pile hammer will be attached to the head of the pile. Using small hammer drops to ensure the penetration is vertical the pile will be driven to the design depth. The pile will be prepared, protection material applied underwater and the batteries, solar panels and specified lights installed.

Piling activities using an impact hammer for the installation of new navigation aids are the major underwater noise sources during this process.

2.6 Other Construction Activities

The Project will also require the establishment of a construction compound and the construction of internal stormwater ponds at the WBE reclamation area along with the daily mobilisation of the workforce. The temporary construction works are not expected to be noise intensive activities, and potential noise and vibration levels are not expected to result in impacts within the underwater environment. Consequently, a detailed assessment of underwater noise and vibration has been deemed to not be necessary for those other construction activities.

2.7 Maintenance Dredging

Maintenance dredging will generally be required annually for the Gatcombe and Golding Cutting duplicated channels, and the barge access channel following the Project dredging works as the sediments stabilise. Based on previous maintenance dredging in the Port of Gladstone, maintenance dredging requirements are unlikely to be significant and will be restricted to batter slipping and siltation at the toe of dredged areas.

Analysis of the sediment dynamics modelling results indicates that the overall net annualised siltation rate within the shipping channels of the Port is likely to increase by approximately 7% following the completion of the Project.

Based on the previous maintenance dredging for the existing channels, the use of a TSHD is likely to be the preferred maintenance dredging methodology. The Port-wide maintenance dredging campaign, including the Channel Duplication project areas to be dredged, would place material within the existing East Banks dredged material placement area (DMPA) (until full capacity is achieved). The Port-wide maintenance dredging campaign would typically be 4 to 6 weeks per year.

2.8 Project Schedule

An overview of the Project timeframe and the anticipated hours of work are provided below.

- The transport of bund wall material and the construction of the WBE reclamation area (southern and northern areas) would be completed over an 18 month period per area (36 months in total) and is expected to be undertaken Monday to Saturday during daytime construction hours of 6.30 am to 6.30 pm.

- The construction of the BUF is expected to be conducted over a 12-month period from Monday to Saturday during daytime construction hours of 6.30 am to 6.30 pm. Although the construction of the BUF may take approximately 12 months, the actual period of sheet pile driving or similar earth retaining structure construction is likely to be about 2 to 3 months. The BUF will be constructed simultaneously with the construction of the WBE reclamation area.
- The initial dredging of the barge access channel will be undertaken over a 6.5 week period prior to the Channel Duplication dredging.
- All Project dredging of the duplicate channels and barge operations, including unloading and placement of dredged material, is expected to be undertaken over two dredging campaigns, with the first dredging campaign lasting approximately 33 weeks, and the second dredging campaign lasting approximately 25 weeks. If the dredging is undertaken over a single campaign the total timeframe is expected to be 58 weeks. The dredging activity will generally occur 24 hours per day for 7 days a week, with dredgers ceasing operation for crew changes, bunkering and provisioning.
- The placement of the dredged material within the WB and WBE reclamation areas will generally be 24 hours per day for 7 days a week throughout the dredging campaign program, with dredgers and associated barges and pushbusters ceasing operation for crew changes, bunkering and provisioning.
- The removal, relocation and new navigational aids will be installed Monday to Saturday during standard daytime construction hours of 6.30 am to 6.30 pm.

3 Environmental Values

The noise assessment has considered the potential impacts to marine mammal species, marine turtles and other fish species as listed in Section **4.1**.

This assessment has considered that the key environmental values relevant to aquatic fauna are maintaining an environment that is conducive to the health and wellbeing of aquatic fauna, with particular consideration of:

- Behavioural responses such as vocalisation, resting, diving and breathing patterns, mother-infant relationships and specific behaviour changes to avoid underwater noise sources; and
- Physiological effects associated with the auditory system which could temporarily or permanently affect hearing as well as non-auditory physiological effects to the vestibular system, reproductive system, nervous system, liver or organs with high levels of dissolved gas concentrations and gas filled spaces.

4 Marine Fauna and Underwater Noise

4.1 Significant Marine Fauna Species within the Project Area

A number of marine fauna species of environmental significance occurring or potentially occurring in proximity to the Project area have been identified, with reference to marine ecology information collated as part of the Project EIS. **Table 2** lists each of these species, their conservation status with respect to State (*Nature Conservation Act 1992* (NC Act)) and National (EPBC Act)) legislation, and their likelihood of occurrence within the Project area.

The Port of Gladstone and its adjoining waterways and offshore open waters support a range of megafauna species, including whales, dolphins and dugongs. Analysis of environmental databases suggests that eight whale species and ten dolphin species may be present in offshore waters. Of the eight whale species, humpback whales are known to be seasonally present in close proximity to Port Gladstone. Five of the ten coastal dolphin species (i.e. Common dolphin, Australian humpback dolphin, Spinner dolphin, Indian Ocean bottlenose dolphin and the Coastal bottlenose dolphin) are frequently encountered in the vicinity of the Project area and/or off the coast of Facing Island.

Dugong habitats within the Port generally correspond to the distribution of shallow water seagrasses. Research into the spatial patterns of abundance and temporal trends in dugong populations in the Gladstone area has been undertaken by Sobtzick et al. (2013). Details of this study and other research programs (e.g. *Ecosystem Research and Monitoring Program Project CA14000187, Dugong Feeding Ecology and Habitat Use on Intertidal Banks of Port Curtis and Rodds Bay* (ERMP) and dugong satellite-tracking surveys (Cleguer et al. 2015a; Cleguer et al. 2015b)) are provided in the Project EIS Ecology Technical Report (Aurecon 2019).

Australia has resident or migratory populations of six of the world's seven species of marine turtle, as listed in **Table 2** and all six species occur within the Great Barrier Reef World Heritage Area (GBRWHA). Previous studies have confirmed that Port Curtis and its adjacent regions, including the Port support populations of Green, Loggerhead, Flatback and Hawksbill turtles, while other species such as Olive ridleys and Leatherback turtles are known to occur in the GBRWHA but are seldom seen near the Port of Gladstone. Details on the marine ecological values within the Port of Gladstone are included in the Project EIS Ecology Technical Report (Aurecon 2019).

The Project area and adjacent regions also support a variety of fish species, many of which are significant for their Indigenous, recreational and commercial values. Several of these fish species are of conservation significance, including Great white shark and Green sawfish.

Table 2 Conservation Significant and Migratory Marine Fauna Species that Potentially Occur within the Project Area

Marine Fauna Species	Scientific Name	Conservation Status		Likelihood of Occurrence in the Project Area
		EPBC Act	**NC Act**	
Megafauna (Marine Mammals)				
Humpback whale	*Megaptera novaeangliae*	Vulnerable Migratory	Vulnerable	Confirmed

<table>
<tr><th>Marine Fauna Species</th><th>Scientific Name</th><th colspan="2">Conservation Status</th><th>Likelihood of Occurrence in the Project Area</th></tr>
<tr><td>Southern right whale</td><td>Eubalaena australis</td><td>Endangered
Migratory</td><td rowspan="6">Least Concern</td><td rowspan="7">Low</td></tr>
<tr><td>Bryde's whale</td><td>Balaenoptera edeni</td><td>Migratory</td></tr>
<tr><td>Blue whale</td><td>Balaenoptera musculus</td><td>Endangered
Migratory</td></tr>
<tr><td>Sei whale</td><td>Balaenoptera borealis</td><td>Vulnerable
Migratory</td></tr>
<tr><td>Sperm whale</td><td>Physeter macrocephalus</td><td rowspan="5">Migratory</td></tr>
<tr><td>Killer whale</td><td>Orcinus orca</td></tr>
<tr><td>Australia snubfin dolphin</td><td>Orcaella heinsohni</td><td rowspan="3">Vulnerable</td></tr>
<tr><td>Australian humpback dolphin</td><td>Sousa sahulensis</td><td rowspan="2">Confirmed</td></tr>
<tr><td>Dugong</td><td>Dugong dugon</td></tr>
<tr><td colspan="5">Marine Turtles</td></tr>
<tr><td>Flatback turtle</td><td>Natator depressus</td><td rowspan="2">Vulnerable</td><td rowspan="2">Vulnerable</td><td rowspan="2">Confirmed</td></tr>
<tr><td>Green turtle</td><td>Chelonia mydas</td></tr>
<tr><td>Loggerhead turtle</td><td>Caretta caretta</td><td rowspan="4">Endangered
Migratory</td><td rowspan="4">Endangered</td><td rowspan="2">Moderate</td></tr>
<tr><td>Hawksbill turtle</td><td>Eretmochelys imbricate</td></tr>
<tr><td>Olive Ridley turtle</td><td>Lepidochelys olivacea</td><td rowspan="2">Low</td></tr>
<tr><td>Leatherback turtle</td><td>Dermochelys olivacea</td></tr>
<tr><td colspan="5">Fish, sharks and rays</td></tr>
<tr><td>Estuary stingray</td><td>Dasyatis fluviorum-</td><td>-</td><td>Near threatened</td><td>Moderate</td></tr>
<tr><td>Giant manta ray</td><td>Manta biorostris</td><td>Migratory</td><td>Least Concern</td><td>Moderate</td></tr>
<tr><td>Great white shark</td><td>Carcharodon carcharias</td><td>Vulnerable
Migratory</td><td>Vulnerable</td><td>Moderate</td></tr>
<tr><td>Longfin mako shark</td><td>Isurus paucus</td><td rowspan="4">Migratory</td><td rowspan="4">Least Concern</td><td rowspan="4">Moderate</td></tr>
<tr><td>Porbeagle shark</td><td>Lamna nasus</td></tr>
<tr><td>Reef manta ray</td><td>Manta alfredi</td></tr>
<tr><td>Shortfin mako shark</td><td>Isurus oxyrinchus</td></tr>
</table>

4.2 Marine Fauna Hearing Sensitivities

Acoustic energy propagates in water more efficiently than almost any other form of energy. Therefore, many marine fauna species primarily rely on sound and their auditory system to perform various functions associated with their life cycle such as communication, navigation, foraging and sensing their surrounding environment (Whitlow et al, 2008).

The hearing sensitivity of marine fauna species varies with frequency. Audiograms, defined as the frequency-dependent absolute hearing threshold (decibel (dB) re 1µPa), are normally used to represent marine fauna species' sensitivity to sounds of different frequencies. Audiograms can also be used to derive standard frequency weighting functions for functional groups of marine mammals. A frequency weighting function refers to the filtering of noise to reflect the sensitivity of an animal or group of animals to noise at different frequencies, as (like humans) animals do not hear equally well at all frequencies.

Fish species have highly variable sensitivity to sound energy, with hearing sensitivity that can range from 20Hz to several kHz, and with highest sensitivity typically in the mid frequency range (100Hz to 1kHz). In comparison to fish, marine mammals, including cetaceans (e.g. whales and dolphins) and pinnipeds, have much broader hearing sensitivity ranges, from a few Hz up to 180kHz, with very sensitive hearing up to relatively high frequencies (10kHz to 100kHz) (Southall et al, 2007). More limited audiogram information is available for dugongs and sea turtles than for either fish or other marine mammals. The sections below summarise available information on the hearing sensitivity of the various species of interest for this study.

4.2.1 Marine Mammal Hearing Sensitivities

A comprehensive literature review study of marine mammal hearing and on physiological and behavioural responses to anthropogenic sound was undertaken by Southall et al (2007) and it has proposed standard frequency weighting functions, referred to as M-weighting functions, for a series of functional groups of marine mammals.

The functional hearing groups and associated range of hearing sensitivities for cetaceans proposed by Southall et al (2007) are listed in **Table 3**. As can be seen, the marine mammals potentially present in the Project area include low-frequency cetaceans (i.e. humpback whale, southern right whale, Bryde's whale, blue whale, Minke whale and Sei whale), in addition to mid-frequency cetaceans (i.e. killer whales and all Delphinids listed in **Table 3**). No species of high-frequency cetaceans are expected to present within the study area.

Table 3 Marine Mammal Hearing Groups, Auditory Bandwidth, Species of Interest within Each Group and Group-specific (M) Frequency-weightings

Functional Hearing Group	Estimated Auditory Bandwidth	Species of Interest	Frequency-weighting Network
Low-frequency cetaceans	7Hz to 22kHz	Humpback whale, Southern right whale, Bryde's whale, Blue whale and Minke whale	M_{lf}
Mid-frequency cetaceans	150Hz to 160kHz	Australia snubfin dolphin, Bottlenose dolphin, Australian humpback dolphin, Risso's dolphin, Spotted dolphin and Common dolphin	M_{mf}
High-frequency cetaceans	200Hz to 180kHz	-	M_{hf}

The M-weighting functions for the three marine mammal hearing groups are illustrated in **Figure 5**.

More recently, the US National Marine Fisheries Service (NMFS) published an updated guidance on assessing effects on marine mammals (NMSF, 2016). However, due to its recent release, this guidance has not been widely recognised and used within Australia.

Audiogram data are not available for dugongs. Since dugongs and manatees are both classified as sirenians, it is expected that their audiograms may be similar. The literature suggests that manatees have an underwater hearing range that is similar to that of phocid pinnipeds (Southall et al, 2007; US Navy, 2012). The best hearing sensitivity for manatees is between 8kHz and 32kHz (Gerstein et al, 1999; Gaspard et al, 2012).

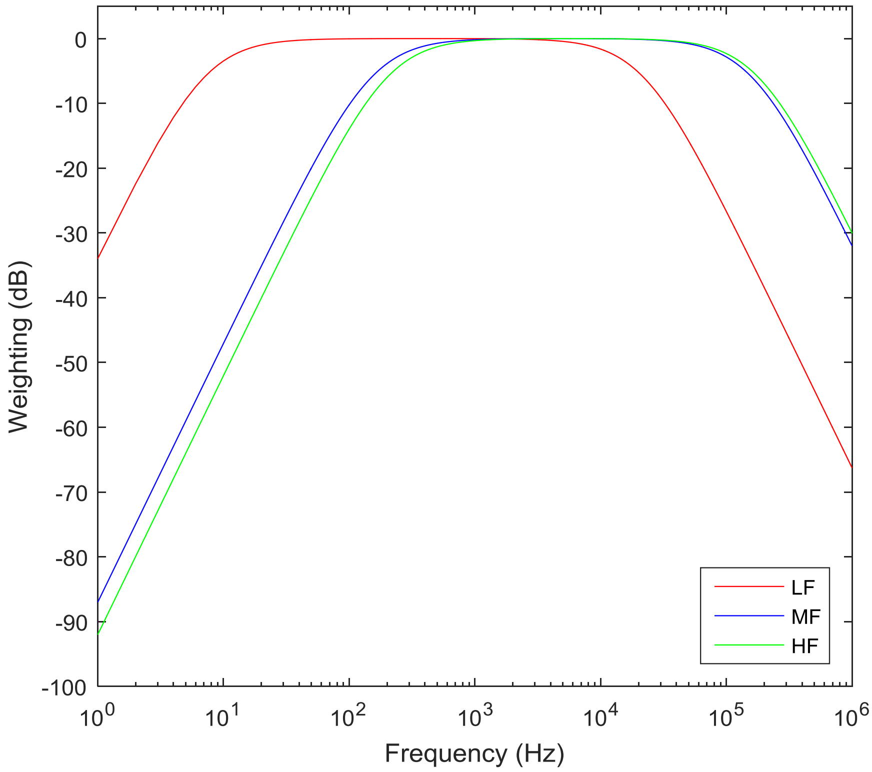


Figure 5 M-weighting Functions for Low-frequency (LF), Mid-frequency (MF) and High-frequency (HF) Cetaceans (Southall et al, 2007)

4.2.2 Marine Turtle Hearing Sensitivity

Popper et al (2014) reviewed the literature on the sensitivity of sea turtles to noise. While data on sea turtle hearing is limited to a few studies, these indicate a hearing range centred at low frequencies, extending approximately between 50Hz and 1,200Hz. Turtles are most sensitive to noise at frequencies of about 100Hz to 400Hz (Ketten et al, 2005; Popper et al, 2014). Popper et al (2014) note that fish hearing, rather than mammalian hearing, is a better model to use for sea turtles, at least until more data becomes available (Popper et al, 2014).

4.2.3 Fish Hearing Sensitivity

Typically, general fish species have a diverse range of hearing capabilities to sound energy, with hearing sensitivity ranging from 20Hz to several kHz, and with highest sensitivity at mid frequency range (100Hz to 1kHz) (Nedwell et al, 2004).

Popper et al (2014) provide examples of fish hearing sensitivity as presented in **Figure 6**, based on measured audiograms of several species that are predominantly sensitive to particle motion (left panel), or sound pressure sensitive (right panel).

A summary of the sensitivity of fish to sound is provided in Popper et al (2014).

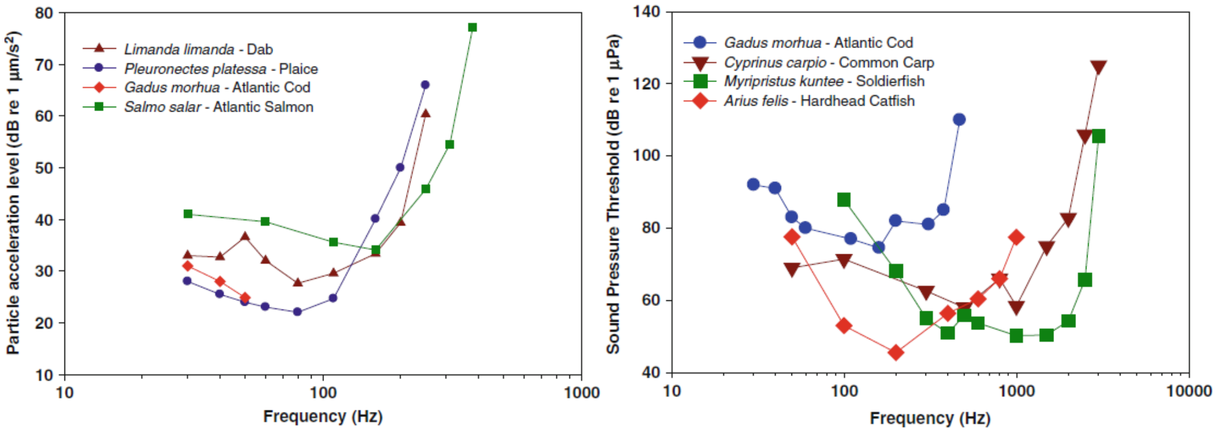


Figure 6 Examples of Fish Hearing Sensitivity from Popper et al (2014). Left Panel: Audiograms for Four Species Being Particle Motion Sensitive. Right Panel: Audiograms for Four Sound Pressure Sensitive Species

4.3 Impact of Noise on Marine Fauna Species

The effects of noise and the distances over which effects extend depend on the acoustic characteristics of the noise (e.g. level, spectral content, temporal characteristics, etc.). The potential impacts of noise on marine fauna species include mortality, physical and hearing damage, masking of communication and other biological important sounds, and alteration of behaviour (Richardson et al, 1995; Hasting and Popper, 2005). In general, underwater noise impacts on marine fauna species may be divided into two categories, behavioural impacts and physiological impacts.

4.3.1 Behavioural Impacts

Behavioural responses to noise include changes in vocalisation, resting, diving and breathing patterns, changes in mother-infant relationships, and avoidance of the noise sources. Masking of biologically important sounds may interfere directly with communication and social interaction. Secondary behavioural effects such as inhibited reproduction cycles and other changes in behaviour may also occur.

4.3.2 Physiological Impacts

Physiological effects of underwater noise are primarily associated with the auditory system which is likely to be most sensitive to noise. The exposure of the auditory system to a high level of noise for a specific duration can cause a reduction in the animal's hearing sensitivity, or an increase in hearing threshold. If the noise exposure is below some critical sound energy level, the hearing loss is generally only temporary, and this effect is called temporary hearing threshold shift (TTS). If the noise exposure exceeds the critical sound energy level, the hearing loss can be permanent, and this effect is called permanent hearing threshold shift (PTS).

In a broader sense, physiological impacts also include non-auditory physiological effects. Other physiological systems of marine animals potentially affected by noise include the vestibular system, reproductive system, nervous system, liver or organs with high levels of dissolved gas concentrations and gas filled spaces. Noise at high levels may cause concussive effects, physical damage to tissues and organs, cavitation or result in rapid formation of bubbles in venous system due to massive oscillations of pressure.

4.4 Noise Impact Criteria for Marine Fauna Species Assessed

There have been extensive scientific studies and research efforts to develop quantitative links between marine noise and impacts on marine fauna species. For example, Southall et al (2007) have proposed noise exposure criteria associated with various sound types (e.g. pulses (e.g. piling noise) and non-pulses (e.g. vessel and dredging noise)) for certain marine mammal species (i.e. cetaceans and pinnipeds), based on review of expanding literature on marine mammal hearing and on physiological and behavioural responses to anthropogenic sounds. McCauley et al (2000a; 2000b) investigated responses of various marine fauna species (including fish and turtles) to marine seismic airgun noise through extensive observation and experiments. Popper et al (2014) established interim, yet broadly applicable, sound exposure guidelines for fishes and sea turtles based on the best available scientific information.

Marine Mammal Species

Southall et al (2007) propose PTS-onset and TTS-onset criteria for both pulses and non-pulsed noise events, as outlined in **Table 4**, which incorporate a dual-criteria approach based on both peak sound pressure level (Peak SPL) and sound exposure level (SEL).

For behavioural changes, the widely used assessment criterion for the onset of possible behavioural disruption in marine mammals is root-mean-square (RMS) SPL of 120dB re 1µPa for non-impulsive noise events such as typical continuous construction noise (Richardson et al, 1995 and NMFS, 2013), and RMS SPL of 160dB re 1µPa for impulsive noise events such as impact pile driving (NMFS, 2013), as shown in **Table 5**.

Marine Turtles and Dugongs

Popper et al (2014) propose the conservative piling noise mortality criteria for sea turtles based on the assessment levels for fish species, due to the fact that data on the effects of piling noise on sea turtles are lacking. McCauley et al (2000a) conclude the SEL threshold levels of behavioural changes (i.e. 155dB re 1µPa^2·S) and avoidance (i.e. 164dB re 1µPa^2·S) for piling noise, as listed in **Table 6**, based on the experimental trials investigating sea turtle responses to impulsive signals.

The impact risks of injuries and behavioural changes for sea turtles due to shipping noise or other continuous noise are considered as low. Therefore, no relevant assessment criteria for continuous noise for sea turtles are suggested (Popper et al, 2014).

The above piling noise assessment criteria for sea turtles are also adopted in this assessment for dugongs, as no assessment levels in the literature to piling noise for dugongs. This interim approach is in consistency with assessment approach undertaken by other similar major projects (e.g. McCauley et al, 2012).

Table 4 Proposed PTS and TTS Criteria for Individual Marine Mammals Exposed to "Discrete" Noise Events (Either Single or Multiple Exposures within a 24-h Period)

Marine mammal hearing group	Injury (PTS-Onset) threshold levels			
	Single/multiple pulses		Non-pulses (inc. continuous noise)	
	Peak SPL, flat, dB re 1µPa	SEL, 24hr, weighted, dB re 1µPa²·S	Peak SPL, flat, dB re 1µPa	SEL, 24hr, weighted, dB re 1µPa²·S
Injury (PTS-Onset) Criteria				
Low-frequency cetaceans	230 (flat)	198 (M_{lf})	230 (flat)	215 (M_{lf})
Mid-frequency cetaceans		198 (M_{mf})		215 (M_{mf})
High-frequency cetaceans		198 (M_{hf})		215 (M_{hf})
TTS (TTS-Onset) Criteria				
Low-frequency cetaceans	224 (flat)	183 (M_{lf})	224 (flat)	195 (M_{lf})
Mid-frequency cetaceans		183 (M_{mf})		195 (M_{mf})
High-frequency cetaceans		183 (M_{hf})		195 (M_{hf})

Table 5 Proposed Criteria for the Onset of Possible Behavioural Changes for Individual Marine Mammals

Marine mammal hearing group	Behavioural changes threshold levels	
	Pulses – pile driving	Non-pulses (inc. continuous noise)
	RMS SPL, dB re 1µPa	
All cetaceans	160	120

Fish Species

Popper et al (2014) identify several categories of fish for the purpose of analysing the potential effects of sound, including:

- Fish with no swim bladder or other gas chamber – these species only detect particle motion, not sound pressure, and are less susceptible to barotrauma than other categories of fish.
- Fish with swim bladders in which hearing does not involve the swim bladder – these species are susceptible to barotrauma, even though their hearing involves only particle motion, not sound pressure.
- Fish in which hearing involves a swim bladder or other gas volume – these species are susceptible to barotrauma, and can detect sound pressure as well as particle motion.
- Fish eggs and larvae.

Among these categories fish with a swim bladder involved in hearing are most vulnerable to the noise impact from piling and other non-pulses events relevant to this study. Based on a conservative consideration, the guiding criteria for fish with a swim bladder involved in hearing, as listed in **Table 7**, are adopted for general fish species.

Table 6 Proposed Piling Noise Assessment Criteria for Sea Turtles and Dugongs

Noise impacts on sea turtles and dugongs	Impact threshold levels	
	Peak SPL, dB re 1µPa	SEL, dB re 1µPa^2·S
Mortality and potential mortal injury	207	210 (cum)
Avoidance	N/A	164 (per strike)
Behavioural changes		155 (per strike)

Note: cum = cumulative

Table 7 Proposed Assessment Criteria for Fish Species

Noise impacts on fish species	Impact threshold levels			
	Pulses – pile driving		Non-pulses (inc. continuous noise)	
	Peak SPL, dB re 1µPa	SEL, dB re 1µPa^2·S	Peak SPL, dB re 1µPa	SEL, 24hr dB re 1µPa^2·S
Mortality and potential mortal injury	207	207 (cum)	N/A	N/A
Recoverable injury	207	203 (cum)		216 (cum)
TTS	N/A	186 (cum)		204 (cum)
Avoidance	N/A	150 (per strike)		N/A
Behavioural changes		145 (per strike)		

Note: cum = cumulative

4.5 Zones of Bioacoustics Impact

The received noise levels in and around the Project area can be predicted using known source levels in combination with models of sound propagation transmission loss between the source and the receiver locations. Zones of impact can be determined by comparison of the predicted received levels to the noise exposure criteria.

Predicted zones of impact define the environmental footprint of the noise generating activities and indicate the locations within which the activities may have an adverse impact on a marine fauna species, either behaviourally or physiologically. This information can be used to assess the risk (likelihood) of potential adverse noise impacts, by combining the acoustic zones of impact with ecological information such as habitat significance and species abundance or density in the affected area.

5 Existing Underwater Noise Baseline Environment

5.1 General Ocean Underwater Noise

Ocean ambient noise poses a baseline limitation on the use of sound by marine animals as signals of interest must be detected against noise background. The level and frequency characteristics of the ambient noise environment are the two major factors that control how far away a given sound signal can be detected (Richardson et al. 2013).

Ocean ambient noise is comprised of a variety of sounds of different origin at different frequency ranges, having both temporal and spatial variations. It primarily consists of noise from natural physical events, noise produced by marine biological species and anthropogenic noise (Wenz, 1962). These sources are detailed as follows:

- Natural events: The major natural physical events contributing to ocean ambient noise include, but are not limited to, wave/turbulence interactions, wind, precipitation (rain and hail), breaking waves and seismic events (e.g. earthquakes/tremors):
    - The interactions between waves/turbulence can cause very low frequency noise in the infrasonic range (below 20Hz). Seismic events such as earthquakes/tremors and underwater volcanos also generate noise predominantly at low frequencies from a few hertz to a few hundred hertz;
    - Wind and breaking waves, as the prevailing noise sources in much of the world's oceans, generate noise across a very wide frequency range, typically dominating the ambient environment from 100Hz to 20kHz in the absence of biological noise sources. The wind-dependent noise spectral levels also strongly depend on sea states which are essentially correlated with wind force; and
    - Precipitation, particularly heavy rainfall, can produce much higher noise levels over a wider frequency range of approximately 500Hz to 20kHz.
- Bioacoustic production: Some marine animals produce various sounds (such as calls, whistles, clicks) for different purposes (for example, communication, navigation or detection):
    - Baleen whales (e.g. great whales like humpback whales) regularly produce intense low-frequency sound (whale songs) that can be detected at long range in the open water. Odontocete whales, including dolphins, can produce rapid burst of high-frequency clicks (up to 150kHz) that are primarily for echolocation purposes;
    - Some fish species produce sounds individually, and some species also make noise in choruses. Typically fish chorusing sounds depend on species, time of day and time of season; and
    - Snapping shrimp are important contributors among marine biological species to the ocean ambient noise environment, particularly in shallow coastal waters. The noise from snapping shrimp is extremely broadband in nature, covering a frequency range from below 100Hz to above 100kHz. Snapping shrimp noise can interfere with other measurement and recording exercises, for example it can adversely affect sonar performance.

- Anthropogenic sources: Anthropogenic noise primarily consists of noise from shipping activities, offshore seismic explorations, marine industrial developments and operations, as well as equipment such as sonar and echo sounders:
    - Shipping traffic from various sizes of ships is the prevailing man-made noise source around nearshore port areas. Shipping noise is typically due to cavitation from propellers and thrusters, with energy predominantly below 1kHz;
    - Pile driving and offshore seismic exploration generate repetitive pulse signals with intense energy at relatively low frequencies (hundreds of hertz) that can potentially cause physical injuries to marine species close to the noise source; and
    - Dredging activities and other marine industry operations are additional man-made sources, generating broadband noise over relatively long durations.

A summary of the spectra of various ambient noise sources based on a review study undertaken by Wenz (1962) is shown in **Figure 7**.

It should be noted that the spectral curves are based on average levels from reviewed references primarily for the North Atlantic Ocean and therefore are qualitative and indicative only at other locations.

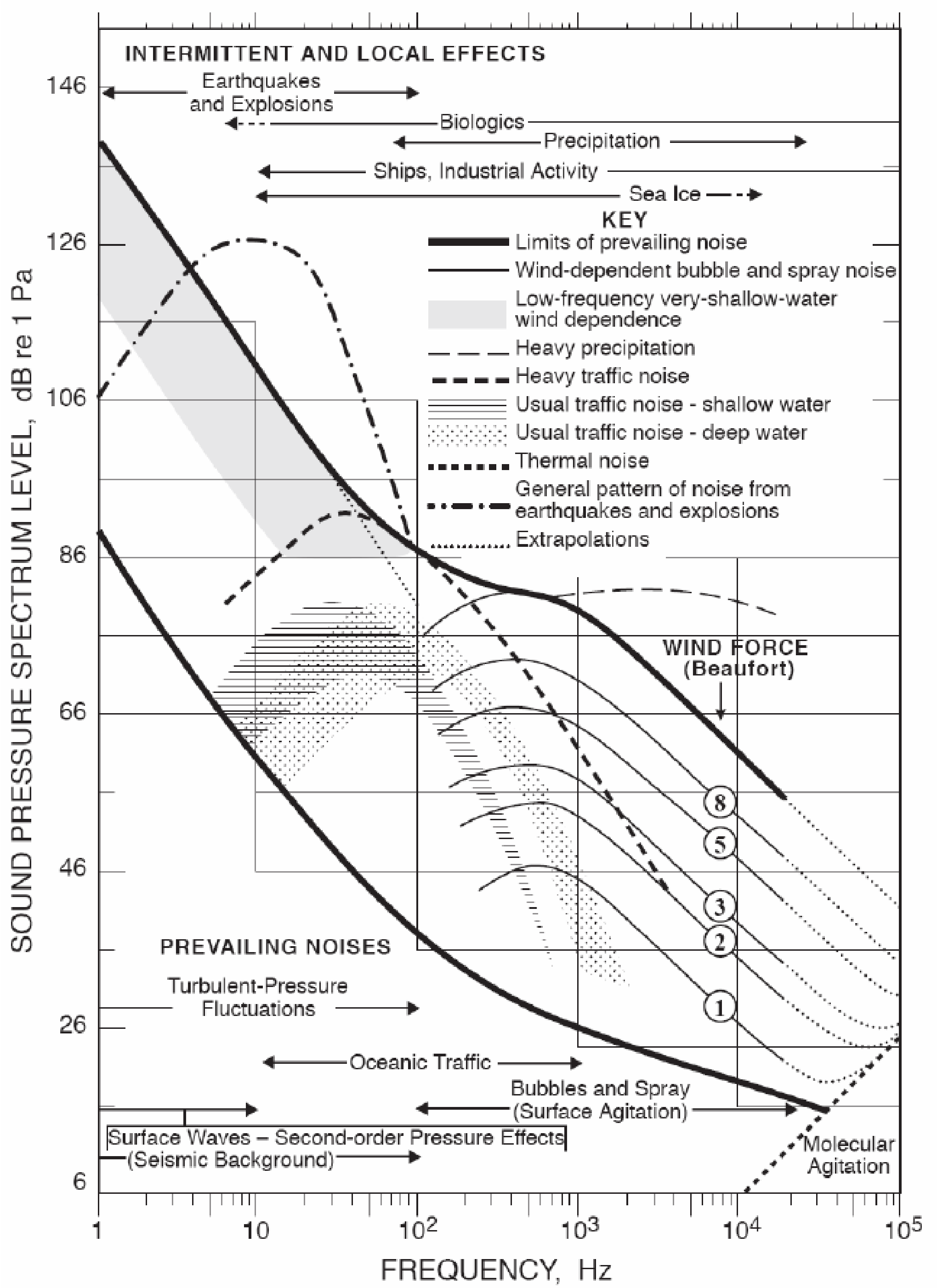


Figure 7 Composite of Ocean Ambient Noise Spectra (from Wenz (1962))

Studies in Australian waters have shown that there are some significant differences in the ambient noise compared to the colder Northern Hemisphere waters where most existing measurements have been recorded. **Figure 8** summarises the main components of ambient noise for the Australian regions, where the differences from Wenz's ambient noise spectra are due to the different environment of tropical waters, particularly in respect to noise from marine animals. Wind-generated noise and the traffic noise due to shipping activities are generally consistent in level range between the two studies (Wenz, 1962 and Carto, 1997).

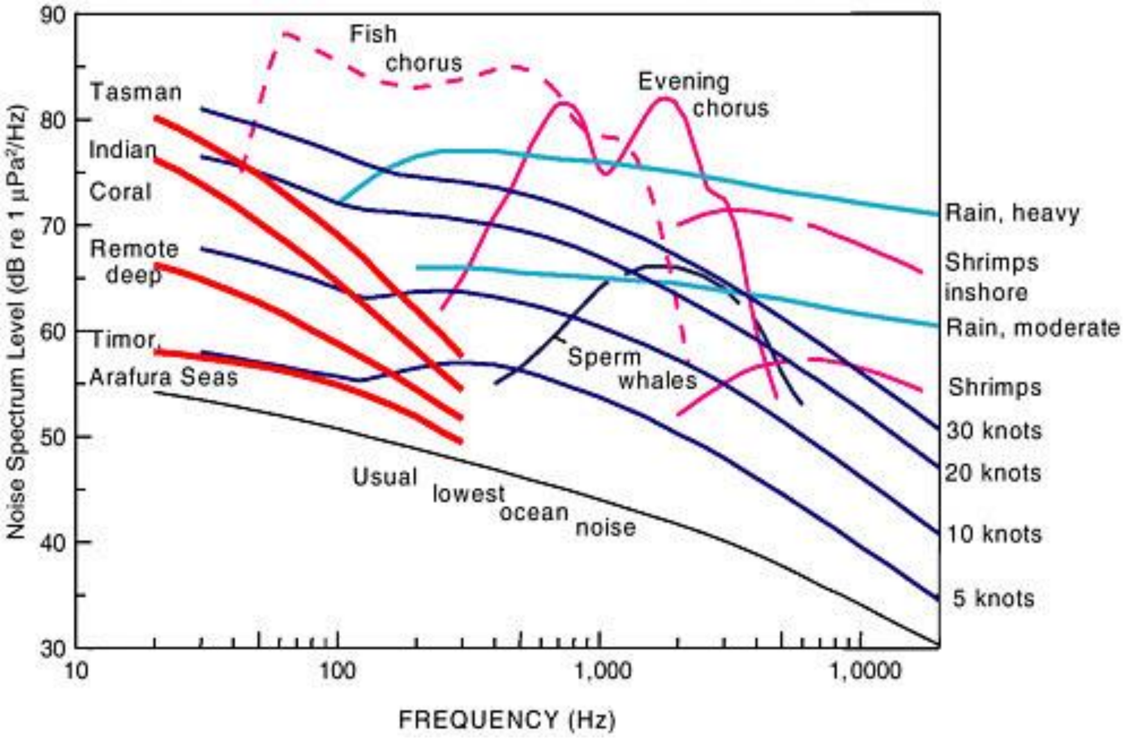


Figure 8 Summary of Ocean Ambient Noise Spectra for the Australian Region (from Cato (1997))

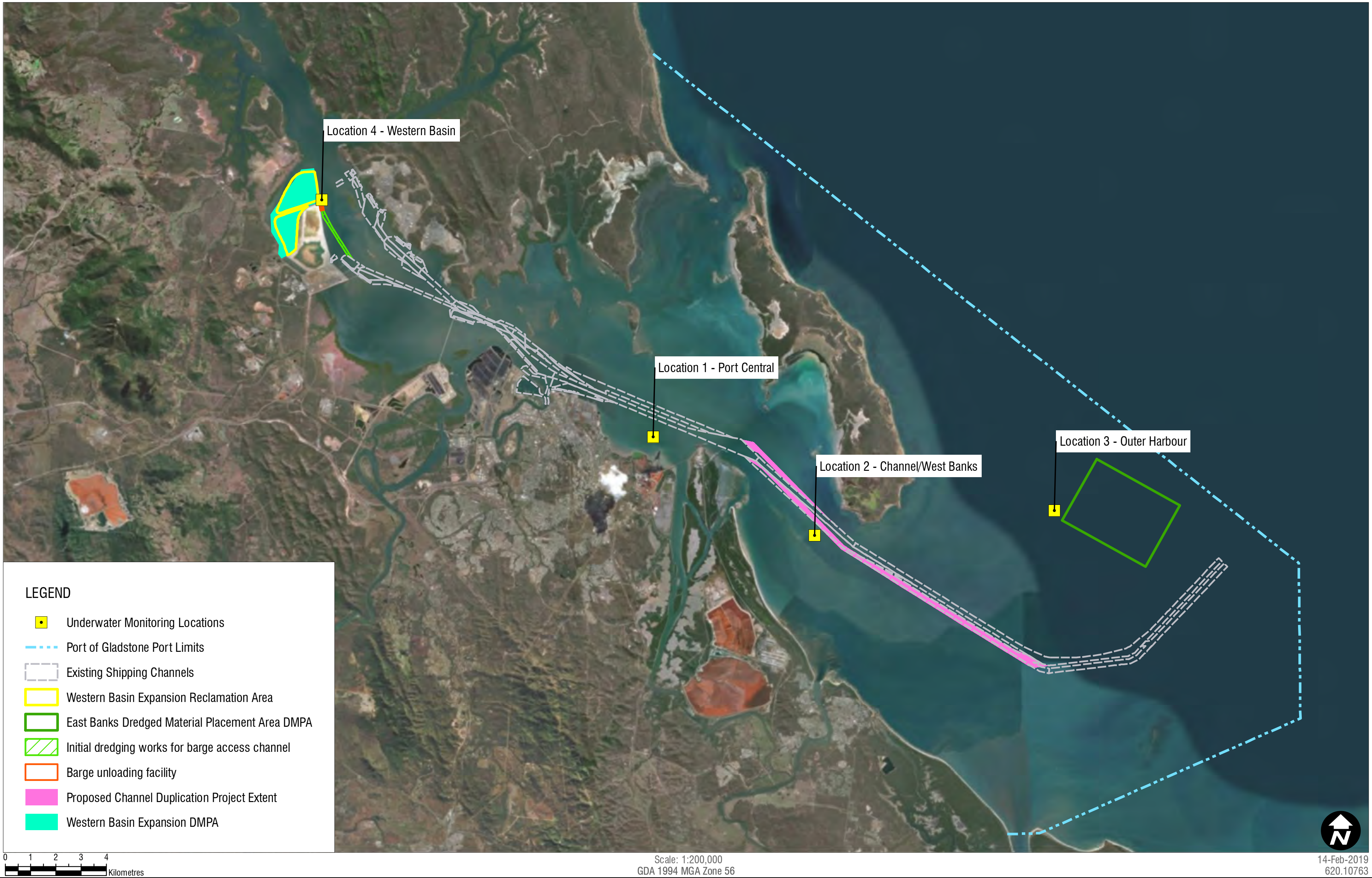
5.2 Defining Existing Underwater Noise Environment - Baseline Monitoring

5.2.1 Noise Monitoring Locations

To characterise the baseline noise environment and its variations with various source contributions, both temporally and spatially, a baseline noise monitoring program was undertaken at four monitoring locations as detailed in **Table 8** and shown in **Figure 9**. These four monitoring locations were selected on the basis that they are spatially representative for the four typical Project areas, including the Western Basin area, Port Central, Port Channel/West Banks and the Outer Harbour.

Table 8 Underwater Noise Baseline Monitoring Locations

Location	GPS Coordinates
Location 1 - Port Central	23°50.94’ S, 151°17.59’ E
Location 2 - Channel/West Banks	23°53.09’ S, 151°21.32’ E
Location 3 - Outer Harbour	23°52.62’ S, 151°26.92’ E
Location 4 - Western Basin	23°45.78’ S, 151°09.94’ E



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Port of Gladstone Channel Duplication
Underwater Noise Baseline Modelling

FIGURE 9

5.2.2 Noise Monitoring Methodology

At each monitoring location, a noise logger was deployed to continuously measure ambient noise levels over three consecutive months, as detailed in **Table 9**. It is expected that the monitoring duration is sufficient to cover various weather conditions, sea state and tidal variations, as well as a wide range of shipping and other operational activities within the Port area, so that the typical baseline noise environment could be characterised based on the monitoring program.

Underwater noise levels were monitored from 10 September to 31 October 2014 at the Port Central, Port Channel/West Bank and Outer Harbour monitoring locations. At the Western Basin underwater noise monitoring location, noise levels were monitored from 27 February to 16 April 2015.

Table 9 Logger Systems Deployment Information

Logger Location	Logger System Serial No.	Calibrated Sensitivity (dB re 1v/µPa)	Deployment Depth (m)	Data Recording Period
Location 1 – Port Central	681549	-163.8	~ 7.0	10 September – 30 October 2014
Location 2 - Channel/West Banks	681551	-164.1	~ 19.0	10 September – 29 October 2014
Location 3 – Outer Harbour	681550	-164.5	~ 22.0	10 September – 31 October 2014
Location 4 – Western Basin	681549	-163.8	~ 5.0	27 February – 16 April 2015

Due to the continuous recording settings and alkaline battery capacity, the recorded data covers approximately 50 days at each of the four locations.

5.2.3 Instrumentation

The Wildlife Acoustics Song Meter SM3 Marine (SM3M) Submersible bioacoustics recording (logging) system was used for the baseline noise monitoring program. The SM3M Submersible logging system has the capability of long term monitoring of ambient noise levels for baseline characterisation as well as capturing high level anthropogenic noise such as from pile driving and seismic airguns.

The SM3M Submersible logging system comprises an electronic circuit board, a heavy duty polyvinyl chloride (PVC) cylindrical housing unit and a top cap with built-in hydrophone unit. The electronic circuit board includes integrated battery bay, control panel, liquid-crystal display (LCD) screen and four memory slots**. Figure 10** shows the SM3M logging system. Specifications for the system and the settings for this monitoring program are listed in **Table 10**.

The sensitivity of each hydrophone is calibrated to a 0.1dB resolution by the manufacturer. The frequency responses for four hydrophone options are presented in **Figure 11**. The frequency response for the standard hydrophone is constantly flat up to 30kHz, with variations of less than 2dB.

Table 10 Detailed Specifications – SM3M Submersible Logging System

Key Features	Specification Details	Settings for Monitoring Program
Working depth	Up to 150m	< 30m
Operating temperature	0°C to 40°C	~ 20°C
Dimensions	16.5cm in diameter/79.4cm in length	-
Weight	Without batteries - 9.5kg in air; Fully populated with batteries - 13.5kg in air and 1.5kg buoyancy in salt water	-
Power	Maximum 32 alkaline D cell batteries or lithium manganese batteries (4.5 to 17V DC)	32 alkaline D cell Energizer
Sampling rate	4kHz to 96kHz	48kHz
Storage	Up to 512GB with SDXC	256GB with two SDXC Cards
Recording schedules	Programmable	Continuous
Data format	WAC (compressed) or WAV	WAC (compressed)
Dynamic range	78 to 165dB re 1µPa with 0 gain input	-
Gain setting	0 to 59.5dB in 0.5dB steps	Gain AUTO – 0dB
Hydrophone	Hydrophones of different specifications (Low Noise, Standard, Ultrasonic, High-SPL) can be selected depending on the monitoring purpose	Standard hydrophone unit
Noise floor with standard hydrophone	-134dBfs/sqrt(Hz) @ 48kHz sample rate, 1 K input impedance, 1dB gain	-
Calibration	The electronics of the board and hydrophone were calibrated and are not expected to shift the value in years, unless some damage occurs.	Spot calibration check undertaken before and after each deployment.

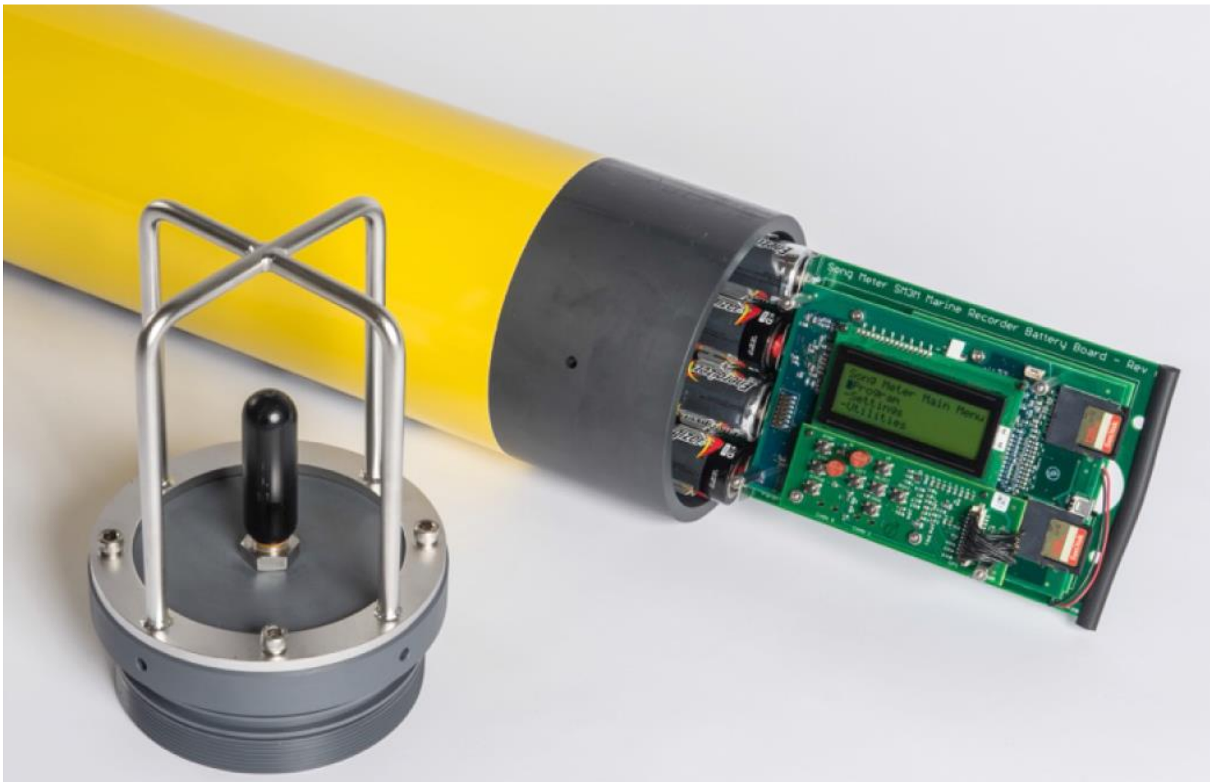


Figure 10 SM3M Logging System with Top Cap containing Hydrophone Unit, Cylindrical Housing unit and Circuit Board

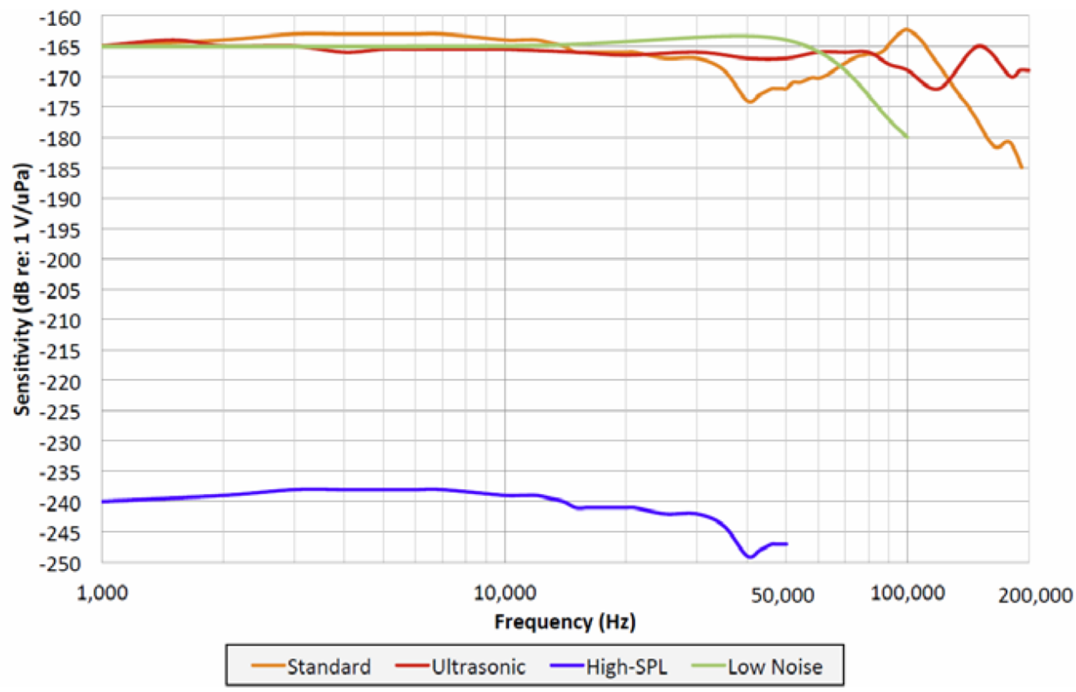


Figure 11 Frequency Responses for Different Hydrophone Options

5.2.4 Deployment and Retrieval

Considering the highly active vessel movements within Port Curtis and potential severe weather impacts, the logger was deployed with a subsurface arrangement as illustrated in **Figure 12**.

The arrangement included two anchor points (~40kg each), with connecting lines and drop weights (~0.5kg each) in between, in order to prevent any location drifts with seabed movements and strong current forces. The logger was attached to the primary anchor weight with approximately 0.5m clearance, floating in the water column due to its own buoyancy.

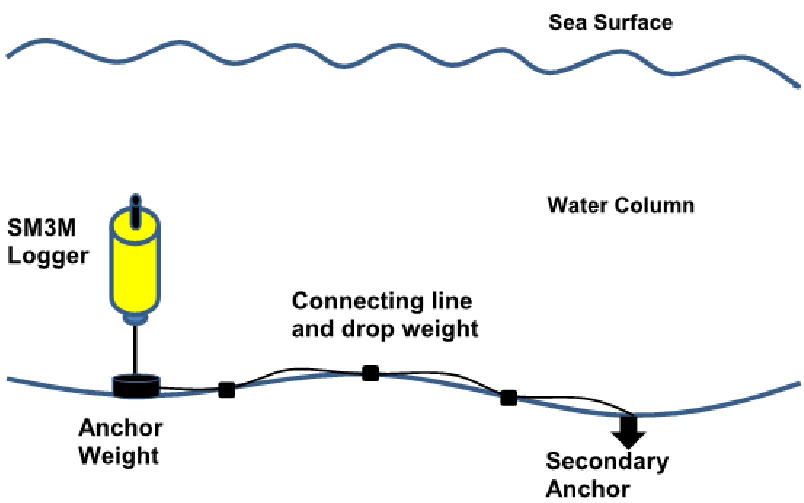


Figure 12 Schematic Arrangement for Logger Deployment

For the first three monitoring locations (Port Central, Port Channel/West Banks and Outer Harbour), commercial diving services were engaged to deploy and retrieve the logger systems. Due to the favourable water depth (~5m) at the Western Basin monitoring location, the logging system was deployed and retrieved manually by on-board SLR staff.

Table 13 illustrates the logger deployment and retrieval process.

Note (A): Noise logger onboard, sealed and assembled with other accessories and ready to be deployed
Note (B): Logger attached to the anchor point and floating above seabed with buoyancy
Note (C): Deployment accessories, including anchoring weights, float buoy and ropes
Note (D): Loggers retrieved after approximately 50 days deployment

Figure 13 Site Photographs for the Logger Deployment and Retrieval

5.2.5 Data Processing and Analysis

5.2.5.1 Noise Monitoring Data

The continuous monitoring data collected from the four monitoring locations was processed and analysed following the steps as detailed below and presented in a flow chart (refer **Figure 14**).

Step 1 - Data acquisition, conditioning and conversion

The monitoring data initially acquired and saved in Wav Compressed (WAC) format were decompressed to WAV format using Wildlife Acoustics Kaleidoscope software, and then signal conditioning was carried out, including checking the quality and removing the direct current (DC) component of the signals.

The recordings in volts were converted to pressure values in micropascal (µPa) based on the calibrated sensitivity of each logging system.

Step 2 – Short term (1-second) data processing and analysis

The dataset was divided into 1-second short term signal segments. For each segment, three key noise parameters, including overall root-mean-square (RMS) level, power spectral density (PSD) and one-third octave spectrum were calculated.

For the overall RMS level, a high-pass filter was applied to exclude noise components below 20Hz, in order to minimise the impact of flow noise on the natural ambient noise measurement. PSD values were computed using Welch's averaging technique, with a frequency bandwidth of 10Hz, 1-second Hanning windows and without segment overlap. One-third octave band levels were calculated from PSD values by integrating the spectral levels within each band.

Step 3 – Long term (15-minute) data processing and analysis

For each long term data segment of 15 minutes, the overall RMS values were calculated using a similar approach as for the short term 1 second data processing. Various percentile values for the three parameters (i.e. overall RMS, PSD and one-third octave band spectrum) were also estimated using the short term segments within each 15 minute period. The percentile values were estimated based on each frequency band for both PSD and one-third octave band spectrum over the entire monitoring period.

Step 4 – Baseline noise characterisation

Various processing and analysis outcomes as described above have been analysed, and the temporal variations of the spectrum over the entire monitoring period (presented via spectrograms) have been investigated, with consideration of weather data and site specific activities for each monitoring locations. As a result, it has been possible to identify the predominant characteristics of baseline underwater noise environment within Port Curtis and the outer harbour, including:

Temporal and spatial variations in overall underwater noise levels;

Spectral variations in underwater noise levels;

Major noise contributors of various origins; and

Correlations with other natural environment parameters such as weather, sea states and tides.

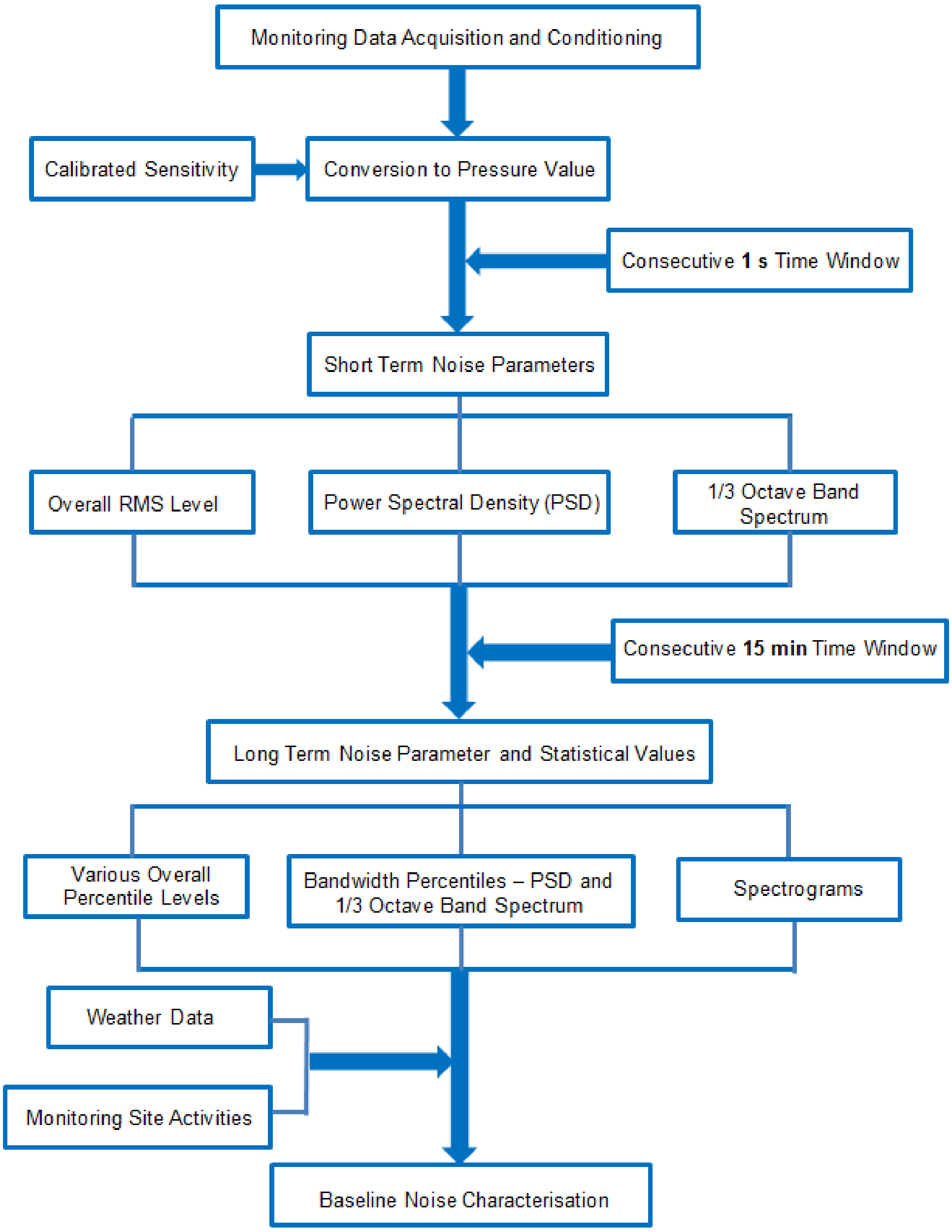
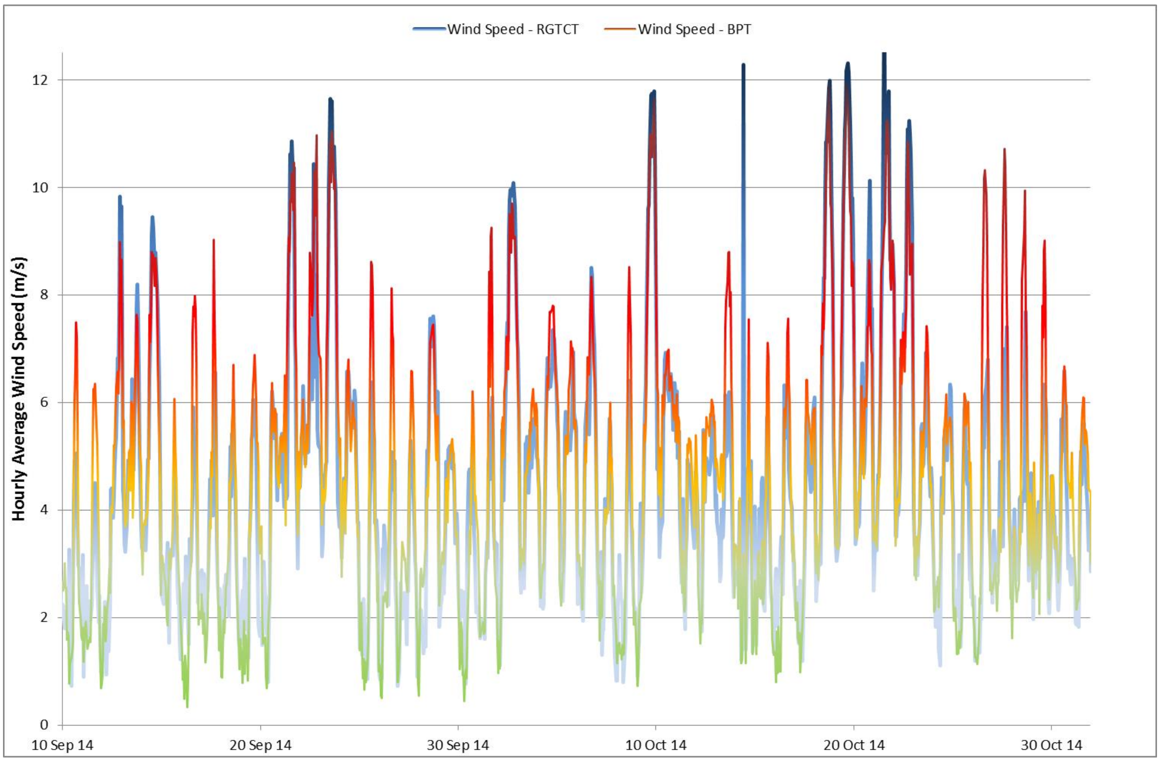


Figure 14 Monitoring Data Processing and Analysis Flow Chart

5.2.6 Weather Data

Hourly average wind speed (m/s) and rainfall rate (mm/h) data was sourced from the two GPC operated weather stations in Gladstone (i.e. RG Tanna Coal Terminal (RGTCT) and Port Central). The data covering the two monitoring periods, 10 September to 31 October 2014 and 27 February to 16 April 2015, are presented in **Figure 15** and **Figure 16,** respectively.

The weather data was used to investigate the correlation between the weather conditions and the temporal and spectral variations of the ambient underwater noise environment at the four baseline monitoring locations.



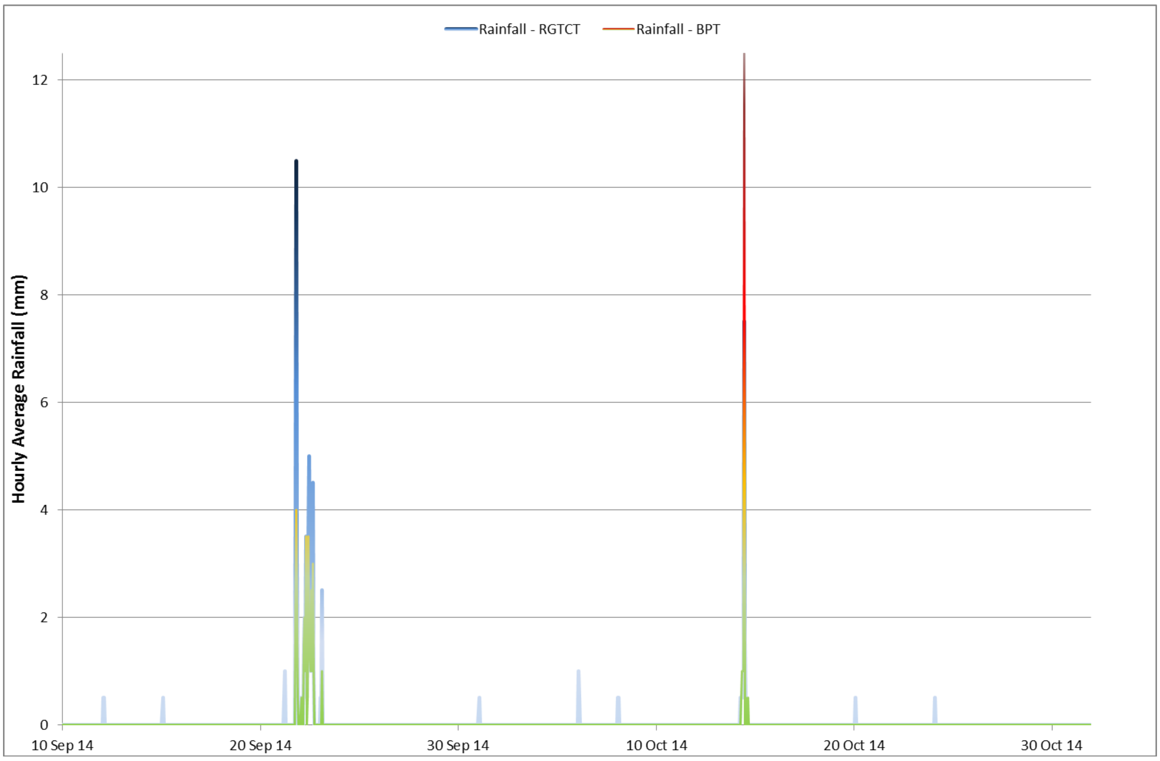
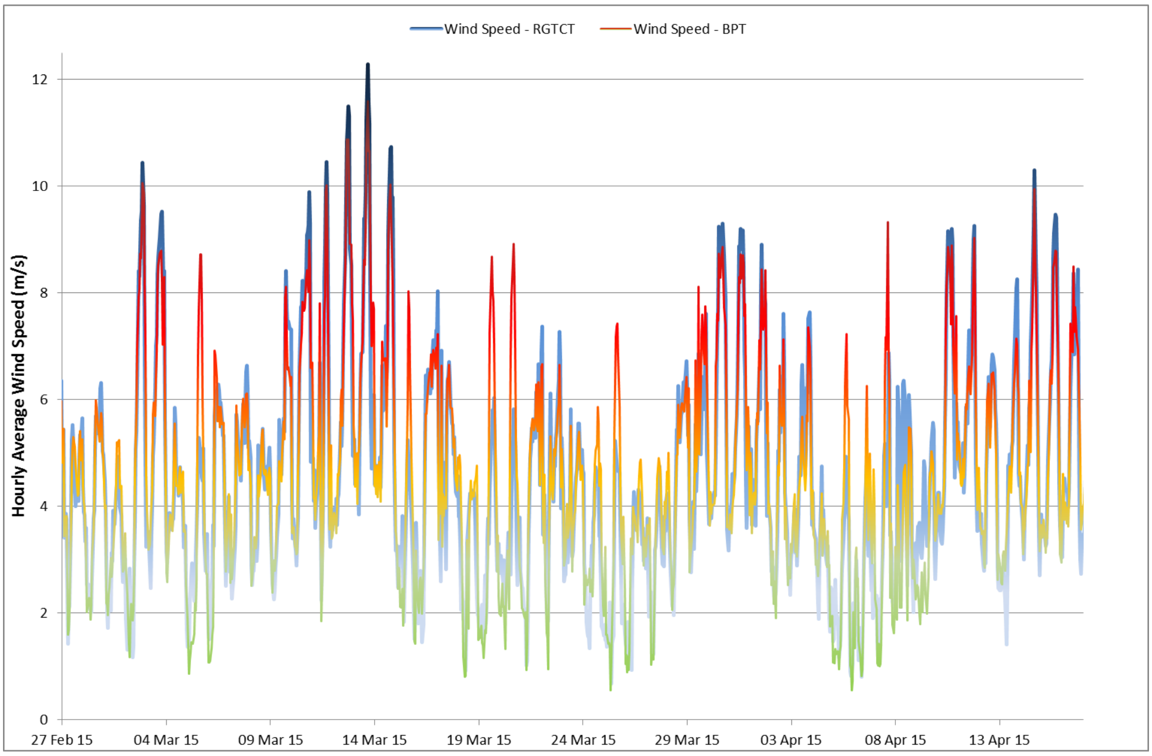


Figure 15 Hourly Average Wind Speed (Top) and Rainfall (Bottom) at RGTCT and Port Central Weather Stations, 10 September to 31 October 2014



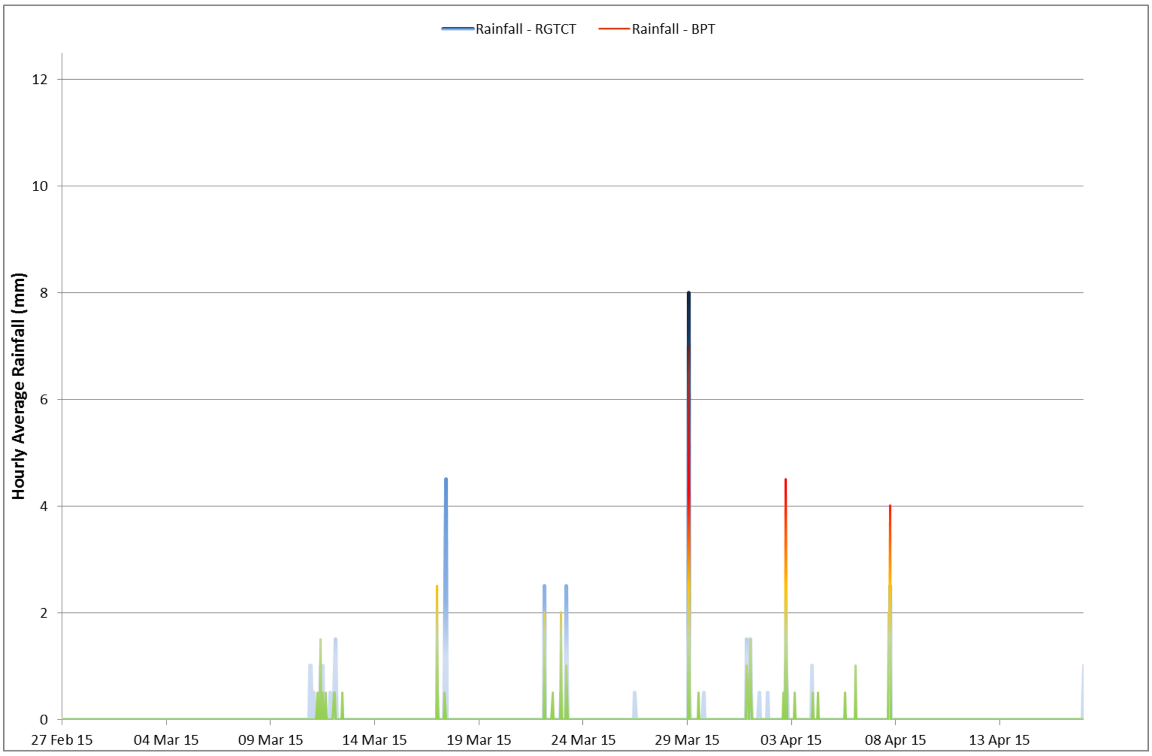


Figure 16 Hourly Average Wind Speed (Top) and Rainfall (Bottom) at RGTCT and Port Central Weather Stations, 27 February to 16 April 2015

5.3 Existing Environment Resulting from the Baseline Monitoring

The data processing and analysis results for all four monitoring locations are presented in the form of spectrograms based on the 15 minute average PSD, the percentile value variations of the overall noise levels within each 15 minute signal segment and the percentile value variations of the spectral levels within each bandwidth for PSD and one-third octave band spectrum.

These results are illustrated in the following figures:

Port Central - **Figure 17** and **Figure 18**;

Port Channel/West Banks - **Figure 19** and **Figure 20**;

Outer Harbour - **Figure 21** and **Figure 22**; and

Western Basin - **Figure 23** and **Figure 24**.

The ranges of percentile value variations of the overall noise levels over the entire monitoring period for the four locations are presented in **Table 11**.

Table 11 Ranges of Overall Noise Level Variations

Logger Location	Range of Percentile Value Variations of the Overall Noise Level Variations (dB)			
	90%, 15min	50%, 15min	10%, 15min	RMS, 15min
Location 1 - Port Central	103 to 125	104 to 128	106 to 137	105 to 130
Location 2 – Port Channel/West Banks	106 to 126	107 to 133	110 to 138	108 to 135
Location 3 - Outer Harbour	100 to 108	101 to 114	104 to 120	102 to 116
Location 4 - Western Basin	110 to 118	101 to 124	114 to 130	112 to 125

Note: RMS = root-mean-square

In summary, the following general conclusions are drawn from the monitoring data processing and analysis results:

For the three monitoring locations in the inner harbour area (i.e. Port Central, Port Channel/West Banks and Western Basin), the anthropogenic noises associated with marine operations are the prevailing sources, dominating the low-frequency component below a few kilohertz at the monitoring locations. Biological noise, particularly noise from snapping shrimp, is another major noise source covering the mid to high frequency ranges from a few kilohertz up to 10kHz.

For the monitoring location in the Outer Harbour, the measured noise levels strongly correlate with weather and sea-state variations, with dominant frequency components ranging approximately from 100Hz to 2kHz.

The respective temporal and spectral characteristics of the baseline underwater noise environment for each monitoring location are detailed in the sections below.

Location 1 – Port Central

The recorded overall noise levels at Port Central over the entire monitoring period have significant variations (over 20dB). The correlation between the spectrograms and the overall noise level variations presented in **Figure 17** demonstrate that such variations are due to the numerous low-frequency transient events occurring predominantly during daytime periods. It is expected that these transient events are from the vessel movements through the nearby shipping channel.

The broadband noise from constant snapping shrimp clicks as another major noise sources is also evident from the spectrogram in **Figure 17** and spectral information contained in **Figure 18**.

Due to the dominant influence of the transient vessel noise, the overall noise levels at Port Central do not have apparent correlations with weather conditions (wind speed and rainfall as shown in **Figure 15**).

Location 2 – Port Channel/West Banks

The monitoring location at Port Channel/West Banks is located close to the existing Gatcombe shipping channel. The deployed noise logger recorded significant low-frequency noise events presented in the spectrograms in **Figure 19**. These events are expected to be from bulk carriers travelling in and out of the Port and, as a result, the overall noise levels received at the monitoring location are the highest among the three locations within the Port, with a high level noise component even at very low frequencies between 10Hz and 100Hz.

The snapping shrimp clicks are the second major noise source and dominate the ambient noise in the absence of vessel movements, as indicated by the 90 percentile spectral values for both PSD and one-third octave spectrum in **Figure 20**.

There is no clear correlation between the overall noise level and weather conditions (i.e. wind speed and rainfall).

Location 3 - Outer Harbour

The consistency between the various spectral percentile values presented in **Figure 22** and the dominant noise spectrum frequency range approximately between 100Hz and 2kHz suggests that the prevailing noise sources at the Outer Harbour location are sea-state variations (wave breaks) and wind-generated noise. The occasional significant variations in noise level presented in **Figure 21** are likely from ad-hoc marine operations or vessel movements in close proximity to the monitoring location.

Location 4 - Western Basin

The overall noise level and the spectral variations over the monitoring period at Western Basin, as presented in **Figure 23**, indicate that the major low frequency components occur predominately during day and evening periods and not on weekends. As such, the dominant low frequency noise sources are likely the continuous marine operation activities adjacent to the monitoring location.

The noise from snapping shrimp has higher levels at the Western Basin location than at the other two locations within the inner harbour (i.e. Port Central and Port Channel/West Banks). Snapping shrimp dominate the ambient noise in the absence of noise from marine operations as indicated by the 90 percentile spectral values for both PSD and one-third octave spectrum in **Figure 24**.

There is no clear correlation between the overall noise levels with weather conditions (i.e. wind speed and rainfalls as shown in **Figure 16**) at Western Basin, as per the Port Central, Port Channel/West Banks monitoring locations.

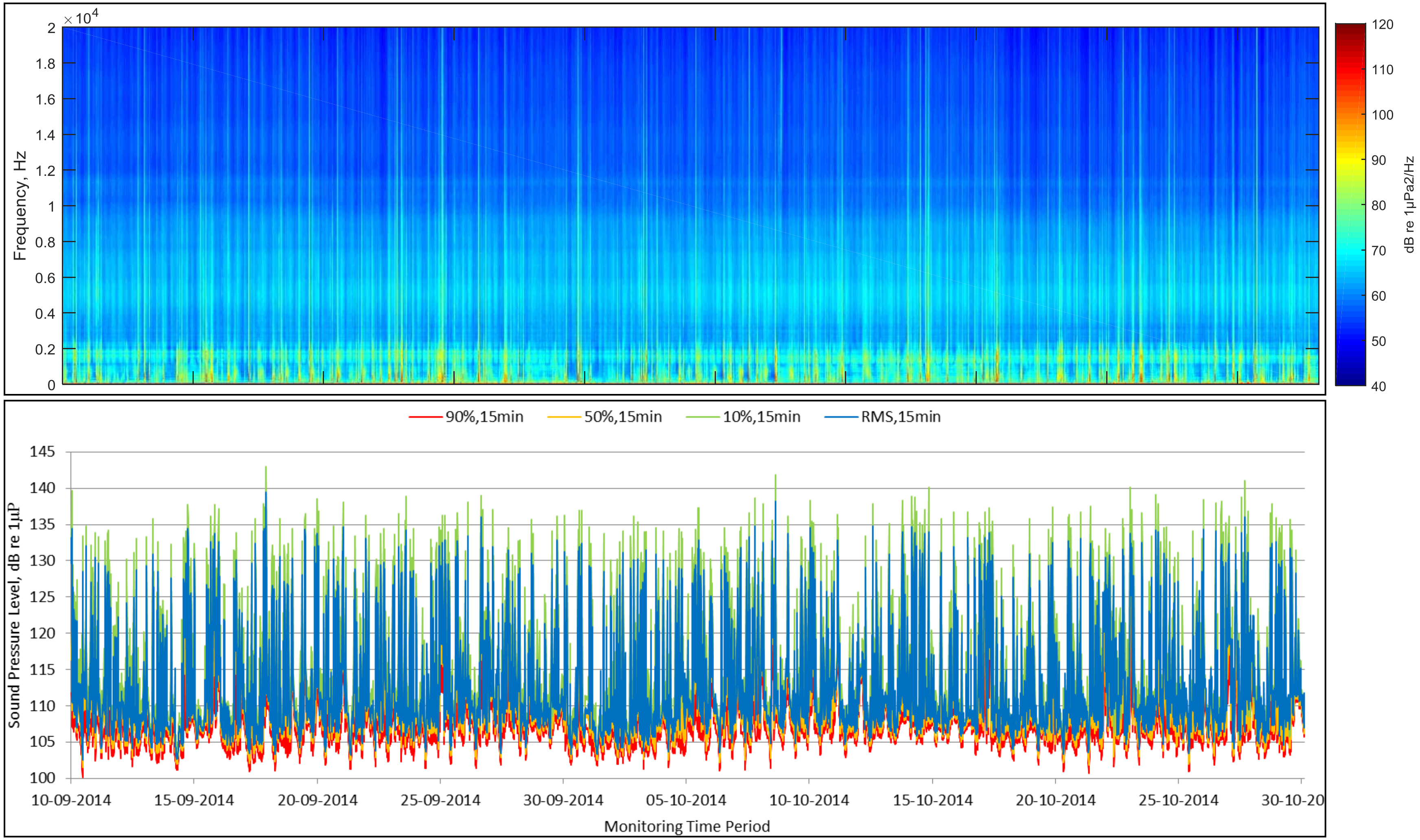


Figure 17 Spectrogram (top) and Overall Noise Levels (bottom) for Location 1 – Port Central

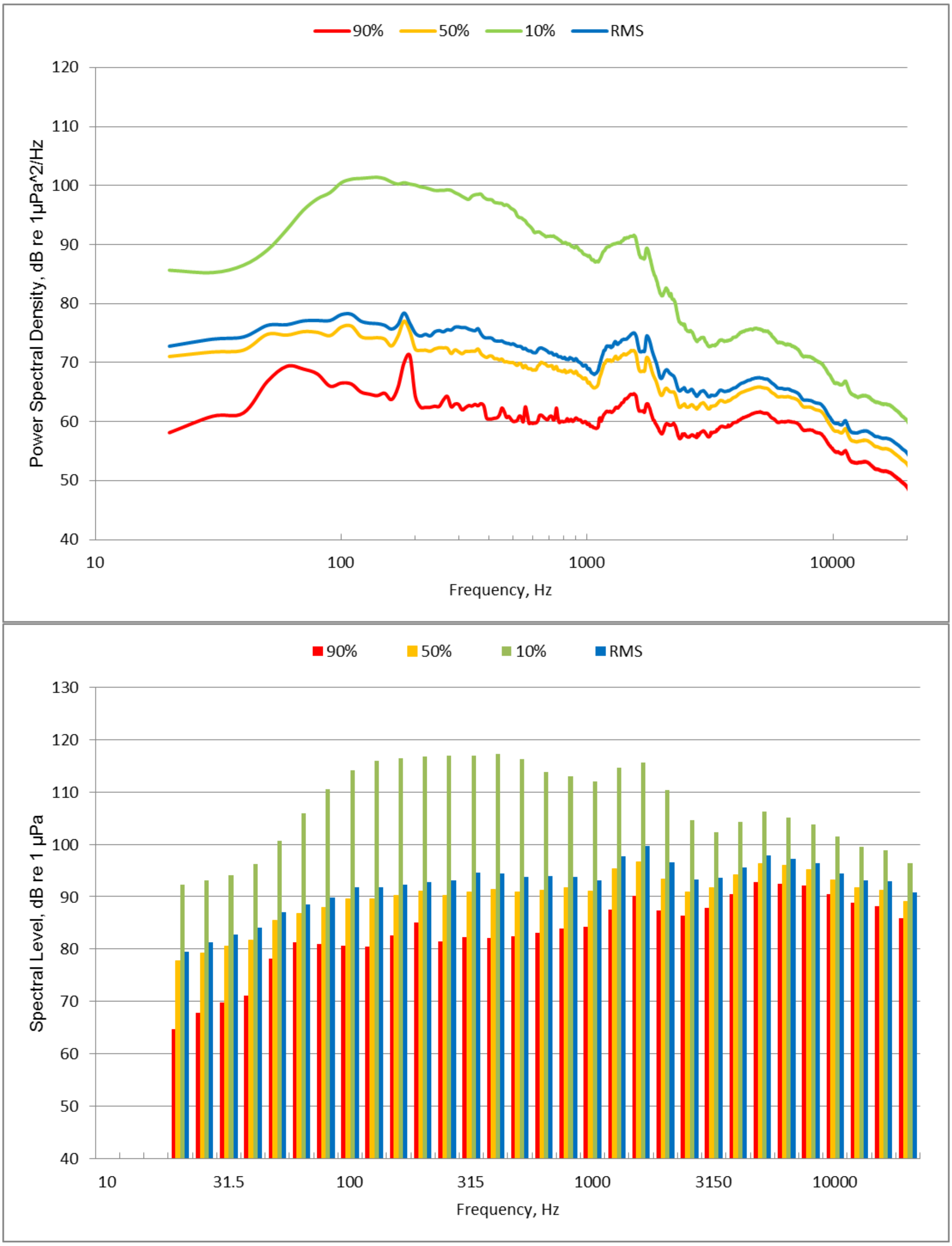


Figure 18 Spectral Levels for PSD (top) and 1/3 Octave Band Spectrum (bottom) for Location 1 – Port Central

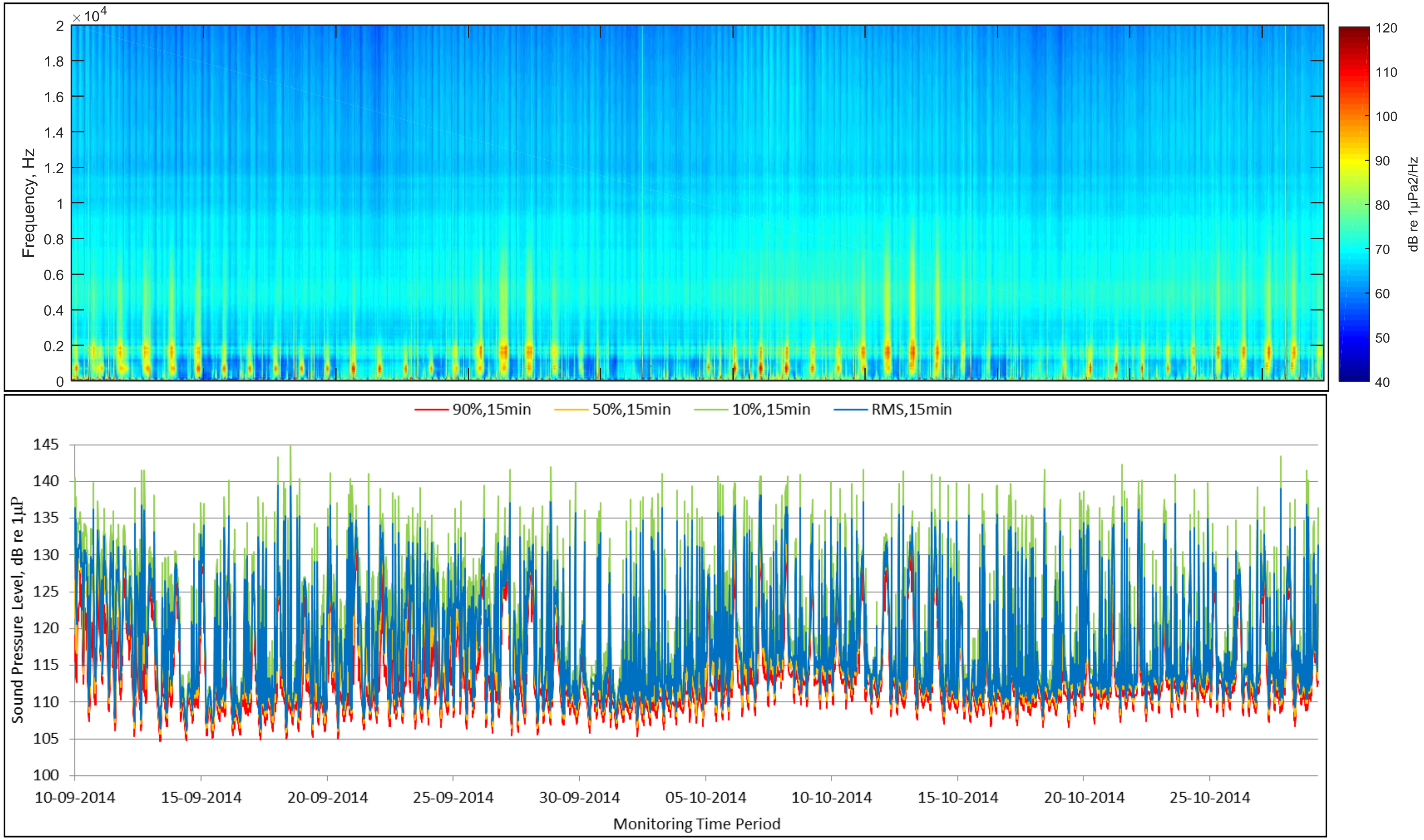


Figure 19 Spectrogram (top) and Overall Noise Levels within each 15-minute Signal Segment (bottom) for Location 2 – Port Channel/West Bank

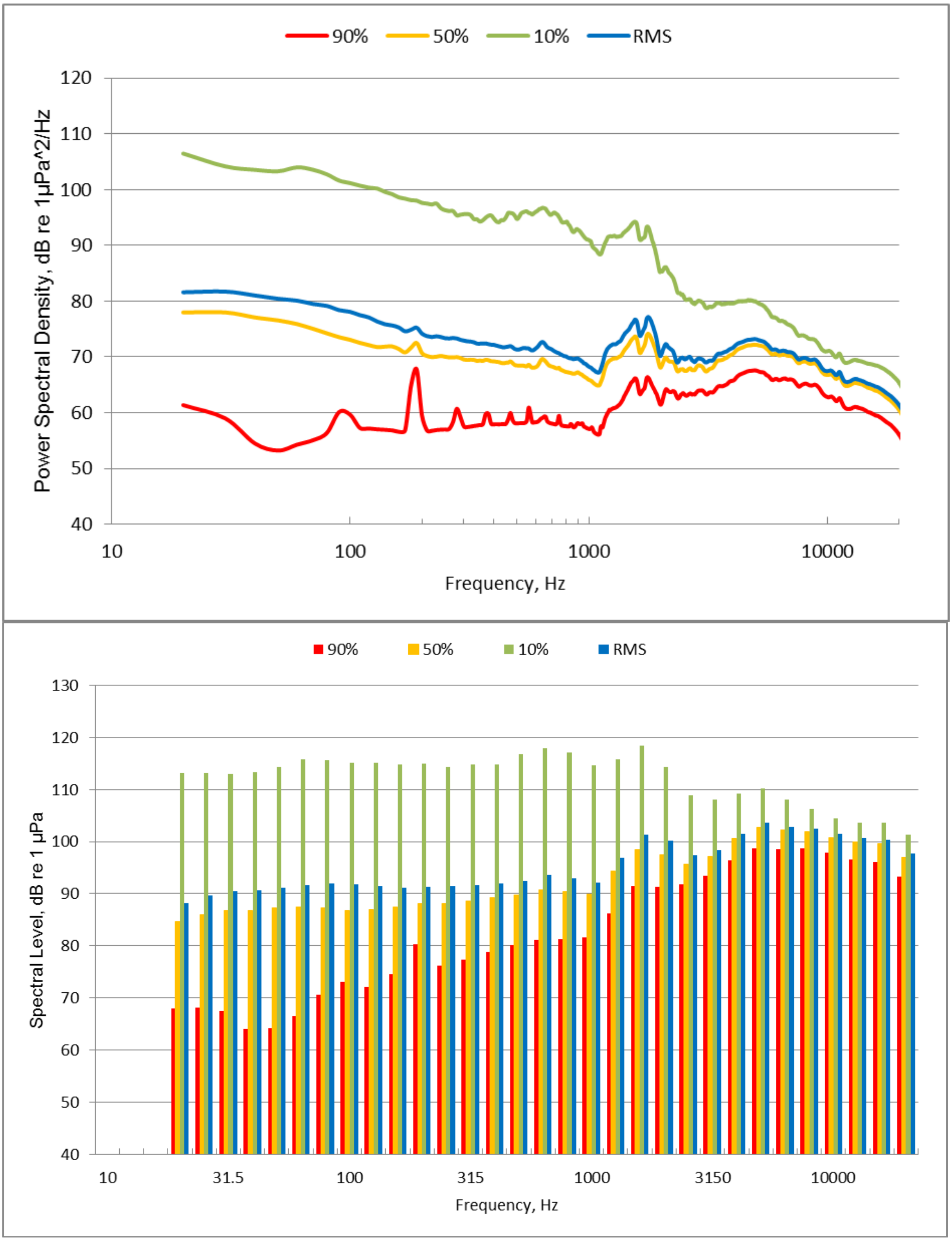


Figure 20 Spectral Levels for PSD (top) and 1/3 Octave Band Spectrum (bottom) for Location 2 – Port Channel/West Bank

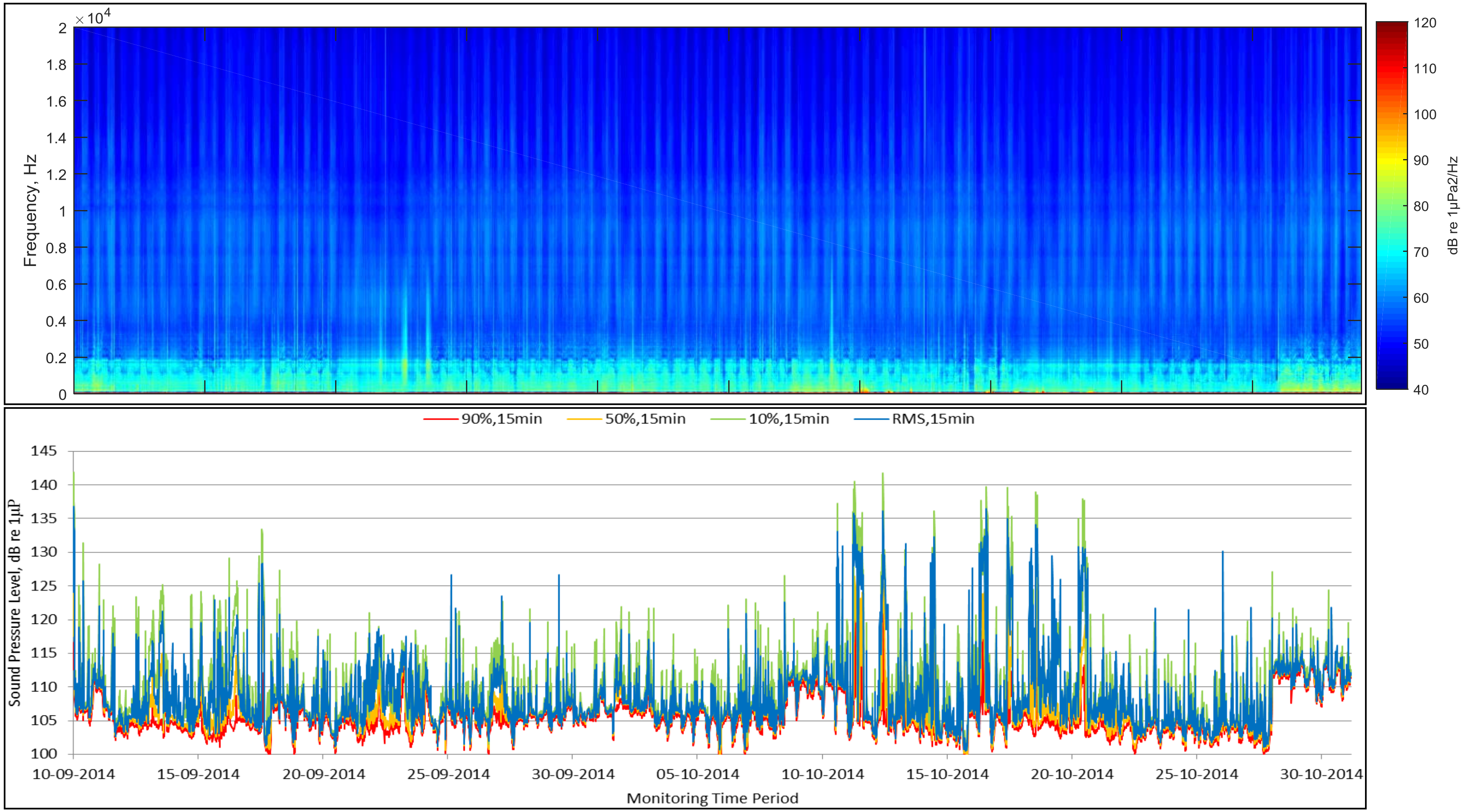


Figure 21 Spectrogram (top) and Overall Noise Levels within Each 15-minute Signal Segment (bottom) for Location 3 – Outer Harbour

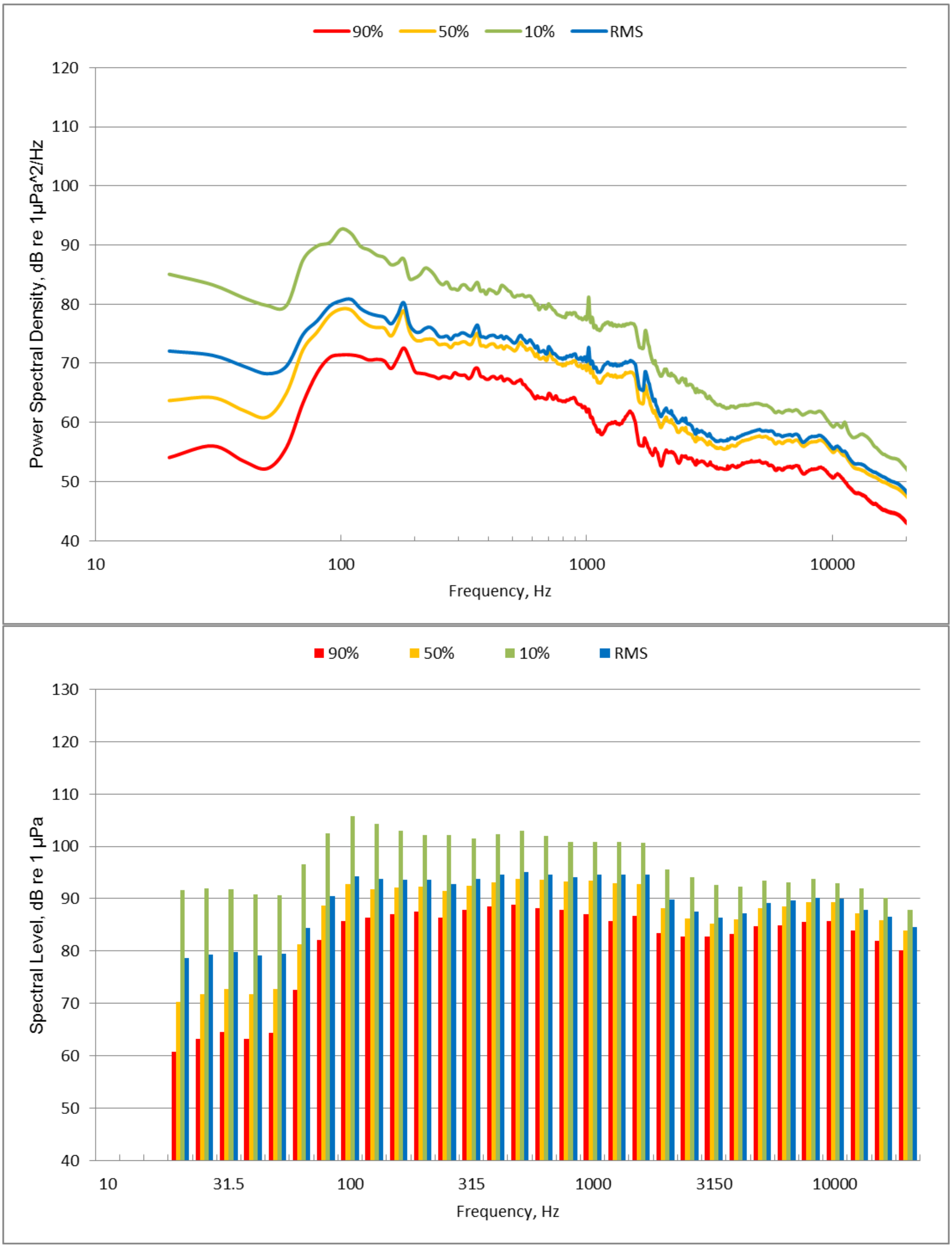


Figure 22 Spectral Levels for PSD (top) and 1/3 Octave Band Spectrum (bottom) for Location 3 – Outer Harbour

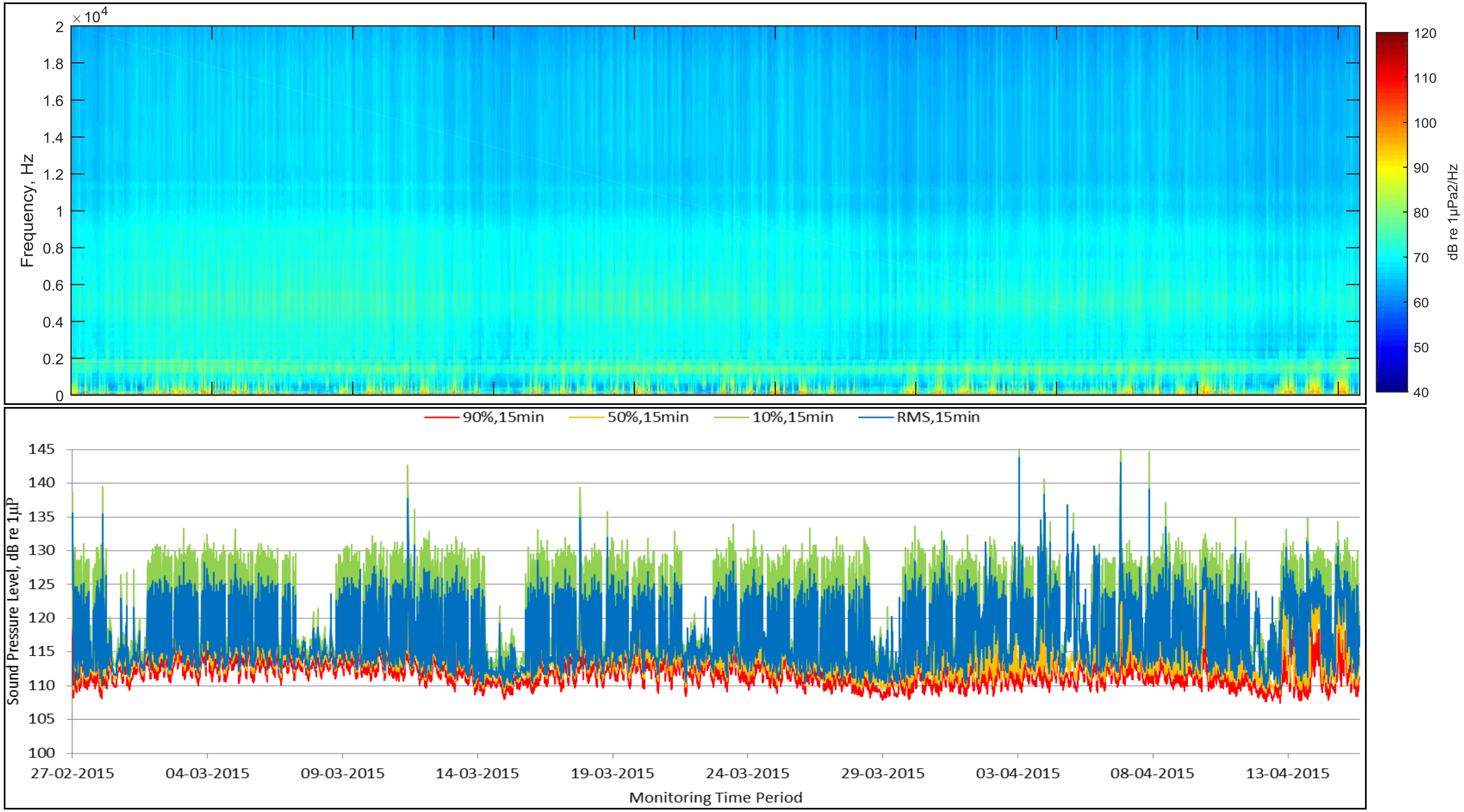
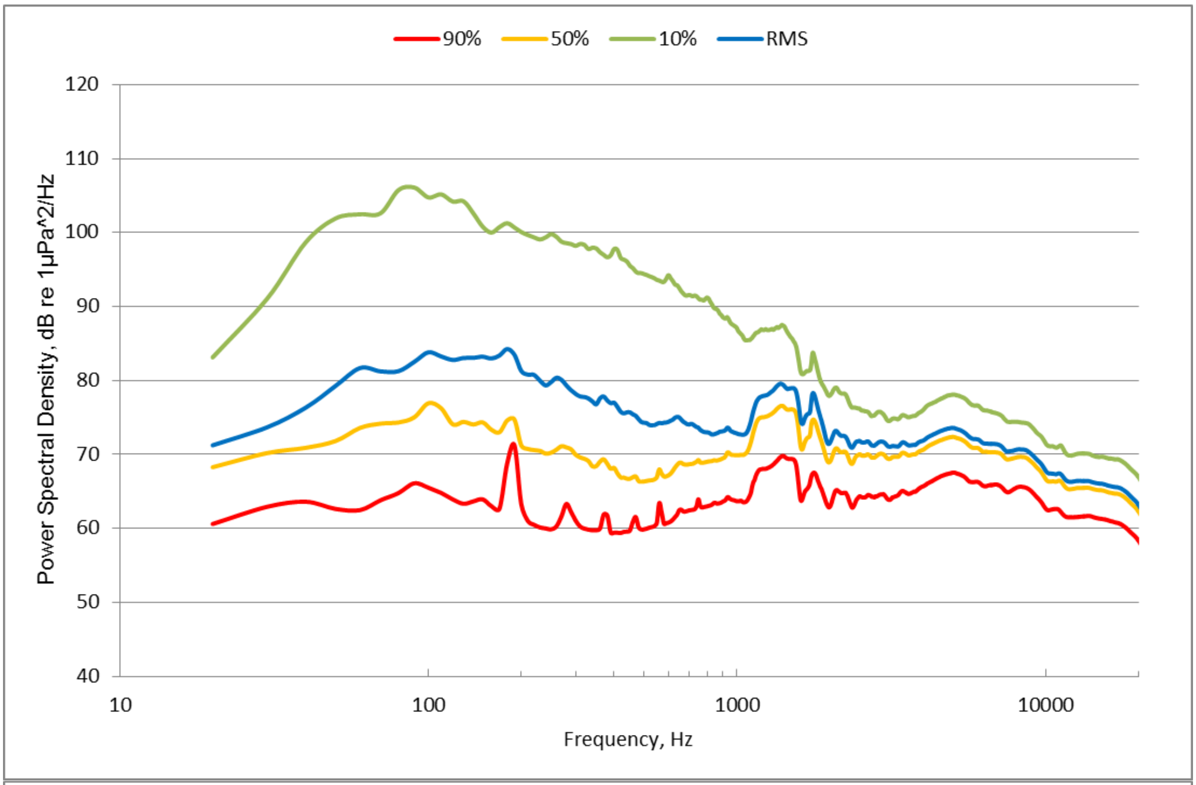


Figure 23 Spectrogram (top) and Overall Noise Levels within Each 15-minute Signal Segment (bottom) for Location 4 – Western Basin



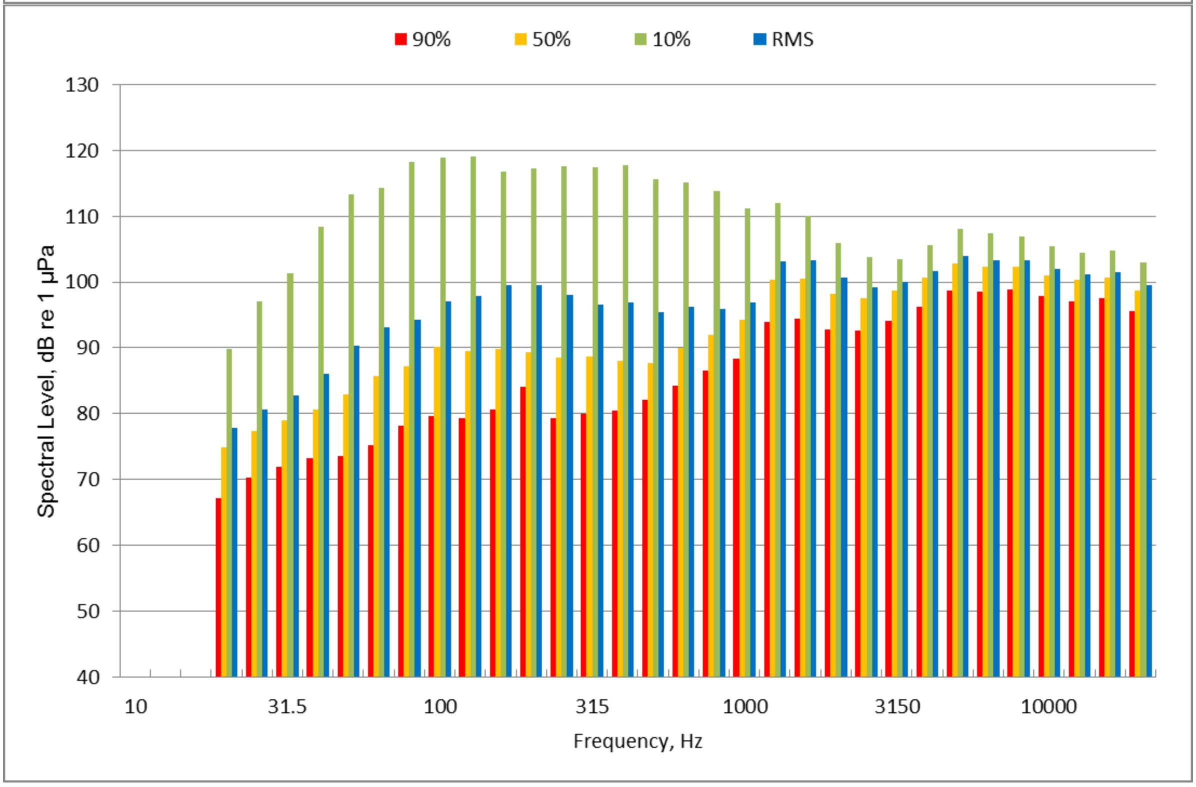


Figure 24 Spectral Levels for PSD (top) and 1/3 Octave Band Spectrum (bottom) for Location 4 – Western Basin

6 Underwater Noise Modelling Predictions

6.1 Modelling Input Parameters

6.1.1 Bathymetry

The bathymetry dataset covering the Port of Gladstone and the surrounding areas has been provided by BMT WBM, and was initially established for hydrodynamic modelling purposes. The bathymetry dataset is based on a Digital Elevation Model (DEM) of the Port and the surrounds which has been derived from various survey components, including:

- Detailed hydrographic survey data (in digital spot-height format) of the dredged channels, swing basins and berths as provided by the Hydrographic Services section of Maritime Safety Queensland (MSQ) and GPC;
- Detailed hydrographic survey data (in digital spot-height format) of broad areas of the Port as provided by the Hydrographic Services section of MSQ and GPC;
- Hydrographic survey data (in digital spot-height and contour format) and outlines of the edges of the shoreline, mangroves and saltpans used in producing Boating Safety Charts of the area as provided by the GIS and Cartography section of MSQ; and
- Typical levels have been adopted for the edges of the mangroves and saltpan areas for interpolation in those upper inter-tidal zones where no specific survey level data is available. The various data components have been combined and prioritised with respect to date and detail where there is overlap in producing a base DEM.

All bathymetry data contained within the dataset has been adjusted to a constant datum (i.e. Australian Height Datum (AHD)), using information provided by MSQ at various sites. The coverage of the dataset and the bathymetry contour map are shown in **Appendix B**.

The available tidal height information within the Port (GHD, 2009) indicates that the AHD is over 2m higher than the lowest astronomical tide (LAT), and approximately 2.5m lower than the highest astronomical tide (HAT). To consider the conditions most favourable to underwater sound propagation, the bathymetry data under the HAT tidal height condition is used as the bathymetry input for predicting the received noise levels for this study.

Table 12 Tidal Heights Relative to the Lowest Astronomical Tide (LAT) for the Western Basin Study Area of the Gladstone Port (GHD, 2009)

Tidal Heights	Relative height to the LAT, m
Australian Height Datum (AHD)	2.43
Highest astronomical tide (HAT)	4.97

6.1.2 Sound Speed Profiles

Temperature and salinity data required to derive the sound speed profiles were obtained from the World Ocean Atlas 2009 (Locarnini et al, 2010; Antonov et al, 2010). The hydrostatic pressure needed for calculation of the sound speed based on depth and latitude of each particular sample was obtained using Sanders and Fofonoff's formula (Sanders and Fofonoff, 1976). The sound speed profiles were derived based on Del Grosso's equation (Del Grosso, 1974).

Figure 25 shows typical seasonal sound speed profiles within both shallow water region and nearshore regions in close proximity to the Port.

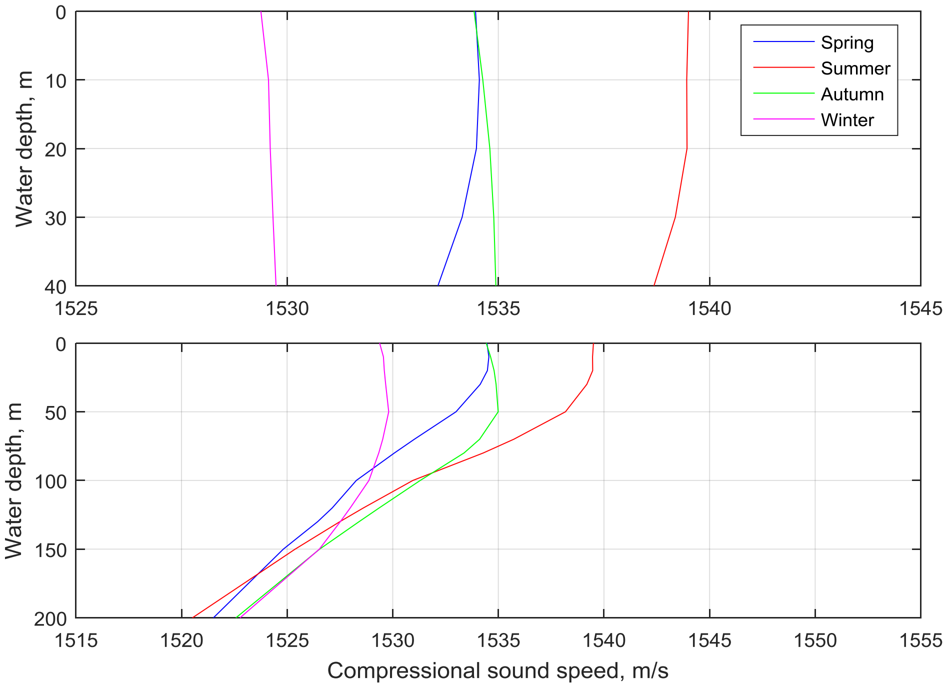


Figure 25 Typical Sound Speed Profiles within Shallow Water Regions (Top) and Nearshore Region (Bottom) in Close Proximity to the Port for Different Southern Atmosphere Seasons

The most significant seasonal differences in speed profiles occur within the mixed layer near the surface. The depth of the mixed surface layer varies with the seasons, and is deeper in the winter than in other seasons. The seasonal speed profiles indicate that the winter season is expected to be most favourable to propagation of sound for near-surface acoustic sources. With increasing depth below the mixed layer, the speed profiles of four seasons become very similar for the depth range below a few hundred metres.

The sound speed profile for the winter season has been used for all sound propagation modelling scenarios in this study, as this is anticipated to represent the worst-case scenario for efficient noise propagation from various noise sources considered.

6.1.3 Seafloor Geo-acoustic Models

The geological survey data collected along the Project areas to be dredged as presented in **Figure 26**, suggest that sand and gravel materials, mixed with silt and clay, dominate the seafloor surface layers down to a depth of approximately 10m.

No survey data is available for the deeper ground layers. As a conservative approach, more solid weathered rock granite is assumed as the ground material beneath the unconsolidated top sediment layer and above the bedrock. This assumption is generally in line with the seabed model established for similar port development within the region of northern Queensland (McCauley et al, 2012).

The overall seabed model parameters used for prediction purposes over the entire study area are detailed in **Table 13**. These include the geoacoustic properties and thickness for the top sandy sediment layer, and the weathered rock granite beneath overlaying the Basalt substrate. The geoacoustic properties for each layer of material are based on relevant literatures (e.g. Hamilton, 1980 and Jensen et al, 2000).

Table 13 Geoacoustic Properties for a Seabed Model with a Top Sandy Sediment Layer, a Weathered Rock Granite Substrate Layer and a Basalt Bedrock Layer

Seafloor Materials	Thickness, m	Density, ρ, ($kg.m^{-3}$)	Compressional Wave		Shear Wave	
			Speed, c_p, ($m.s^{-1}$)	attenuation, α_p, (dB/λ)	Speed, c_s, ($m.s^{-1}$)	attenuation, α_s, (dB/λ)
Loose sand (fluid)	10	1900	1650	0.8	-	-
Weathered rock granite	40	2400	2800	0.8	1400	0.2
Basalt	∞	2700	5250	0.1	2500	0.2

It is noted that the modelling algorithm (i.e. RAMGeo) proposed for this modelling study, as detailed in **Section 6.2**, is a fluid seabed model (all layers are modelled as fluid). Therefore, the seabed model inputs only consider the compressional wave parameters for the substrate layer materials as listed in **Table 13**, with the shear wave parameter values set as zeros.

The effect of representing a seabed model with elastic substrate layers as fluid substrates in the modelling has been investigated by examining the seafloor reflection coefficients for the two seabed models (elastic and fluid). **Figure 27** shows the reflection coefficient variations with grazing angle and frequency for the two seabed models, calculated using the plane-wave reflection coefficient program BOUNCE (Porter, 2007). Both seabed models include the same 10 m thick loose sand top layer. The bottom panel in the figure considers the sediment and substrate layer without elastic characteristics, while the top panel in the figure includes the elastic characteristics in the substrate layers.

As can be seen from the panel, the sediment layer is thin compared with the incident wavelength at low frequencies (below 100Hz), making the layer transparent to the incident wave. The reflection coefficient has an apparent critical angle slightly over 70 degrees. As frequency increases, the sediment layer gradually overtakes the substrate as being predominant in determining the reflection coefficient. The critical angle of the reflection coefficient is around 25 degrees for frequencies above 400Hz. The panel also reveals an evident angle-dependent resonance pattern, relating to the quarter and half-wavelength layer effects in the sediment layers. Apart from having similar features as shown in the bottom panel, the top panel has more complex features at the low frequency range below 200Hz. The corresponding loss mechanisms relate to the presence of the shear characteristics in the substrate layers (Li and Hall, 2012).

As evident from the two panels in **Figure 27**, the reflection coefficients are in general higher within the bottom panel than within the top panel, particularly for the grazing angles higher than approximately 25 degrees. Therefore, it is considered to be conservative to use the fluid seabed model with parameters described in **Table 13** for the modelling predictions.

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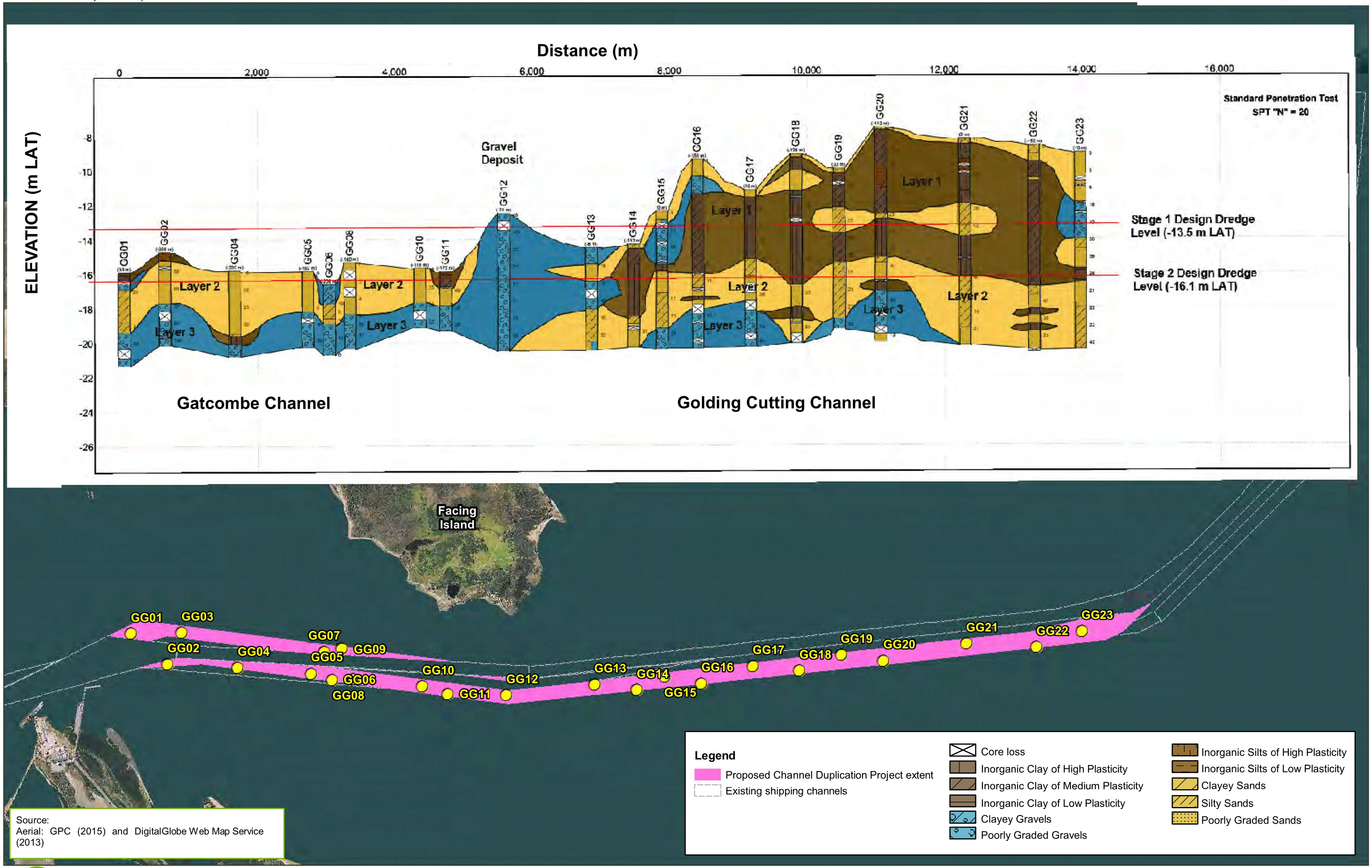

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0 625 1,250 Metres

Date: 13/11/2017 Version: 2 Job No: 237374

Coordinate system: GDA_1994_MGA_Zone_56

Gatcombe and Golding Cutting Channel Duplication Project

Figure 26 : Interpreted geological section for the combined Gatcombe and Golding Cutting Channels

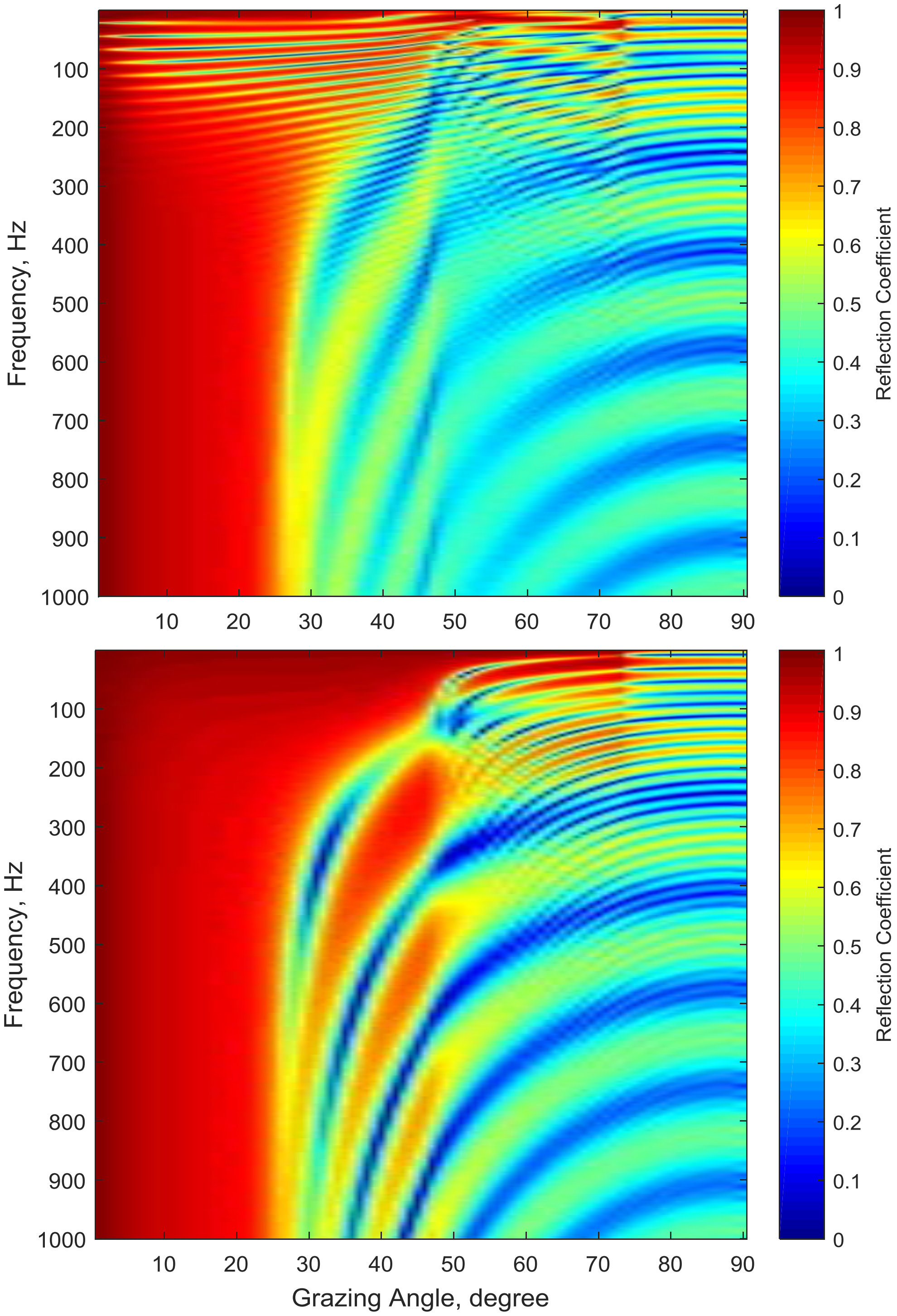


Figure 27 Reflection Coefficient Variations with Grazing Angle and Frequency for the Geoacoustic Model. Top Panel - Elastic Substrate Model; Bottom Panel - Fluid Substrate Model

6.2 Modelling Methodology and Procedure

Underwater noise propagation models predict the sound transmission loss between the noise source and the receiver. When the source level (SL) of the noise source based on is known, the predicted transmission loss (TL) is then used to predict the received level (RL) at the receiver location as:

$$RL = SL - TL \tag{6.2.1}$$

The fluid parabolic equation (PE) modelling algorithm RAMGeo (Collins, 1993) is used to calculate the transmission loss between the source and the receiver. RAMGeo is an efficient and reliable PE algorithm for solving range-dependent acoustic problems with fluid seabed geoacoustic properties. The noise sources were assumed to be omnidirectional and modelled as point sources.

With the known noise source levels, the received noise levels are calculated following the procedure outlined below.

1. One-third octave source spectral levels are obtained via reference spectral curves with their subsequent corrections based on their corresponding overall source levels;
2. Transmission loss is calculated using RAMGeo at one-third octave band central frequencies from 32Hz to 4kHz, based on appropriate source depths corresponding to relevant source scenarios. The acoustic energy of higher frequency range is significantly lower, and therefore is not included in the modelling.
3. Propagation paths for the TL calculation have a maximum range of 20km and bearing angles with a 5-degree azimuth increment from 0 degrees to 355 degrees around the source locations. The bathymetry variation of the vertical plane along each modelling path is obtained via interpolation of the bathymetry dataset;
4. The one-third octave source levels and transmission loss are combined to obtain the received levels as a function of range, depth and frequency; and
5. The overall received levels are calculated by summing all frequency band spectral levels.

To extend the modelling to consider other sound parameters, constant conversion factors have been applied between SEL per strike, RMS SPL and Peak SPL for the impact piling scenario. The conversion factors are based on measurements undertaken at the locations close to the piling rig, as described in the literature (Hastings and Popper, 2005). This approach does not take into account increasing distortion effects (including dispersion and interference) that occur when impulsive signals propagate over distances. In principal, this approach will result in increasing over-predictions of RMS SPL and Peak SPL at increasing distances from the sound source. Therefore, it is a conservative approach for the prediction of the RMS and Peak SPL parameters out of the SEL parameter.

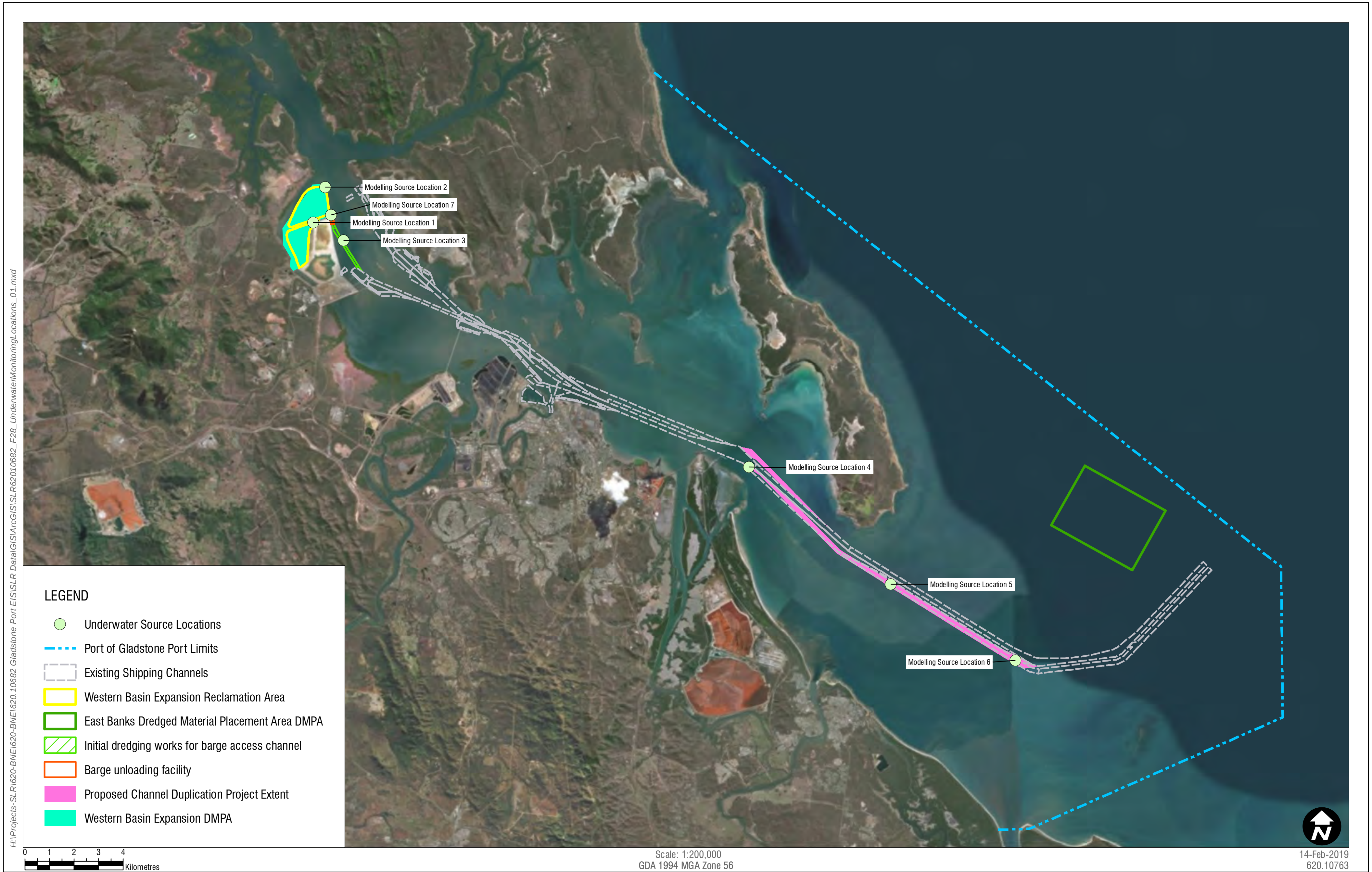
6.3 Modelling Scenarios and Source Locations

In order to understand the underwater noise impacts as a result of the relevant Project activities throughout both the construction and operational phases, a number of modelling scenarios have been established as listed in **Table 15**.

Seven representative source locations for the development activities during both construction and operational phases of the Project are identified and are presented in **Figure 28**, and detailed in **Table 14** with their corresponding coordinates, water depths and related modelling scenarios.

Table 14 Modelled Source Locations, the Corresponding Water Depths and Related Modelling Scenarios

Location #	Easting, m	Northing, m	Water Depth, m	Scenario #
1	3.1214×10^{5}	7.3704×10^{6}	4. 65	1
2	3.1280×10^{5}	7.3718×10^{6}	6.06	2
3	3.1350×10^{5}	7.3698×10^{6}	12.80	6
4	3.3000×10^{5}	7.3606×10^{6}	19.88	7 and 8
5	3.3600×10^{5}	7.3555×10^{6}	14.11	4
6	3.4080×10^{5}	7.3527×10^{6}	13.80	5
7	3.1315×10^{5}	7.3707×10^{6}	13.02	9



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Port of Gladstone Channel Duplication
Underwater Noise Modelling Source Locations

FIGURE 28

Table 15 Underwater Noise Modelling Scenarios

Scenario #	Project stage / phase	Project activity and justification for modelling location	Underwater noise assessment scenarios	Noise source / Equipment (number)
1	Bund wall construction at WBE reclamation area (southern area)	Construction of reclamation bund walls (marine environment) involving the placement of core material Northern bund wall location to be modelled is located in the marine environment adjacent to intertidal seagrass meadows and closer to The Narrows than other areas	Modelling underwater noise from the WBE reclamation area construction activities, primarily from rock dumping in the marine environment	Rock fill/dumping only
2	Bund wall construction at WBE reclamation area (northern area)			
3	Construction of the BUF	Use of a sheet piling rig to create U shaped barge dock adjacent to the WB reclamation area Works are proposed the marine environment adjacent to intertidal seagrass meadows and close to The Narrows	Vibratory sheet piling and rock dumping at the BUF location	Sheet piling Rock dumping
4	CSD and TSHD dredging for the barge access channel and transfer of dredged material into the WB reclamation area	CSD and TSHD dredging for the barge access channel	Modelling underwater noise from the small CSD and TSHD operating during initial dredging works for the barge access channel	CSD (1) (small sized), and TSHD (1) (small sized dredger (most likely the Brisbane TSHD))

5	TSHD dredging of Gatcombe Channel (northern end)	TSHD operation at an area to be dredged, i.e. near GC02 geotechnical borehole location, which is located adjacent to the South Trees Island seagrass meadows used by dugongs and turtles	Modelling underwater noise from the Gatcombe Channel dredging and barges (pushbusters (4) and tug (1)) operating during the Stage 2 campaign, primarily from dredging operations: 1) pushbusters assisting barges 2) travelling to BUF 3) travelling back to shipping channels 4) waiting for barges to be filled by TSHD	TSHD (1) (large sized dredger (e.g. Rotterdam)) Barges (4) Pushbusters (4) Tug (1)
6	TSHD dredging of Golding Cutting Channel (middle area)	TSHD operation at an area to be dredged, i.e. near GC16 geotechnical borehole location, which is located adjacent to seagrass meadows potentially used by dugongs and turtles	Modelling underwater noise from the Golding Cutting Channel dredging and barges (pushbusters (4) and tug (1)) operating during Stages 1 and 2 campaigns, primarily from dredging operations	
7	TSHD dredging of Golding Cutting Channel (southern end)	Modelling underwater noise from the Golding Cutting Channel dredging during Stages 1 and 2 campaigns, primarily from dredging operations	Modelling underwater noise from the TSHD and barges (pushbusters (4) and one tug) operating during Stages 1 and 2 campaigns, primarily from dredging operations	
8	Navigation aid installation - Golding Cutting Channel (mid-point of channel length)	Installation of repositioned navigation aid that is located closest to seagrass meadows potentially used by dugongs and turtles	Modelling underwater noise from the installation of a relocated navigation aid for Golding Cutting Channel, primarily from the impact piling activity during the installation (only one pile to be modelled)	Barge (1) Junttan hydraulic impact hammer (1)
9	Project operational maintenance dredging	TSHD operation in the duplicated Golding Cutting Channel adjacent to seagrass meadows potentially used by dugongs and turtles (i.e. near GC16 geotechnical borehole location	Modelling underwater noise from the TSHD maintenance dredging activities during the operational phase	TSHD (1) (small sized dredger (most likely the Brisbane TSHD))

6.4 Details of Modelled Noise Sources and Source Levels

As described in **Table 15**, the noise modelling prediction process includes seven major noise generating activities/equipment. This section details the principal noise generating mechanisms of these major noise sources, and their noise spectral and temporal characteristics. **Table 16** summarises these modelled underwater noise source details. The source levels of these activities are either based on SLR's historical field measurements, or from relevant databases recorded in the literature. Full details of modelled source levels (i.e. sound exposure level (SEL), dB re 1µPa^2·S including the 1/3 octave spectra and overall levels) are documented in **Appendix C**.

Table 16 Summary of Modelled Underwater Noise Source Details

<table>
<tr><th>Noise source</th><th>Noise generating mechanism</th><th>Modelled point source depth</th><th>Noise Type</th><th>Reference</th></tr>
<tr><td>Rock fill/dumping</td><td>Rock tumbling and grinding</td><td>Near seafloor</td><td>Non-pulses, transient</td><td>Wyatt (2008)</td></tr>
<tr><td>Large sized TSHD (e.g. Rotterdam)</td><td rowspan="2">Underwater pump and pipe, Draghead dragging</td><td rowspan="2">Deeper section of the water column</td><td>Non-pulses, continuous</td><td rowspan="2">CEDA (2011)
de Jong et al (2010);
WODA (2013);
Jones et al (2016)</td></tr>
<tr><td>Small sized TSHD (likely the Brisbane TSHD)</td><td>Non-pulses, continuous</td></tr>
<tr><td>Medium sized CSD (e.g. Eastern Aurora)</td><td>Underwater pump and pipe,
cutting head digging</td><td>Deeper section of the water column</td><td>Non-pulses, continuous</td><td>BPM (2013);
CEDA (2011)
Jones et al (2016)</td></tr>
<tr><td>Junttan hydraulic impact hammer</td><td>Impact piling</td><td>Mid water column</td><td>Multiple pulses</td><td>McCauley et al (2012)
Kent et al (2009)</td></tr>
<tr><td>Supporting vessels including navigation aid installation, supporting barge, pushbusters and tug</td><td>Propeller/thruster</td><td>Near surface</td><td>Non-pulses, continuous</td><td>Wyatt (2008)</td></tr>
<tr><td>Vibratory sheet piling</td><td>Vibratory hammering</td><td>Mid water column</td><td>Non-pulses, continuous</td><td>Oestman et al (2009)</td></tr>
</table>

Rock Fill/Placing

Underwater noise generated by rock dumping activities is mainly as a result of the splash, tumble and grinding of rocks during the placement process. Generally, noise from one rock placement event has a slow signal rise time and then reaches its peak level, then followed by a slow drop in levels. Placement activities can be regarded as a sporadic occurrence.

The overall source level and the one-third octave spectra have been obtained from Wyatt (2008) for dredging and rock placement of boulders by a TSHD. Dredging is undertaken with a TSHD, placement of rock for the bund wall will be done by B-Doubles.

Trailer Suction Hopper Dredger (TSHD) and Cutting Suction Dredger (CSD)

A TSHD uses hopper and a CSD uses pipes to transport entrained material from the seabed into reclamation area, as shown in the schematic overviews for the two typical dredgers in **Figure 29** (CEDA, 2011). Potential noise sources from dredging activities by the two dredgers are also presented in the figure.

For a TSHD, the major sources generating continuous noise emissions during operation are underwater pumps / piping, as well as from the draghead dragging seabed materials during the dredging operations. For a CSD, the major noise sources are underwater pumps and piping, and the cutting head digging the seafloor.

The spectral curve for the TSHD was taken from measurement data for the large sized TSHD Maasvlakte 2 with total power 30,000 kilowatt (kW) (de Jong et al, 2010; WODA, 2013), and then converted to the spectral curve for the large sized TSHD to be used (e.g. Rotterdam) with high total power of 27,470kW while dredging in channels or small sized TSHD with total power below 5,000kW, based on the following power conversion factor (CF) (Jones et al, 2016):

$$CF = 20log10\ (P_{TSHD1}/\ P_{TSHD2}) \qquad (6.4.1)$$

Similarly, for the CSD, the spectral curve for the CSD was taken from field data collected by SLR for the large sized CSD Athena amd Al Mahaar (total installed power 11,224 KW) (BPM, 2013), and converted to the levels for the medium sized CSD (e.g. Eastern Aurora, total power 7,426 KW). It should be noted that small sized CSD is proposed for the initial barge access channel dredging works, and it is considered as conservative to use medium sized CSD noise data for noise prediction and the subsequent impact assessment.

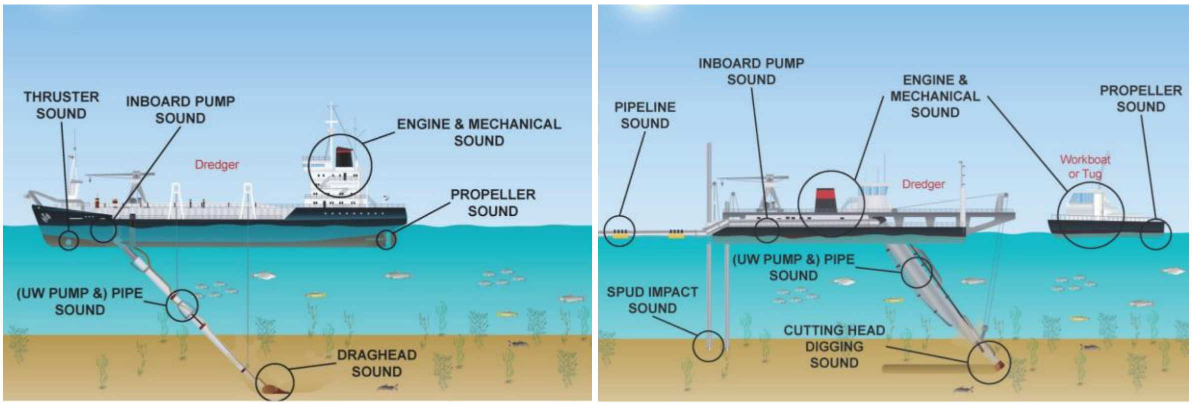

Figure 29 Noise Sources from a Typical TSHD (left) and CSD (right) (CEDA, 2011)

Navigation Aid Impact Piling

Piling noise associated with navigation aid installation using the proposed JUNTTAN hydraulic impact hammer (JUNTTAN HHK 10S) is impulsive in character, with a designed blow rate in the order of 30 to 100 impacts per minute. The maximum hammer energy for the JUNTTAN impact hammer is 147 kilonewton metre (kNm).

The source levels (overall and one-third octave spectral levels) for the proposed piling activities are based on reference piling signals from a 49kNm impact hammer (Kent et al, 2009) which were averaged to account for hammer energy variability. To scale the reference piling signal to a signal corresponding to the proposed JUNTTAN hydraulic impact hammer, it has been assumed that the underwater noise emission from the pile from a hammer strike is proportional to the energy delivered to the pile, according to the following scale factor (SF):

$$SF = 10log_{10}\ (E_1 / E_{ref}) \qquad (6.4.2)$$

Where E_1 *is* the impact hammer energy delivered to the proposed navigation aid piles and E_{ref} the piles corresponding to the reference signal case, respectively. As such, the SF to be applied to the reference piling signal is 4.8 dB.

As a worst-case consideration, it is assumed the hydraulic impact hammer is to be operated with a maximum impact rate of 100 strikes per minute.

Supporting vessels including barge, pushbusters and tug

The underwater noise produced by supporting vessels, including barge operation supporting the relocation and installation of the navigational aids, pushbusters supporting the dredging operations and tug for sheet piling, is predominantly generated by the propeller and thruster of the vessels.

On-board vibration energy from crane operations for the navigational aids supporting barge is also expected to be transmitted via the barge hull structure and re-emitted into the water, particularly for vibration energy in the low-frequency range.

The source levels for the supporting barge have been obtained from Wyatt (2008) based on the operation of a pipe-lay barge (*Castoro*) within a shallow water environment. The source levels for the tug supporting sheet piling was assumed as similar to the pushing gravel barge (Wyatt, 2008) with the same spectral content as the navigational aids supporting barge. Pushbusters from Van Oord are proposed to be used for supporting dredging operations, each with a propulsion capacity of 2 x 1,825 kilowatt. Their source levels are obtained by applying a SF of -1.4 dB (as of equation (6.4.2)) to the source level of the navigational aids supporting barge.

Vibratory sheet piling

The sheet pile vibratory driver, normally being hydraulically powered, consists of contra-rotating eccentric masses which are in a housing attached to the sheet pile head. The majority of vibratory pile drivers operate at frequency between 20 and 40 Hz, and can generate centrifugal forces of up to 4,000 kN (Wyatt, 2008).

In contrast to impact piling noise, vibratory piling noise is continuous in nature. However, it has broadband spectral content which is similar to the impact piling noise.

The source levels for vibratory sheet piling are assumed based on a near-source noise measurement for a 0.6-m AZ steel sheet vibratory piling installation within a shallow water environment (Oestman et al, 2009).

7 Modelling Results and Impact Assessment

7.1 Modelling Prediction Results

The noise contour maps for all nine modelling scenarios as listed in **Table 15** are presented in **Appendix D**. The contour maps are the modelling results based on SEL source levels in dB re 1µPa^2·S as given in **Appendix C**.

For impact piling noise from aid navigation installation, the additional two relevant SPL parameters, (i.e. RMS SPL and Peak SPL), are derived based on conservative conversion factors of 15dB and 28dB, respectively, applied to the predicted SEL values for the receiving distances closer to the source (<2km). These adjustments have been derived from historical measurements described in the literature (Hastings and Popper, 2005). For receiving distances further away from the source location (>10km) where significant pulse signal dispersion is expected, a conservative conversion factor of 10dB is applied to the predicted SEL values to derive the parameter RMS SPL.

To estimate the impact ranges for marine mammal species conservatively, no frequency weightings have been applied to the modelled SEL levels.

For other non-pulsed events it is assumed that the predicted SEL levels are equivalent to their corresponding RMS SPL levels, considering the consistency and longer durations that are typical for these events.

Based on the noise modelling prediction results, the zones of impact from the impact piling noise (i.e. modelling scenario #8) for marine mammals, sea turtles/dugongs and fish species are summarized in **Table 17**, **Table 18** and **Table 19,** respectively. The zones of impact from all other eight modelling scenarios involving non-pulse noise events are provided in **Table 20**.

7.2 Impact Assessments and Discussions

7.2.1 Piling Activities

The most significant noise impacts from the development activities on the assessed marine fauna species are from impact piling events during the installation of the navigation aids, due to the high piling source noise emissions, and the impulsive characteristics of piling noise.

Marine Mammals

The summary of zones of impact for marine mammals in **Table 17** suggest that noise from a single piling strike would not cause injury (PTS-onset) for assessed marine mammal species. However, due to cumulative noise impact, the zones of impact for PTS-onset extend from up to 50m for 100 strikes (1-minute duration) to up to 310m for 1,000 strikes (10-minute duration). Piling strikes in the order of 6,000 (1-hour duration) can cause PTS-onset for assessed animals that remain within a distance of up to 1.4km from the piling location for that duration.

Noise from one single piling strike is predicted to cause TTS-onset for marine mammals within 18 m from the source. Marine mammals remaining within a distance of 120m from the piling location are predicted to experience TTS-onset due to the cumulative noise exposure of 10 piling strikes. The zones of TTS-onset increase up to 700m, to 2.2km and 6.0km for piling exposure duration of 1 minute (100 strikes), 10 minutes (1,000 strikes) and 1 hour (6,000 strikes), respectively.

It should be noted that the zones of impact due to the cumulative SEL levels are based on worst case assumptions, including that marine mammals remain within certain distances from the source location for the defined period of time. In reality, high level impulsive noise such as piling noise would be expected to cause animals to avoid or move away from the noise source.

The zone of impact for possible behavioural changes is predicted to be up to 3.4km from the impact piling location.

Marine Turtles and Dugongs

As summarised in **Table 18**, noise from one single piling strike could potentially cause mortal injury for marine turtle and dugongs within a distance of up to 35m from the piling location. Avoidance of the source may occur at a distance of up to 600m and a behavioral changes zone is identified at a distance of up to 2km from the piling location.

An extended duration of piling noise exposure at further distances can also potentially cause mortal injury for sea turtles and dugongs. It is predicted that the maximum zone of impact for 1-hour exposure duration (6,000 strikes) can be up to 160m from the piling location.

Fish Species

As for marine turtles and dugongs, noise from one single piling strike can potentially cause injuries for fish species within a distance of up to 35m from the piling location, as summarised in **Table 19**. Noise from one piling strike is also predicted to cause avoidance at a distance of up to 3.4km and behavioral changes at a distance of up to 5.5km from the piling location for fish species.

The zones of impact for cumulative SEL levels are up to 80m for injuries with exposure duration of 10 minutes (1,000 strikes). If the exposure duration increases to 1 hour (6,000 strikes), then a maximum distance from the source location of up to 270m is predicted for potential mortal injury, and up to 500m for recoverable injury. The threshold level for TTS-onset is much lower for fish species compared with physical injury thresholds, and therefore the TTS zones of impact are much bigger for the same exposure duration. For example, an exposure duration of 10-minutes (1,000 strikes) has a zone of TTS impact of up to 1.8km, and an 1-hour exposure duration (6,000 strikes) is predicted to have a zone of TTS impact of up to 4.2km from the piling location, respectively.

7.2.2 Non-pulse Development Activities

As summarised in **Table 20**, scenarios with non-pulse development activities such as rock dumping, dredging operations, supporting vessels and vibratory sheet piling are not expected to result in significant adverse noise impacts to sea turtles/dugongs and fish species. This is due to the relatively low noise emissions from these activities. For marine mammal species, these activities only can possibly cause behavioural changes and the assessed impact zones range from 3.5km to 4.5km from the source locations for rock dumping, medium sized CSD and small sized TSHD dredging activities, 5.5 km for the vibratory sheet piling at the BUF, and can be up to 12km for large sized TSHD dredging activities.

7.2.3 Implications from Baseline Noise Environment

Comparing the behavioural disturbance assessment criteria of RMS SPL 120 dB re 1µPa with the existing baseline noise environment as detailed in **Section 5.3**, it can be concluded that within the inner harbour areas the criterion level is significantly lower than frequently occurring baseline noise events, particularly during the day time period when the majority of existing marine operations and weather events normally occur.

A received RMS SPL 130 dB re 1µPa would be more comparable with the majority of baseline noise events within the inner harbour area. If this noise level were used as a less conservative disturbance threshold, the zones of impact for marine mammal species would be reduced to a maximum distance of less than 1km from rock dumping, medium sized CSD and small sized TSHD dredging activities, a maximum distance of 3.0km from vibratory sheet piling, and a maximum distance of less than 5km from the large sized TSHD dredging activities.

For outer harbour areas, however, the recorded baseline noise levels are predominantly lower than the assessment criteria level of RMS SPL 120dB re 1µPa and therefore in this area RMS SPL 120 dB re 1µPa is an appropriate threshold for use as an indicator of potential behavioural disturbance.

Table 17 Zones of Impact (Maximum Distances from Source to Impact Threshold Levels) from Navigational Aid Impact Piling Noise – Marine Mammals

Piling noise impacts on marine mammals (all cetaceans)	Zones of impact – maximum distances from source to impact threshold levels							
	Criteria – Peak SPL, dB re 1µPa	Zones of Impact, m	Criteria – SEL, dB re $1\mu Pa^2 \cdot S$	Zones of impact, m (per strike no./time period)				
				1	10	100 (1min)	1000 (10min)	6000 (1hr)
PTS on-set	230	N/A	198	N/A	<10	50	310	1,400
TTS on-set	224	<10	183	18	120	700	2,200	6,000
Behavioural changes	160 (RMS SPL, dB re 1µPa)	3,400	N/A	N/A				

Table 18 Zones of Impact (Maximum Distances from Source to Impact Threshold Levels) from Navigational Aid Piling Noise – Marine Turtles/Dugongs

Piling noise impacts on sea turtles and dugongs	Zones of impact – maximum distances from source to impact threshold levels							
	Criteria – Peak SPL, dB re 1µPa	Zones of Impact, m	Criteria - SEL, dB re $1\mu Pa^2 \cdot S$	Zones of impact, m (per strike no./time period)				
				1	10	100 (1min)	1000 (10min)	6000 (1hr)
Mortality and potential mortal injury	207	35	210 (cum)	N/A		<10	30	160
Avoidance	N/A	N/A	164 (per strike)	600				
Behavioural changes			155 (per strike)	2,000				

Table 19 Zones of Impact (Maximum Distances from Source to Impact Threshold Levels) from Navigation Aid Piling Noise – Fish Species

Piling noise impacts on fish species	Zones of impact – maximum distances from source to impact threshold levels							
	Criteria – Peak SPL, dB re 1µPa	Zones of Impact, m	Criteria - SEL, dB re 1µPa^2·S	Zones of impact, m (per strike no./time period)				
				1	10	100 (1min)	1000 (10min)	6000 (1hr)
Mortality and potential mortal injury	207	35	207 (cum)	N/A			70	270
Recoverable injury			203 (cum)	N/A	<10	20	80	500
TTS	N/A	N/A	186 (cum)	10	80	450	1,800	4,200
Avoidance			150 (per strike)	3,400				
Behavioural changes			145 (per strike)	5,500				

Table 20 Zones of Impact (Maximum Distances from Source to Impact Threshold Levels) from Non-pulses Development Activities

Scenario #	Project stage / phase	Noise source / Equipment (number)	Zones of impact (in m) - maximum distances from source to impact threshold levels		
			Marine mammals – behavioural changes	Sea turtles and dugongs	Fish species - TTS
1, 2 and 3	WBE reclamation area (southern and northern), and BUF construction	Rock fill/dumping only	4,000	N/A	N/A
3	BUF construction	Vibratory sheet piling	5,500		
4	Initial dredging works – CSD and TSHD dredging of the barge access channel and placement into the WB reclamation area	CSD (1) (small sized dredger), and TSHD (1) (small sized dredger (most likely the Brisbane TSHD))	4,500 for CSD, and 3,500 for TSHD		
5, 6 and 7	TSHD dredging of Golding Cutting Channel (northern end, middle area and southern end)	TSHD (1) (large sized dredger (e.g. Rotterdam))	12,000		
8	Project operational maintenance dredging	TSHD (1) (small sized dredger (most likely the Brisbane TSHD))	3,500		

8 Monitoring and Mitigation Measure Recommendations

8.1 Acoustic Monitoring

Passive acoustic measurement and monitoring will be conducted during the Project construction and operation phases. This monitoring would enable the following:

- Noise model verification. A program of attended measurements would verify the modelling undertaken to date, and enable confirmation or revision of the estimated zones of impact. Attended noise measurements will be undertaken in close proximity to the noise sources to obtain the source spectra, and at various distances and directions from the noise sources to verify the modelling predictions for noise propagation.
- Soundscape variation investigation prior to Project commencement. Noise monitoring prior to Project activities will be undertaken at the same locations as for the baseline noise monitoring as detailed in Section **5.2.1**, so that the variations of the soundscape within the Project area as a result of the period of time between baseline and commencing Project activities can be investigated. The pre-Project noise monitoring results will be incorporated into the Dredging EMP and Project EMP review and updating process prior to commencing Project activities.

8.2 Mitigation Measures for Marine Mammals

Based on the modelling predictions and the subsequent impact assessment results as detailed in **Section 7.2**, there is potential for unmitigated impact piling to install navigational aids to cause injuries to marine mammals. Therefore, specific underwater noise mitigation measures will be implemented for piling noise.

Guidance on procedures for piling noise mitigation has been taken from the Government of South Australia's *Underwater Piling Noise Guidelines* (2012), as illustrated in **Figure 30**.

The South Australian guideline includes a framework for management and mitigation of underwater noise from piling, incorporating:

- Safety zones – these are observation and shut-down zones sized based on the likely noise levels produced by the piling activity.
- Standard management and mitigation procedures – these procedures are recommended for all piling activities, irrespective of location and time of year, when marine mammal species may potentially be present within the noise footprint of the piling activity.
- Additional management and mitigation procedures – to be used when the impacts of the piling activity on listed marine mammal species are likely to be significant.

The underwater noise impact assessment described in this report has identified that vulnerable or endangered marine mammals may potentially be present within the piling noise footprint. In light of the large offset distances to sensitive habitat areas, and the temporary short duration of impact piling activities, the behavioural impacts on listed species are considered unlikely to be significant. Therefore, the mitigation measures to be implemented for this Project are standard management and mitigation measures intended to prevent injury to marine mammals.

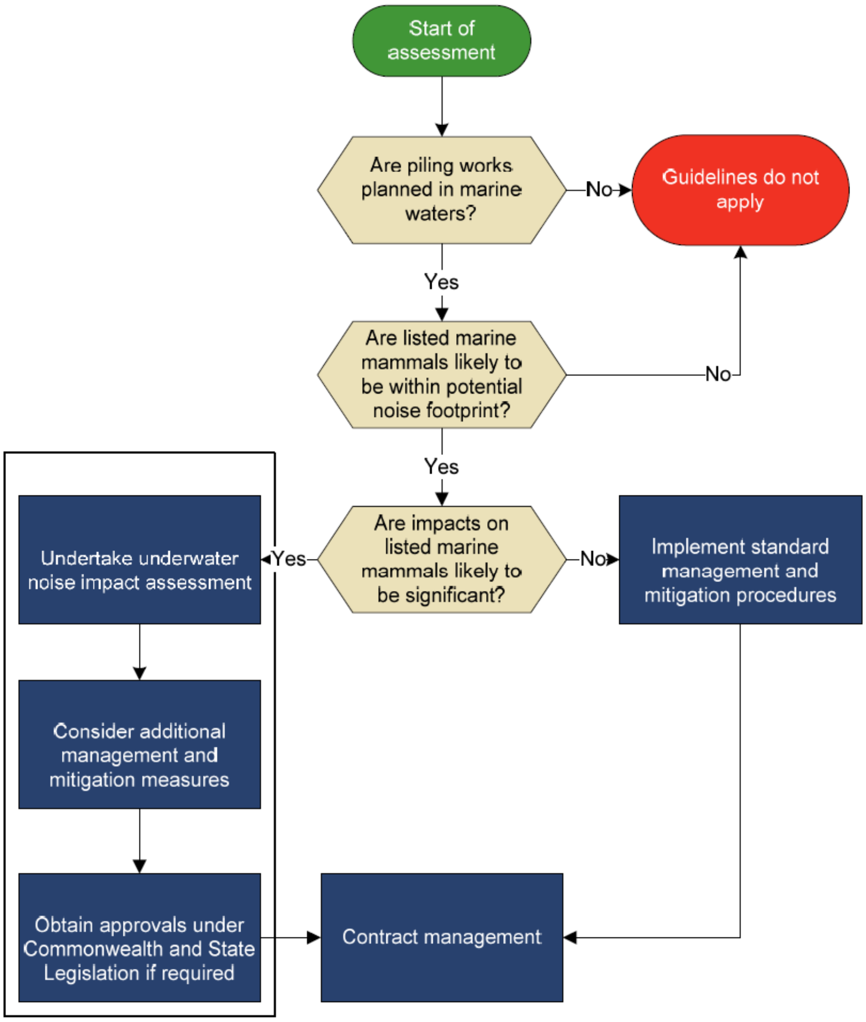

Figure 30 Noise Impact Assessment and Mitigation Flow Chart (Government of South Australia, 2012)

8.2.1 Safety Zones

Safety zones would be applied in two stages around each piling location, an observation zone and a shut-down zone. In the observation zone, the movement of marine mammals would be monitored to identify any approach to the shut-down zone. In the event that a marine mammal is sighted within or appears to enter the shut-down zone, piling activities would be stopped as soon as reasonably practical. The use of safety zones aims to minimise the potential for injury, but does not aim to prevent behavioural responses. Avoidance of the noise source is a behavioural response that also reduces the likelihood of hearing injury.

The shut-down zones proposed in **Table 21** are based on estimated zones of impact as in **Table 17**, and take into account the cumulative effect of multiple pile driving impacts. This allows some time to move away from the noise source thereby reducing the likelihood of hearing injury to occur.

Table 21 Proposed Safety Zones for Continuous Impact Piling Durations

Noise exposure threshold based on cumulative SEL (within a 24-hour period)		Observation zone	Shut-down zone
Duration with continuous piling @ 100 strikes / min	**Cumulative SEL < 198dB re 1µPa^2·S**		
≤ 1 min	≤ 50m	1.0km	50m
10 min	310m	1.0km	310m
60 min	1.4km	2.0km	1.4km

8.2.2 Standard Management and Mitigation Measures

In addition to the proposed safety zones, the following management and mitigation measures will be implemented:

- Contract documentation – include these requirements for piling noise management and mitigation measures in the contract documentation.
- Timing and duration – avoid conducting impact piling during times when marine mammals are likely to be breeding, calving, feeding or resting in biologically important habitats nearby. Where practical, avoid piling during whale migration season. The seasonal presence of humpback whale with the project area has been recorded within the months of June and September (ALA, 2018; DES, 2018). For marine turtles, the recorded peak period of nesting activity for Green turtle and Flatback turtle on Curtis Island and Facing Island is November to December (Limpus et al. 2014).
- Trained crew – ensure a suitably qualified person is available during piling to conduct the recommended standard operational procedures to manage noise impacts.
- Standard operational procedures – standard operating procedures to be undertaken by contractors during piling activities include pre-start, soft start, normal operation, stand-by operation, and shut-down procedures, as follows and as shown in **Figure 31**.
    - Pre-start monitoring – the presence of marine turtles and marine mammals will be visually monitored by a suitably trained crew member for at least 30 minutes before piling commences using a soft start procedure.
    - Soft start – if marine turtles and marine mammals have not been observed inside the shut-down zone during the pre-start observations, soft start may commence with piling impact energy gradually increased over a 10-minute time period. A soft start will also be used after long breaks of more than 30 minutes in piling activity.
    - Normal piling – if marine turtles and marine mammals have not been observed inside the shut-down or observation zones during the soft start, piling at full impact energy may commence. Visual observations will continue throughout piling activities.
    - Stand-by – if marine turtles or marine mammals are sighted within the observation zone during the soft start or normal operation piling, the operator of the piling rig will be placed on stand-by to shut down the piling rig, while visual monitoring of the animal continues.

- Shut-down – if a marine turtle or marine mammal is sighted within or are about to enter the shut-down zone, piling activity should be stopped immediately. If the animal is observed to move outside the zone again, or 30 minutes have elapsed with no further sightings, piling activities will recommence with the soft start procedure. If a marine turtle or marine mammal is detected in the shut-down zone during a period of poor visibility, operations will stop until visibility improves.

- Compliance and sighting report – the contractor will maintain a record of procedures employed during piling, including information on any marine mammals sighted, and their reaction to the piling activity. A report will include the location, date, start and completion time, information on the piling rig (hammer weight and drop height), pile size, number of piles, number of impacts per pile, details of the trained crew members conducting the visual observations, times when observations were hampered by poor visibility or high winds, times when start-up delays or shut-down procedures occurred, and the time and distance of any marine mammal or sea turtle sightings.

8.3 Additional mitigation measures for marine turtle, Dugong and fish species

Impact assessment in **Section 7.2** demonstrates that the cumulative impact from piling noise could cause injuries to marine turtle, dugong and fish species. Due to the limitation of visual surveys for marine turtle, dugong and fish species, measures based on safety zones are not as effective as to marine mammals. The following additional mitigation measures could be considered to further minimise noise impact on marine fauna species. However, the practicality of implementing these measures needs to be investigated, and the actual effectiveness to be validated via site acoustic testing.

- Lower piling duration/piling strike number per day. As per presented in **Section 7.2**, lower number of piling strikes within a 24-hour period results in lower cumulative SELs, and therefore has smaller impact zones.
- Use of piling noise attenuation measures. Various attenuation measures have been developed to attenuate underwater piling noise to minimise exposure of marine fauna species during piling activities (Caltrans, 2009). These measures include but not limited to:
  - Air bubble curtains. Air bubble curtains are designed to infuse the water column surrounding the pile with air bubbles, generating a bubble screen that attenuate the sound propagation from the pile. For a mid-sized steel pile as used in this project (with a dimension greater than 24 but less than 48 inches), the previous experiment data indicates that an air bubble curtain will provide about 10 dB of noise reduction (Caltrans, 2009).
  - Isolation casings. Isolation casings are hollow casing slightly larger in diameter than the pile to be driven. The casing is inserted into the water column and bottom substrate, and then dewatered so that the work area could be isolated from the surrounding water column in order to attenuate the sound propagation. Dewatered isolation casings generally can be expected to provide attenuation that is at least as great as the attenuation provided by air bubble curtains.
  - Cushion blocks. Cushion blocks consist of blocks of material atop a pile during piling to minimise the noise generated during impact hammering. Materials typically used for cushion blocks include wood, nylon and micarta blocks. The resulted noise reduction could be from a few dB to over 20 dB. This measure can be used in conjunction with air bubble curtains or isolated casings as above.

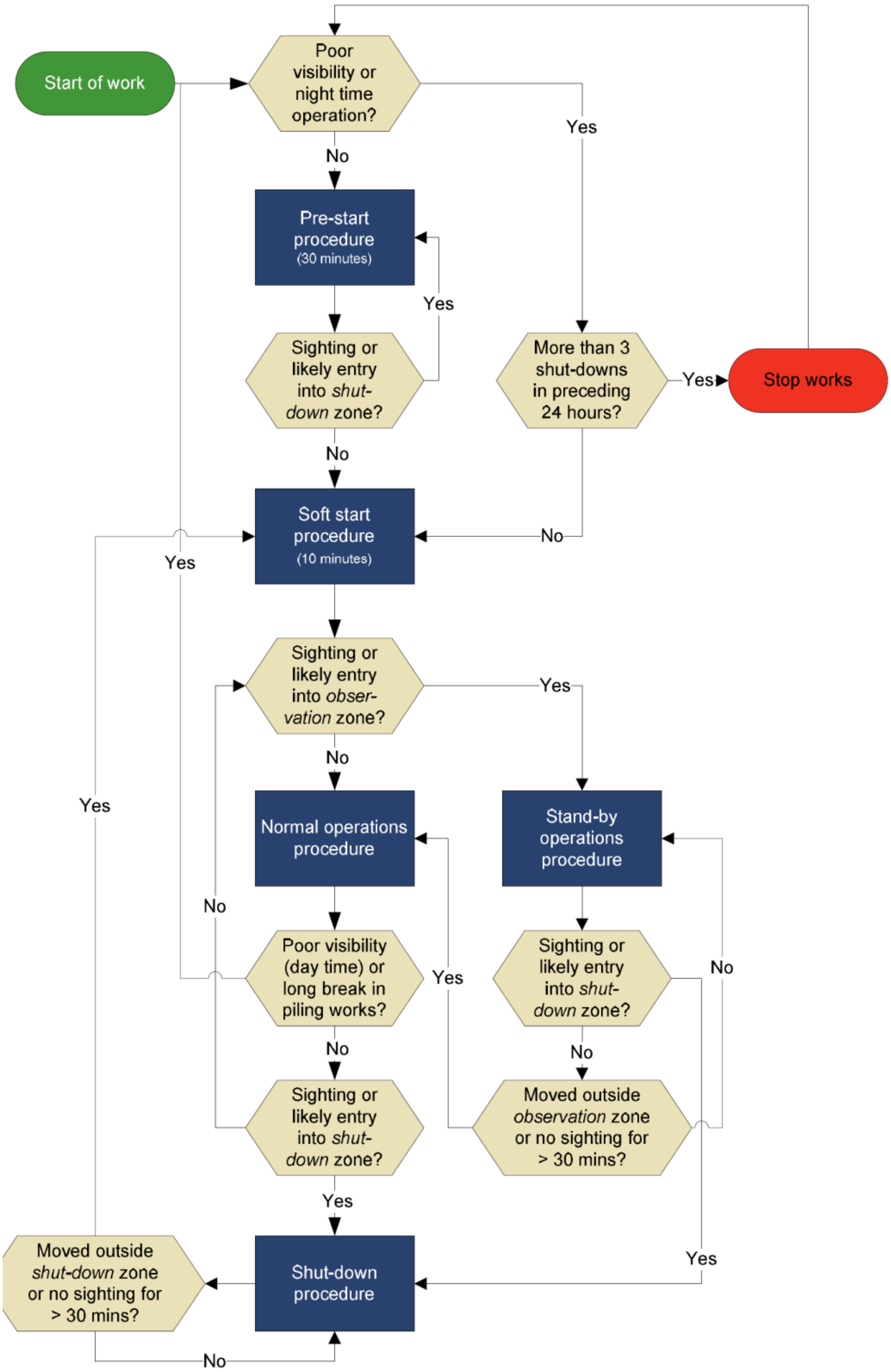

Figure 31 Piling Noise Management Procedures Flow Chart (Government of South Australia, 2012)

9 Summary and Conclusions

This report provides an assessment of underwater noise impacts associated with the construction and operational phases of Project.

A number of marine fauna species of environmental significance, including megafauna species (i.e. whales, dolphins and dugongs), marine turtles and other fish species (e.g. Great white shark, Green sawfish, etc.) occurring or potentially occurring in proximity to the project area have been identified. The noise impact criteria in terms of physiological and behavioural impacts for these marine fauna species have also been established via a review of the most relevant guidelines or literature.

The long term baseline underwater noise monitoring demonstrates that within the inner harbour area, anthropogenic noises associated with marine operations are the prevailing sources, dominating the low-frequency component below a few kHz. Biological noise, particularly noise from snapping shrimp, is another major noise source covering the mid to high frequency ranges from a few kilohertz up to 10kHz. The outer harbour area, however, has much lower underwater baseline noise environment which strongly correlates with weather and sea-state variations, and with dominant frequency components ranging approximately from 100Hz to 2kHz.

The detailed noise modelling prediction and assessment results show that impact piling events during the installation of the navigation aids are predicted to result in the highest noise impacts on the assessed marine fauna species, due to the high piling source noise emissions and the impulsive characteristics of piling noise. Piling noise is predicted to potentially cause physical injuries for marine fauna species in close proximity to the piling location. Other development activities such as rock dumping, dredging, supporting vessels and vibratory sheet piling are unlikely to result in significant adverse underwater noise impacts to assessed marine fauna species, due to their relatively low noise emissions, the non-impulsive characteristics, and relatively higher baseline underwater noise environment within the inner harbour area.

The acoustic monitoring and relevant mitigation measures will be implemented to minimise the piling noise impact on assessed marine fauna species.

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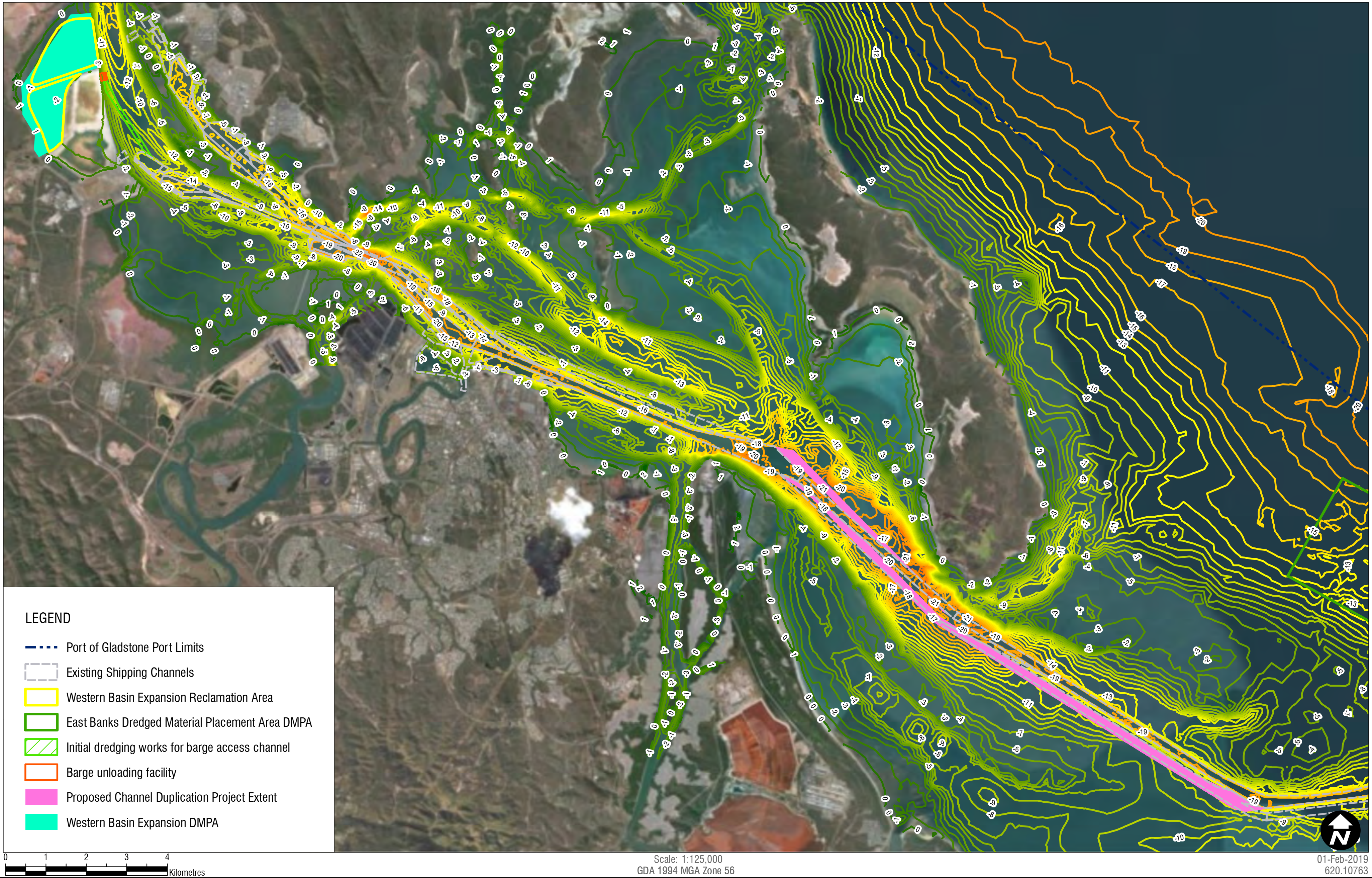
APPENDIX A

Acoustic Terminology

Sound Pressure	A deviation from the ambient hydrostatic pressure caused by a sound wave
Sound Pressure Level (SPL)	The logarithmic ratio of sound pressure to the reference pressure. The reference pressure underwater is P_{ref} = 1 µPa
Root-Mean-Square Sound Pressure Level (RMS SPL)	The mean-square sound pressure is the average of the squared pressure over the pulse duration. The root-mean-square sound pressure level is the logarithmic ratio of the root of the mean-square pressure to the reference pressure. Pulse duration is taken as the duration between the 5% and the 95% points on the cumulative energy curve
Peak Sound Pressure Level (Peak SPL)	The peak sound pressure level is the logarithmic ratio of the peak pressure over the impulsive signal event to the reference pressure
Peak-to-Peak Sound Pressure Level (Peak-Peak SPL)	The peak-to-peak sound pressure level is the logarithmic ratio of the difference between the maximum and minimum pressure over the impulsive signal event to the reference pressure
Sound Exposure Level (SEL)	SEL is a measure of energy. Specifically, it is the dB level of the time integral of the squared instantaneous sound pressure normalised to a 1-s period
Power Spectral Density (PSD)	PSD describes how the power of a signal is distributed with frequency
Source Level (SL)	The acoustic source level is the level referenced to a distance of 1m from a point source
1/3 Octave Band Levels	The energy of a sound split into a series of adjacent frequency bands, each being 1/3 of an octave wide
Sound Speed Profile	A graph of the speed of sound in the water column as a function of depth

APPENDIX B

Bathymetry Contour Map



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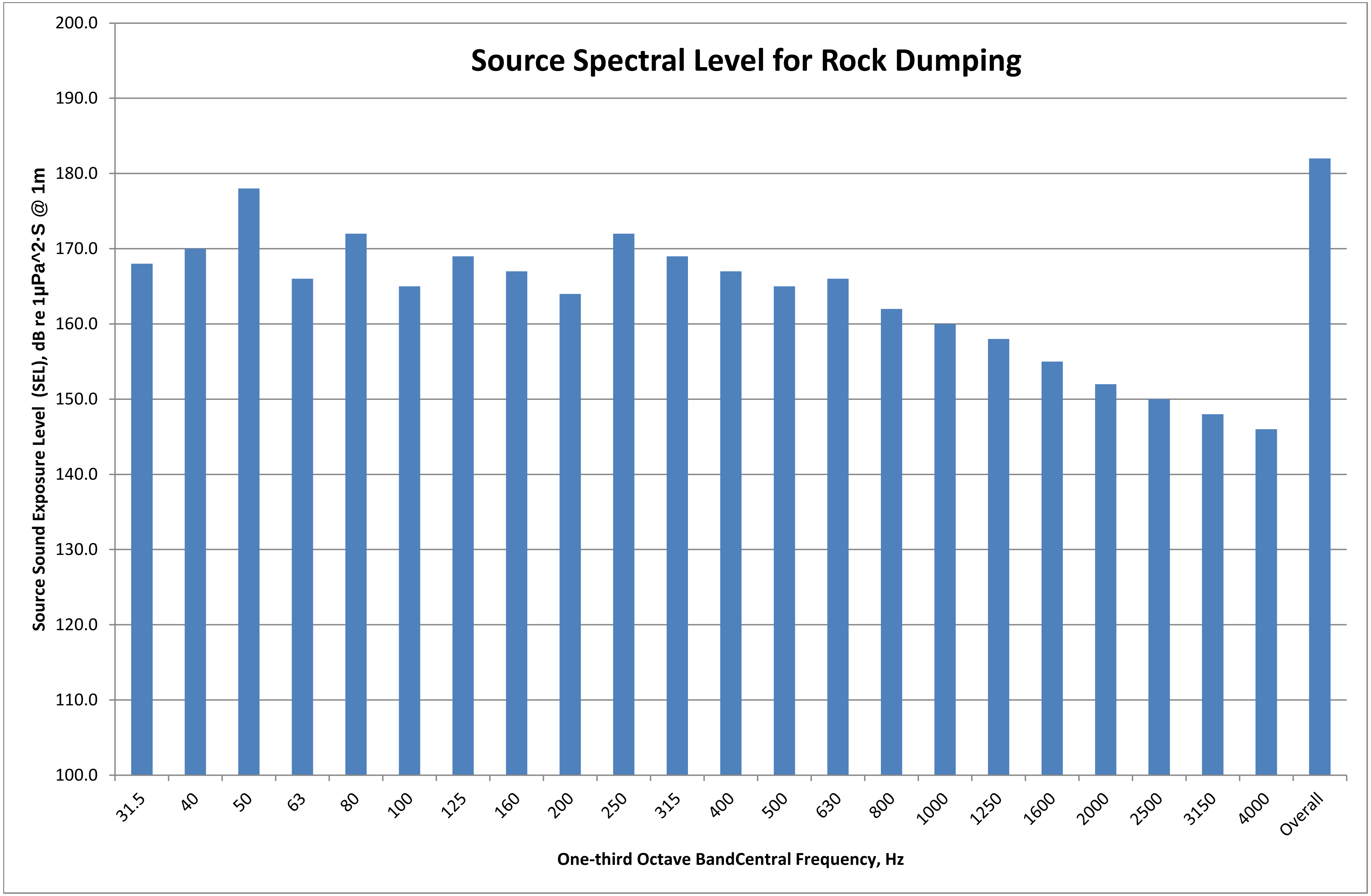
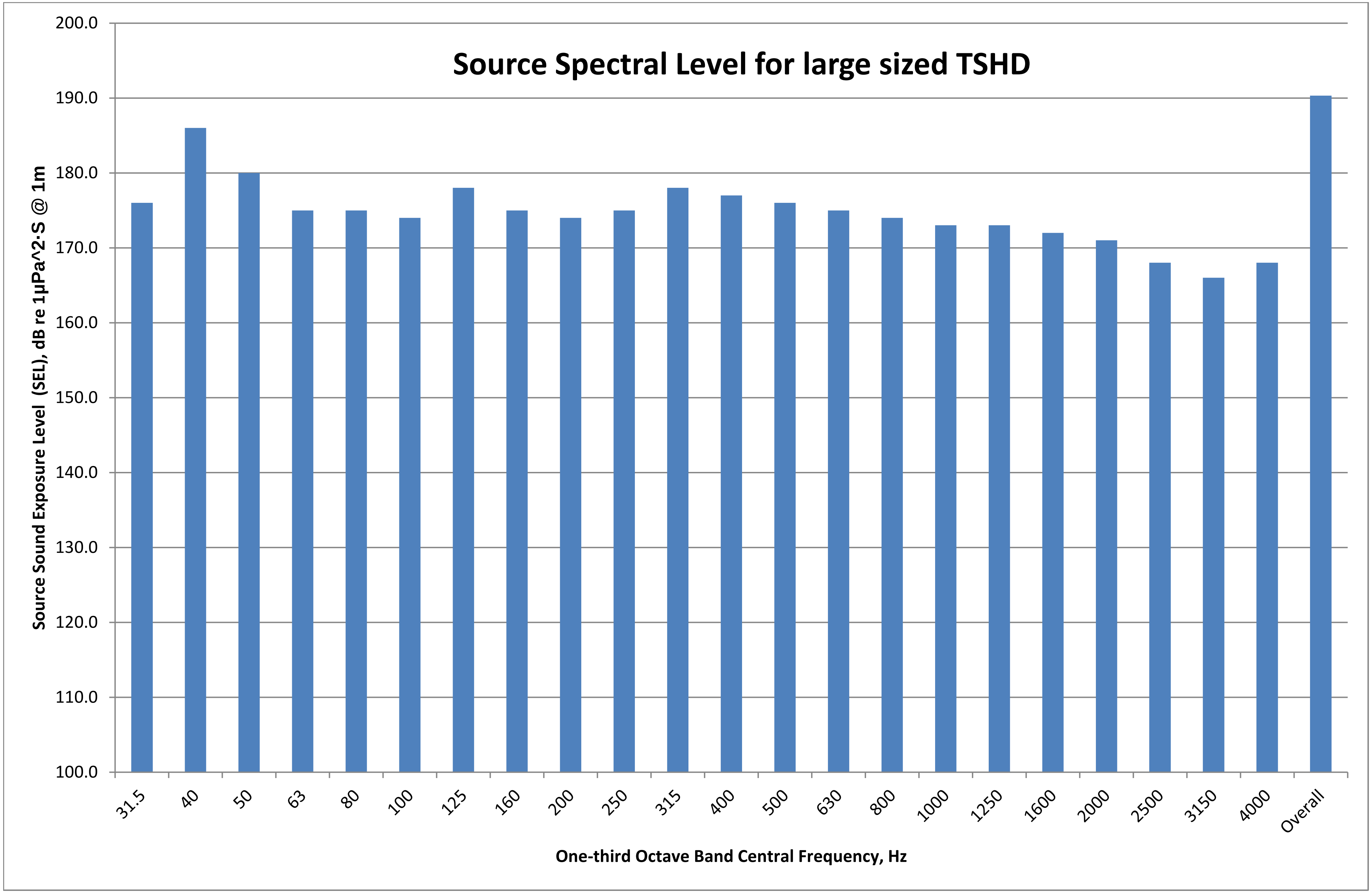
Port of Gladstone Channel Duplication Bathymetry Contour Map

APPENDIX B

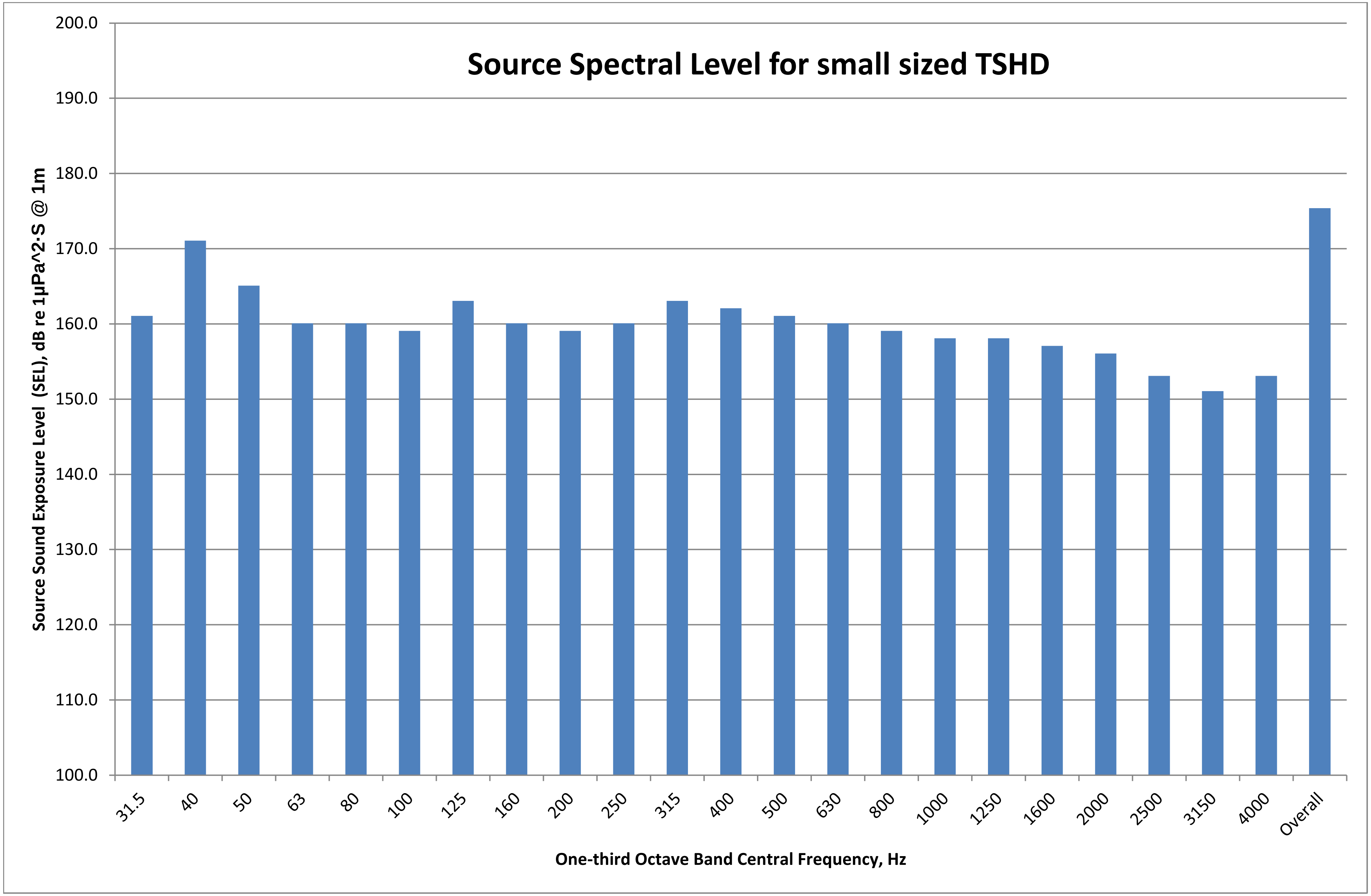
APPENDIX C

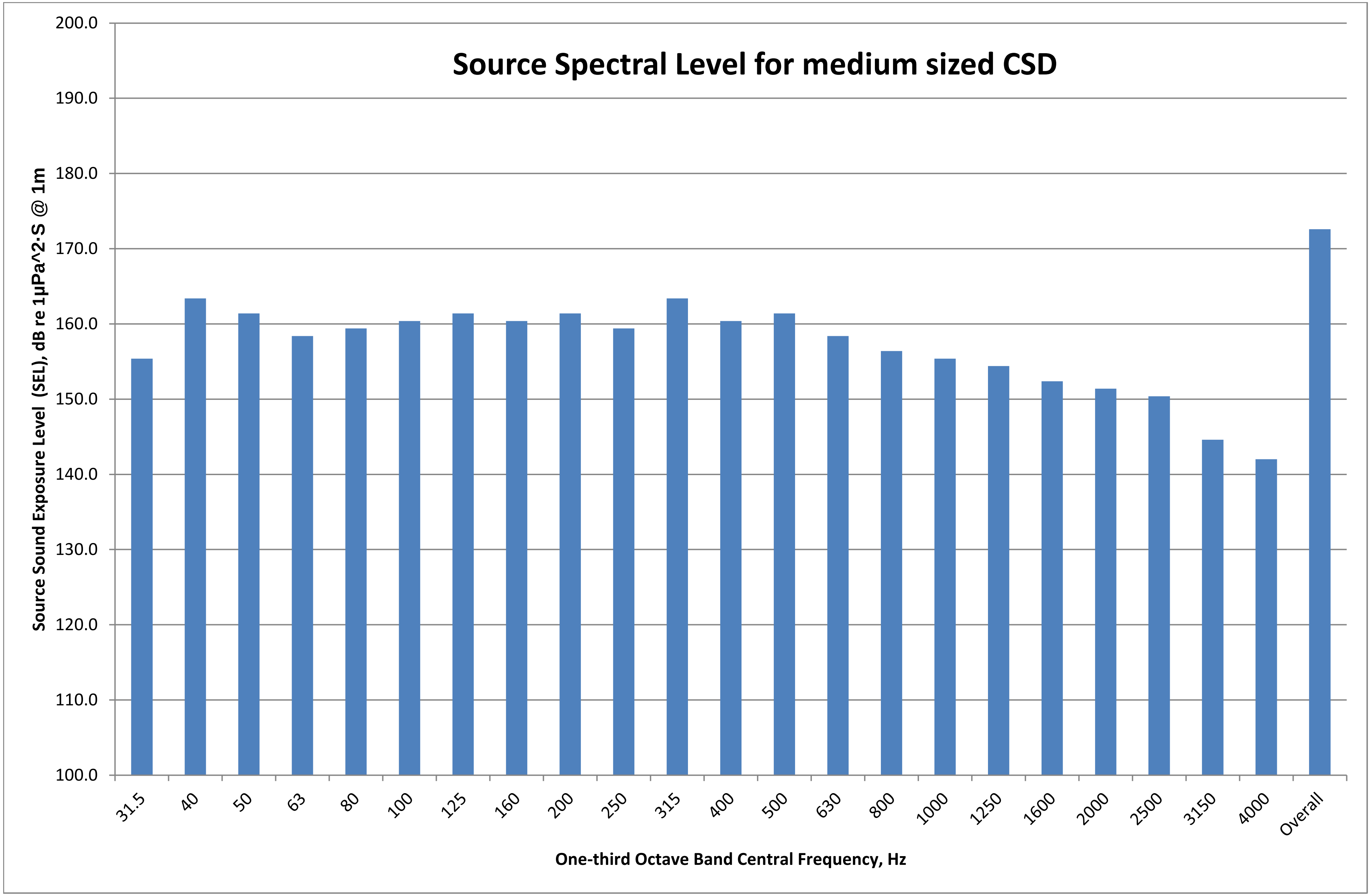
Noise Source Spectral Levels

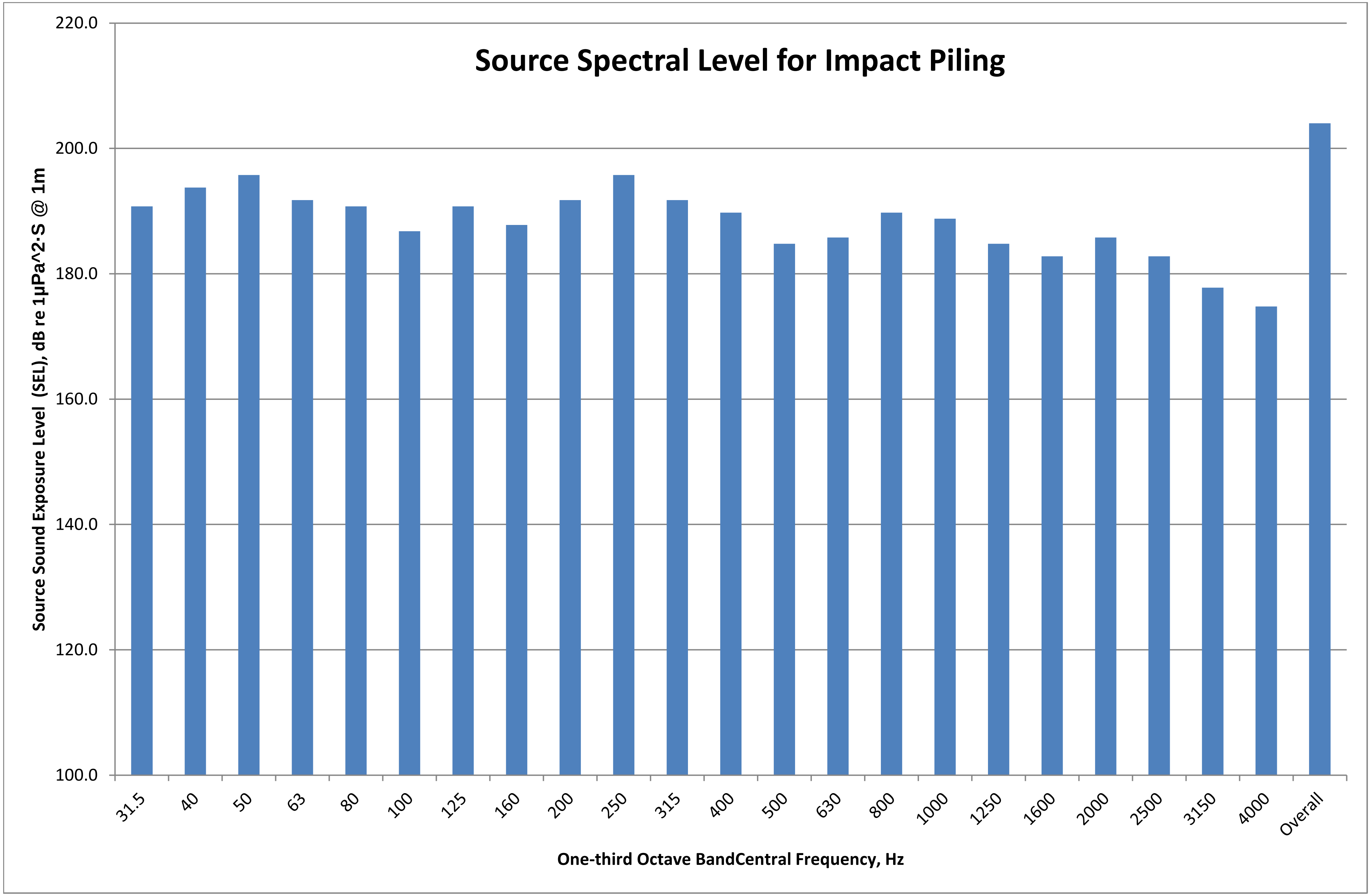

Source Spectral Level for Rock Dumping
Source Sound Exposure Level (SEL), dB re 1µPa^2·S @ 1m
200.0
190.0
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
Overall
One-third Octave BandCentral Frequency, Hz



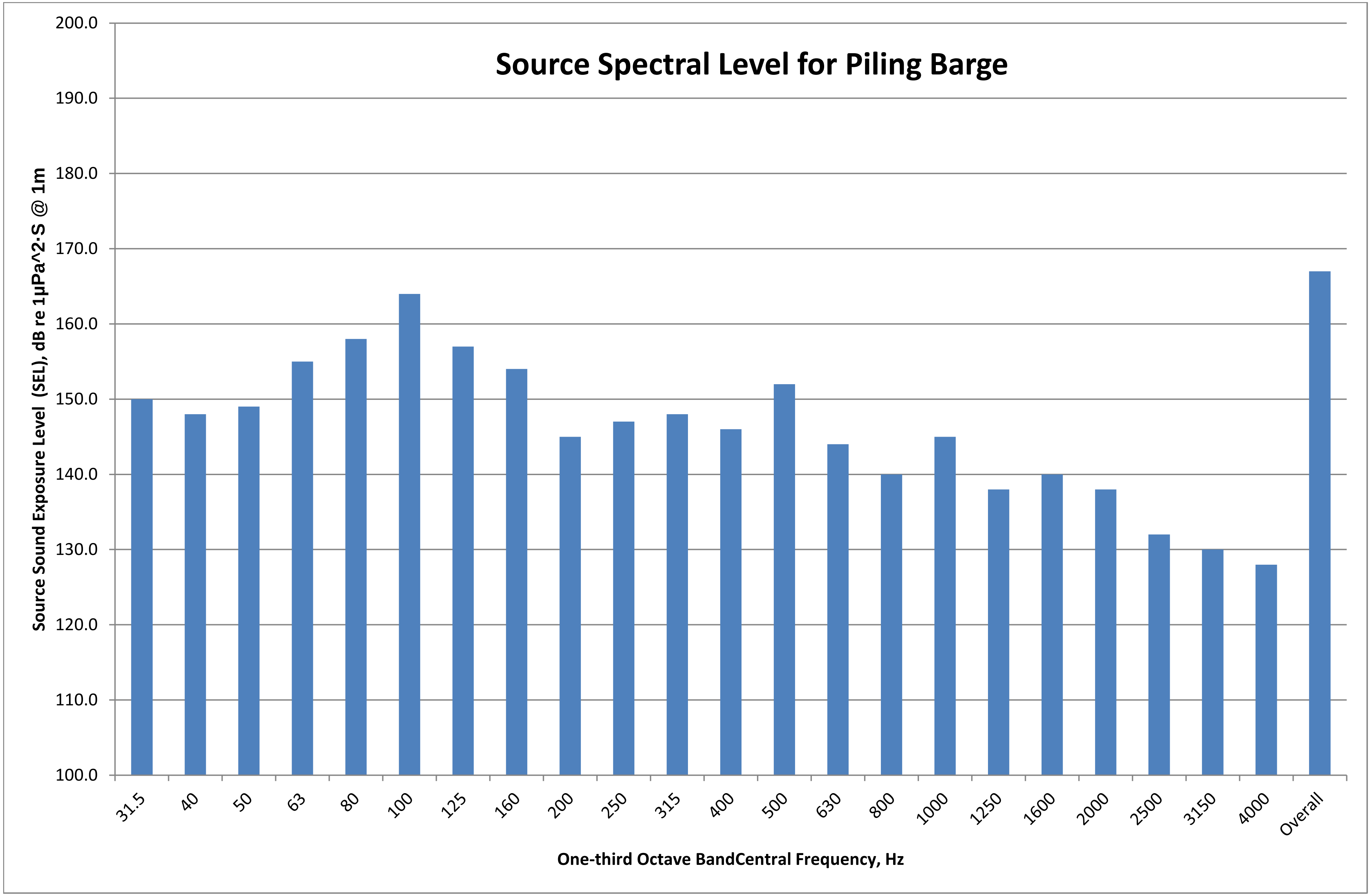
Source Spectral Level for large sized TSHD
Source Sound Exposure Level (SEL), dB re 1µPa^2·S @ 1m
200.0
190.0
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
Overall
One-third Octave Band Central Frequency, Hz

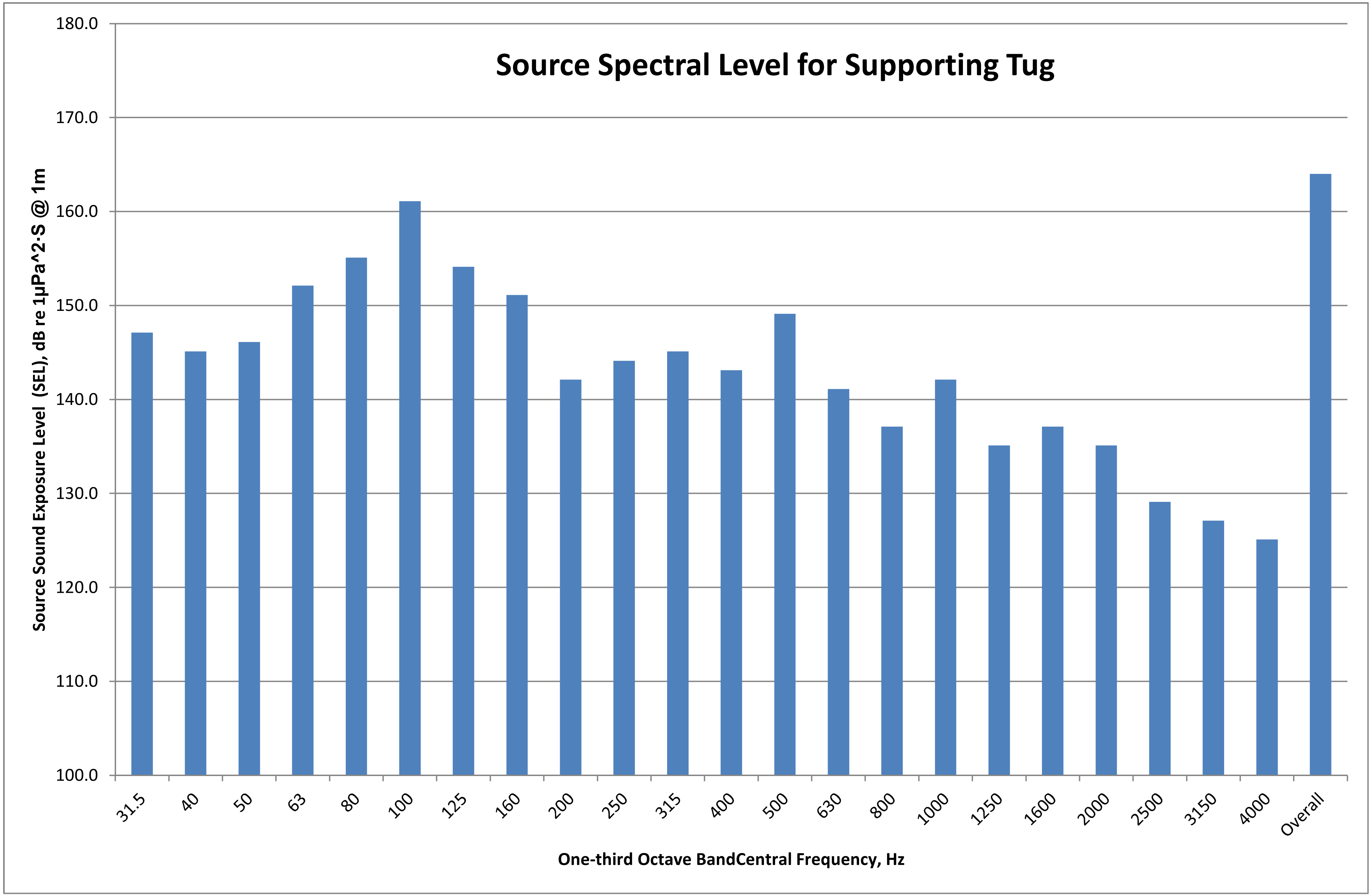

Source Spectral Level for small sized TSHD
Source Sound Exposure Level (SEL), dB re 1µPa^2·S @ 1m
200.0
190.0
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
Overall
One-third Octave Band Central Frequency, Hz

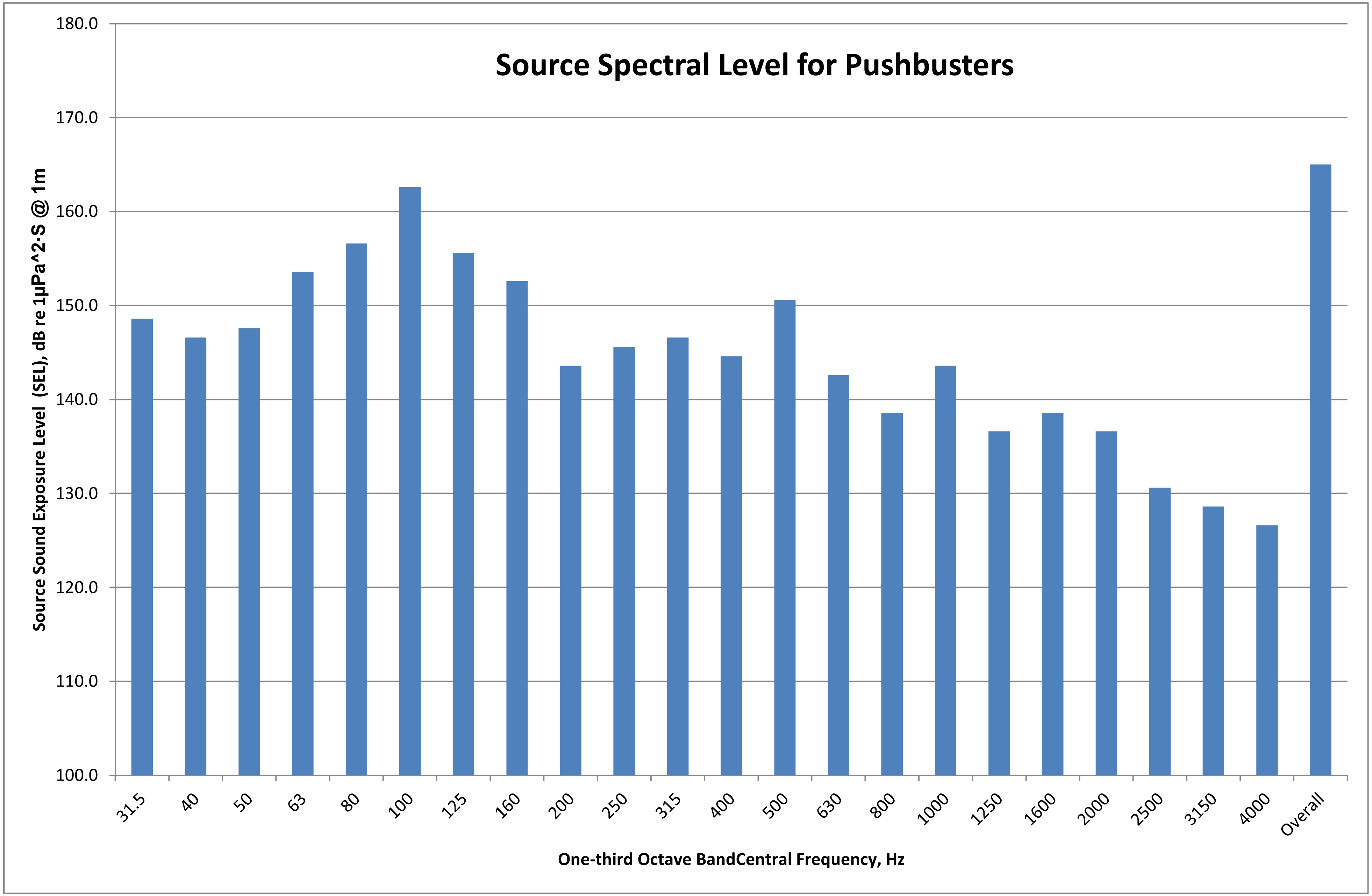

Source Spectral Level for medium sized CSD
Source Sound Exposure Level (SEL), dB re 1µPa^2·S @ 1m
200.0
190.0
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
Overall
One-third Octave Band Central Frequency, Hz

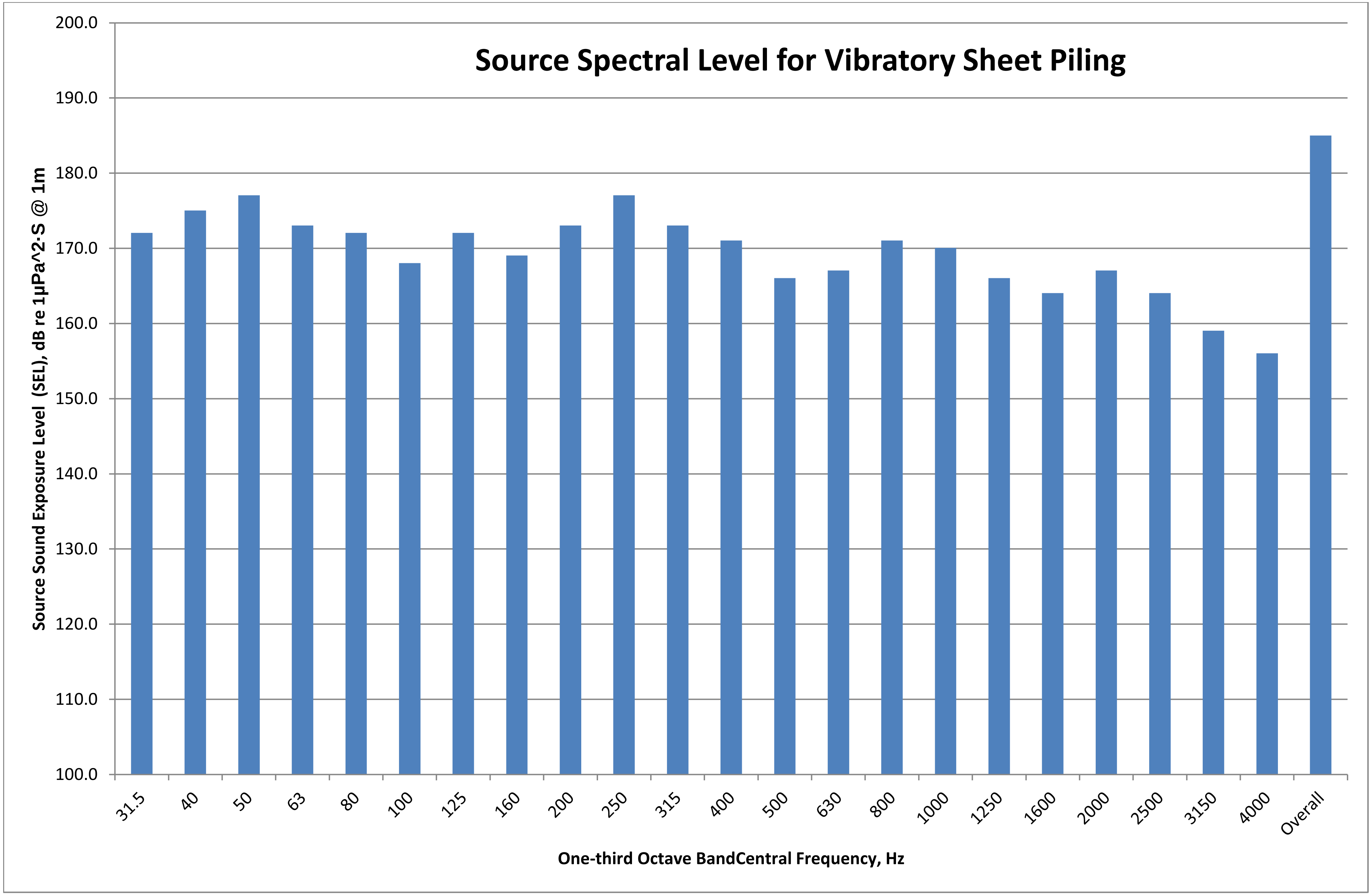


Source Spectral Level for Impact Piling
Source Sound Exposure Level (SEL), dB re 1µPa^2·S @ 1m
220.0
200.0
180.0
160.0
140.0
120.0
100.0
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
Overall
One-third Octave BandCentral Frequency, Hz


Source Spectral Level for Piling Barge
Source Sound Exposure Level (SEL), dB re 1µPa^2·S @ 1m
200.0
190.0
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
Overall
One-third Octave BandCentral Frequency, Hz

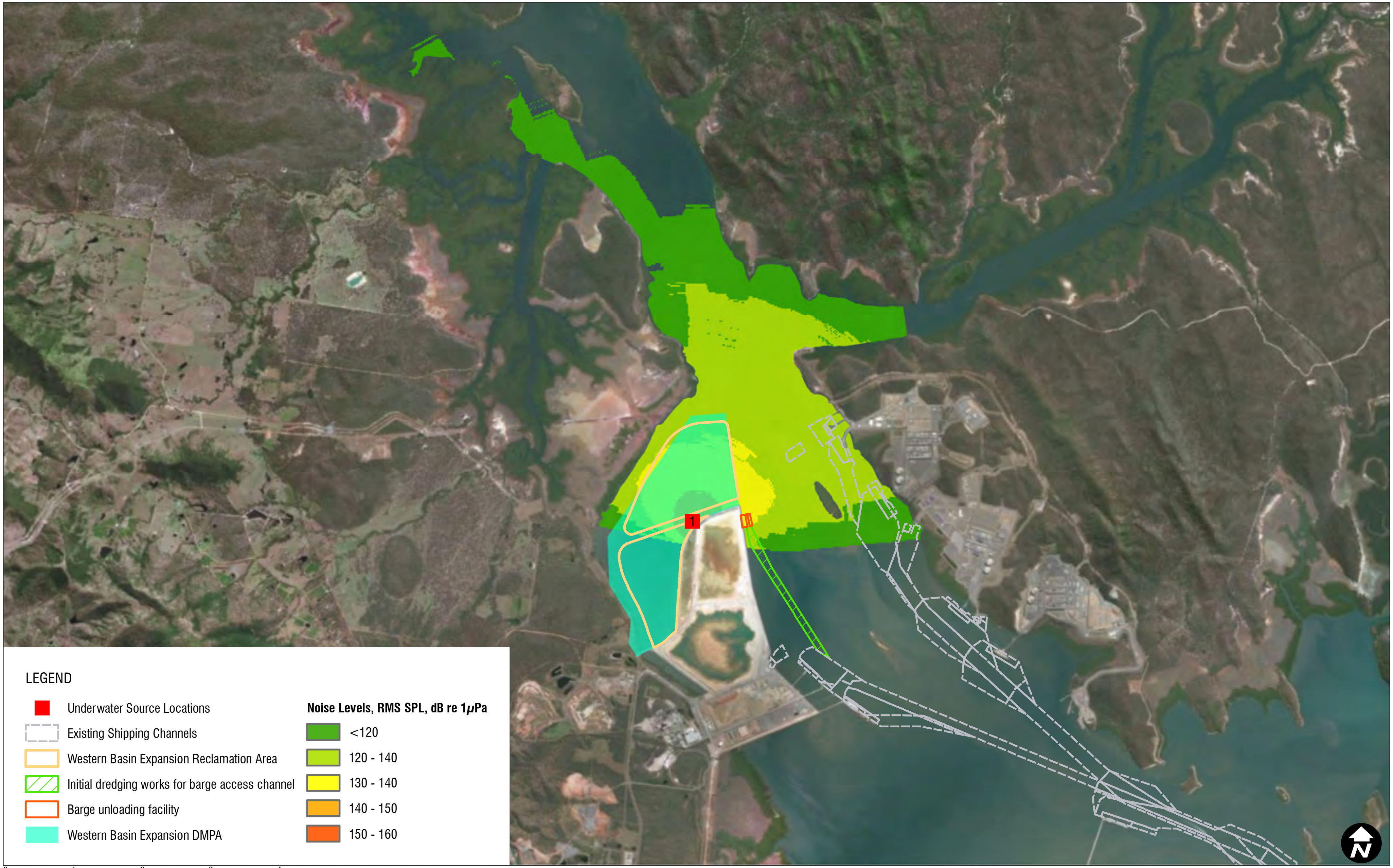

Source Spectral Level for Supporting Tug
Source Sound Exposure Level (SEL), dB re 1µPa^2·S @ 1m
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
Overall
One-third Octave BandCentral Frequency, Hz


Source Spectral Level for Pushbusters
Source Sound Exposure Level (SEL), dB re 1µPa^2·S @ 1m
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
Overall
One-third Octave BandCentral Frequency, Hz


Source Spectral Level for Vibratory Sheet Piling
Source Sound Exposure Level (SEL), dB re 1µPa^2·S @ 1m
200.0
190.0
180.0
170.0
160.0
150.0
140.0
130.0
120.0
110.0
100.0
31.5
40
50
63
80
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
Overall
One-third Octave BandCentral Frequency, Hz

APPENDIX D

Modelled Underwater Noise Contours



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0 1 2 3 4 Kilometres

Scale: 1:75,000
GDA 1994 MGA Zone 56

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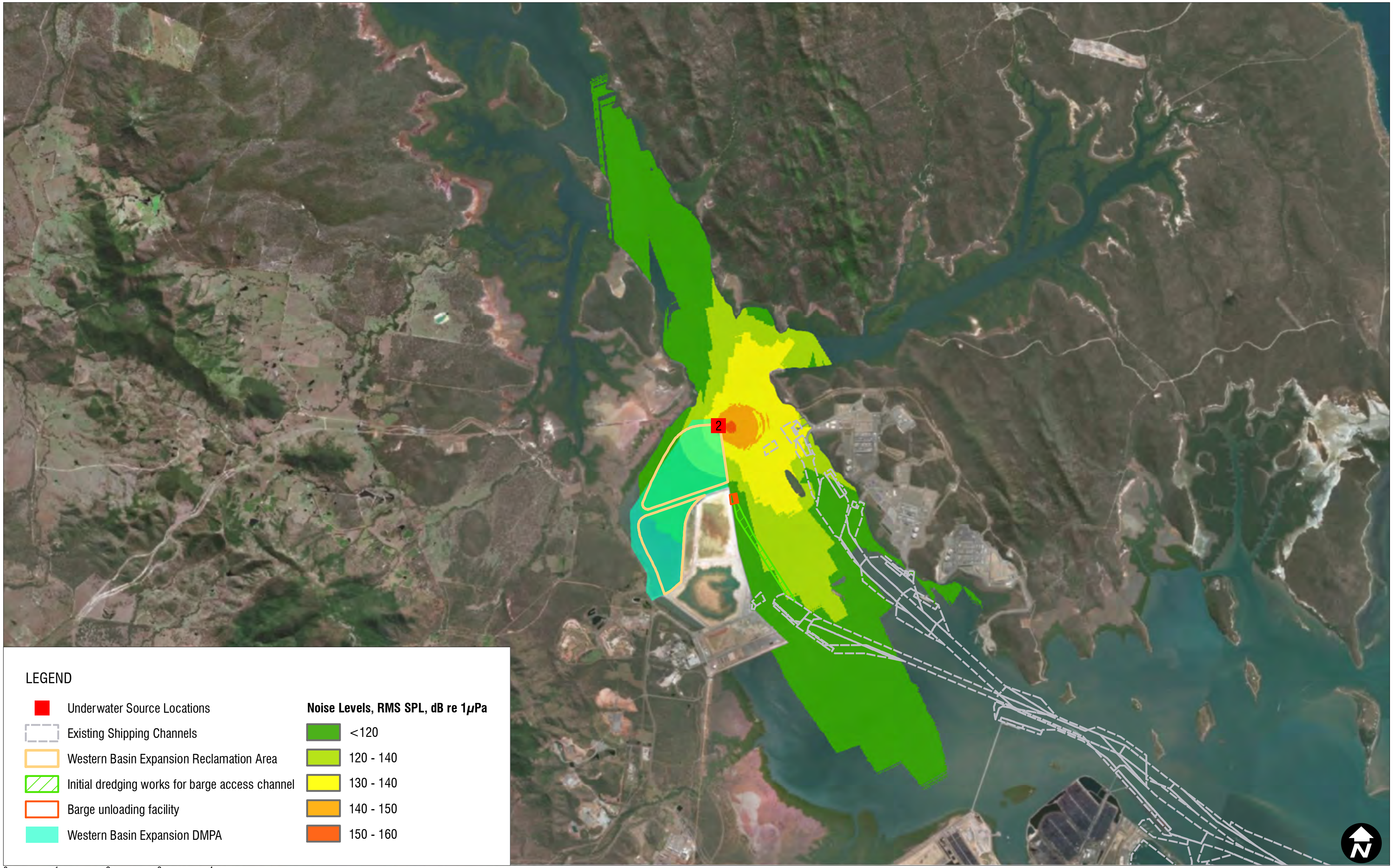
Port of Gladstone Channel Duplication
Scenario 1 - Rock Dumping WBE
Reclamation Area (South)

FIGURE D.1



0 1 2 3 4 Kilometres

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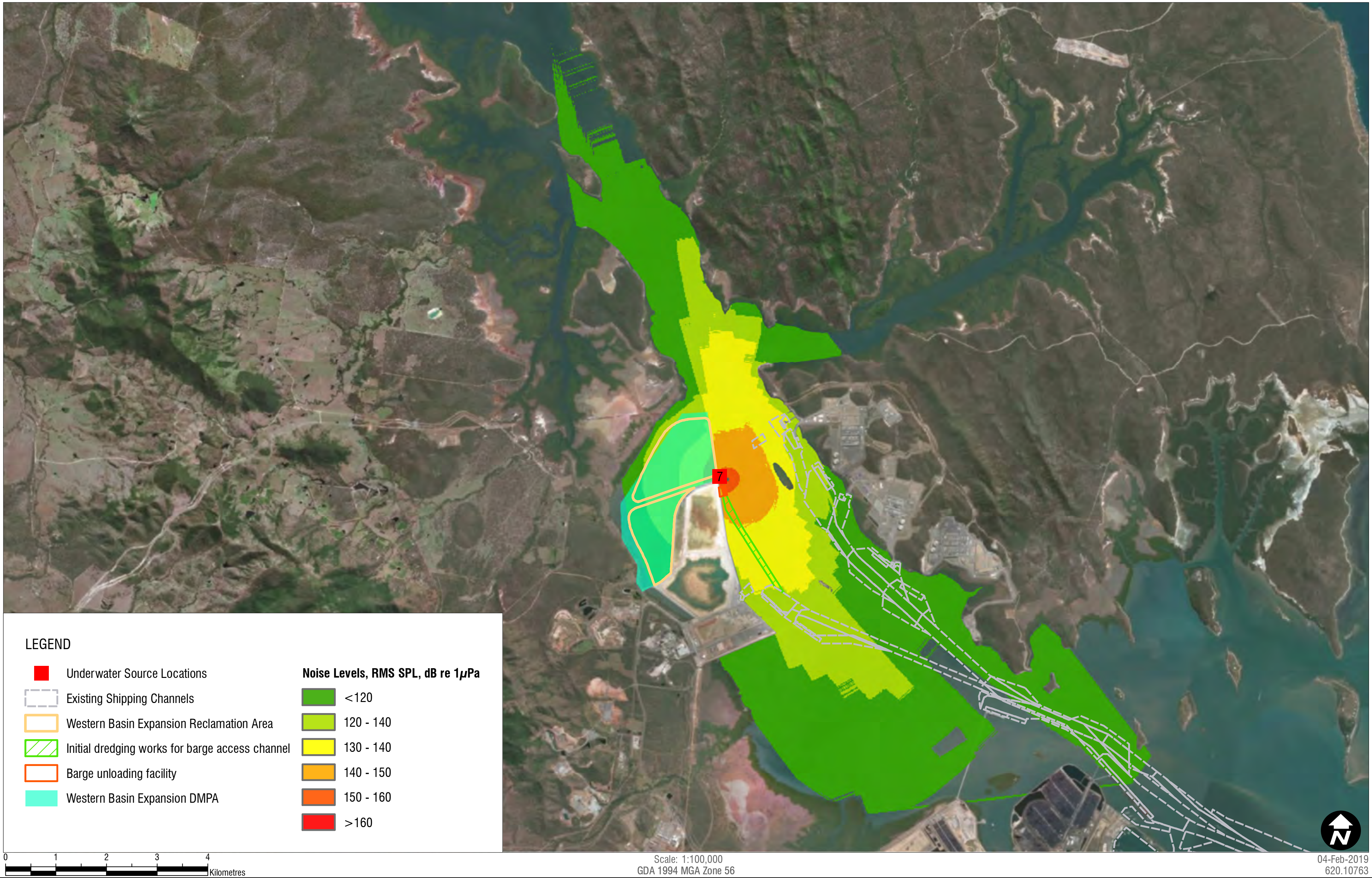
Port of Gladstone Channel Duplication
Scenario 2 - Rock Dumping WBE Reclamation Area (North)

FIGURE D.2



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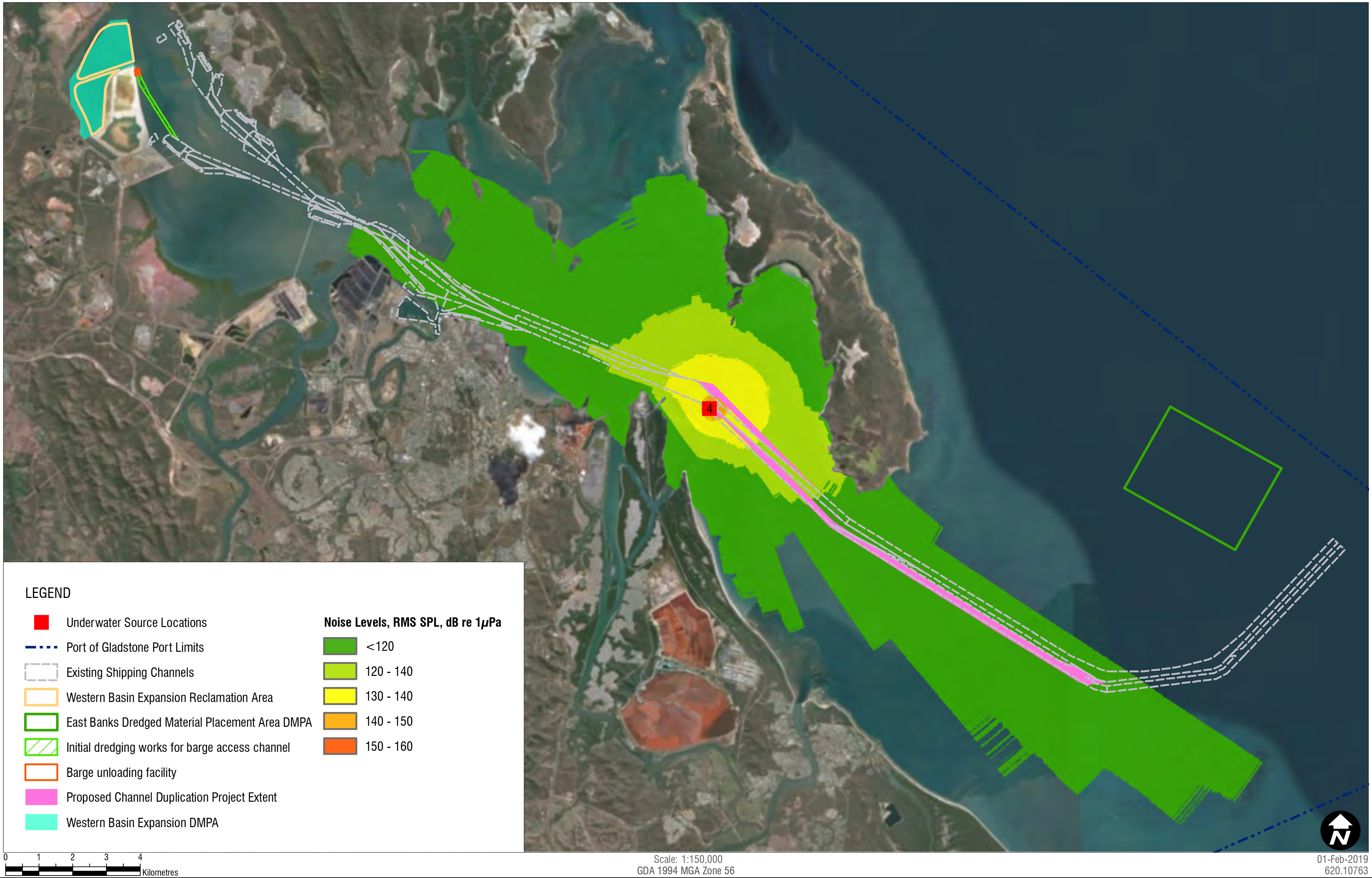
Port of Gladstone Channel Duplication
Scenario 3 - Construction of the BUF
Sheet Piling and Rock Dumping

FIGURE D.3



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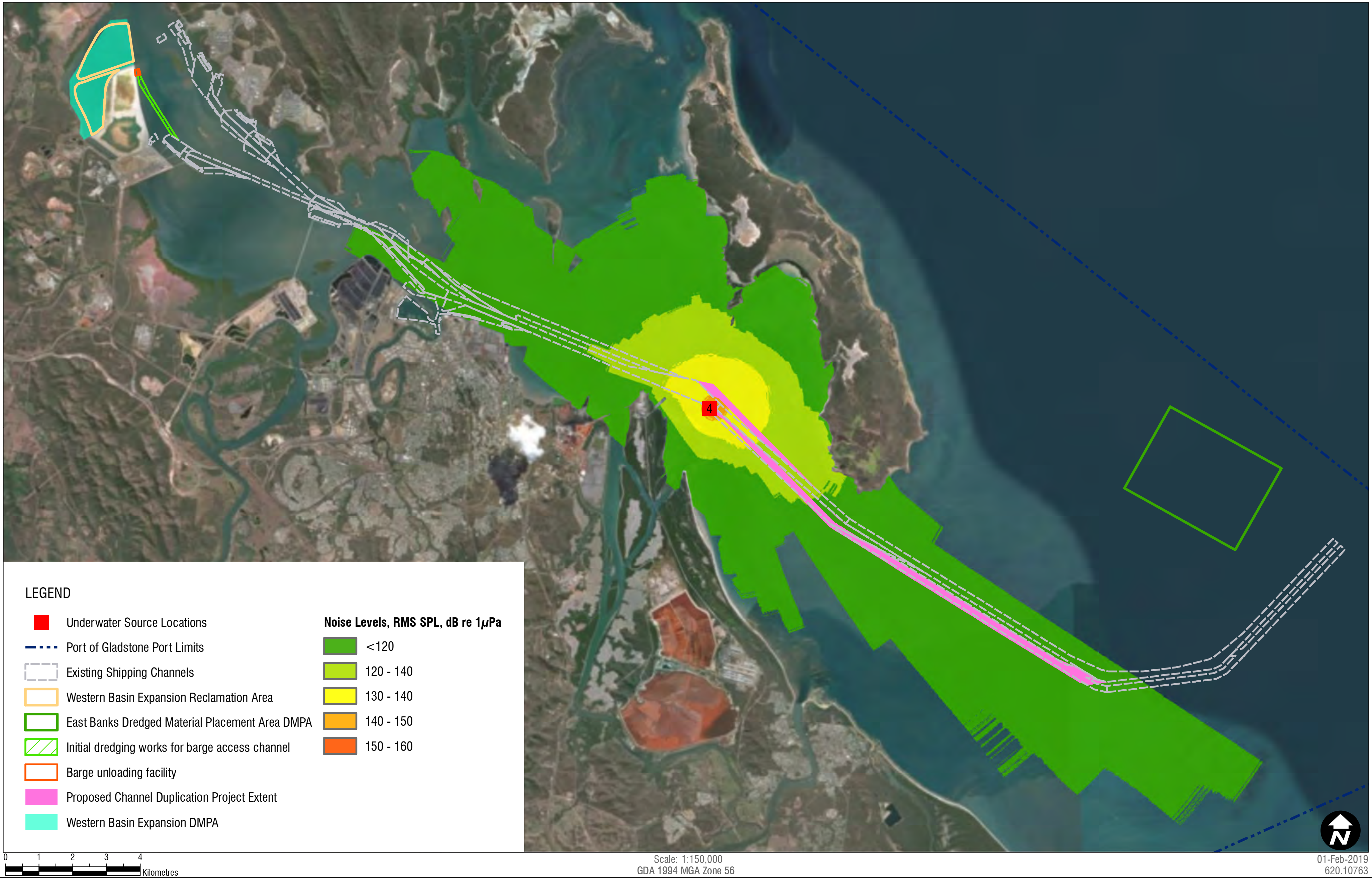
Port of Gladstone Channel Duplication
Scenario 4 - CSD and TSHD Dredging of the Barge Access Channel

FIGURE D.4



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GDA 1994 MGA Zone 56

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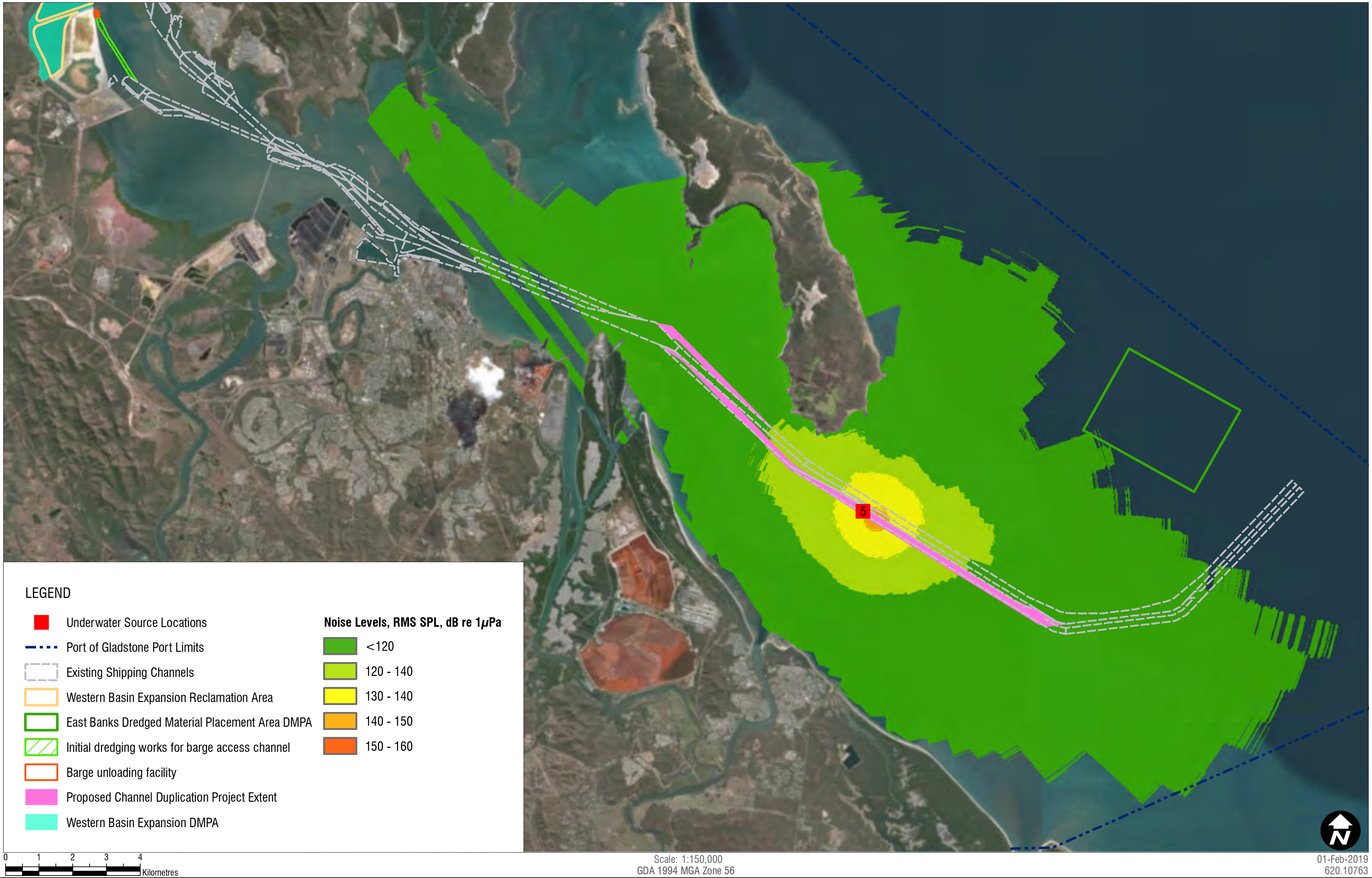
Port of Gladstone Channel Duplication Scenario 5 - TSHD Dredging of Gatcombe Channel (Northern End)

FIGURE D.5



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GDA 1994 MGA Zone 56

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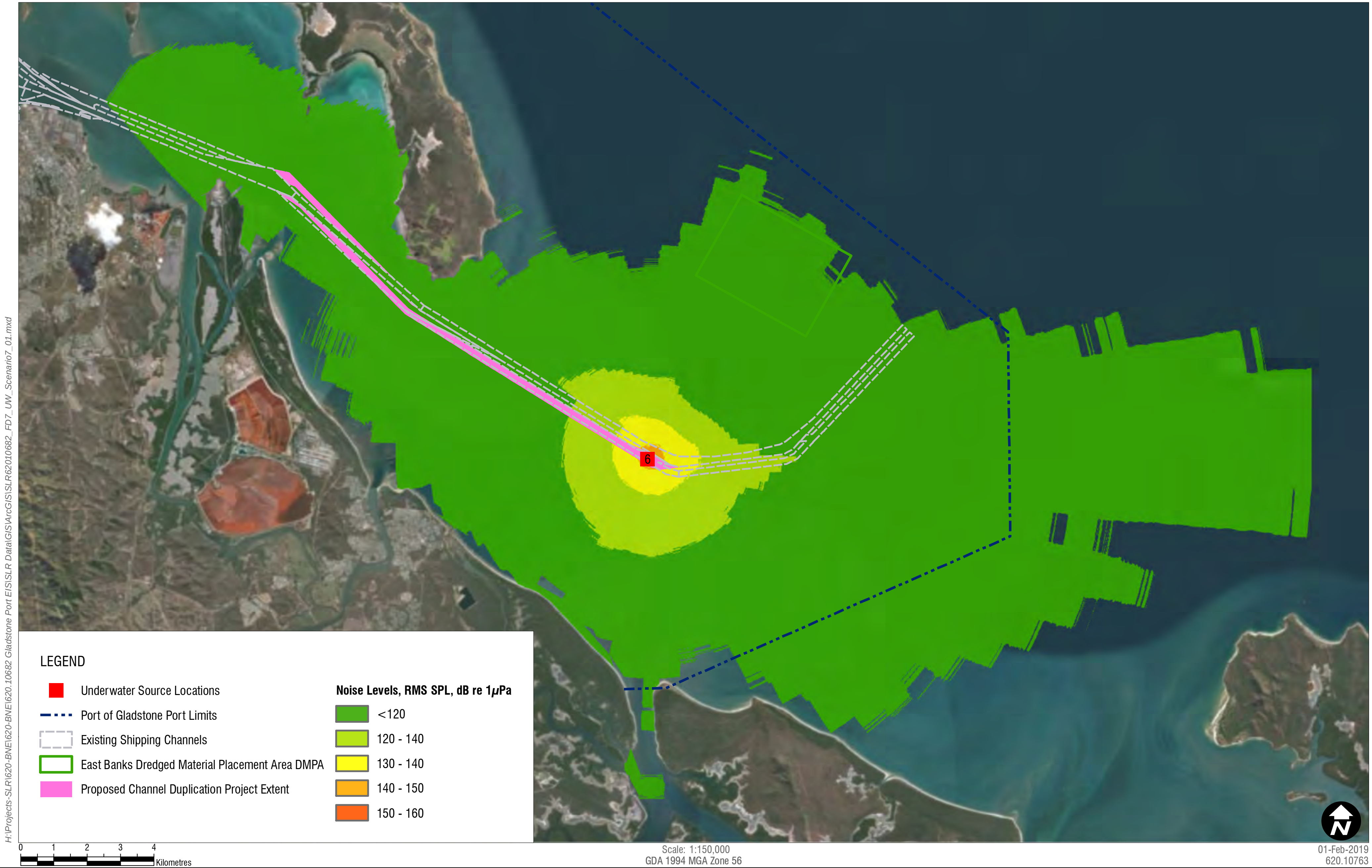
Port of Gladstone Channel Duplication
Scenario 6 - TSHD Dredging of Gatcombe Channel (Middle Area)

FIGURE D.6



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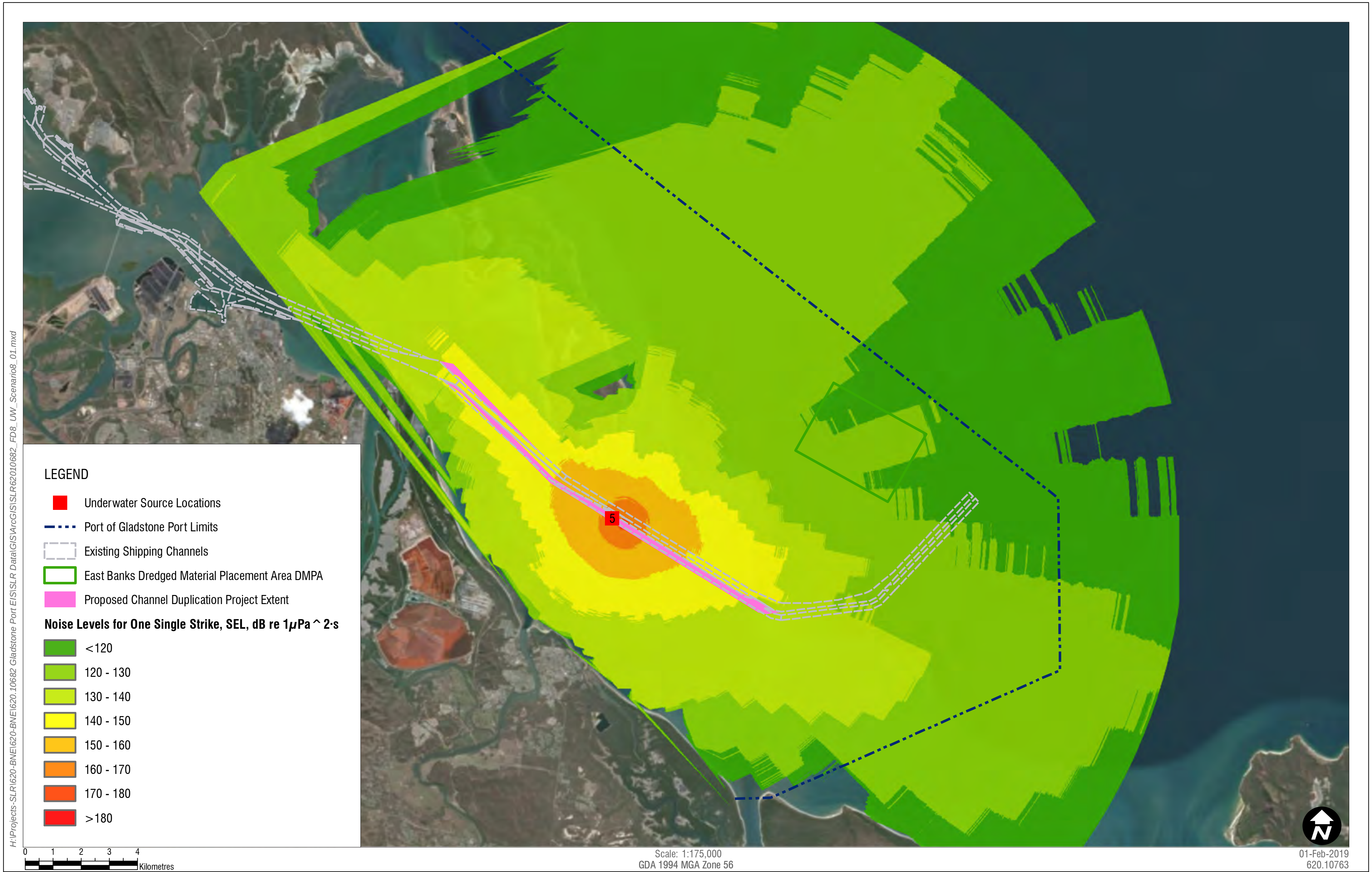
Port of Gladstone Channel Duplication
Scenario 7 - TSHD Dredging of Gatcombe Channel (Southern End)

FIGURE D.7



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Port of Gladstone Channel Duplication
Scenario 8 - Impact Piling Navigation Aid Installation (mid-point of Channel length)

FIGURE D.8

Sheet Size : A4

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Port of Gladstone Channel Duplication
Scenario 9 - Project Operational Maintenance Dredging

FIGURE D.9