Australia Pacific LNG Project

Volume 5: Attachments

Attachment 33: Noise and Vibration Impact Study – Pipeline

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Australia Pacific LNG Project
Gas Transmission Pipeline
Noise and Vibration Study

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Contents

1. Introduction

Savery & Associates Pty Ltd was commissioned by WorleyParsons Resources & Energy to report on construction noise and vibration impacts associated with construction of the proposed Australia Pacific LNG coal seam gas (CSG) pipeline between the gas fields starting point near Miles, and the proposed Curtis Island LNG plant near Gladstone. The location of the main transmission pipeline is shown on Figure 1.

This report summarises the investigations that have been conducted to:-

- describe the acoustic and vibration environmental values in the project area
- sample marine baseline noise levels in the vicinity of the proposed pipeline crossing
- describe the potential noise and vibration impacts associated with the pipeline construction process, including underwater noise levels associated with the option of a dredged pipeline-crossing to Curtis Island
- identify suitable noise/vibration management goals and noise/vibration mitigation measures for land-based pipeline construction works, and
- identify suitable noise management measures to ensure acceptable impacts on marine fauna.

This report does not address the possible vibration-induced mechanical impacts of pipeline construction on buried services that may transect the pipeline route, other than to acknowledge that such impacts are manageable and are subject to detailed design processes and standard precautionary trenching procedures.

2. Identification of noise and vibration sources

2.1 General

The proposed alignment of the main high pressure gas pipeline between Miles and Friend Point Gladstone is illustrated on Figure 1. The location of the pipeline crossing from Friend Point across 'The Narrows' to Laird Point on Curtis Island is illustrated on Figure 2.

The pipeline will be constructed of steel, with a diameter in the nominal range of 0.7m (28 inches) to 1.1m (42 inches) depending on the position along the alignment. The pipeline will typically be buried to a minimum depth of cover between 0.75m and 1.2m.

The route selection is proposed to achieve a minimum separation distance between the pipeline and sensitive locations (e.g. residences and commercial buildings) of at least 100m.

The nominal proposed construction hours are 6am to 6pm, seven days a week. Extended construction hours (evening or night-time) may be utilised along route sections that are remote from habitation, to maintain time schedules in the event of possible project delays (e.g. adverse sustained rain periods).

Trenching and pipe-laying will occur simultaneously at multiple locations. From the perspective of a resident or business near the route, the rate of trenching and pipe-laying in a given location will typically vary between 200m and 3km per day, depending on ground conditions.

The duration of active pipeline construction activities at any particular location along the route (i.e. including clearing of the alignment, trenching, pipe-laying, backfilling and remediation, but excluding downtime between these processes) is expected to amount to approximately one week.

2.2 Trench excavation

The majority of the pipeline alignment will be trenched using either a dedicated continuous trencher or excavator. The steady noise generation is predominantly diesel engine noise with intermittent noise from ground engagement of the trenching bar (scraping, rattling) or bucket engagement (scraping, knocking).

Along the pipeline alignment the excavation process will encounter sections dominated by continuous rock. In these areas it may be necessary to use an excavator-mounted rock-breaker and rock-saw. In addition to the excavator mounted equipment, blasting may be required. During blasting activates, blast design controls would be required to ensure vibration and blast over-pressure levels meet regulatory requirements.

2.3 Directional-drilled crossings

It is possible that horizontal directional-drilling of a curved pipeline path may be used to traverse major roads, railway lines or watercourses to prevent disruption to the thoroughfare or watercourse. The drilling activities may require 24 hour per-day operation to prevent disruptions. The extended hour drilling program may last as long as one week or longer than a month depending on the site specific requirements of the pipeline path.

The process is illustrated schematically on Figure 3. The primary noise sources would consist of the elevated diesel powered hydraulic drill drive, a diesel driven electricity generator, and electrically driven spoil treatment plant for mechanical separation of solids from working fluid.

2.4 Narrows pipeline crossing

The pipeline crossing of The Narrows between Friend Point and Laird Point will be achieved either by the preferred methodology of horizontal directional-drilled (HDD) drive, or by the alternative method of dredging a trench.

The drilling rig would be located at either side of 'The Narrows' for the HDD option. The drive may be as far as 10m below the natural passage seabed level. Drilling is expected to take several weeks of continuous operation and would only generate significant airborne noise.

The dredged trench pipeline crossing option may utilise a combination of a suction-cutter dredge (refer Figure 12 and Figure 13) and a trailing-arm suction hopper dredge (refer Figure 14 and Figure 15). The type of dredge used depends on the digging resistance of the seabed and the availability of a shore-based spoil detention area. The suction-cutter dredge is better suited to more precise dredging, and for sea-beds with higher digging resistance, but normally requires a land-based spoil detention and dewatering area. The trailing-arm suction hopper dredge is better suited to looser sea-bed material as it does not mechanically loosen the sea-bed during suctioning. Spoil can either be pumped to a shore-based detention/dewatering area or alternatively the spoil can be accumulated in the ships hoppers for bottom dump at sea. The Australia Pacific LNG Project would not use sea dumping for any dredge spoil, in keeping with the draft Port of Gladstone Western Basin Master Plan 2009.

After trench excavation and lowering of the weighted pipeline into the trench, the pipeline would be anchored by a backfilling with ballast rock to the sea-bed. General low-speed manoeuvring of tugs, barges and smaller workboats would occur in the area.

The significant noise sources associated with the dredged pipeline crossing option are the underwater noise generated by dredges, particularly when gravelly materials are being drawn and various tug, barge and workboat movements associated with pipeline laying and deployment of ballast material.

2.5 Accommodation camps

Construction camps will be positioned at intervals along the pipeline alignment to accommodate the workforce (see Figure 1). Construction camps are a relatively minor source of noise associated with the pipeline construction and indistinguishable in most respects from a normal residential suburban environment. Noteworthy noise sources include domestic reverse-cycle split-type air-conditioning units, dining-hall kitchen exhaust fan(s) and modular sound-attenuated power generation plant. The only significant noise associated with a camp is passing vehicular traffic of a morning and evening. Loud outdoor recreation such as amplified music is not allowed as the proper rest of employees that utilise these camps is paramount to on-the-job safety.

2.6 Traffic and transportation

Transportation associated with construction of the main transmission pipeline will primarily consist of:-

- low-loader transport of heavy plant to the pipeline alignment (excavators, front-end loader, trencher, bulldozer, grader, roller)
- employee light vehicular traffic
- semi-trailer trucking of piping to pipeline sites
- long-bodied trucking of engineered fill to, and spoil from, pipeline sites

- semi-trailer trucking of supporting facilities (temporary buildings and associated infrastructure etc) to and from construction and camp sites

Of the heavy transportation, the trucking of pipe will be the most conspicuous operation, occurring at an average of 20 truck-loads per day for an anticipated period of 12 months. In addition, there will be significant transportation of water for dust suppression.

Light vehicular traffic is expected to be noticeable on local roads to accommodation camps and construction sites only. A typical construction workforce of approximately 900 employees is anticipated across a number of simultaneous work fronts.

3. Airborne noise impact assessment

3.1 Airborne noise criteria

A revised Queensland policy and regulation framework for the management of environmental noise came into effect on 1 January 2009. The revised policy defines the acoustic values to be protected in the state of Queensland, and acoustic quality objectives to provide guidance on acceptable levels of total noise in the community where source-specific noise guidelines or limits are unavailable.

3.1.1 Environmental values to be protected

The Queensland Environmental Protection (Noise) Policy 2008 (EPP Noise) identifies the environmental values to be enhanced or protected as:-

the qualities of the acoustic environment that are conducive to protecting the health and biodiversity of ecosystems

the qualities of the acoustic environment that are conducive to human health and wellbeing, including by ensuring a suitable acoustic environment for individuals to do any of the following:-

- sleep
- study or learn
- be involved in recreation, including relaxation and conversation
- the qualities of the acoustic environment that are conducive to protecting the amenity of the community.

3.1.2 Criteria - standard daytime construction hours

Under the Queensland *Environmental Protection Act 1994* (EP Act), local government authorities may gazette local laws for the management of environmental nuisance, including construction noise.

However, if specific local laws are not enacted to manage construction noise, the division 3 default noise standard “section 440R Building work” of the EP Act applies as per the following extract:

“440R Building work

(1) A person must not carry out building work in a way that makes an audible noise

(a) on a business day or Saturday, before 6:30am or after 6:30pm; or

(b) on any other day, at any time.”

There are no specified construction noise limits or guidelines[1] that must be followed within the regulated construction hours of 6:30am to 6:30pm on business days and Saturdays. However, the Act does provide a mechanism for controlling unreasonable construction noise in the event that a noise complaint is investigated and validated by an authorised officer.

Examples of unreasonable daytime construction noise would include sustained daytime rock-hammering or rock-sawing noise that impacted the function of a premise (e.g. a restaurant, school classroom, medical or professional consulting room) by interfering with

[1] The former Department of Environment and Heritage E1: Guideline for construction noise was formally withdrawn and has not been replaced.

the ability of persons to communicate successfully. This type of noise could also unreasonably affect the resting of persons in a hospital or the resting of children in a childcare centre.

Pipeline construction does not neatly fit the definition of 'building work' as defined in the Act. Hence, it is conventional for construction work that may require evening or night-time audible noise (at a noise sensitive place) to be permitted subject to the preparation of an environmental noise management plan for 'out-of-hours' construction work. The appropriate basis for noise goals in such a plan are the "acoustic quality objectives" defined in the EPP Noise.

3.1.3 Criteria - other times of the day or night

The EPP Noise defines "acoustic quality objectives" for the environment that are conducive to human health and wellbeing, including the ability for individuals to sleep, study, relax or converse. The acoustic quality objectives relevant to noise sensitive locations are reproduced below in Table 1. Whilst not intended for setting noise limits for permanent noise sources, it is recommended that these objectives be adopted as goals for assessing any construction noise on Sundays, and other evening and night-time periods.

Table 1: EPP Noise acoustic quality objectives

Column 1	Column 2	Column 3			Column 4
Sensitive receptor	**Time of day**	**Acoustic quality objectives (measured at the receptor) *dB(A)***			**Environmental value**
		$L_{Aeq,adj,1hr}$	$L_{A10,adj,1hr}$	$L_{A1,adj,1hr}$	
dwelling (for outdoors)	daytime and evening	50	55	65	health and wellbeing
dwelling (for indoors)	daytime and evening	35	40	45	health and wellbeing
	night-time	30	35	40	health and wellbeing, in relation to the ability to sleep
library and educational institution (including a school, college and university) (for indoors)	when open for business or when classes are being offered	35			health and wellbeing
childcare centre or kindergarten (for indoors)	when open for business, other than when the children usually sleep	35			health and wellbeing
childcare centre or kindergarten (for indoors)	when the children usually sleep	30			health and wellbeing, in relation to the ability to sleep
school or playground (for outdoors)	when the children usually play outside	55			health and wellbeing, and community amenity
hospital, surgery or other medical institution (for indoors)	visiting hours	35			health and wellbeing

Table 1 (continued): EPP Noise acoustic quality objectives

Column 1	Column 2	Column 3			Column 4
Sensitive receptor	**Time of day**	**Acoustic quality objectives (measured at the receptor) *dB(A)***			**Environmental value**
		$L_{Aeq,adj,1hr}$	$L_{A10,adj,1hr}$	$L_{A1,adj,1hr}$	
hospital, surgery or other medical institution (for indoors)	anytime, other than visiting hours	30			health and wellbeing, in relation to the ability to sleep
commercial and retail activity (for indoors)	when the activity is open for business	45			health and wellbeing, in relation to the ability to converse
protected area, or an area identified under a conservation plan under the *Nature Conservation Act 1992* as a critical habitat or an area of major interest	anytime	the level of noise that preserves the amenity of the existing area or place			health and biodiversity of ecosystems
marine park under the *Marine Parks Act 2004*	anytime	the level of noise that preserves the amenity of the existing marine park			health and biodiversity of ecosystems
park or garden that is open to the public (whether or not on payment of an amount) for use other than for sport or organised entertainment	anytime	the level of noise that preserves the amenity of the existing park or garden			community amenity

The measurement parameters for the acoustic quality objectives ($L_{Aeq,adj,1hr}$ $L_{A10,adj,1hr}$ $L_{A1,adj,1hr}$)[2] include an adjustment (designated by the 'adj' subscript) for tonal and/or impulsive characteristics of the noise under investigation, that increase the subjective loudness of a noise. The required adjustment for tonal and/or impulsive characteristics is the sum of correction factors K_1 and K_2 summarised in Table 2 in accordance with AS1055:1997 Acoustics – Description and measurement of environmental noise Part 1: General procedures.

[2] See glossary for explanation of acoustic terminology and abbreviations

Table 2: Adjustments for audible characteristics "adj" = K1 + K2

Audible characteristic	Criterion	Correction
Tonality	Subjectively just detectable	K1 = 2-3dB
	Subjectively prominent (clearly audible)[3]	K1 = 5-6dB
Impulsivity	Subjectively detectable[4]	K2 = 2dB

Where predictive modelling indicates that noise goals are likely to be exceed by construction works, then consultation, reasonable and practicable mitigation and noise monitoring should be undertaken in consultation with owners and occupants of potentially affected premises.

3.2 Ambient noise levels

The ambient noise levels in the vicinity of the pipeline route are generally very quiet, with a diurnal cycle of morning and evening bird-chorus, evening insect chorus and daytime vegetation rustling noise generated by breezes. Daytime background noise levels are typically less than 25dBA, and night-time background levels typically less than 15dBA.

Anthropogenic noise is generally limited to intermittent traffic pass-by noise near (<1000m) significant roadways, and low levels of night-time air-conditioner noise and domestic noise (radio, television, children's play, domestic animal noise) emitted from dwellings in inhabited areas. Sounds of distant agricultural processes in cultivated areas are seasonally significant (e.g. tilling, planting, harvesting, irrigation pumps). Intermittent stock calling noise (cattle in particular) can also be significant at night in pastoral areas.

Ambient noise levels increase as the pipeline route approaches the Yarwun area of Gladstone, associated with significant industrial noise sources.

3.3 Pipeline laying

3.3.1 Standard daytime hours

The noise level, character and duration of standard pipeline trenching (with a trencher or excavator) and other pipeline operations is comparable to that of road-paving operations. Each process in pipeline construction (right-of-way clearing, trenching, pipe-laying, and backfilling) is expected to progress past residence or other the sensitive receptor within the space of a working day. This noise will be noticeable at the minimum distance of 100m but acceptable during the standard daytime hours, in accordance with the default noise standards under the EP Act.

If non-standard noisy operations such as rock-sawing, rock-hammering or directional-drilling are required within 200m of (but more than the minimum 100m from) a sensitive place during standard daytime working hours, it is recommended that dwellings and businesses within this envelope be notified in advance of such daytime works.

3.3.2 Non-standard hours

Out-of-hours[5] standard trench excavation (trencher or excavator) and other pipeline construction operations within 1km of a residence, would need to be conducted according

[3] The objective test of tonality is as per AS1055.1 Clause 6.6.3

[4] The objective test of impulsive characteristics is as per AS1055.1 Clause 6.6.4

[5] Sundays, evenings and nights as per EP Act section 440R.

to an approved noise management plan addressing the EPP Noise acoustic quality objectives.

Out-of-hours non-standard trench excavation (rock-sawing, rock-hammering or directional drilling) within 2km of a residence would need to be conducted according to an approved noise management plan addressing the EPP Noise acoustic quality objectives.

3.4 The Narrows crossing – HDD option

Preliminary noise modelling has been conducted to explore the significance of HDD rig noise on the western side of The Narrows pipeline crossing. While the drill rig could be located on Curtis Island, it was considered that noise impacts on sensitive receptors from this location would not be significant.

The nearest permanent residential dwelling to the proposed HDD rig site at Friend Point is approximately 5km west, and any temporary accommodation camp associated with LNG plant construction would be more than 2km east.

The predicted noise level contours from the HDD drill site are illustrated on Figure 5 and Figure 6.

It is concluded that HDD noise would not be significant at any time of the day or night.

3.5 Accommodation camps

Potential noise impacts associated with accommodation camps generally relate to low impact noises such as power generation and air-conditioning plant within the camp itself, or vehicles entering and departing from the camp.

No adverse noise impacts are anticipated in association with temporary accommodation camps providing they are located at least 500m from existing dwellings.

3.6 Traffic and transportation

The potential for significant traffic and transportation noise impacts lies in the use of quiet country roads close to residences during the night or early morning, when traffic may otherwise be completely absent. This could result in sleep disturbance or unwanted noise intrusion to individuals and will be subject to individual circumstances and sensitivities.

It is recommended that where sensitive receptors are located close to construction access tracks deliveries to construction sites out-of-hours should not occur unless in compliance with an approved traffic management plan recognising the potential impact on nearby residences.

A traffic management plan will be prepared prior to construction identifying suitable routes and times of travel to minimise disturbances to residents and traffic conditions.

4. Vibration impact assessment

4.1 Vibration criteria

4.1.1 Environmental values to be protected

Community concern about temporary construction vibration or blast vibration normally relates to the perceived possibility of cracking of, or structural damage to, valued property. Examples of valued property include dwelling, business premises, swimming pool or a significant masonry fence.

Less commonly, stakeholder concerns relate to the potential from construction activities to cause vibrations which disrupt vibration sensitive equipment associated with a business or hospital, livestock or cause distractions within an educational institution.

It is uncommon for construction vibration associated with pipeline development to cause sleep disturbance or disturbance to relaxation, independent of concern or anxiety about perceived potential property damage. Similarly, there is no known adverse health effects associated with pipeline construction vibration in the community (excluding direct occupational vibration impacts to employees that operate plant and equipment) other than concern or anxiety directly relating to perceived potential property damage.

The values to be protected in relation to vibration are therefore:-

- the 'peace of mind' that property is not at risk of damage
- the monetary value of properties and business processes, as may be affected by cosmetic/structural damage or interference to profitable processes or other valuable assets

4.1.2 Blasting criteria

The EP Act defines acceptable levels of ground vibration and air-blast over-pressure for buildings in section 440ZB, as follows:

- airblast overpressure not to exceed 115dBZ for 4 out of 5 consecutive blasts with a maximum of 120dBZ Peak for any blast
- ground vibration not to exceed 25mm a second, peak particle velocity respectively, for vibrations of more than 35 Hz and 10mm a second for vibrations no more than 35 Hz.

Appendix J of Australian Standard (AS) 2187.2-2006 'Explosives - Storage and use part 2: Use of explosives' provides detailed information about blast vibration and air-blast over-pressure estimation and control.

In regard to prevention of minor or cosmetic damage in structures, AS2187.2 refers directly to British Standard (BS)7385.2 1993 'Evaluation and measurement for vibration in buildings Part 2. Guide to damage levels from ground-borne vibration', for recommended maximum vibration levels. These recommendations are detailed Section 4.1.3 for non-blast vibration sources .

4.1.3 Other sources of construction vibration

Significant ground-borne vibration may be experienced close to construction processes such as piling, vibratory rolling, tunnel-boring, excavation or rock-hammering.

British Standard BS 7385.2 provides guidance on vibration levels to prevent cosmetic vibration-induced damage to buildings due to a variety of sources.

The ground vibration guide values, recommended by BS 7385.2 for 'transient' vibration sources above which cosmetic damage could occur, are shown numerically and graphically in Table 3. It is recommended that the limits be halved for 'cyclic' vibration sources, which are more likely to generate an accumulated resonant vibration response within the structure being protected.

'Transient' vibration sources refers to sources of vibration where successive vibration impulses can be considered as separate disturbances with respect to the vibration response of the structure being protected. Examples of transient vibration sources include single drop-hammer-blows from impact piling (each impact separated by a number of seconds), the dropping of heavy objects, or irregular vibration from an excavator bucket stalling/releasing during digging through uneven ground.

'Cyclic' vibration refers to repetitive sources of vibration where evenly sequenced (periodic) vibration peaks produce an accumulated vibration response in the structure being protected. Cyclic sources include vibratory rolling, vibratory pile driving, rock-hammering, and rapid air-hammer impact piling.

Table 3: BS 7385.2 Guide values for avoiding cosmetic building damage

Line (see figure 1)	Type of building	Peak component particle velocity in frequency range of predominant pulse	
		4 Hz to 15 Hz	15 Hz and above
1	Reinforced or framed structures Industrial and heavy commercial buildings	50 mm/s at 4 Hz and above	
2	Unreinforced or light framed structures Residential or light commerical type buildings	15 mm/s at 4 Hz increasing to 20 mm/s at 15 Hz	20 mm/s at 15 Hz increasing to 50 mm/s at 40 Hz and above
NOTE 1. Values referred to are at the base of the building (see 6.3). NOTE 2. For line 2, at frequencies below 4 Hz, a maximum displacement of 0.6 mm (zero to peak) should not be exceeded.			

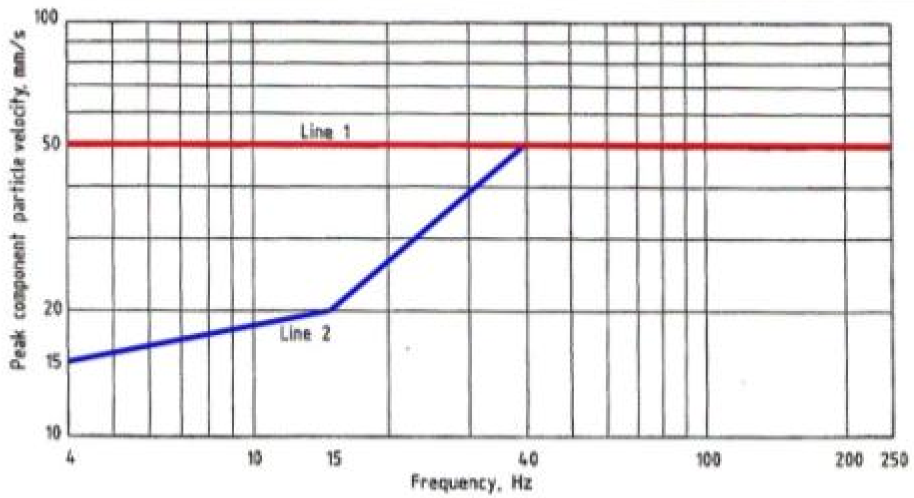

Figure 1. Transient vibration guide values for cosmetic damage

Minor damage is possible at vibration magnitudes which are greater than twice those given in Table 3, i.e. at peak component particle velocity of 100mm/s, or greater for a line 1 building (i.e. reinforced or framed structures, industrial and heavy commercial buildings).

Major damage to a building structure would be expected at ground vibration values greater than four times the values given in Table 3, i.e. at peak component particle velocity of 400mm/s, or greater for a line 1 building.

4.1.4 Criteria for protection of vibration sensitive property

The most common concern regarding the influence of construction vibration on sensitive processes relates to computer hard-drives. However with the advent of portable computing, computer drives are no longer particularly vibration sensitive. Vibration guidelines for protection of buildings against cosmetic damage are sufficient to protect desktop computers also.

Receptors that are highly sensitive to vibration are generally limited to major hospitals or precision manufacturing processes containing precision microscopes and medical scanning devices.

In some instances heritage-listed structures may also be deemed to be vibration-sensitive, however this should not be assumed. Specific vibration management plans are normally developed for each such facility or structure on a case-by-case basis.

4.2 Ambient vibration levels

Ambient vibration levels are generally not significant in the study vicinity. The exception is close to heavy vehicle road corridors that contain pot-holes or other significant surface irregularities. This situation may produce perceptible transient vibration levels during heavy vehicle pass-by in dwellings located at minimum road set-back distances. Well formed and sealed roads are not a significant source of ambient vibration at habitable distances from roadways.

4.3 Pipeline laying – mechanical excavation

Levels of ground vibration associated with a range of mechanical construction vibration sources are illustrated in Figure 4.

A preliminary or 'rule-of-thumb' threshold criterion for evaluating the significance of ground vibration on 'sound' structures is a peak particle velocity of 5mm/s. Refering to Figure 4, normal construction processes are unlikely to generate vibration levels over 1mm/s at receiver distances greater than 100m.

It is concluded that the proposed minimum separation distance of 100m between the pipeline alignment and sensitive dwellings or commercial premises will ensure no vibration impact to buildings associated with any possible mechanical excavation technique (trencher, excavator, rock-sawing, rock-hammering, directional drilling).

4.4 Blasting excavation

There are no specific locations where it is known that blasting will be required in the vicinity of residences or commercial properties.

However, if blasting is required, the blast will be designed to comply with the statutory criteria set down in Section 4.1.2 and with regard to any particular vibration requirements or sensitivities of the nearby receptor location(s).

The level of vibration associated with blasting is controlled by the number, mass and depth of explosive charges used in a blast. Formulae for estimating the vibration level resulting from a given charge mass at a given distance can be found in Appendix J of AS 2187.2-2006.

Blast vibration can be felt at levels much lower than levels that damage property. Perception of vibrations and possible rattling of windows and contents often leads to heightened awareness and discovery of cracks that are usually pre-existing. It is critical therefore that where concern about cracking may arise as a result of significant 'noticeable'

vibration, consultation with residents be undertaken ahead of construction commencing. A pre-construction inspection of the building condition by both the owner and a construction representative should be conducted if there is a perceived threat to the value of the property, with post-construction follow-up inspection if necessary.

Vibration monitoring should be considered if predicted vibration levels are more than 20% of the statutory vibration limit values. Lower vibration goals should be considered in the case of heritage-listed structures, or where there is elevated sensitivity of persons (e.g. infirmity) or building contents to vibration.

5. Marine noise impact assessment

5.1 Environmental values to be protected

There are a range of potential impacts of underwater noise on marine creatures that may be relevant to conservation and protection of the species.

Behavioural disturbance is the mildest form of marine noise impact. The impact is deemed significant if the behavioural response may impact the long term survival chances of the individual or species.

An example behavioural response of an animal to marine noise is relocation away from the noise source. If this relocation caused displacement from a unique feeding ground during critical stages of a breeding cycle, the behavioural disturbance could result in impaired reproduction and may therefore be significant to survival chances. However, if alternative foraging grounds were readily available and accessible, the behavioural response of relocation may not be significant.

Direct physiological impacts associated with higher levels of underwater noise are normally described in terms of the effect on the auditory system. The types of impacts are described similarly to the impacts of high levels of noise on humans.

Temporary threshold shift (TTS) describes the effect of sudden or cumulative noise exposure, causing temporary loss of hearing sensitivity. This can directly impact survival by diminishing response to danger, or by diminishing the acuity of acoustic methods of food detection.

Permanent threshold shift (PTS) describes the effect of more severe sudden or cumulative noise exposure, causing permanent loss of hearing sensitivity due to tissue damage within the auditory system.

The most severe possible acoustic impact on marine species is mortality, as may occur close to underwater explosive noise sources. Damage may occur in the form of vascular damage to critical organs, or damage to air-filled cavities such as swim-bladder damage in the case of fish.

5.2 Significant species to be protected

There are many marine creatures that use sound to communicate, navigate, forage and detect danger. These include marine mammals such as dugong and dolphins, turtles and fish. The most significant marine species in the context of marine construction noise disturbance in the vicinity of the proposed pipeline crossing of The Narrows are outlined below.

5.2.1 Dugong

The Rodds Bay/Port Curtis area, including the area adjacent and south of the proposed pipeline crossing of The Narrows, is designated a dugong protection area by the Great Barrier Reef Marine Park Authority. This area is illustrated on Figure 7.

The primary management intent for dugong conservation is to facilitate the recovery of dugong populations such that they fulfil their ecological role within the Great Barrier Reef ecosystem. To do this there are two relevant management objectives:

- reduced mortality of dugongs from all human-related causes[6] to facilitate population recovery
- protection of the quality and extent of habitat for dugongs, including feeding, calving and mating areas and migratory pathways.

Consideration of the marine acoustic environment is relevant to this second objective.

5.2.2 Dolphin

The Australian *Environment Protection and Biodiversity Conservation Act 1999* protected matters database identifies ten (10) cetacean[7] species that may occur in the Port Curtis region including offshore areas. Of these, it is understood that the Indo-Pacific humpback dolphin (*Sousa chinensis*), the Australian snubfin dolphin (*Orcaella heinsohni*) and the bottlenose dolphin (*Tursiops aduncus* and *Tursiops truncatus*) are known to occur in the general vicinity of the proposed pipeline crossing.

5.2.3 Marine turtles and fish

Marine turtles and a wide range of fish species occur in the general vicinity of The Narrows and Grahams Creek.

5.3 Marine noise management guidelines

5.3.1 Dolphins

The auditory and behavioural effects of anthropogenic (man-made) marine noise on dolphin species has been extensively studied, reviewed and summarised by Southall et al. 2007[8]. The authors for this study represented specialists in behavioural, physiological and physical aspects of noise impacts on marine mammals. The recommendations of this study have been utilised as the basis of marine noise exposure criteria for this assessment.

The dolphin species reported to occur in the general vicinity of The Narrows pipeline crossing site [9] are classified by Southall et al as 'medium-frequency cetaceans'. These dolphins produce and use high-frequency sounds (tens of kHz to 100+kHz) for eco-location of prey and for navigation. Lower frequency sounds (approximately 1kHz to tens of kHz) are produced for communication, resulting in an overall sound production frequency range of approximately 1kHz to greater than 100kHz. The estimated auditory frequency range of mid-frequency cetaceans reported by Southall et al. is 150Hz to 160kHz.

Noise exposure criteria

In developing marine noise criteria for temporary loss of hearing sensitivity (i.e. temporary threshold shift or TTS) and permanent auditory tissue damage (permanent threshold shift or PTS), distinction is made between:-

- noise sources that are pulsed (e.g. marine air-gun noise, pile-strike), and
- continuous noise sources that are 'non-pulses' (e.g. vessel pass-by noise, continuous dredging noise).

[6] Excluding lawful traditional hunting
[7] aquatic mammals with no hind limbs and a blowhole for breathing, including whales dolphins and porpoises
[8] Southall B L; Bowles A E; Ellison W T; Finneran J J; Gentry R L; Green C R; Kastak D; Ketten D R; Miller J H; Nactigall P E; Richardson W J; Thoas J A; and Tyack P L. *Marine Mammal Noise Exposure Criteria* Aquatic Mammals, Volume 33(4) 2007.
[9] Indo-Pacific humpback dolphin (*Sousa chinensis),*Australian snubfin dolphin (*Orcaella heinsohni)* and Bottlenose Dolphin (*Tursiops truncates)*

Laboratory studies of the effect of both pulsed and non-pulsed sound on TTS in cetaceans (principally bottlenose dolphins and Beluga whales) were reviewed by Southall et al. to develop TTS criteria for mid-frequency cetaceans. The large body of TTS and PTS data from other mammals, including humans were utilised to develop conservative estimates of PTS criteria based on the measured TTS data.

It is recommended that the un-weighted[10] wave-form peak sound pressure level (SPL) measurement parameter is used to assess the potential for TTS and PTS. This is the same measurement parameter used to assess the potential for immediate auditory damage in human hearing conservation programs.

Southall et al. recommend that the noise measurement metric utilised should not include sound energy that lies outside the functional hearing range of a species to assess potential for cumulative TTS and PTS. Southall et al also recommend use of M-weighted measurements of cumulative noise exposure for marine mammals. The recommended M-weighting curve for sound exposure measurement pertaining to medium-frequency cetaceans is shown in Figure 8, reproduced from Southall et al.

Noise criteria for TTS and PTS

The recommended criteria for dolphin, for avoidance of TTS and PTS impacts are detailed in Table 4. The SPL or sound exposure level (SEL) criteria should be tested, and the more stringent criterion deemed to apply.

Table 4: Criteria for avoidance of TTS and PTS in mid-frequency cetaceans

Impact	Unit of measure	Single or multiple pulses	Non-pulses
TTS	SPL Re: 1µPa (un-weighted Peak)	224dB	224dB
	SEL Re: $1\mu Pa^2$-s (M_{mf}-weighted)	183dB	195dB
PTS	SPL Re: 1µPa (un-weighted Peak)	230dB (TTS + 6)	230dB (TTS + 6)
	SEL Re: $1\mu Pa^2$-s (M_{mf}-weighted)	198dB (TTS + 15)	215dB (TTS + 20)

Noise criteria for behavioural disturbance

Southall et al. conducted an extensive review of documented behavioural studies of cetaceans and pinnipeds (seals) and critically summarised the range and significance of behaviours associated with documented noise level exposures for specific quantified noise sources. This analysis summarised studies of both free-ranging and laboratory subjects.

In the context of marine mammal conservation, significant behavioural responses were defined as responses that that may result in demonstrable effects on individual growth, survival, or reproduction. Examples given for the onset of significant behavioural response include:-

- individual and/or group avoidance of a sound source
- aggressive behaviour
- startled response (that may expose an individual to danger)
- brief or minor separation of mother-and-calf
- extended cessation of vocal behaviour
- brief cessation of reproductive behaviour.

[10] 'un-weighted' is also termed 'flat-weighted' or 'linear-weighted'

The behavioural response of marine mammals to man-made noise was concluded to be highly context specific, depending on the significance of the noise to the subject and depending on the prior experience of a subject to a given stimulus. There was not a consistent linear relationship between increasing stimulus (as measured by SPL or SEL metrics) and the onset of significant behavioural responses. (Southall et al summarise their findings as follows: "Current available data, pooled by functional hearing group, do not support specific numerical criteria for the onset of disturbance. Rather, they indicate the context-specificity of behavioural reactions to noise exposure and point to some general conclusions about response severity in certain, specific conditions."

Marine noise sources associated with dredging a trench for construction of the proposed pipeline crossing would include various work vessels and a range of possible dredges. Qualitatively, suction dredging noise has similarities to vessel noise, with gradual on-set of noise generation, but much slower physical movement than vessels. It is therefore considered reasonable for the behavioural response of dolphin species to dredge noise to be considered on the basis of the documented response of dolphins to vessel noise.

In the summary of behavioural studies presented by Southall et al., vessel noise was not found to result in a significant behavioural response for free-ranging mid-frequency cetaceans (e.g. Beluga Whale, Bottlenose Dolphin, Indo Pacific Dolphin).

It can be expected that dolphin species in the general vicinity of Port Curtis are very familiar with vessel noise and dredging noise associated with existing traffic and previous and ongoing dredging works (e.g. Fisherman's Landing berth dredging).

5.3.2 Dugong

Auditory system

The auditory system of the dugong (*Dugong dugon)* is beginning to receive detailed research attention to support the development of appropriate marine conservation measures, to address lethal and sub-lethal risks posed by boat-strike, seismic surveys and use of explosives in marine defence artillery practice areas(Hodgson 2007) [11] . A photo of a dugong is shown in Figure 9. In relation to boat-strike, recent research effort has been directed at improving knowledge of the extent to which dugong are able to detect the approach of motor-vessels.

Iwashina 2008[12] conducted anatomical studies on deceased dugong subjects to estimate the dugong auditory range at between 24-34Hz and 24-27kHz, based on comparative studies of cochlea geometry in dugong and humans. Iwashina also investigated the physical nature of the sound conduction structures of the outer ear, skull and middle-ear. Iwashina concludes that it is unclear whether the sound transmission via the narrow external ear canal is redundant in comparison to sound conduction to the middle-ear via tissue and the skull. It is noted that the connection of the middle-ear structures to the dugong skull may preclude significant binaural hearing capability, as sound conduction via the skull tends to present the same external sound signal to both ears (in contrast to dolphin where the left

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[11] Hodgson, A. *A Dugong Research Strategy for the Torres Strait, Great Barrier Reef World Heritage Area and south-east Queensland 2006-2011* Great Barrier Reef Marine Park Authority, Townsville, Research Publication No.86, 2007

[12]Iwashina, Y. *A Preliminary Study of the Basic Ear Anatomy of the Dugongs* School of Earth and Environmental Science, James Cook University, Queensland 2008

and right sound transmission structures to the middle-ear are mechanically isolated to a greater degree).

Based on the experimental work of Hodgson[13] and Hodgson and Marsh 2007[14] in relation to dugong boat-strike potential, and anatomical studies by Iwashina, it does not appear that dugong use binaural processing of differentially received sound to help localise the source of sound in water. Hodgson reported experimental observations of dugong behaviour in response to close vessel pass-bys at distances less than 50m. Dugong did not show a tendency to move away from the boat, and appeared to be inclined to move towards the boat if this direction led to deeper water. Hodgson reports that some planned experimental close-range pass-by testing was not conducted due to the absence of evidence that the dugong would exhibit a successful rather than erroneous avoidance response.

Estimates of the optimal hearing sensitivity of dugong are based on the evolutionary logic that the optimal hearing sensitivity would likely match the frequency range of dugong vocalisations. These vocalisations have been quantified by Anderson and Barclay 1995[15] to be within the range of 3kHz to 18kHz for 'chirp-squeaks', and between 500Hz and 2.2kHz for 'barks'.

Noise management criteria

Noise criteria have not been developed specifically for dugong to manage potential TTS and PTS impacts. However, a conservative approach can be developed by comparing what is known about the dugong auditory system with better-studied cetaceans for which TTS and PTS guidelines are available.

The reported range of optimal hearing sensitivity of dugong spans the low-frequency hearing sensitivity reported for 'mid-frequency cetaceans' and high-frequency sensitivity reported for 'low-frequency cetaceans' as illustrated on Figure 8. It can be concluded that measurements using the M_{mf} frequency weighting for mid-frequency cetaceans will not under-estimate the significance of noise to dugong.

The anatomical work of Iwashina suggests that the overall hearing sensitivity of dugong would likely be less than that of dolphins, which appear to have far more evolved sound conduction structures to the middle-ear.

On this basis, it is assumed that the TTS and PTS criteria for mid-frequency cetaceans as detailed in Table 4, would provide a conservative management basis for considering TTS and PTS impacts on dugong.

5.3.3 Fish

Noise impacts on fish have been studied in detail, principally in the context of marine pile-driving, marine explosions and marine air-gun arrays. These noise sources at high intensities can damage the auditory structures of fish (soft sensory tissue on the fish otolith becomes damaged), rupture swim bladders and cause vascular damage.

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13 Hodgson, A J *Dugong behaviour and responses to human influences* PhD Thesis, School of Earth and Environmental Science, James Cook University, Queensland 2004

14 Hodgson, A J and Marsh H.. *Response of dugongs to boat traffic: The risk of disturbance and displacement* Journal of Experimental Marine Biology and Ecology 340 (2007) 50-61

15 Anderson, P.K. and Barclay, M.R *Acoustic Signals of Solitary Dugongs: Physical Characteristics and Behavioural Correlates*, Journal of Mammology, Vol.76, No.4(Nov, 1995) pp.1226-1237

The American National Marine Fisheries Service (Stadler and Woodbury 2009[16]) noise management criteria for avoidance of tissue damage in fish during marine piling have been adopted for assessment of both pulsed and non-pulsed sound, as reproduced in Table 5.

Table 5: Criteria for avoidance of tissue injury in fish

Application	Unit of measure	Single or multiple pulses	Non-pulses
All fish	SPL Re: 1μPa (un-weighted Peak)	206dB	206dB
Fish ≥ 2g	SEL Re: 1μPa²-s (un-weighted)	187dB	187dB
Fish < 2g		183dB	183dB

5.3.4 Marine turtles

Auditory system

Marine turtles have an external ear-drum with mechanical connection to the middle-ear. The external acoustic transmission tissue shows adaptations not observed in terrestrial and semi-aquatic turtles (Moein Bartol 2008[17]).

Early research into the auditory response of marine turtles was motivated by the possibility of developing acoustic deterrent devices to keep turtles away from sources of mechanical harm, such as suction dredges (Moein et al 1995[18]). However, little is known about levels of acoustic energy that may harm the auditory function.

The auditory frequency range of marine turtles is significantly lower than that of dolphin and dugong, with estimates for a range of species (including the Green Turtle and Loggerhead Turtle) in the range of 100Hz to 1kHz (Ketten and Moein Bartol 2005[19]) and best sensitivities near 400-1000Hz (Ketten 2008[20]). These estimates were based on auditory brain stem response studies of live subjects. Ketten notes that little more is currently known about the hearing sensitivity of turtles or their dependency on sound that may be relevant to the many facets of survival.

It may be noted that the known auditory frequency range of marine turtles is fully contained within, and represents a small fraction of the auditory frequency range of mid-frequency cetaceans (refer Figure 8).

In the absence of recommended damage criteria for marine turtles from scientific literature it is proposed to utilise the same criteria as for dolphin species.

5.4 Baseline marine noise survey

5.4.1 Methodology

Attended underwater noise sampling was conducted on the 17 June and the 24 June 2009, in the vicinity of the proposed pipeline crossing and in the vicinity of existing operational wharfs. Monitoring was conducted to provide baseline data on the range of noise levels in

[16] Stadler J H and Woodbury D P *Assessing the effects to fishes from pile driving: Application of new hydroacoustic criteria* National marine Fisheries Service USA, Proceedings Internoise 2009 August 2009 Ottawa, Canada.

[17] Bartol S M *A review of auditory function of sea turtles* Bioacoustics Vol 17(1-3) 57-59 2008

[18] Moein S E, Musick JA, Keinath J A, Barnard D E, Lenhardt M L, and George R *Evaluation of seismic sources for repelling sea turtles from hopper dredges* In *Sea Turtle Research Program: Summary Report* (Ed by L Z Hales) pp.90-93 Technical Report CERC95

[19] Ketten D R and Bartol S M *Functional Measures of Sea Turtle Hearing –Final Report* Woods Hole Oceanographic Institution

[20] Ketten DR *Underwater ears and the physiology of impacts: Comparative Liability for Hearing Loss in Sea Turtles, Birds and Mammals* Bioacoustics 17(103) 315-318 2008

the study area, and also to provide numerical context to the underwater noise metrics utilised for assessment of marine construction noise sources.

The location of all underwater noise sampling points within the Port of Gladstone area are illustrated on Figure 10. A detailed view of sampling locations in the general area of The Narrows pipeline crossing site is illustrated on Figure 11.

Sampling was conducted in low-wind conditions with negligible noise from wave-action. This condition is not uncommon in the relatively protected waters of The Narrows where wind-fetch distances for wave generation are relatively short.

The hydrophone was suspended at approximately mid-depth, which was determined from depth-sounder records and depth markers on the hydrophone cable. Sampling was conducted with the boat motor off while drifting, with the start and finish points of the drift marked by a global positioning system.

Sampling in the vicinity of The Narrows crossing was conducted around low-tide or high-tide to minimise tidal turbulence and flow turbulence over the hydrophone .

5.4.2 Instrumentation

The acoustic instrumentation used for testing is summarised in Table 6. The test system was calibrated immediately before commencement of measurements and immediately after measurements, with less than 0.2dB drift in system calibration recorded.

Full sound signals were recorded to enable replay of samples for post-analysis identification of noise sources.

A laser rangefinder was utilised to determine the pass-by distance of vessels, and to determine hydrophone separation distance from wharf structures and moored ships.

Table 6: Instrumentation and equipment

Item	Notes
Hydrophone	Single-ended Reson TC4032 low noise with 10dB preamp S/N4307048 Usable frequency range 5 Hz to 120 kHz Linear frequency range 15 Hz to 40 kHz ± 2 dB Receiving sensitivity -170 dB re 1 V/µPa (3mV/Pa)
Extension cable	Reson TL8058 10m extension cable and lemo cable junction box
Sound analyser and data storage	Panasonic CF19 Toughbook incorporating a SINUS Harmonie Type 1 sound analyser, hard-drive digital audio storage, and Samurai control software S/N06268 -40kHz 3201 line FFT, 1µPa reference pressure
Calibrator	Type 1 GRAS 42AA pistonphone S/N91003 with RESON TL8089 coupler S/N1108033

5.4.3 Results

A representative summary of the results of ambient noise sampling are collated in Table 7, cross-referenced to the geographical locations illustrated on Figure 10 and Figure 11, and graphical sound spectral data for specific sound samples illustrated in **Appendix A**.

Under water noise sample location Numbers 1 to 11 were collected on 17 June 2009, and Sample Numbers 12 to 18 on 24 June 2009. The duration of each sample was generally five minutes.

Ambient noise in the vicinity of the pipeline crossing was found to be dominated by the 'cracking' sound of many Snapping Shrimp, with some relatively low-level noise contribution from distant wharf ship-loader activity at Fisherman's Landing.

Sound from a transient fish chorus was noted in Sample 9, with this type of sound occurring within the general frequency range of 200Hz to 2kHz. This event is described as transient as this sound was not evident at the nearby location of Sample 8 approximately 10 minutes earlier or at Sample 11 approximately 10 minutes later.

The overall root mean squared[21] (RMS) sound pressure contribution of shrimp and ship-loader noise were comparable at distances of 250m to 350m from ship-loading activities.

The peak sound pressures throughout the study area were dominated by Snapping Shrimp noise[22]. Levels were consistently in the range of 155-165dB$_{(peak)}$ throughout the study area.

Snapping Shrimp produce sound energy over a very wide frequency range from around 500Hz to greater than 100kHz, whereas the ambient sound energy associated with ship-loading noise generally occurs at frequencies below approximately 2kHz.

Table 7: Marine ambient noise sample summary[23]

Sample point no. (refer Figure 10 and Figure 11)	Time	Water depth	Dominant noise sources	Peak pressure SPL Re: 1µPa (un-weighted Peak)	RMS pressure SPL Re: 1µPa (M_{mf}-weighted)
1 (Crossing)	8:35am	14m	Snapping Shrimp Distant speedboat Wave-slap	157dB (shrimp)	106 – 122dB (refer Figure 21)
3 (Crossing)	9:05am	14m	Snapping Shrimp Speedboat at 80m	126dB (boat) 155dB (shrimp)	108 – 124dB (refer Figure 22)
5 to 6 (Hamilton Pt)	11:20am	15m	Snapping Shrimp Distant shiploading	162dB (shrimp)	114 – 127dB (refer Figure 23)
9 (Crossing)	1:34pm	15m	Snapping Shrimp Fish chorus	160dB (shrimp)	105 – 126dB(M_{mf}) 106 – 126dB(linear) (refer Figure 24)
12A to 12B (Grahams Ck)	12:31pm	9-11m	Snapping Shrimp Speedboat at 400m Wave-slap	165dB (shrimp)	103 – 129dB (refer Figure 25)
13A to 13B	12:45pm	17m	Snapping	160dB	114 – 125dB

[21] See acoustic glossary for discussion of this factor.
[22] generated by water-jet induced cavitation bubble implosion
[23] Data from sample points 3,4,7,8,11,14, and 16 duplicates the data presented, and is omitted for brevity.

Sample point no. (refer Figure 10 and Figure 11)	Time	Water depth	Dominant noise sources	Peak pressure SPL Re: 1µPa (un-weighted Peak)	RMS pressure SPL Re: 1µPa (M_{mf}-weighted)
(Crossing)			Shrimp Distant shiploading	(shrimp)	(refer Figure 26)
15A to 15B (Crossing)	1:03pm	5m	Snapping Shrimp Distant shiploading	160dB (shrimp)	104 – 122dB (refer Figure 27)
17A to 17B (Fisherman's Landing)	1:24pm	9-14m	Shiploading at 350m Snapping Shrimp	161dB (shrimp)	118 – 127dB (refer Figure 28)
18A to 18B (Clinton Wharf)	2:20pm	19m	Shiploading at 250m Snapping Shrimp	156dB (shrimp)	121 – 130dB (refer Figure 29)

5.5 Assessment of dredge and vessel noise

5.5.1 Source underwater noise levels

Marine noise levels during dredging operations and a range of vessel pass-by events have been sampled to provide indicative noise levels associated with a dredged pipeline crossing methodology. This previous sampling was conducted whilst dredges and vessels were operating in protected water passages (Port of Brisbane and Port of Bundaberg) that are similar in water depth, wave conditions and bottom conditions to The Narrows study area.

Noise levels were sampled utilising the instrumentation and methodology as detailed in Section 5.4 for baseline noise monitoring.

A summary of the results of source noise sampling are collated in Table 8, and cross-referenced graphical sound spectral data for specific sources is provided in **Appendix A**.

All noise sources sampled are described as 'non-pulsed' noise sources for assessment of potential auditory effects on marine creatures as the impulse-response RMS levels were no more than 1dB higher than the fast-response RMS level.

Table 8: Sample marine dredging and vessel noise summary

Noise source	Measurement distance	Receiver water depth	Dominant noise sources	Peak pressure SPL Re: 1µPa (un-weighted Peak)	RMS pressure SPL Re: 1µPa (M_{mf}-weighted)
'Amity' cutter-suction dredge Figure 12 Figure 13	45m beam	14m	Hydraulic drive Suction noise	145dB	128-142 dB (refer Figure 30)
'Brisbane' 2900m³ trailing-arm suction hopper dredge Figure 14 Figure 15	45m pass-by of stationary observer by traversing dredge	11m	Gravel noise in suction head Engine noise	176dB	147-158dB(M_{mf}) (refer Figure 31) 148-160dB(linear)
Sea-service freighter Figure 16	220m pass-by	7m (source depth ~14m)	Engine and drive noise	<140dB - Shrimp noise dominant	127-135dB (refer Figure 32)
Stolt tanker Figure 17	155m pass-by	3m (source depth ~14m)	Engine and drive noise	<140dB - Shrimp noise dominant	124-136dB (refer Figure 33)
Pilot boat Figure 18	150m pass-by	2m (source depth ~14m)	Engine and propeller cavitation noise	<140dB - Shrimp noise dominant	113-126dB (refer Figure 34)
Passenger ferry Figure 19	200m pass-by	2m (source depth ~14m)	Engine and propeller cavitation noise	<140dB - Shrimp noise dominant	120-133dB (refer Figure 36)
Tug and barge	200m pass-by	2m (source depth ~14m)	Engine and propeller cavitation noise	<140dB - Shrimp noise dominant	113-126dB (refer Figure 36)

The levels of noise associated with the sources in Table 8 at distances less than the measurement distance can be conservatively over-estimated by simplistic modelling[24], by assuming free-field spherical propagation between the source and the measurement position (the level is approximated to increase by 6dB for each halving of distance).

[24] More accurate predictions require detailed modelling of the water depth, wave conditions, the acoustic absorptive properties and profile of the sea-bed, in addition to more detailed account of the directional characteristics and frequency spectrum of the noise source. The sound field at any distance will be a complex composite of direct and multiple surface and bottom- reflected sound paths, with the reflected sound-paths dominating in the far-field. In the far-field where reflected sound-paths dominate, the propagation of low frequency components will also be limited by the water depth, as the water column is unable to support the reflected propagation of soundwaves at wavelengths more than 4 times the water depth.

Levels at separation distances beyond the measurement distance can be conservatively over-estimated by assuming planar wave-guide cylindrical propagation beyond the measurement position (the level is approximated to decrease by 3dB for each doubling of distance).

5.5.2 Impacts on hearing sensitivity

The potential for TTS is examined by comparing typical levels of marine noise generated by dredging and vessel movements (refer Table 8) with instantaneous peak sound pressure level (peak SPL) and cumulative sound exposure level (SEL) criteria that have been developed by scientists (refer Table 4 and Table 5).

Peak sound pressure level

A comparison of measured ambient levels, source noise levels and criteria for peak SPL is presented in Table 9. Pressure criteria for dolphin have been utilised for consideration of dugong and turtle in the absence of scientifically recommended criteria.

The highest peak acoustic pressures associated with dredging occurs when a suction dredge is lifting rocky material, which generates significant impact noise in the hopper arm (176dB_{peak} at 45m). It is predicted that the most stringent pressure criterion for this operation of 206dB_{peak} (relating to fish) could be reached at distances within 1m to 2m of the suction head. The dolphin criterion of 224dB_{peak} would be reached at distances of less than 1m from the suction head.

It can be concluded that there is low risk of damage to any marine species associated with the peak sound pressure levels from dredging operations, or miscellaneous vessel movements. To put this risk into context, any creature close enough (<1m) for significant sound pressure impact would be at risk of direct mechanical damage from a dredge suction head or boat propeller.

Table 9: Assessment of peak pressure from dredging activities

Quantity	Comment	Source distance	SPL Re: 1μPa (un-weighted peak)
Criterion	Dolphin TTS peak pressure criterion	n/a	224dB
Criterion	Fish peak pressure criterion for on-set of permanent damage	n/a	206dB
Ambient	Ambient peak pressure in vicinity of The Narrows crossing (Snapping Shrimp)	n/a	155 -165dB measured
Cutter-suction dredge	'Amity' cutter-suction dredge	45m	145dB measured
Trailing-arm suction hopper dredge	'Brisbane' suction hopper dredge	45m	176dB measured
Vessel pass-bys	Freighters, ferries, workboats	150m	≤140dB measured
	Freighters, ferries, workboats	45m	≤150dB estimated

Cumulative sound exposure level

The potential cumulative sound exposure level (SEL) that a marine creature may experience in the vicinity of dredging operations would be dependent on both the separation distance from the noise source, and the duration of exposure. Both the exposure

distance and duration are difficult to define, as these quantities are inherently dependent on the behavioural avoidance response of the species in question to the noise source, which is uncertain. In practice, the SEL is quantified by making 'what-if' assumptions about separation distance and exposure duration.

A comparison of measured ambient levels, source noise levels and criteria for cumulative SEL sound pressures is presented in Table 10. As for the Peak SPL assessment, SEL criteria for dolphin are utilised for consideration of dugong and turtles.

Table 10: Assessment of cumulative SEL from dredging activities

Quantity	Comment	Source Distance	SEL Re: 1µPa².s
Criterion	Dolphin TTS SEL criterion	n/a	195dB(M_{mf}) non-pulsed
Criterion	Fish SEL criterion for on-set of permanent damage (fish ≥ 2g)	n/a	187dB(linear) non-pulsed
Criterion	Fish SEL criterion for on-set of permanent damage (fish < 2g)	n/a	183dB(linear) non-pulsed
Ambient	Ambient peak pressure in vicinity of The Narrows crossing - Sample 9 (Snapping Shrimp)	n/a	111dB(M_{mf}) measured (1second) 146dB(M_{mf}) calculated (1hour) 160dB(M_{mf}) calculated (24hour) (Note: linear-weighted ambient SELs are 1dB higher)
Trailing-arm suction hopper dredge	'Brisbane' suction hopper dredge lifting sandy material	45m	142dB(M_{mf}) measured (1second) 172dB(M_{mf}) calculated (15 minutes) (Note: linear-weighted ambient SELs are 1dB higher)
Trailing-arm suction hopper dredge	'Brisbane' suction hopper dredge lifting rocky material	45m	158dB(M_{mf}) measured (1second) 173dB(M_{mf}) measured (2 minutes) 182dB(M_{mf}) calculated (15 minutes) (Note: linear-weighted ambient SELs are 1dB higher)
Cutter-suction Dredge	'Amity' cutter-suction dredge in sandy material	45m	142dB(M_{mf}) measured (1second) 156dB(M_{mf}) measured (2 minutes) 165dB (M_{mf}) calculated (15 minutes) (Note: linear-weighted ambient SELs are 1dB higher)
Vessel pass-bys	Freighters, ferries, workboats Freighters, ferries, workboats	150m 45m	150dB(M_{mf}) measured 90s pass-by ≤160dB(M_{mf}) estimated 90s pass-by

The highest SEL associated with dredging would occur if a suction dredge encountered pebbly or rocky material, which generates significant additional noise emission from the hopper arm. It is predicted that the most stringent SEL criterion for this operation of 183dB(lin) relating to small fish (<2g) could be exceeded at distances within 45m of the suction head if an individual fish remained in the area for longer than 15 minutes, which

would seem unlikely. Much lower SELs would result if the dredge was operating over sandy material, in which case fish individuals would need to remain within 45m of the suction head for longer than 150 minutes.

The SEL criterion of 195dB(M_{mf}) for dolphin species[25] is predicted to be exceeded if an individual remained for longer than 5 hours within 45m of the suction head lifting rocky material, which is considered unlikely.

The marine sound energy levels associated with the cutter-suction dredge and vessel pass-by noise levels are not significant in relation to the SEL criteria. Hundreds of vessel pass-bys each day within 45m of an individual creature would be necessary for the sound exposure to become significant.

5.5.3 Behavioural impacts

In theory, the behavioural response of marine creatures to anthropogenic noise is dependent on both instinctive responses (e.g. flight), and cognitive responses (curiosity, understanding of danger, irritation).

Dolphin species exhibit a high degree of cognition of marine sounds and are very mobile. Dolphin may temporarily be driven by curiosity to venture closer to dredging. Research literature indicates no significant adverse behavioural response (in the context of survival) to vessel noise and this is also expected to be the case for dredging noise.

The inclusion of turtle-excluding design features on modern dredge suction-heads indicates that turtles (unfortunately) may not exhibit a significant behavioural avoidance response to marine dredging noise. The problems of boat-strike with turtles suggest that there is also not a strong behavioural avoidance response to vessel noise.

The behavioural response of dugong to marine dredging noise is unknown. The history of low mortality from boat-strike and scientific literature on the auditory response of dugong may suggest that cognition of dredging noise as a threat may be low.

[25] also simplistically used in this assessment as a guideline for Dugong and turtles in the absence of recommended criteria

6. Conclusions and recommendations

6.1 Airborne noise impacts

The proposed main transmission pipeline has been located to ensure it is at least 100m from any dwelling. As such, noise associated with standard pipeline trenching operations (trencher or excavator) during the standard daytime hours is expected to be in accordance with the default noise standards under the EP Act.

It is recommended that dwellings and/or businesses within 200m of non-standard trenching operations, such as rock-sawing, rock-hammering or directional-drilling, be notified before any of these activities occur during standard daytime working hours.

Out-of-hours[26] construction operations near sensitive receptors should be conducted subject to a noise management plan addressing the EPP Noise acoustic quality objectives where standard pipeline construction activities are conducted within 1km of a residence, or non-standard noisier trench excavation (rock-sawing, rock-hammering or directional drilling) is within 2km of a residence.

Preliminary modelling indicates that drilling a HDD crossing on a 24 hour basis at Friend Point on the western side of 'The Narrows' would not result in significant noise levels at the nearest dwelling 5km west.

The potential for significant transportation noise impacts may impact residences along typically quiet country roads during the night or early morning. It is recommended that deliveries to construction sites occur in compliance with an approved traffic management plan to minimise noise disturbance during the night or early morning. Night and early morning periods are considered out-of-hours and is defined by the EP Act section 440R and set down in Section 3.1.2.

Temporary construction camps should be located at least 500 metres from residences and other sensitive receptors to minimise noise impacts.

6.2 Vibration impacts

The proposed minimum separation distance of 100m between the pipeline alignment and sensitive dwellings or commercial premises will ensure no vibration impacts to buildings from all possible trench excavation techniques, excepting blasting.

Blasting is not expected in the vicinity of residences or commercial properties. If blasting is required, the blast should be designed to achieve the statutory vibration and air-blast criteria set out in section 440ZB of the EP Act and provided in Section 4.1.2, and with regard to any particular vibration requirements or sensitivities of the nearby receptor location(s).Concerns about potential vibration impacts on buildings should be managed by pre-construction and post-construction building condition surveys. Vibration monitoring should be considered if predicted vibration levels are more than 20% of the statutory vibration limit values. Lower vibration goals should be considered on a case-by-case basis for heritage-listed structures, or where there is elevated sensitivity of persons (e.g. infirmity) or building contents to vibration.

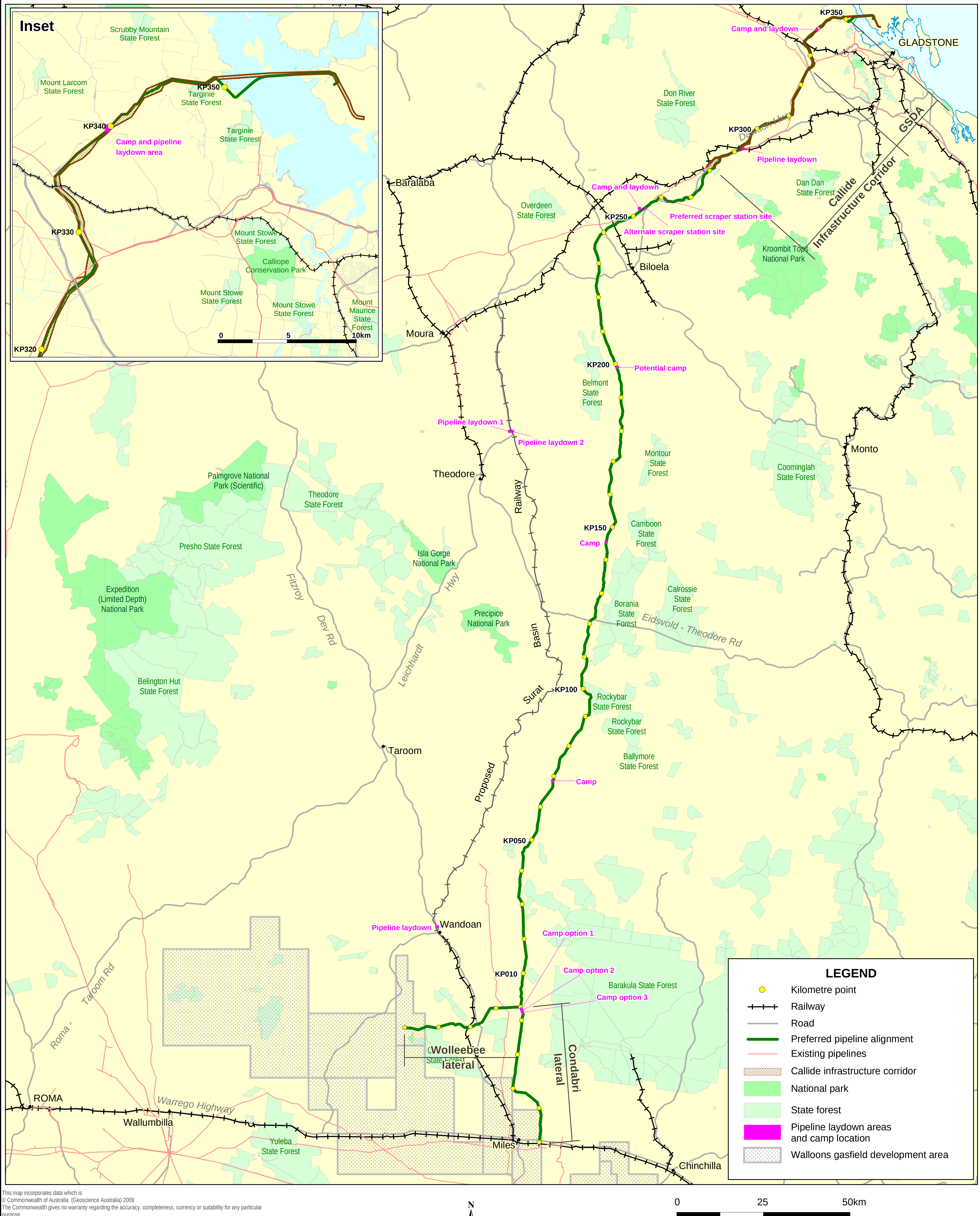
[26] Sundays, evenings and nights as per EP Act section 440R.

6.3 Marine noise impacts – dredged pipeline crossing option

Quantitative assessment of typical noise levels associated with dredging and vessel movements indicates that dredging operations for a marine pipeline crossing are unlikely to result in temporary loss of hearing sensitivity for dolphins, dugong and fish, that otherwise may theoretically impact their survival chances.

The same conclusion is drawn in respect of marine turtles based on an assumption that turtle hearing sensitivity is no less robust than dolphins.

Significant adverse behavioural responses of marine animals to dredging noise or vessel noise are not anticipated.



CCIC route supplied by the client 28/10/2009
Preferred pipeline alignment provided by Origin Energy 03/11/2009

Rev	Date	Revision Description	ORIG	CHK	ENG	APPD
0	09/12/2009	Issued for use	DH	KM		

WorleyParsons
resources & energy

AUSTRALIA PACIFIC LNG

AUSTRALIA PACIFIC LNG PTY LIMITED

AUSTRALIA PACIFIC LNG PROJECT EIS

Preferred pipeline alignment

Project No: 301001-00448	Figure: 00448-00-EN-DAL-0197	Rev: 0

Compiled by BRISBANE INFRASTRUCTURE GIS SECTION

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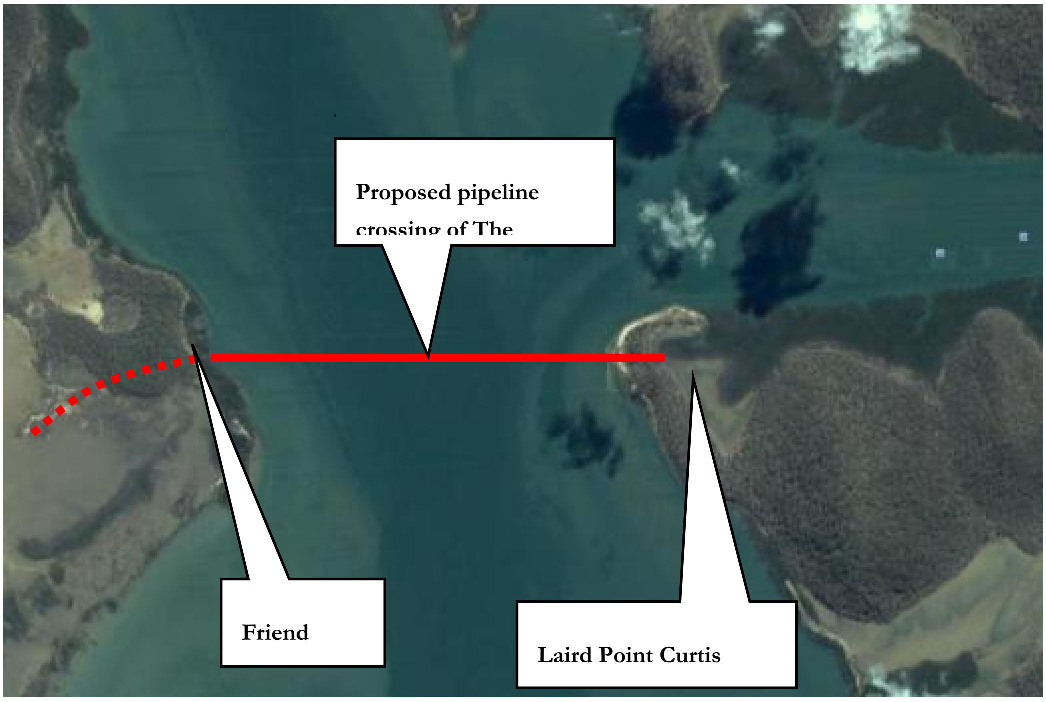


Figure 2: Proposed alignment of pipeline crossing to Curtis Island

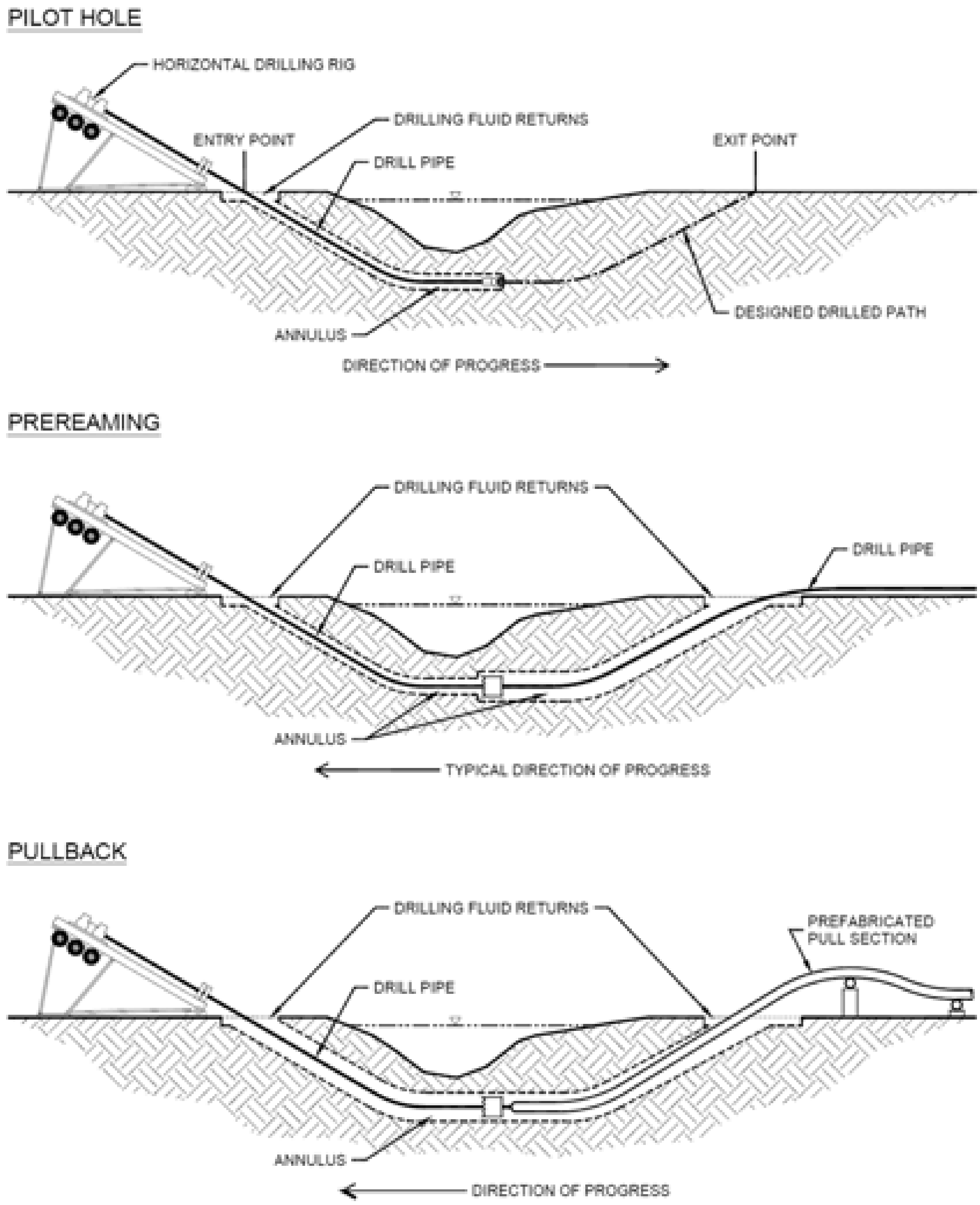


Figure 3: Schematic horizontal directional drilling Methodology (source: J.D. Hair & Associates, Inc)

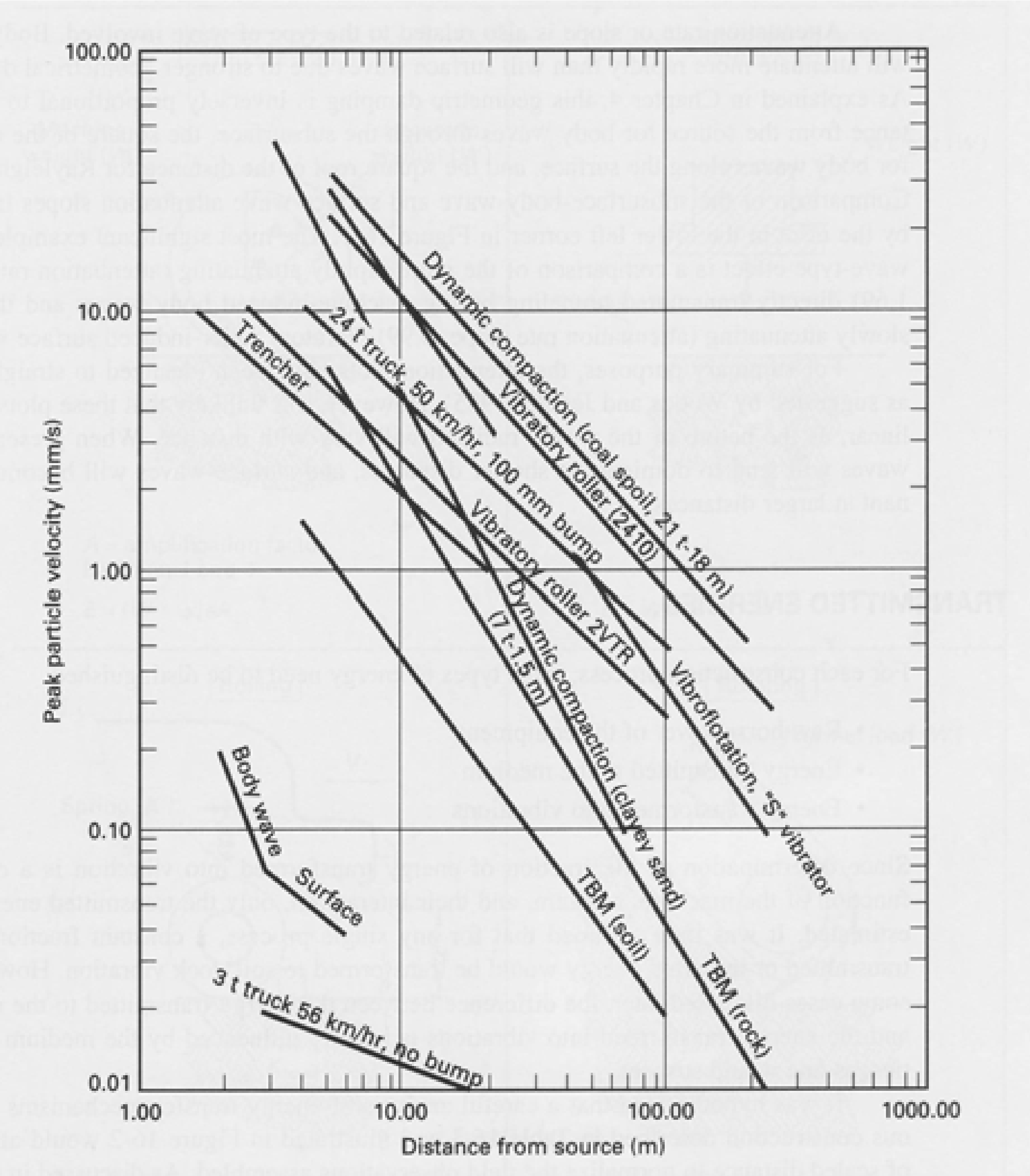


Figure 4: Attenuation of ground vibration with distance from mechanical equipment (source: p247 Construction Vibrations – C H Dowding 2000)

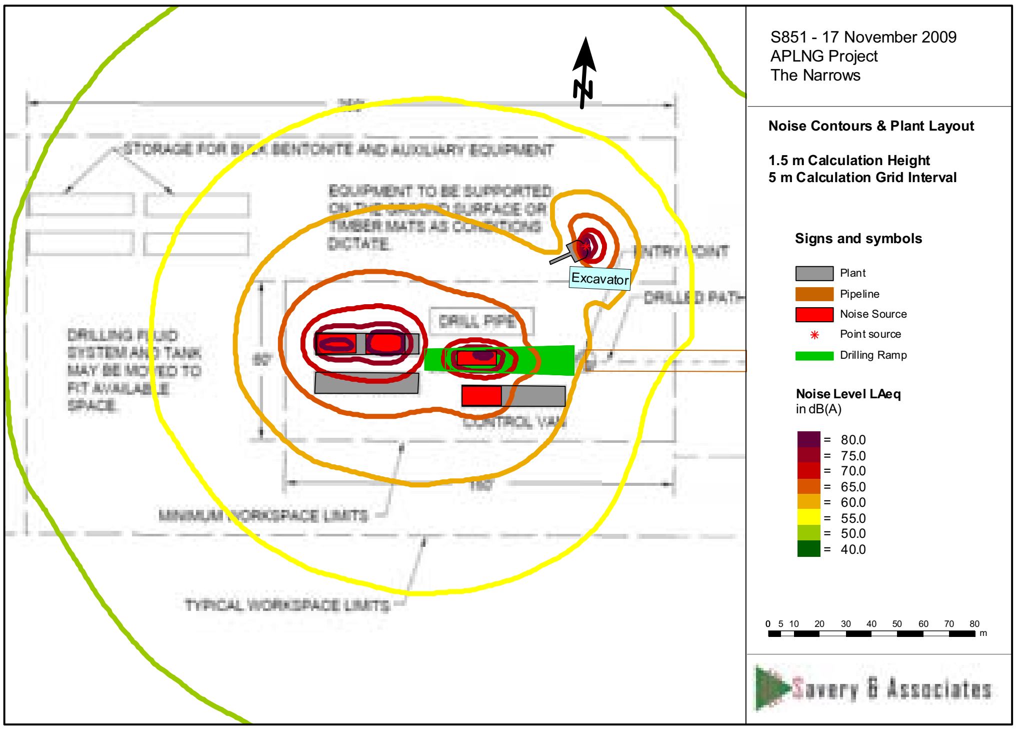


Figure 5: Modelled source noise levels – horizontal directional drill rig

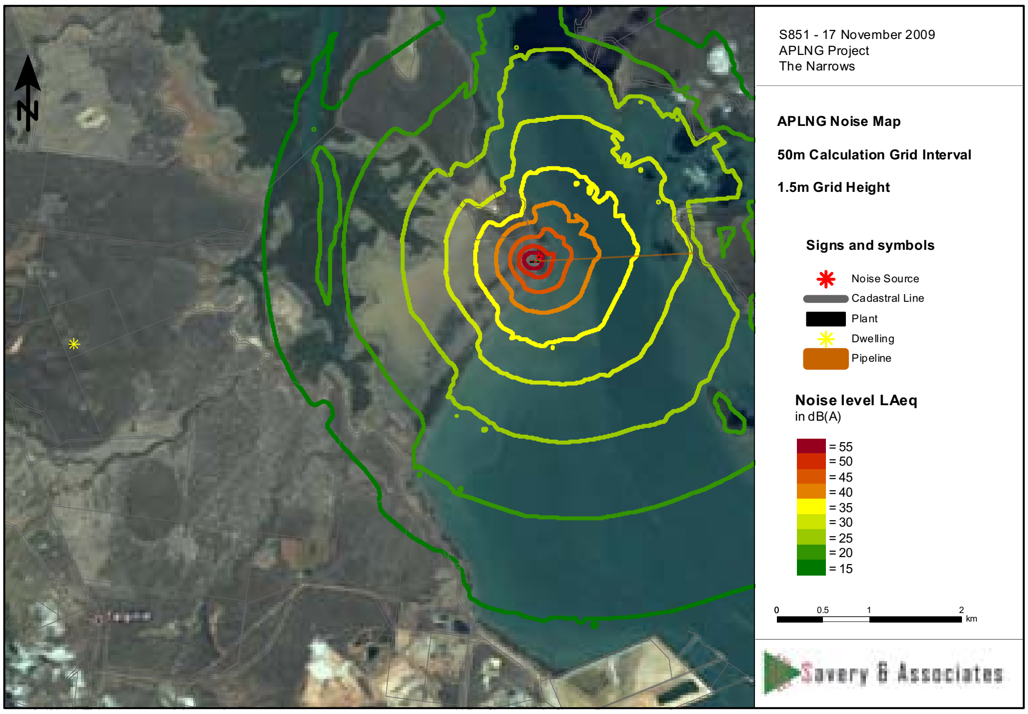


Figure 6: Modelled noise levels – horizontal directional drilled pipeline crossing

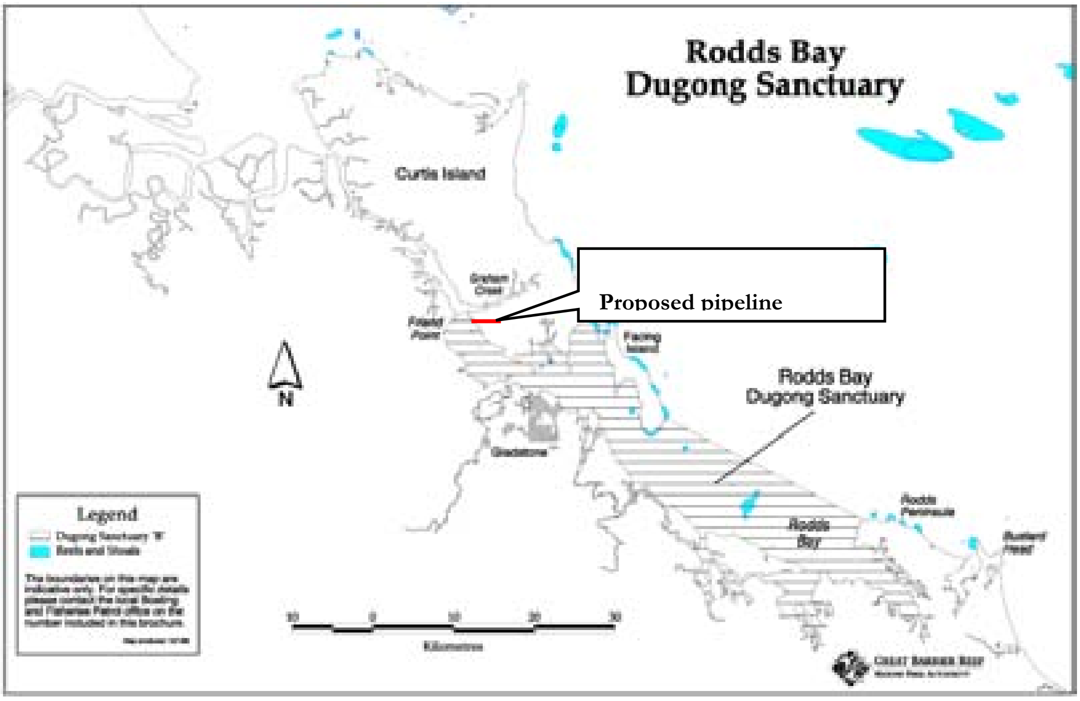


Figure 7 Rodds Bay dugong protection area and Friend Point pipeline crossing site

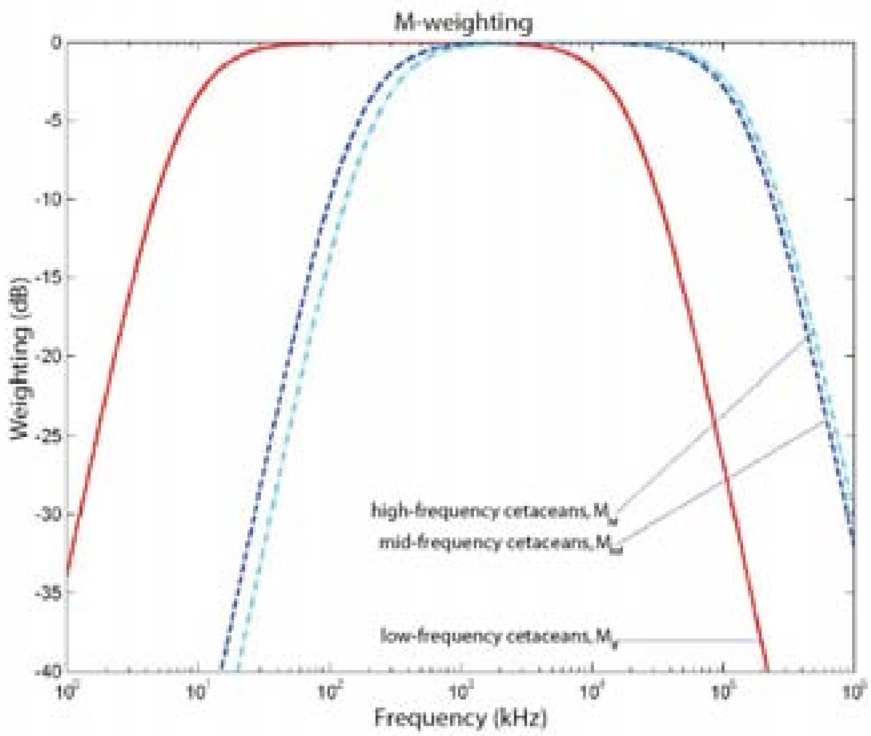


Figure 8 M-weighting curves reproduced from Southall et al.2007[27]

[27] Southall B L; Bowles A E; Ellison W T; Finneran J J; Gentry R L; Green C R; Kastak D; Ketten D R; Miller J H; Nactigall P E; Richardson W J; Thoas J A; and Tyack P L. *Marine Mammal Noise Exposure Criteria* Aquatic Mammals, Volume 33(4) 2007.

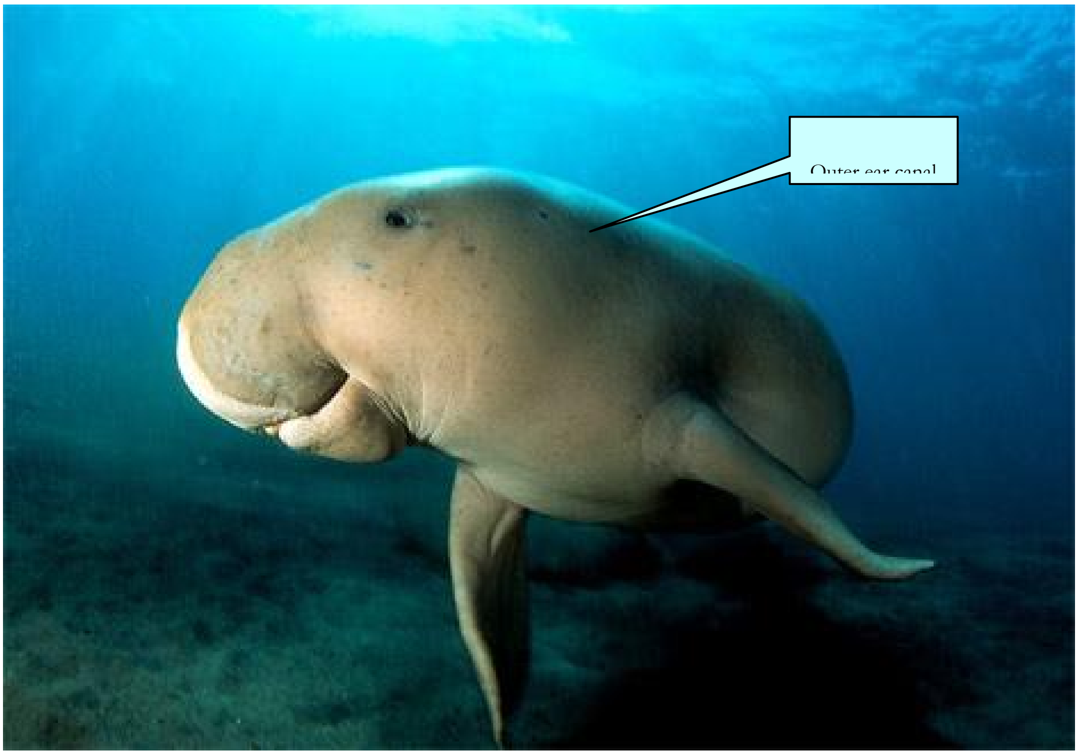


Figure 9 Dugong (Dugong Dugon)

Source:
http://animals.nationalgeographic.com/staticfiles/NGS/Shared/StaticFiles/animals/images/primary/dugong.jpg

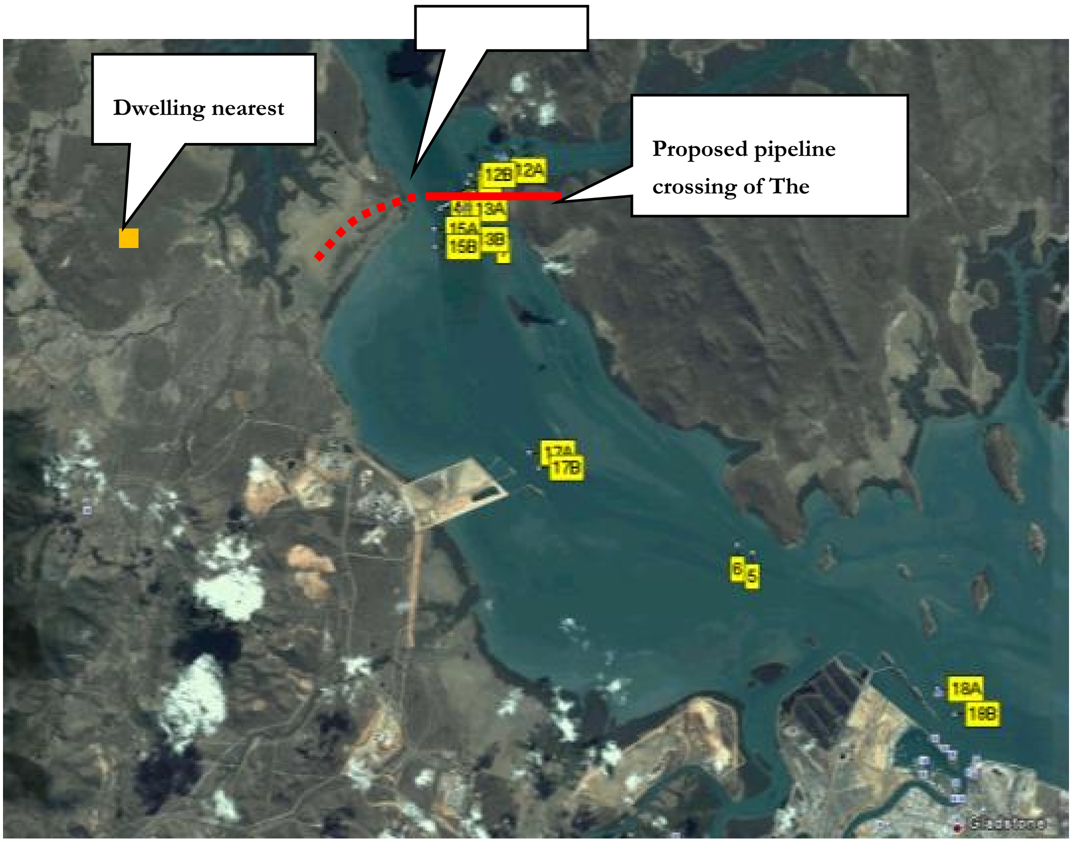


Figure 10: Whole harbour baseline marine noise sampling locations

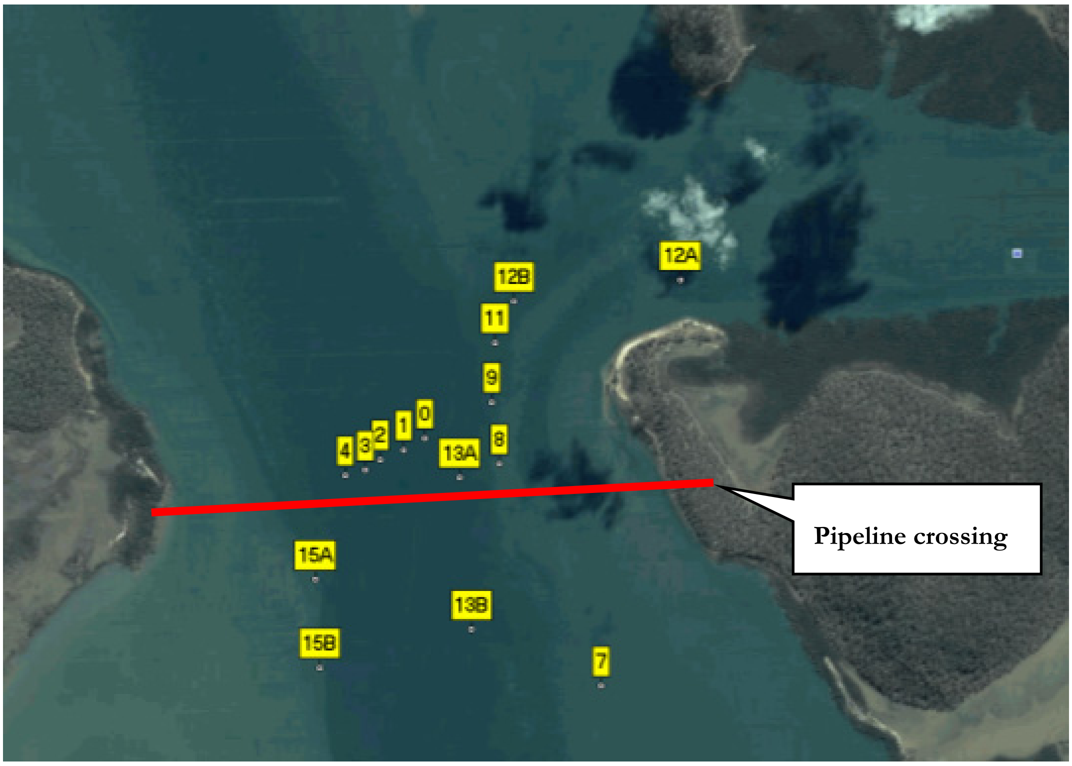


Figure 11: The Narrows area baseline marine noise sampling locations

Figure 12: 'Amity' cutter-suction dredge

Figure 13: Example raised cutter-suction head

Figure 14: 'Brisbane' trailing-arm suction dredge

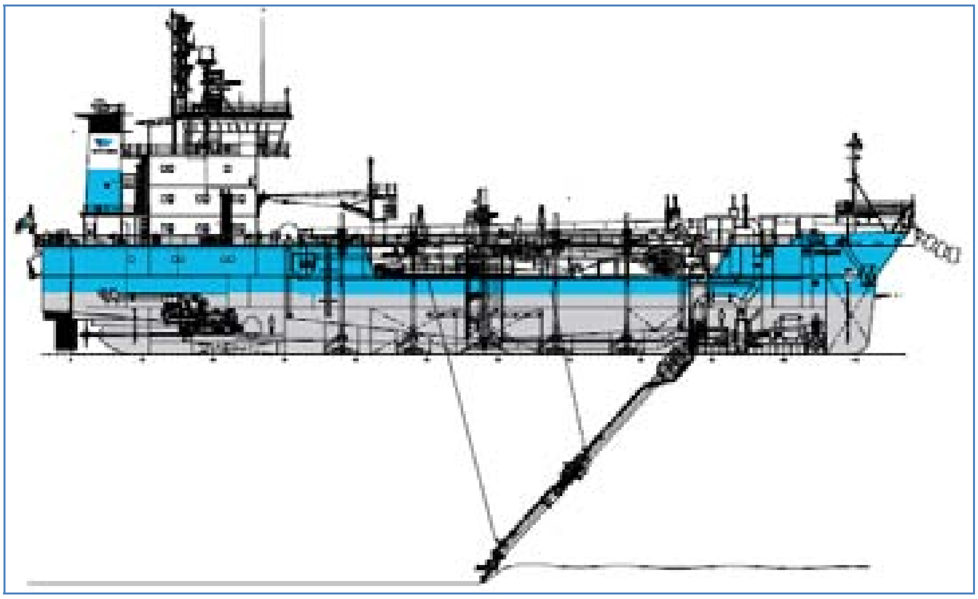


Figure 15: 'Brisbane' trailing-suction dredge schematic

Figure 16: Sea-service freighter (246m x 42m)

Figure 17: Stolt Tanker

Figure 18: Pilot boat

Figure 19: Tangalooma Flyer high speed passenger ferry

Figure 20: Riverside Marine tug and barge

Appendix A – Acoustic terminology and units of measurement

Auditory frequency range

A frequency range in which sounds are potentially perceivable by humans, often reported as 20 Hertz – 20 kiloHertz (1 Hertz = 1 cycle per second).

Airblast overpressure

A measure of the transient air-pressure pulse generated by a blast. Units of un-weighted peak pressure, expressed as a decibel level referenced to 20 microPascals (L_{peak}).

Ambient noise level

Concept of the all-encompassing noise level environment at a location of interest. A full description of the ambient noise level includes description of level variations in time and variations in the frequency composition in time, including subjective audible characteristics.

Background noise level (L_{Abg})

Concept of the typical minimum ambient noise level, numerically evaluated[28] from the level exceeded for 90 percent of 15 minute sample periods ($_{LA90,15\ minute}$) during a defined time period of interest (e.g. daytime, evening or night-time).

Baseline noise level

Concept of the noise level prior to a development, that can be evaluated by a range of level parameters such as the minimum (L_{Amin}), maximum (L_{Amax}) and percentile descriptors (L_{A1}, L_{A10}, L_{Aeq}, L_{A90})

Broadband noise

A noise with approximately equal acoustic energy distribution over a large range of frequencies, for example 100 Hz – 2 KHz. Natural examples include noise from a waterfall, or the sound of wind in trees.

Construction/blast vibration

Transient oscillating movement of the ground or a building structure from transmission of elastic pressure waves from the vibration source, through the ground to the receptor location

Far-field

A distance defined to be so far from the noise source that the source can be treated as a point source.

Hydrophone

A microphone designed to be used underwater for recording or listening to underwater sound.

RMS (root-mean-square) sound pressure

[28] By AS1055 this evaluation is by averaging the $L_{A90,15minute}$ values. By the DERM Planning for noise control guideline this evaluation is more complex, taking the 90th percentile of the $L_{A90,15minute}$ values relevant to the day, evening and night periods on a given day, and then taking the median of the daily results over a minimum seven day period.

Mathematical averaging process for the rapid positive and negative acoustic pressure cycles (relative to atmospheric pressure) that constitutes sound, to define a positive equivalent pressure level relative to atmospheric pressure with the same energy as the cyclical quantity. (because the RMS pressure is a time averaged quantity, it cannot indicate the peak instantaneous pressure such as may be relevant to assessing risk of bursting an ear-drum, as an example)

Sound

Sound consists of small air-pressure fluctuations or pressure waves. The human auditory system responds to both the intensity (pressure-wave amplitude) of a sound and the frequency (number of pressure cycles per second) of a sound. These pressure fluctuations travel along the ear canal and vibrate the ear-drum. The vibrations of the ear-drum are transmitted via the middle-ear to the inner ear where the intensity and frequency are coded into electrical signals for interpretation by the brain. This allows a person to sense the 'pitch' and 'loudness' of a sound.

Statistical acoustic parameters for environmental noise assessment

Common noise sources, such as industrial processes, transportation (cars, trucks, trains), natural noise (wind in trees, birds, insects), vary with time. Therefore, during a measurement period of duration 'T', it is important to define whether the maximum, minimum, average or a percentile statistical level is being specified.

In a quiet rural area, for example, the maximum sound pressure level for a fraction of a second may be 80dBA from a nearby bird call, whereas the minimum sound pressure level between bird calls, and when the trees are still, may be 20dBA. Without statistical definition, the level range of 20dBA to 80dBA would be confusing.

The following sound level parameters are used to describe the 'prevalence' of the acoustic environment at different sound pressure levels (all fast response, A-weighted, RMS sound pressures levels relative to a 20μPa reference pressure):

$L_{Amax,T}$ –the maximum level in time interval 'T'

$L_{Amin,T}$–the minimum level in time interval 'T'

$L_{Aeq,T}$ – the theoretical constant level with the same sound energy as the actual fluctuating level in a time interval 'T'

$L_{A1,T}$ – the level exceeded for 1 percent of time interval 'T'

$L_{A10,T}$ – the level exceeded for 10 percent of time interval 'T'

$L_{A90,T}$ – the level exceeded for 90 percent of time interval 'T', often termed the 'background' level.

One-third-octave spectrum

The frequency content of a noise is described by a frequency spectrum. A frequency spectrum can be expressed as a one-third-octave spectrum, which, instead of displaying every frequency individually, is comprised of sub-frequency ranges centred at the following frequencies, measured in Hertz (1 Hertz = 1 cycle per second):

20,25,31.5,40,50,63,80,100,125,160,200,250,315,400,500,630,800,1000,1250, etc.

Planning noise level (PNL)

Nomenclature specific to the DERM guideline 'Planning for noise control' defining the permissible noise contribution from a proposed facility at a defined receptor

Rating background noise level (RBL)

Nomenclature specific to the DERM guideline 'Planning for noise control' defining the background noise level from $_{LA90,15miute}$ levels during the day, evening and night over a minimum seven day period.

Response time

The human auditory system has a certain delay in responding to noise. For extremely 'fast' sources of noise, such as a gun-shot at the ear of the firer, the increase in sound is so rapid that the hearing system is unable to respond quickly enough for the protective muscular reflex of the ear-drum to operate.

Sound level meters are designed to emulate the 'response-speed' of the human auditory system. This is conventionally described as the 'fast response' sound level meter response setting.[29]

Sensitive receptor

A place that may be sensitive to additional noise associated with a proposed development

Sensitivity to sound frequency

At any instant the acoustic environment contains a complex mix of sound components at different frequencies and at different levels. A person speaking, for example, will simultaneously produce vowel sounds typically in the range of 250Hertz to 1kiloHertz, and higher frequency sounds associated with consonants, such as 'hisses' and 'clicks', in the range of 2kiloHertz to 8kiloHertz.

Human hearing has the greatest 'sensitivity' to sound at frequencies in the range of 2kiloHertz to 4kiloHertz, with decreasing sensitivity at higher and lower frequencies. At 1kiloHertz, the sensitivity is only slightly lower (-1dB, or around 90% of optimal pressure sensitivity), whereas at 100Hertz the sensitivity is much lower (-19dB, or around 10% of optimal pressure sensitivity).

Sensitivity to sound level

Laboratory testing of the hearing of a large number of human subjects has been conducted by scientists to determine the 'threshold' of human hearing. This threshold is the quietest sound that can be just determined by the human ear under ideal (quiet) laboratory conditions. This nominal hearing threshold has been quantified as a root mean squared (RMS), or 'average' pressure fluctuation of 0.00002 Pascals or 20 microPascals (20μPa).

The upper limit of human hearing for sounds of short duration is an RMS pressure fluctuation of around 20Pascals (20Pa). Above this level, the auditory system is rapidly unable to translate information about level and frequency.

To provide a more manageable scale for the wide numerical range of sound pressures that the human ear is able to respond to (i.e. 0.00002Pa to 20Pa), it is conventional to define a 'sound pressure level' as the ratio of a given sound pressure (p) relative to the human threshold of hearing (pref = 20μPa RMS) as follows:-

Sound pressure level, Lp = 10*log10(p2/pref2)

[29] Objective measures of gun-shot noise or other explosive events, in the context of hearing damage potential, use a peak sound pressure level detection to ensure that the actual maximum sound pressure impacting on the human subject is known.

With this definition, the nominal threshold of hearing becomes zero decibels (or 0dB), and the maximum, clearly audible level becomes 120dB, referenced to 20μPa.

0 dB equates to the quietest level of introduced sound that a person with healthy hearing can detect in a much quieter laboratory. A level of 120dB might be experienced close to speakers at a loud rock concert, or near an industrial nailing gun. Two people standing a metre apart and conversing might speak at levels that are about 50dB to 60dB.

Laboratory studies have found that a 10dB increase in a sound is perceived as approximately doubling in loudness. Conversely, a 10dB decrease in a sound is perceived as halving in loudness.

Sound exposure level (SEL)

The total sound energy produced by a noise event of interest, such as an aircraft flyover, a single pile strike, or the total sound exposure over a defined period such as an 8 hour working day, or 24 hour period.

Sound level meters and A-weighting

The sound level meter was invented to enable systematic investigation and study of sound that is of concern to humans. One of its tasks is to gauge the level of a sound as it may be perceived by the human ear. This is not easy as the human ear not only has different sensitivities depending on the frequency of sound, but the sensitivity also changes as the level of sound changes.

The 'A-weighting' system is an internationally agreed system of sensitivity adjustments to measured sound at frequencies ranging from 10Hz to 20kHz, enabling a sound level meter to approximate the sound level response of the human auditory system. A sound pressure level with an 'A frequency weighting' or A-weighting is an approximate gauge of the significance of a measured sound pressure level to the human ear.

A measured sound pressure level that incorporates A-weighting is denoted LpA, and has units of dB(A), often written as dBA.

Sound power

The total sound radiated from a source per unit of time, expressed in decibels relative to 1 x 10-12 Watts.

Threshold shift (temporary, TTS)

Exposure to noise that causes the auditory system of a human or animal to temporarily lose some degree of sensitivity to sound, where the sensitivity is recovered after cessation of the noise exposure.

Threshold shift (permanent, PTS)

Exposure to noise that causes the auditory system of a human or animal to permanently lose some degree of hearing sensitivity. The sensitivity is not recovered after cessation of the noise exposure.

Tonality and impulsivity adjustments to measured levels

The human brain tends to 'tune-in' to tones, sound patterns and rhythms to an extent that is not sufficiently reflected by the A-weight fast-response indication of a sound level meter. For example, a person is able to differentiate a distant siren sound from background noise before it will be apparent on an A-weight indicating sound level meter. Similarly, hearing is attuned to sounds that change rapidly in

level, such as bangs and knocks, which are described as 'impulsive'. To account for these discrepancies between human sensitivity and sound level meter sensitivity, a 'tonal adjustment' or an 'impulse adjustment' to the measured level is defined.[30] A measured sound pressure level that has been adjusted to account for the increased audibility by virtue of its impulsive or tonal characteristics is denoted $L_{A,adj}$.

[30] The methodology for this adjustment is described in AS1055.1-1997 Acoustics-Description and measurement of environmental noise Part 1: General Procedures.

.Appendix B –Marine baseline noise spectra

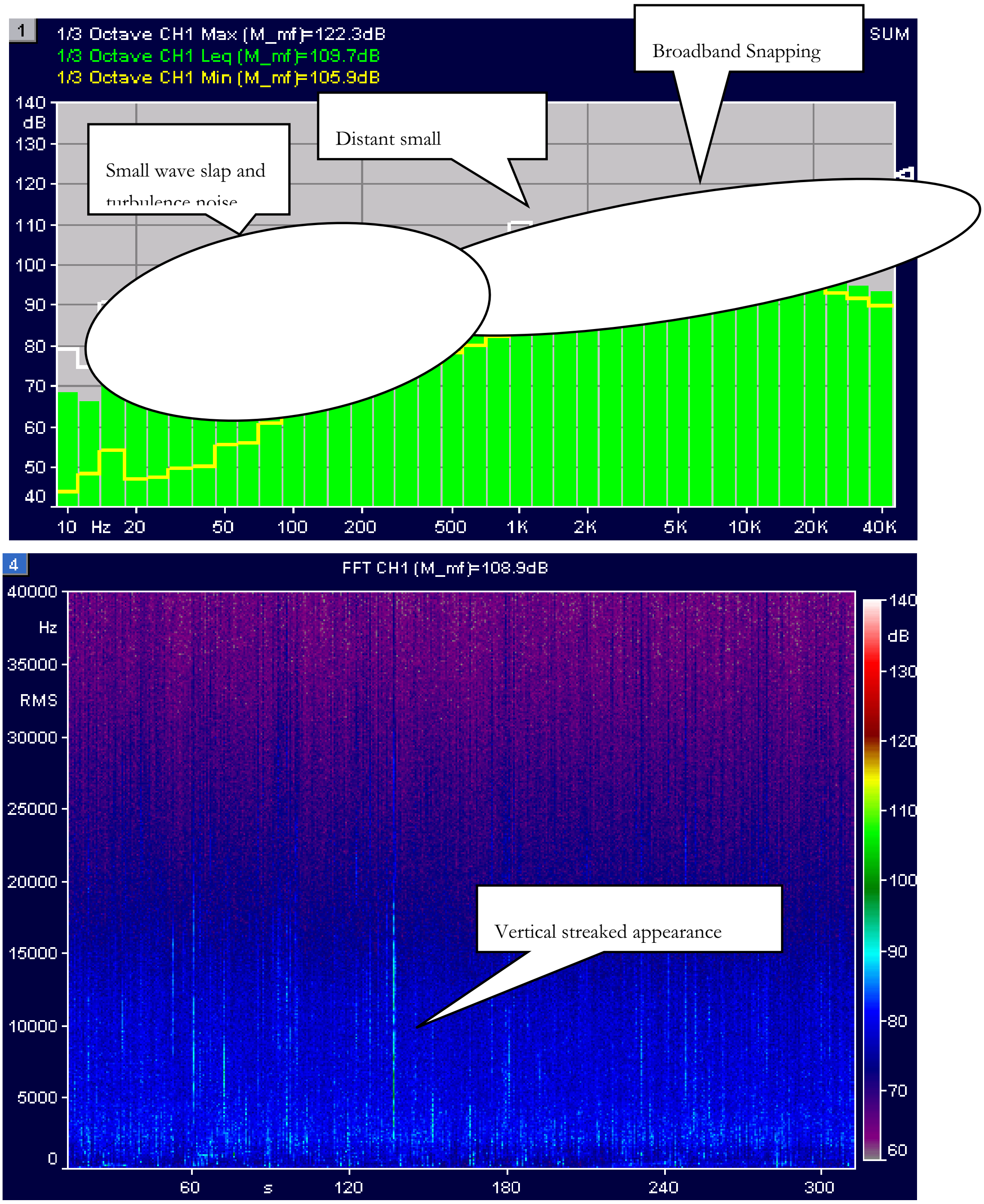


Figure 21: Sample 1: Ambient mid-passage at crossing site –8:35am-8:40am flat water with minimal tidal run – One-third-octave noise spectrum(top graph) and FFT spectral history(bottom graph) – RMS Re: 1µPa

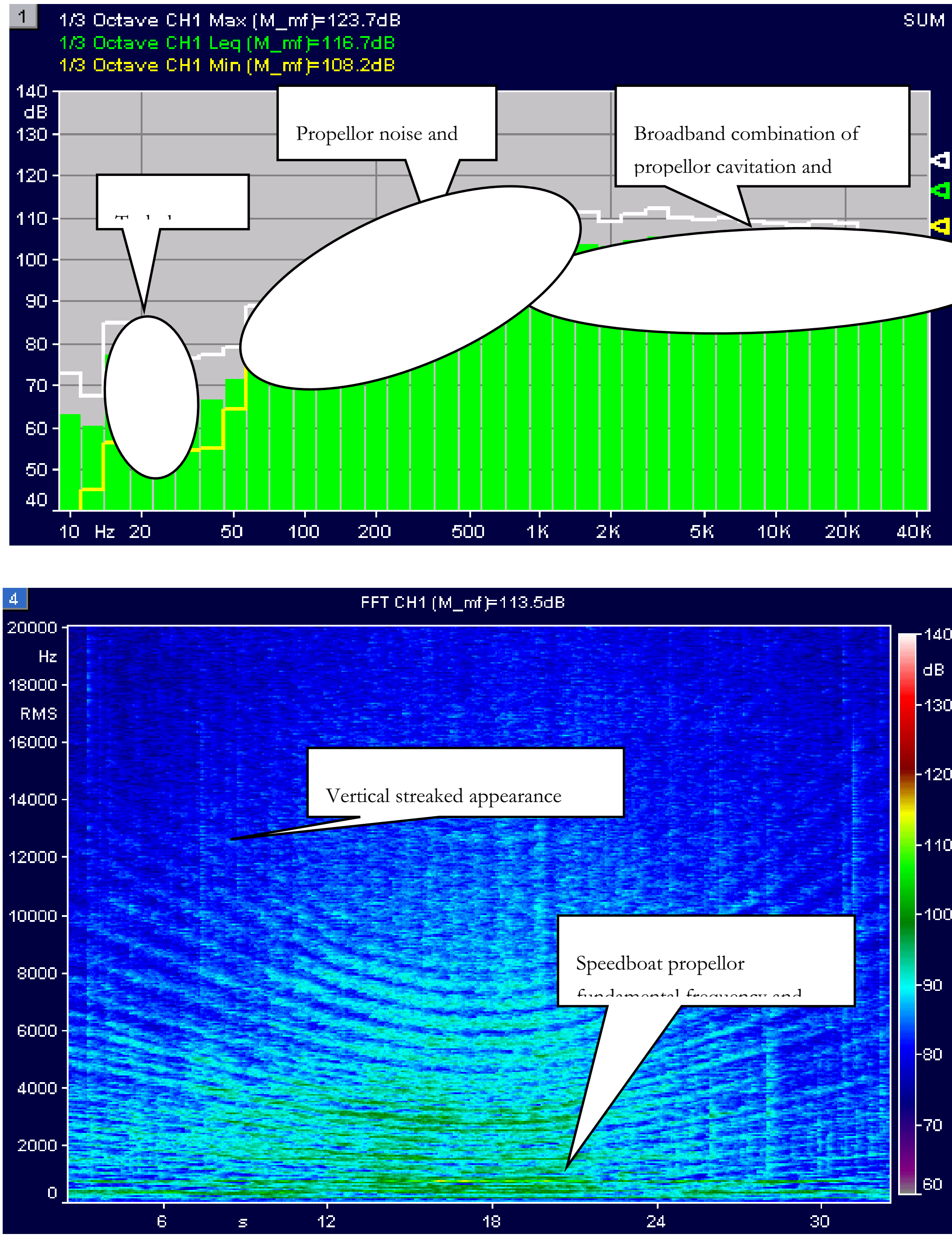
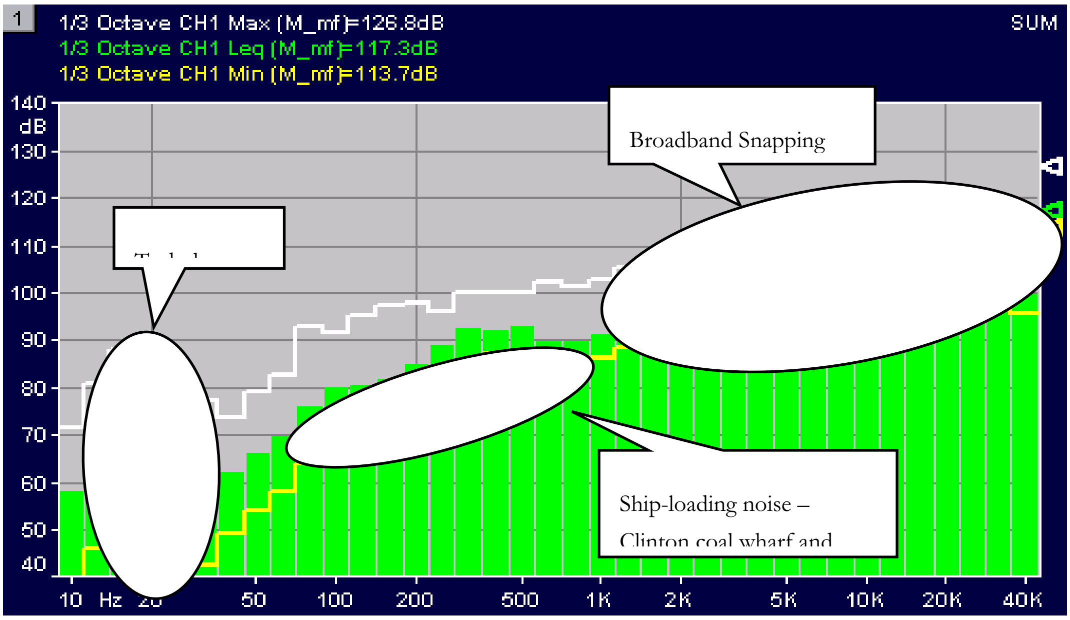


Figure 22: Sample 3: Small speedboat 30 second pass-by along The Narrows at 80m –one-third-cctave noise spectrum(top graph) and spectral history(bottom graph) - RMS Re: 1µPa



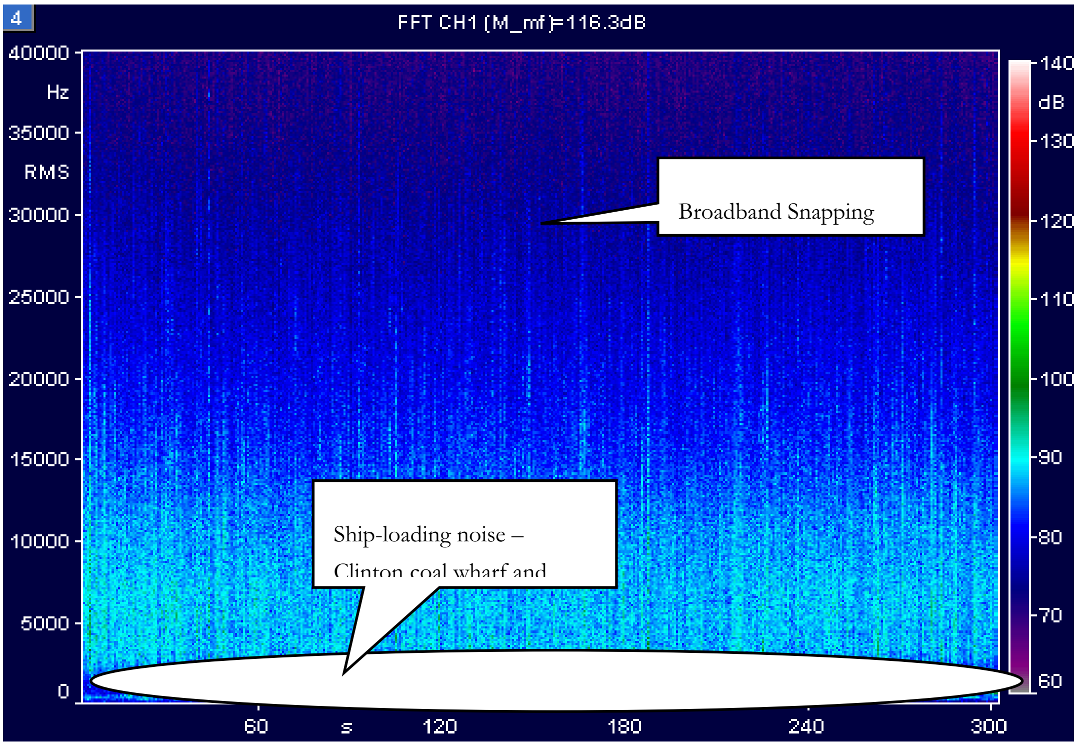
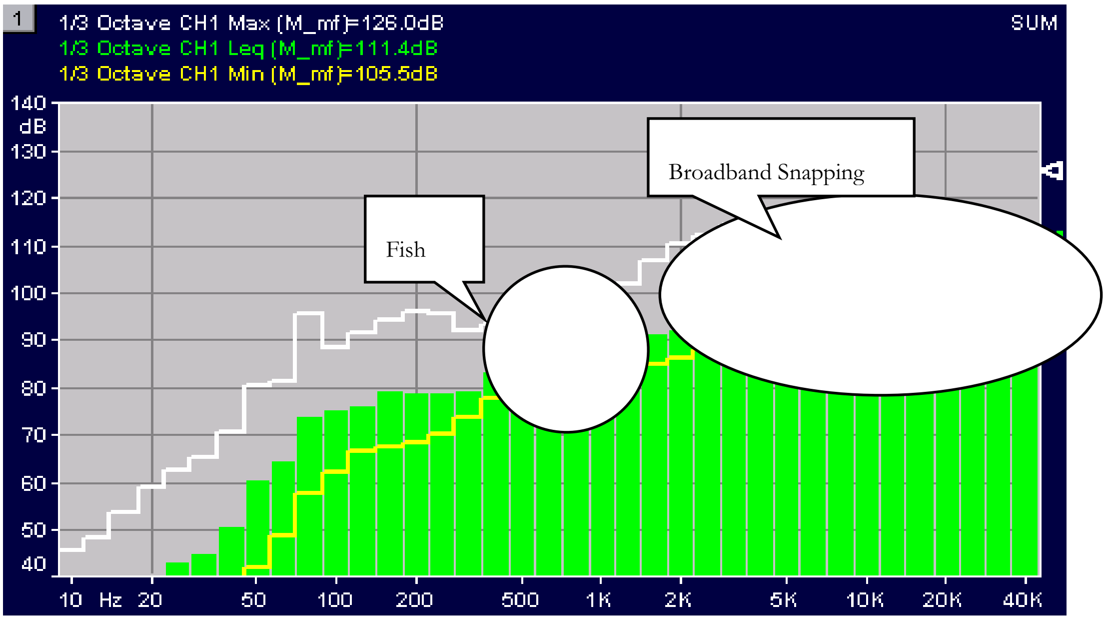


Figure 23: Sample 5: Ambient near Hamilton Point–11:20am flat water with minimal tidal run – one-third-octave noise spectrum(top graph) and FFT spectral history(bottom graph) – RMS Re: 1µPa



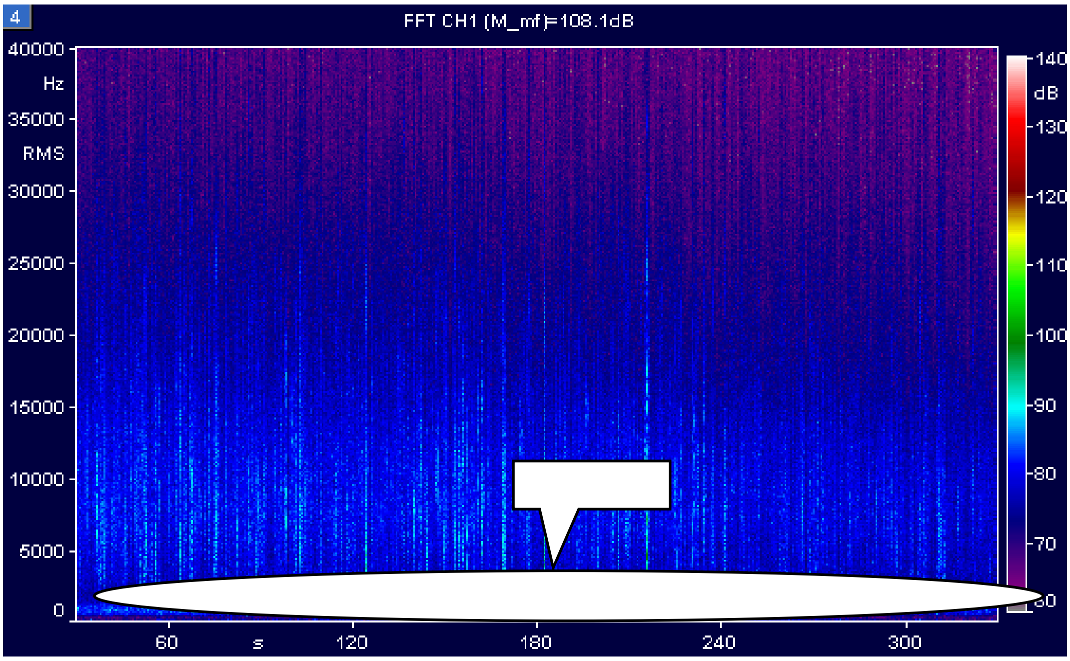
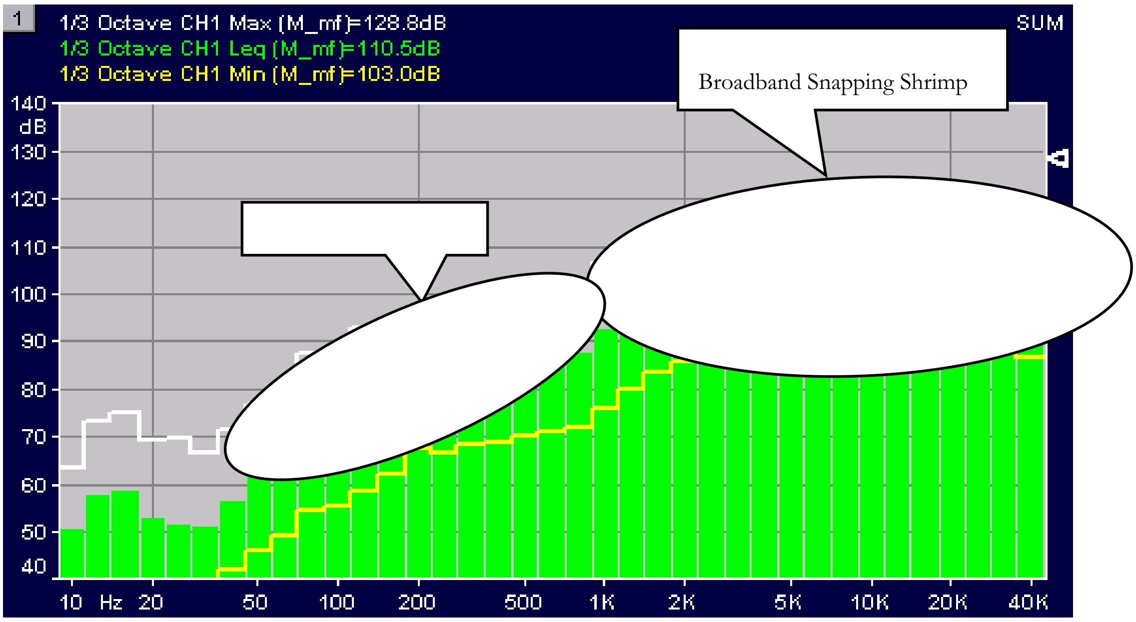


Figure 24: Sample 9: Ambient mid-passage at crossing site –1:35pm flat water with minimal tidal run – one-third-octave noise spectrum(top graph) and 5 minute FFT spectral history(bottom graph) – RMS Re: 1µPa



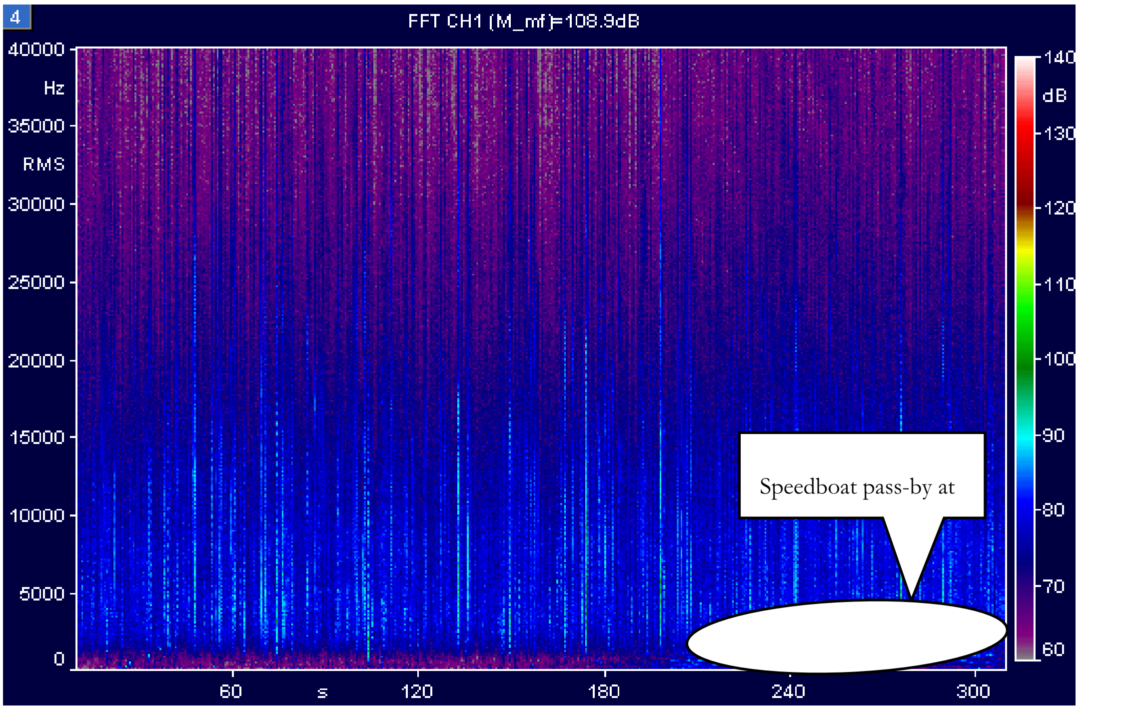


Figure 25: Sample 12: Ambient Grahams Creek entrance –12:30pm flat water with ebb tide – one-third-octave noise spectrum(top graph) and 5 minute FFT spectral history(bottom graph) – RMS Re: 1µPa

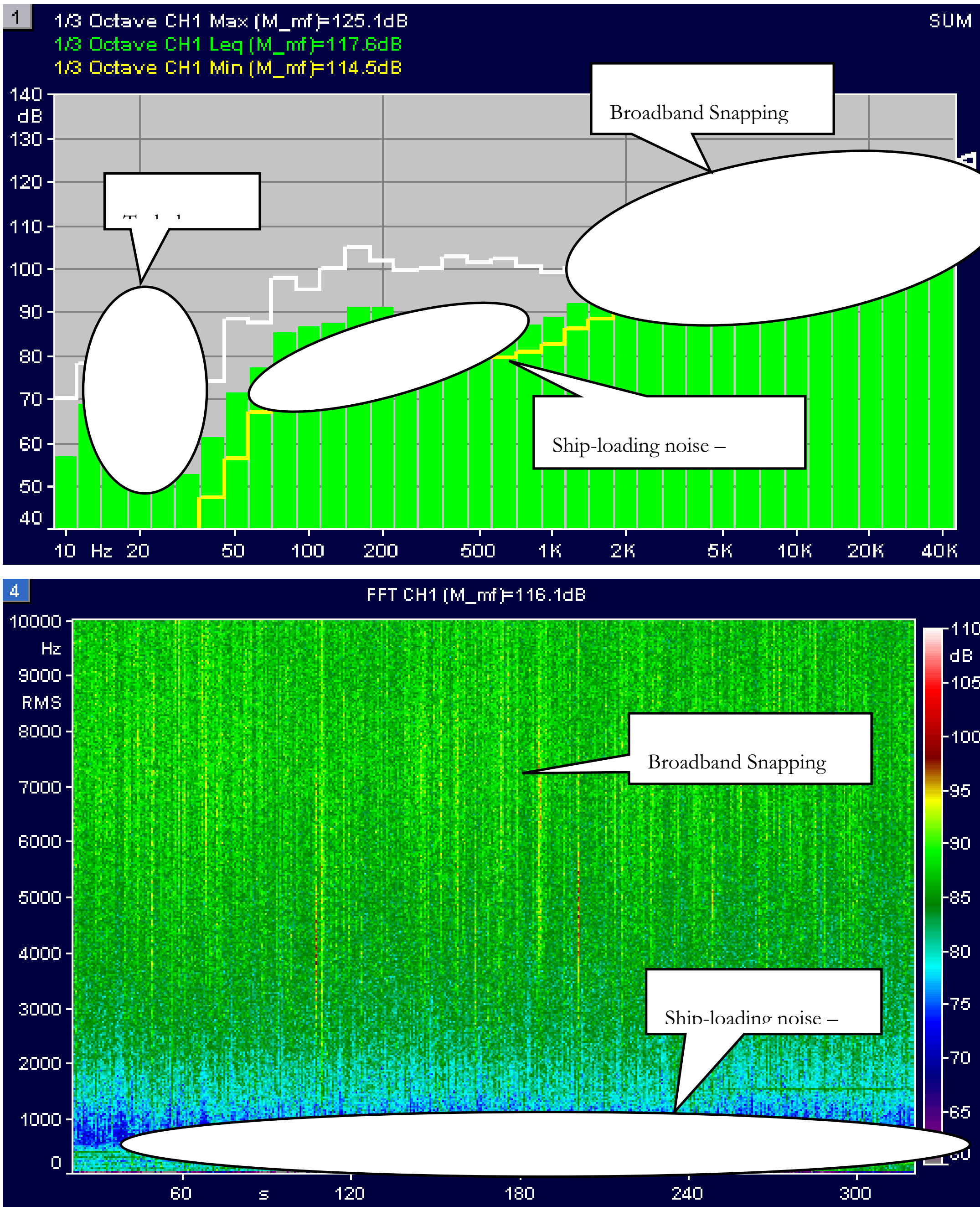


Figure 26: Sample 13: Ambient mid-passage at crossing site –12:45pm flat water with ebb tide – one-third-octave noise spectrum(top graph) and 5 minute FFT spectral history(bottom graph) – RMS Re: 1µPa

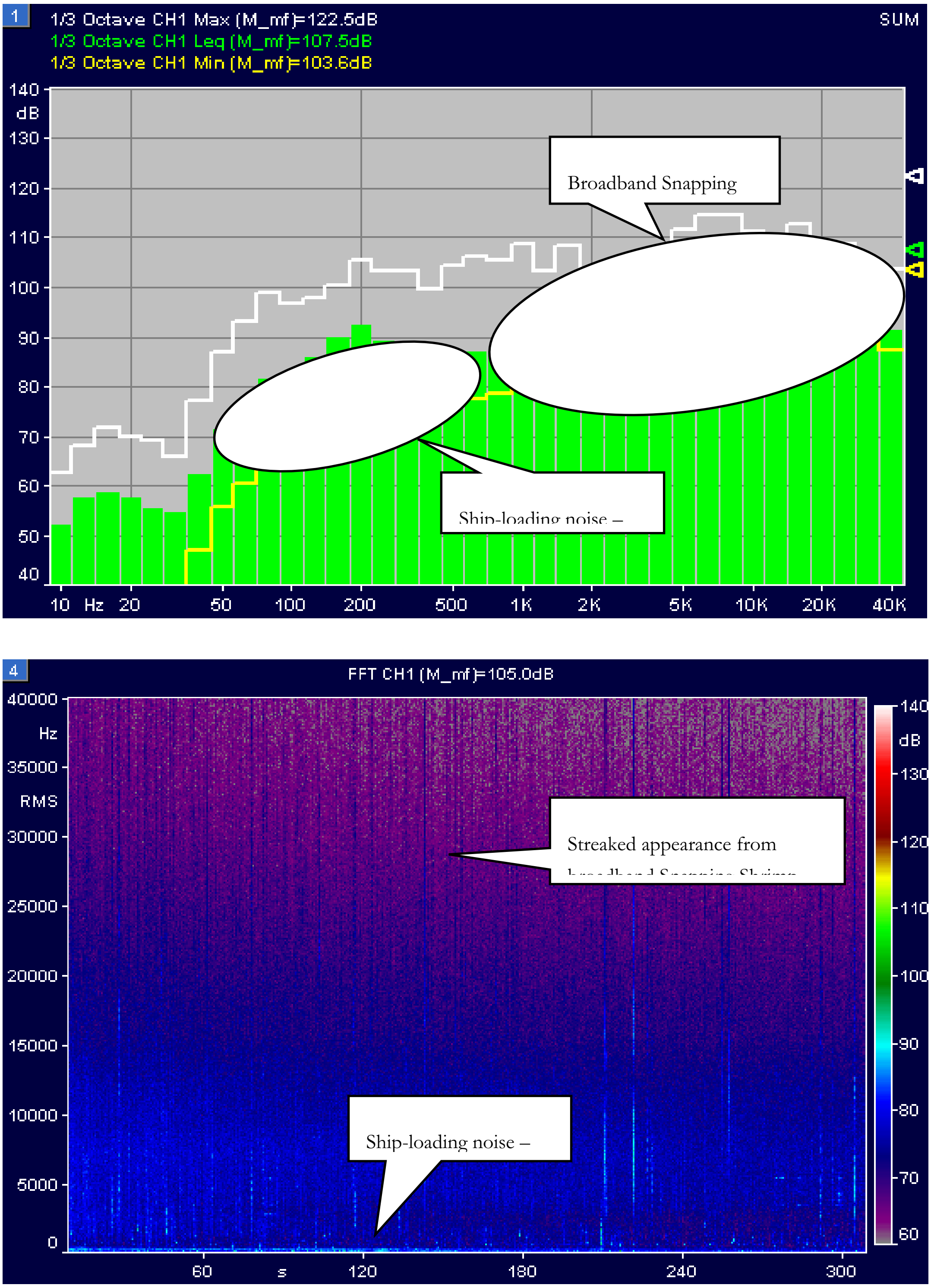
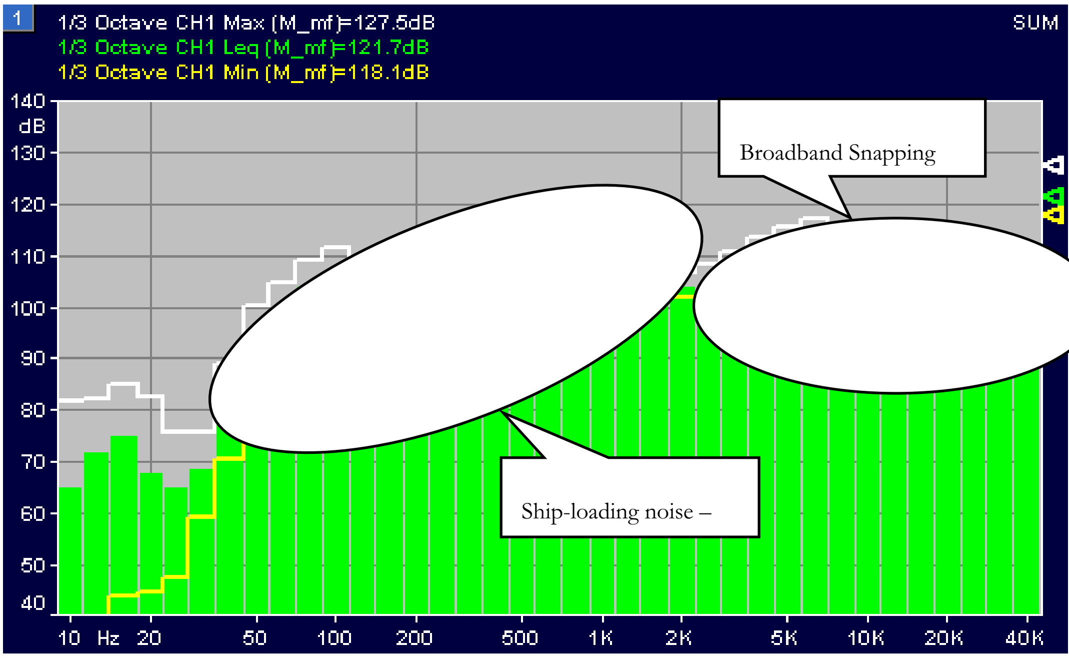


Figure 27: Sample 15: Ambient - passage edge at crossing site –1:03pm flat water with ebb tide – one-third-octave noise spectrum(top graph) and 5 minute FFT spectral history(bottom graph) – RMS Re: 1µPa



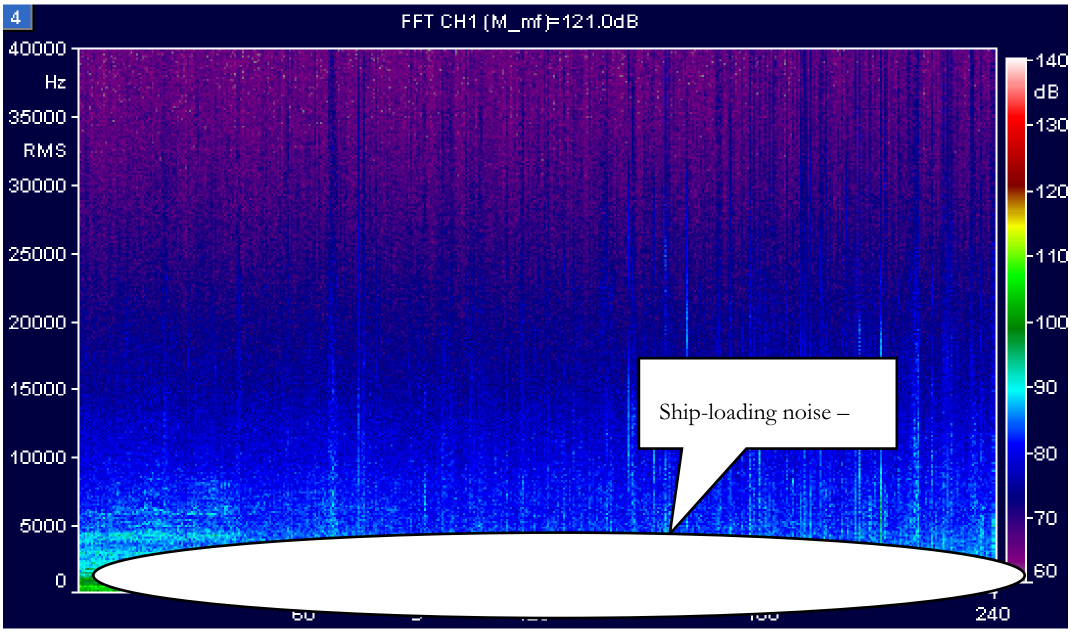


Figure 28: Sample 17: Along-side Fisherman's Landing at 350m –1:24pm flat water with ebb tide – one-third-octave noise spectrum(top graph) and 4 minute FFT spectral history(bottom graph) – RMS Re: 1μPa

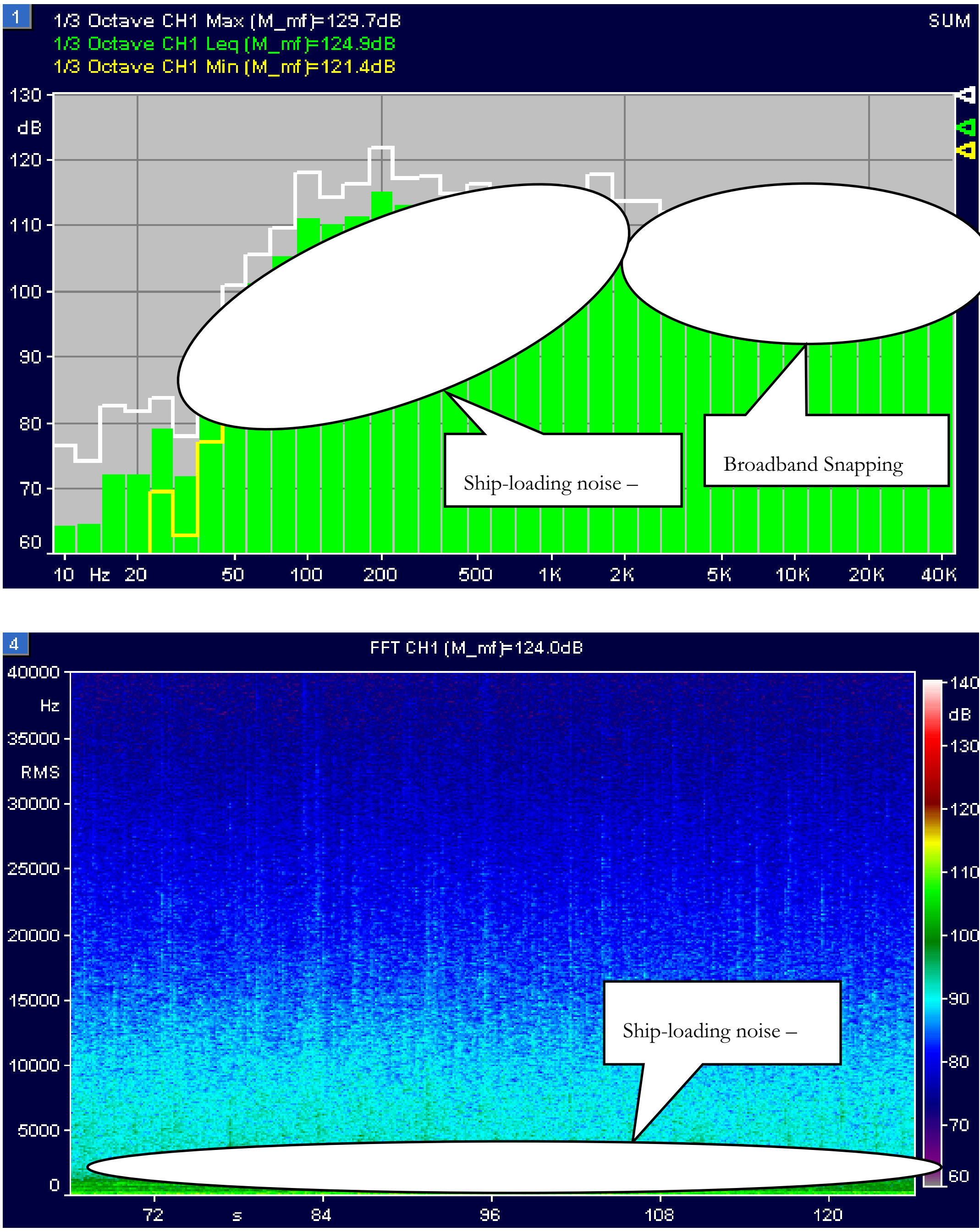


Figure 29: Sample 18: Along-side Clinton coal wharf at 250m –2:06pm flat water with ebb tide – one-third-octave noise spectrum(top graph) and 2 minute FFT spectral history(bottom graph) – RMS Re: 1µPa

.Appendix C –Dredge and vessel noise spectra

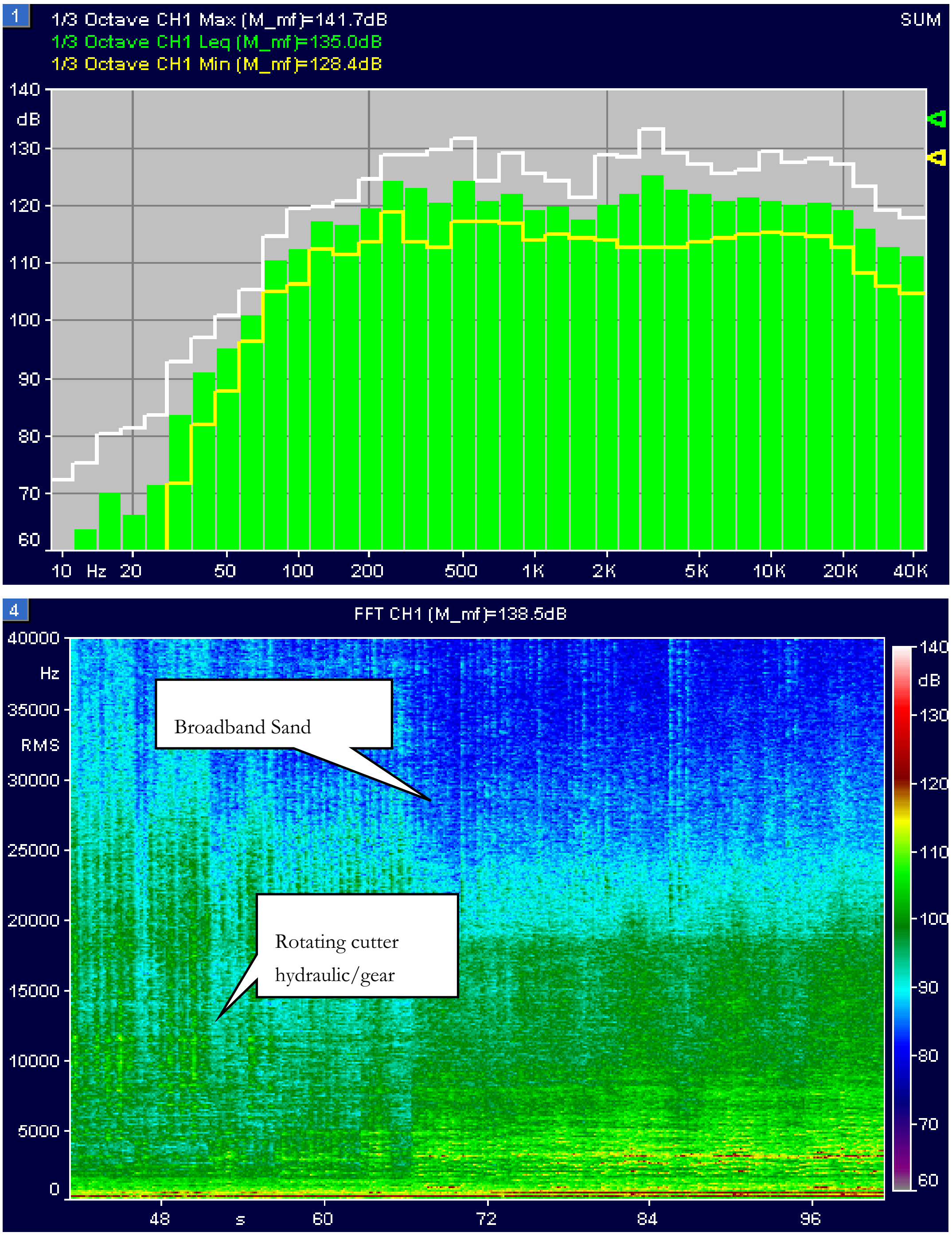


Figure 30: 'Amity' Cutter-suction dredge at 45m Beam – one-third-octave noise spectrum(top graph) and FFT spectral history(bottom graph) – RMS Re: 1µPa

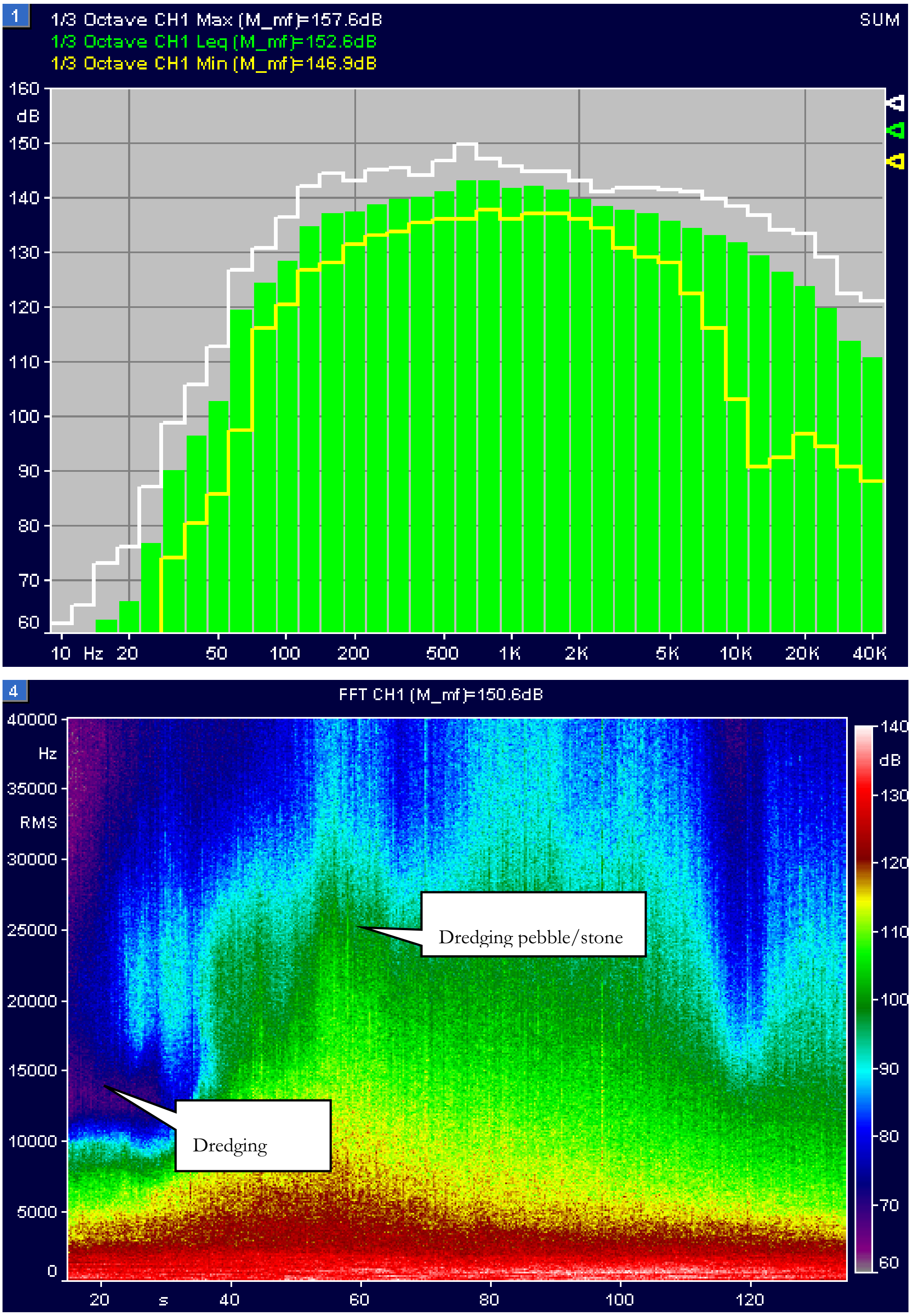


Figure 31: ‘Brisbane’ Trailing-arm Suction Dredge Passby at 45m – One-third-Octave Noise Spectrum(top graph) and FFT Spectral History(bottom graph) – RMS Re: 1μPa

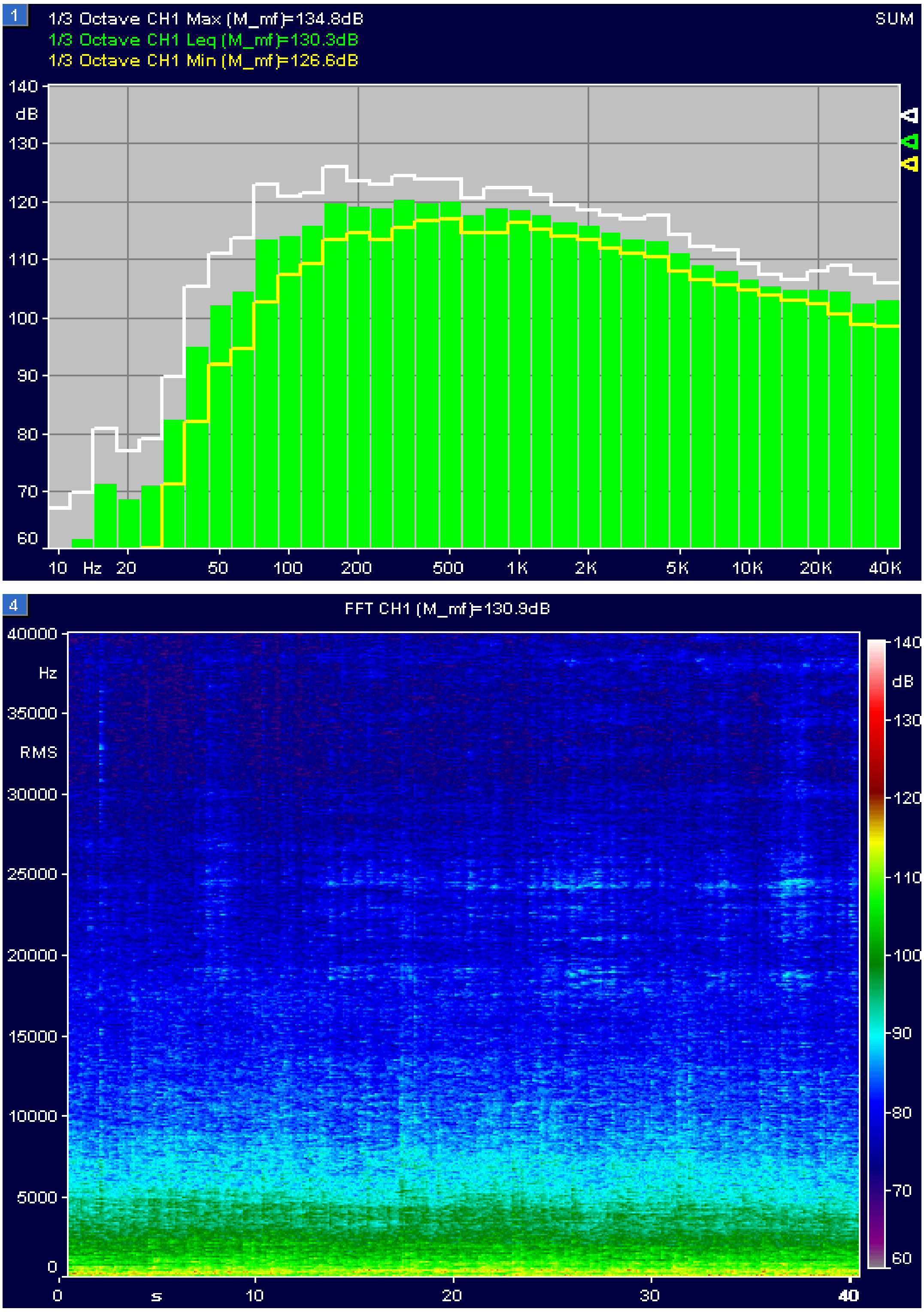


Figure 32: Seaservice freighter pass-by at 220m– one-third-octave noise spectrum(top graph) and FFT spectral history(bottom graph) – RMS Re: 1μPa

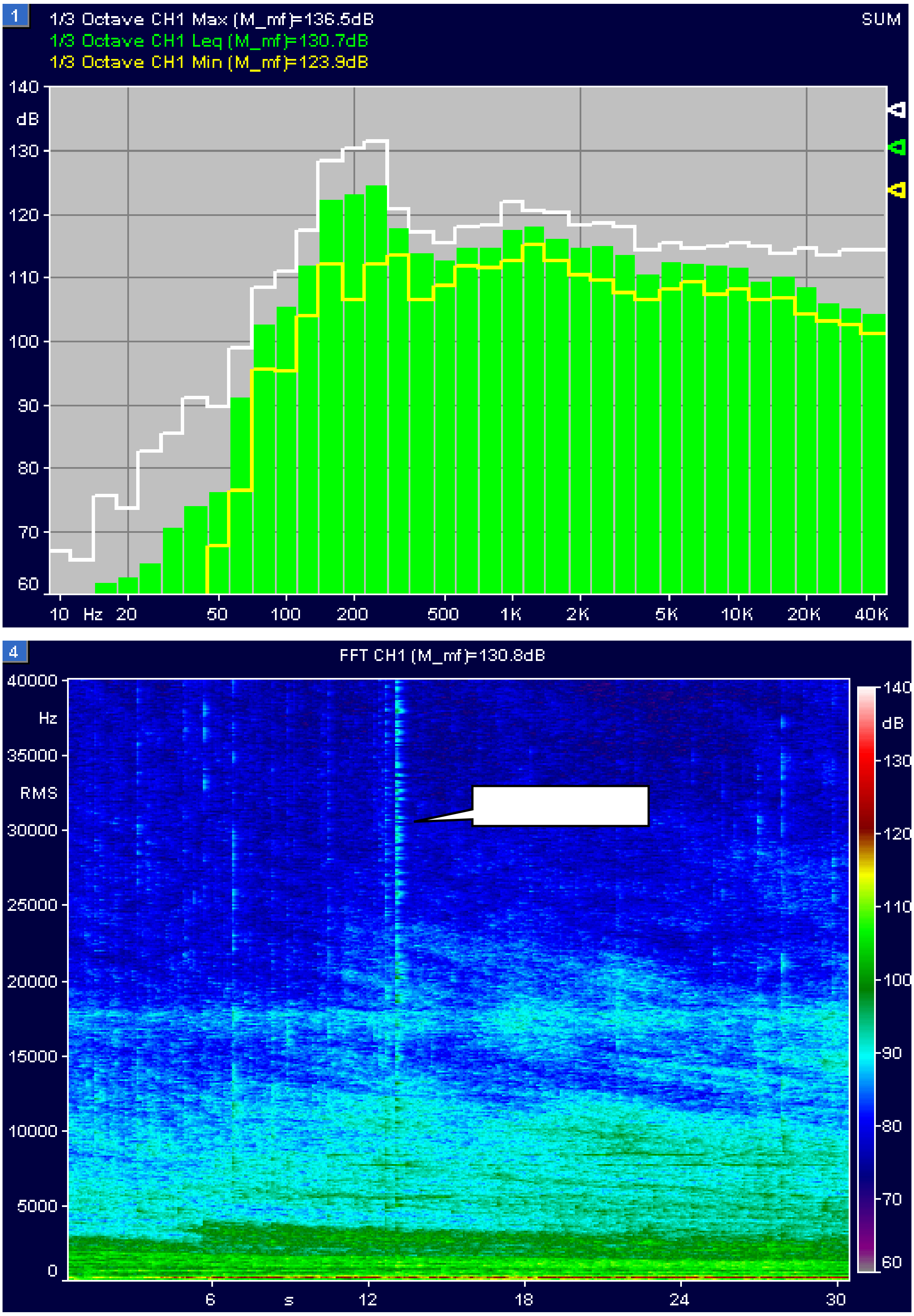


Figure 33: Stolt tanker pass-by approach at 155m– one-third-octave noise spectrum(top graph) and FFT spectral history(bottom graph) – RMS Re: 1µPa

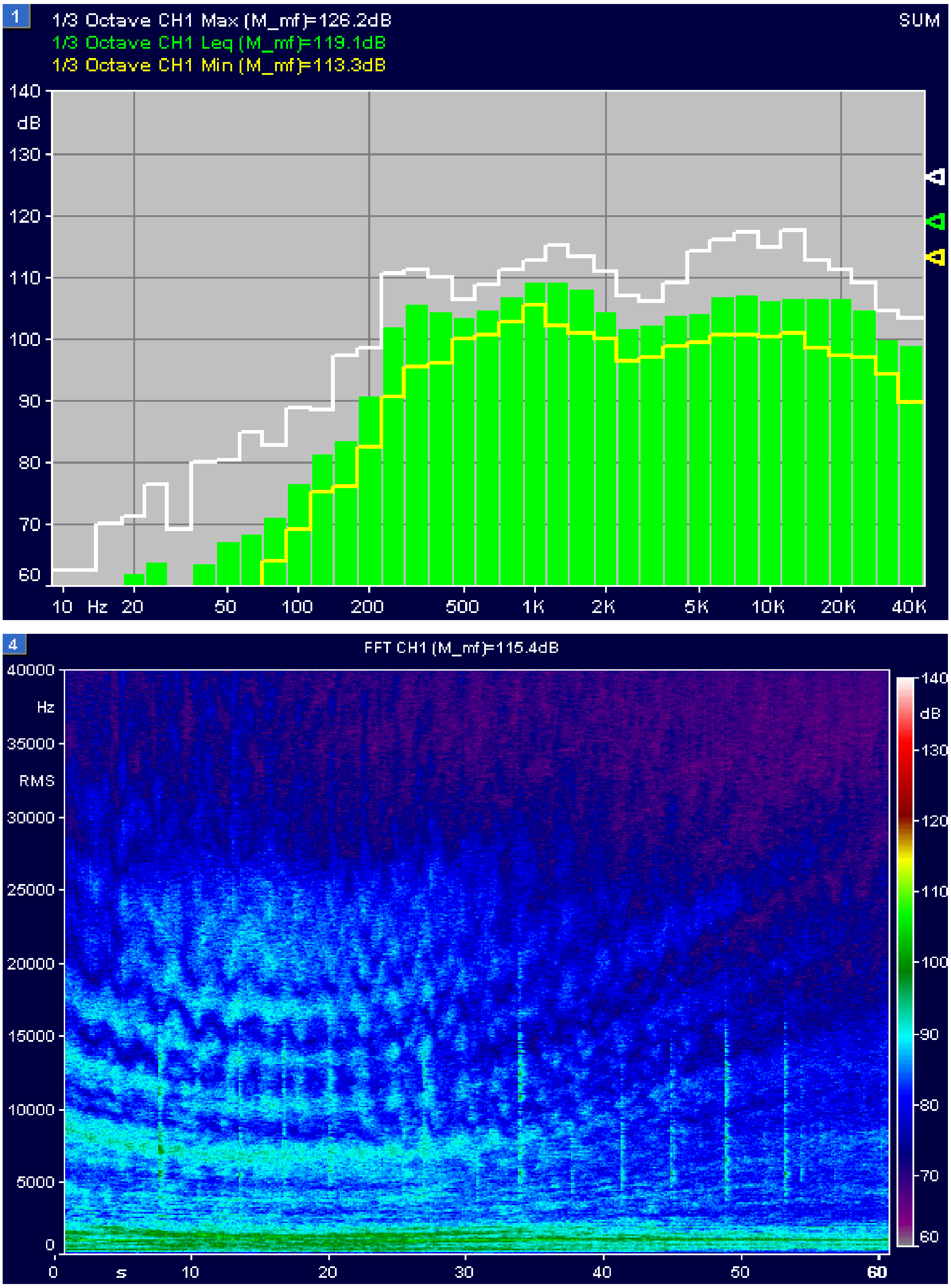


Figure 34: Pilot boat pass-by at 150m– one-third-octave noise spectrum(top graph) and FFT spectral history(bottom graph) – RMS Re: 1μPa

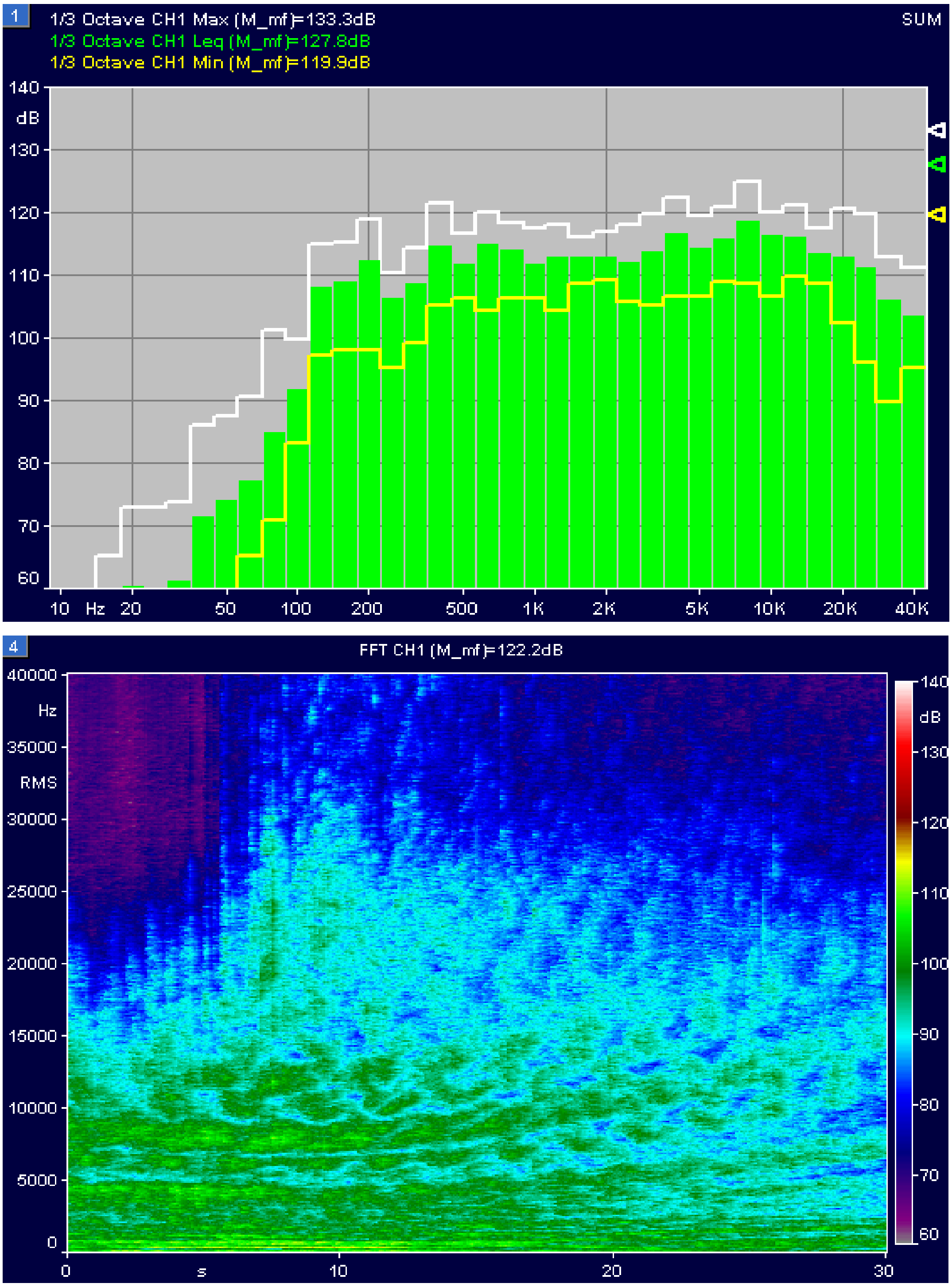


Figure 35: Tangalooma Flyer passenger ferry pass-by at 200m– one-third-octave noise spectrum(top graph) and FFT spectral history(bottom graph) – RMS Re: 1μPa

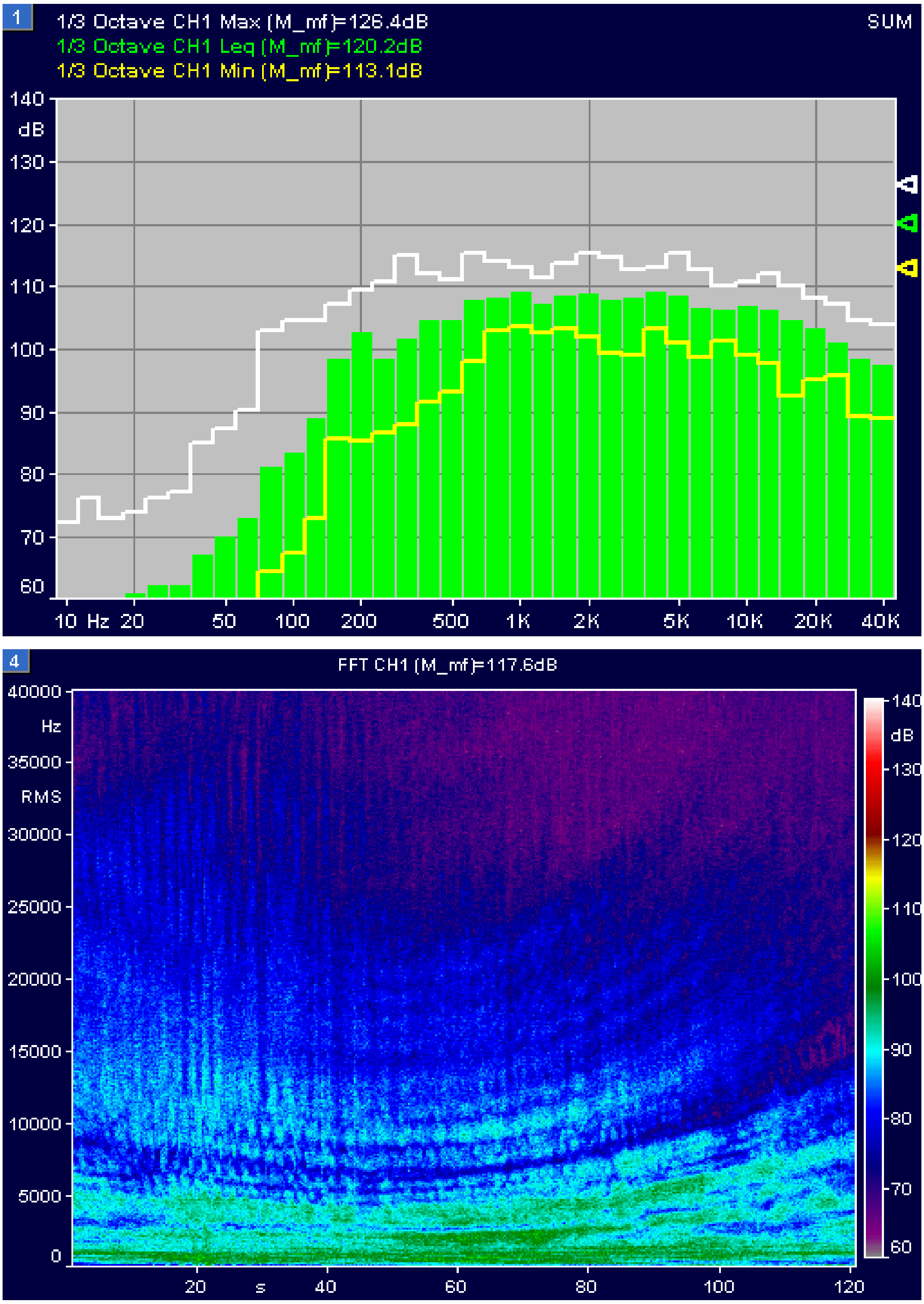


Figure 36: Riverside Marine tug & barge pass-by at 200m– one-third-octave noise spectrum(top graph) and FFT spectral history(bottom graph) – RMS Re: 1μPa