Underwater Sound Transmission Loss Modelling Study

Malta-Italy Second Electrical Interconnector

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Executive Summary

In 2021, the decision was taken by the Maltese government to lay a second electrical interconnector (IC2) between Malta and Sicily in order to cater for the increased electrical demand expected to result from the forecasted economic progress as well as the electrification of road transport.

SLR Consulting Limited (SLR) has been appointed by AIS Environment (AIS) to undertake an underwater Sound Transmission Loss Modelling (STLM) study for the operational activities related to the IC2 deployment between Malta and Sicily. To assess the potential noise impacts on marine fauna and fishing, SLR has been commissioned to determine the zones of impact for relevant marine fauna species of concern for the major noise sources associated with the proposed construction programme.

This report provides a marine noise modelling study and assessment of relevant zones of the impact associated with the proposed drilling operation activities. The study involves the following:

- Establishment of relevant assessment criteria for marine fauna species likely to be potentially impacted by the drilling operation noise emissions;
- Characterization of the existing underwater noise environment based on a literature review of the general ocean noise environment and the site-specific metocean conditions;
- Identification of major noise sources and their noise emission characteristics;
- Detailed modelling prediction of underwater noise propagation; and
- Assessment of subsequent zones of impact for different marine faunal groups.

Noise impact criteria have been established via a review of the most relevant guidelines and literature. These criteria include physiological and behavioural impacts on marine fauna, including marine mammals, fish, fish eggs, fish larvae, and sea turtle species.

Detailed modelling predictions have been undertaken for noise emissions from identified major noise sources, including single pulse Sonar surveying, dredging, and continuous noise emissions from different stages of cable laying operations (including the offshore support vessel and anchor handling tug). In addition, the zones of noise impact from major noise sources have been estimated for different marine faunal species based on comparisons between STLM noise levels and noise impact criteria for both shallow-water and deep-water source location scenarios.

Assessments of relevant zones of impact are detailed in Section 0, with a summary of the maximum zones of impact estimates and residual effects provided in Table 22 and Table 23 within the report. The zones of impact assessment for the study are summaries as below. The zones of impact assessment for the study are summaries as below.

Impact from Immediate Exposure to an SBES pulse

Marine Mammals

For general marine mammal species, low physiological impact, particularly the PTS impact, is predicted from impulsive sonar survey for the nearshore and offshore scenarios. The only marine mammal hearing group with a higher impact is the VHF cetaceans due to their higher hearing sensitivity to high frequencies. For those animals their behavioural response could reach up to approximately 4.5 km from the noise source.

Fish and Sea Turtles

SBES sources are not expected to cause an adverse hearing impact on fish species and sea turtles due to the low-frequency hearing ranges of these animals.

Impact from Cumulative Trench Dredging Activities

Marine Mammals

Under the worst-case consideration (i.e., the cutting dredging operations are continuous and affected marine animals stay at the fixed location over the entire 24-hour period), LF cetaceans is the only one with PTS-onset and has the highest TTS-onset impact zones among all marine mammal hearing groups. The PTS-onset zone for LF cetaceans is up to 80 m, and the TTS-onset zone is up to 690 m for the nearshore scenario. For the offshore scenario, the PTS-onset zone is predicted to be within 175 m from the noise source, and the TTS-onset zone within up 1,455 km for LF cetaceans. The predicted zones of potential behavioural disturbance for all marine mammals are up to 82.91 km from the assessed nearshore scenario and up to 28.11 km from the assessed offshore scenario.

Fish and Sea Turtles

Non-impulsive noise sources such as dredging (i.e., cutting/trenching) are not expected to cause mortality or potential mortal injury on fish species and sea turtles. However, behavioural response from fish species is expected to occur within 1.87 km and 1.45 km distance from the noise source, for the nearshore and offshore scenarios respectively. For sea turtles, the behavioural disturbance is predicted to occur within less than 10m from both assessed scenarios.

Impact from Cumulative Combined Cable Laying Sources

Marine Mammals

Among all identified non-impulsive noise emissions during construction and operation of the IC2 development, the combined cable-lay vessel sources are predicted to have the highest noise impact (PTS and TTS), particularly for low-frequency cetaceans. For the nearshore scenario, the PTS-onset zone is up to 775 m, and the TTS-onset zones are up to 2.35 km. For the offshore scenario, the PTS-onset zone is predicted to be within 1.63 km from the noise source, and the TTS-onset zone within up 12.23 km. Regarding behavioural response, the predicted zones of impact to occur are up to 102.8 km from the assessed nearshore scenario and up to 30.1 km from the assessed offshore scenario.

Fish and Sea Turtles

For general fish species, mortality or potential mortal injury is not expected to occur from non-impulsive noise emissions associated with operational activities. For Sea turtles, low physiological impact (only PTS) is predicted to occur at a close distance from the noise source. The PTS-onset zone for the nearshore scenario is within to 120 m distance from the source location and 40 m for the offshore scenario.

Behavioural responses for fish are expected to occur within 5.1 km and 2.8 km distance from the noise source, for the nearshore and offshore scenarios respectively. For sea turtles, the behavioural disturbance is predicted to occur up to 180 m and 160 m from the noise source, for the respective scenarios (nearshore and offshore).

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Acronyms and Abbreviations

AIS	AIS Environment
AHT	Anchor Handling Tug
dB	Decibel
CSD	Cutter Suction Dredger
CLV	Cable Laying Vessel
DICCA	Dipartimento di Ingegneria Civile, Chimica e Ambientale
DP	Dynamic Positioning
EEZ	Exclusive Economic Zone
GEBCO	General Bathymetric Chart of the Oceans
GPS	Global Positioning System
HF	High Frequency
IC1	First Electrical Interconnector
IC2	Second Electrical Interconnector
KNMI	The Royal Netherlands Meteorological Institute
LF	Low Frequency
NMFS	National Marine Fisheries Services
NOAA	National Oceanic and Atmospheric Administration
OCW	Other marine Carnivores in Water
OSV	Offshore Supporting Vessel
PCW	Phocid Carnivores in Water
PE	Parabolic Equation
Pk	Peak
PTS	Permanent Threshold Shift
RMS	Root Mean Square
SBES	Single-Beam Echo-Sounder
SEL	Sound Exposure Level
SEL_{cum}	Cumulative Sound Exposure Level
SLR	SLR Consulting Limited
SPL	Sound Pressure Level
STLM	Sound Transmission Loss Modelling
TTS	Temporary Threshold Shift
VHF	Very High Frequency
WG	Working Group

1.0 Introduction

SLR Consulting Limited (SLR) has been appointed by AIS Environment (AIS) to undertake an underwater Sound Transmission Loss Modelling (STLM) study for the operational activities related to a second electrical interconnector (IC2) deployment between Malta and Sicily. To assess the potential noise impacts on marine fauna and fishing, SLR has been commissioned to determine the zones of impact for relevant marine fauna species of concern for the major noise sources associated with the proposed construction programme.

1.1 Project Background

In 2021, the decision was taken by the Maltese government to lay an IC2 between Malta and Sicily in order to cater to the increased electrical demand expected to result from the forecasted economic progress as well as the electrification of road transport. The project's main objective is for Malta to import electrical energy through the European grid, including energy sourced from renewables. Malta has been connected to the European electrical grid since March 2015 through an underwater cable – the first electrical interconnector (IC1) from Ragusa to Maghtab. The IC2 will enhance the grid's stability by providing an alternating current link that will give more inertia to the grid and extra spinning reserve capacity to balance the intermittent fluctuations of renewables.

The IC2 will also allow the bi-directional exchange of a nominal continuous rating capacity of 200 MWe. As a result, AIS Environment has requested a noise and vibration study to provide sufficiently detailed information on any impacts on sensitive receptors (fauna and bird life, natural ecosystems) due to increased pressure in the area and noise accumulation from other existing sources, including maritime vessel traffic, and with other anticipated sources, such as new developments.

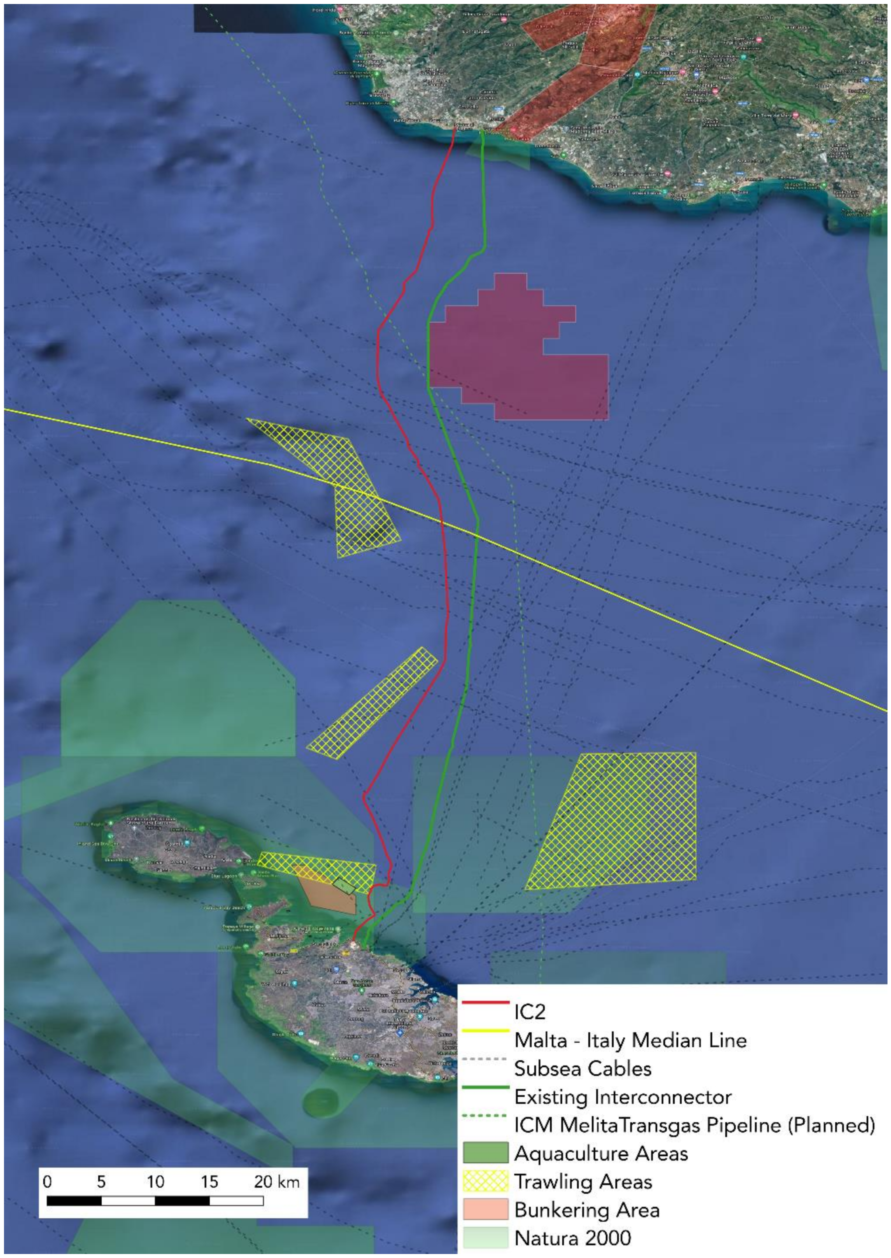
For IC2, the proposed IC2 route has been identified between Malta and Sicily, as shown in **Figure 1**. The proposed route corridor is located east of IC1. The proposed estimated underwater length of this route corridor proposal is 97.4 km. The cable will pass through a series of geological features along the offshore route, such as rocks and rock sub-crops (0-11 km from the Malta coast), a seabed consisting of sandy clay and fine silty sand (11-65 km from Malta coast), and sediments composed of silty clay and very silty sands (65 km to Sicily coast) among others.

Our underwater assessment stops at the Exclusive Economic Zone (EEZ) line from the Malta coast. The proposed offshore route will avoid interference with known underwater cultural heritage sites, such as shipwreck sites. To minimize the environmental impact, the cable will be laid entirely (where feasible) underground.

The operational activities include:

- Sonar bathymetry surveys
- Trench dredging
- Cable laying
    - Offshore supporting vessel
    - Anchor handling tug;

Figure 1: Proposed IC2 Route from Malta to Sicily



1.2 Structure of the Report

Malta has no national legislation or regulatory guidelines for assessing underwater noise impacts on marine fauna species. Therefore, the assessment has been undertaken considering current industry best practices applied internationally and being consistent with impact studies undertaken for other similar major offshore exploration projects elsewhere globally. The assessment methodology comprising several components is detailed in the report structure below.

- Section 2.0 gives an overview of the operational activities expected to generate underwater noise;
- Section 3.0 provides the characterization of the existing acoustic environment based on a review of the general ocean noise environment, as well as the site-specific metocean data in the Malta channel;
- Section 4.0 outlines the assessment criteria for relevant general marine fauna species, including marine mammals, fish and sea turtle species, based on relevant guidelines and criteria that represent current industry best practices;
- Section 5.0 details detailed noise modelling prediction methodology and procedure, relevant modelling environmental inputs and assumptions, and modelling scenarios associated with the operational activities with major noise emissions (i.e., sonar survey, trench dredging, cable laying, anchor handling tug, and offshore supporting vessels), and source levels of these major noise emissions;
- Section 0 provides the detailed modelling results and the subsequent zones of impact estimated for general marine fauna species based on criteria set out in Section 4.0;
- Section 7.0 provides a discussion of the acoustic modelling study; and
- Section 9.0 lists the relevant references cited throughout the report.

2.0 Operational Activities Description

Given that the preferred trenchless boring method is horizontal directional drilling, there are no plans to carry out pre-trenching dredging. Instead, the cable shall be laid on the seabed first, followed by cutting/trenching certain areas after the cable is laid. The following summarizes the operational activities analyzed for this STLM study.

2.1 Sonar Survey

Accurate seafloor mapping is a key component of an integrated exploration and development program in the marine environment. Traditionally, bathymetry data have been acquired using a single-beam echo-sounder (SBES) technology. SBES determines water depth by measuring the travel time of a short sonar pulse. The sonar pulse is emitted from a transducer positioned just below the water surface, and the SBES listens for the return echo from the bottom.

SBES can provide accurate bottom depths by distinguishing the real bottom from spurious signals in the returned echo. SBES may use various sonar frequencies. For example, 200 kHz is typically used in shallow depths under 100 m. However, as the attenuation of sound in water decreases at lower frequencies, 40 kHz is commonly used for deeper water surveys.

2.2 Trench Dredging

Trenching refers to constructing pipeline trenches or removing outcrops to reduce free spans and is typically achieved by dredging. Different dredger types are deployed depending on the type and hardness of the seabed soil. This is a highly specialized process that requires a high degree of precision. Often, the dredgers for these projects are mounted on a specially made vessel that uses high-end electronics and other instruments to dredge the right materials in the right place accurately. A Cutter suction dredger (CSD) vessel is best suited to removing hard substrates. A rotating cutter head breaks up material on the seabed before its removal by a suction pipe. The major sources of noise generation for CSDs are underwater pumps, piping, and the cutting head digging the seafloor. CSD vessels use pumps to suck material through an intake pipe which is discharged through a pipeline into a transport barge or a placement site. A cutter head at the suction end of the intake pipe rotates in contact with the sediment bed while swinging laterally into the sediment surface. Some cutter heads are capable of dredging rock formations such as basalt or limestone (McQueen 2019).

2.3 Cable Laying

IC2 installations are projected to be carried out based on a lay vessel. These types of vessels are specifically designed for laying cables on the seabed. Throughout the cable lay process, Dynamic Positioning (DP) enables a cable lay vessel to maintain its position (fixed location or predetermined track) by means of its propellers and thrusters using a Global Positioning System (GPS). DP vessels possess the ability to operate with positioning accuracy, safety, and reliability without the need for anchors, anchor handling tugs and mooring lines. The underwater noise produced by subsea trenching operations depends on the equipment used and the nature of the seabed sediments but will be predominantly generated by vessel thruster use (Nedwell and Edwards 2004). Cable laying is expected to proceed at a maximum speed of 7 km/day.

Thruster sound source levels may vary partly due to technologies employed and are not necessarily dependent on either vessel size, propulsion power or the activity engaged. Thruster noise is generated by cavitation and has a relatively flat spectrum shape due to the large number of random bursts caused by various-sized bubbles collapsing. Cavitation usually occurs when a liquid is subjected to rapid changes in pressure that cause the formation of cavities in the liquid where the pressure is relatively low. The discrete spectral "blade rate" component occurs at multiples of the rate at which any irregularity in the flow pattern or in the impeller itself is intercepted by the impeller blades (Fischer 2000).

2.3.1 Offshore Supporting Vessels

Supporting vessels facilitate moving equipment and materials between the cable lay vessel and the onshore base. A supply vessel will always be on standby near the lay vessel to support firefighting or rescue in the unlikely event of an emergency and supply any additional equipment that may be required. Support vessels can also be used for medical evacuations or crew transfer if needed.

2.3.2 Anchor Handling Tug

Anchor handling generally refers to work performed by the vessel for the sole purpose of towing or towing an offshore platform, barge, or vessel. Therefore, tugboats are the most suitable for offshore cable lay activities. Tugboat noise source levels can vary considerably, with measured tug source levels identified in the literature ranging from around 164 dB re 1 µPa at 1 m to 202 dB re 1 µPa at 1 m, as described in **Table** 1. Source noise emissions largely relate to the operational effort, with full power operations including higher transiting speeds generating more propeller cavitation and hence more noise than low-power or low-load activities. Anchor handling tug (AHT) can be one of the operations that generate a higher source level.

Table 1: Sources of Measured Tug Source Levels

Tugboat	Source Level @ 1m (dB re 1 µPa)	Description	References
Britoil	193	Anchor handling	Hannay et al. 2004
Tug 1	200	Anchor handling, Strait of Juan de Fuca, ~100 m depth	Laurinolli et al. 2005
Tug 2	182		
Tug 3	202	Anchor handling, Cook Inlet Alaska, ~60 m depth	Austin and Warner 2012
Tug & Barge	164	Transiting, Anchorage Harbor, Alaska, ~40 m depth	Blackwell and Greene 2005
Tug & Barge	179	Docking, Anchorage Harbor, Alaska, ~40 m depth	
Tug & Barge	182	Transiting, Beaufort Sea	Zykov and Hannay 2006

3.0 Existing Underwater Noise Environment

3.1 General Ocean Ambient Noise

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

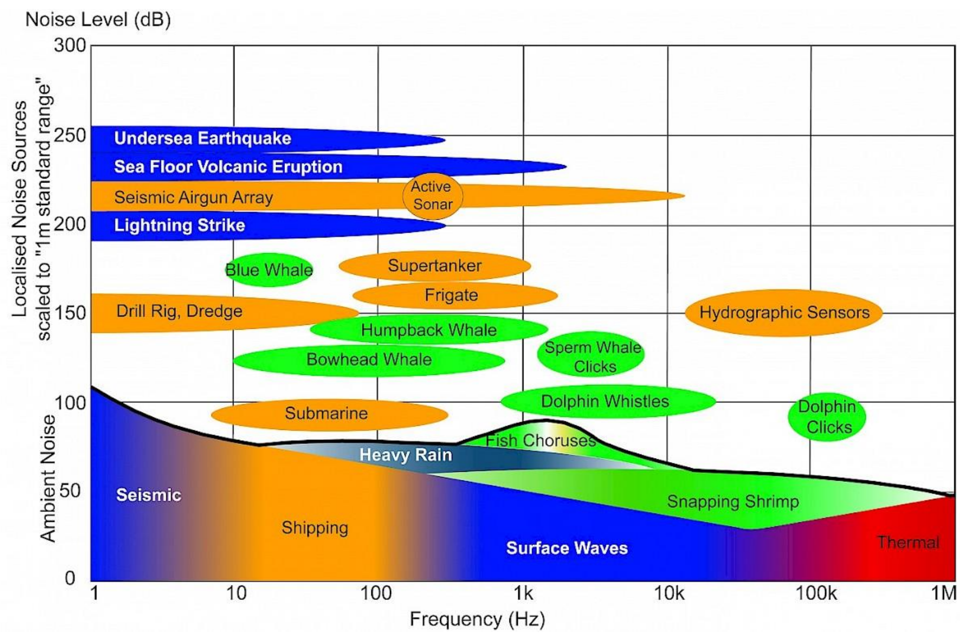
Ocean ambient noise is comprised of a variety of sounds of different origins at different frequency ranges, having both temporal and spatial variations. It primarily consists of noise from natural physical events, the noise produced by marine biological species and anthropogenic noise. These sources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

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

- Anthropogenic sources: anthropogenic noise primarily consists of noise from shipping activities, offshore seismic explorations, marine industrial developments and operations, as well as equipment such as sonar and echo sounders:
    - Shipping traffic from various sizes of ships is the prevailing man-made noise source around nearshore port areas. Shipping noise is typically due to cavitation from propellers and thrusters, with energy predominantly below 1 kHz;
    - Pile driving and offshore seismic exploration generate repetitive pulse signals with intense energy at relatively low frequencies (hundreds of Hz) that can potentially cause physical injuries to marine species close to the noise source. The full frequency range for these impulsive signals could be up to 10 kHz; and
    - Dredging activities and other marine industry operations are additional man-made sources generating broadband noise over relatively long durations.

An overview of the indicative noise spectral levels produced by various natural and anthropogenic sources relative to typical background or ambient noise levels in the ocean is shown in **Figure 2**. Human contributions to ambient noise are often significant at low frequencies, between about 20 Hz and 500 Hz, with ambient noise in this frequency range being predominantly from distant shipping (Hildebrand 2009). In areas away from anthropogenic sources, background noise at higher frequencies tends to be dominated by natural physical or bioacoustics sources such as rainfall, surface waves and spray, fish choruses, and snapping shrimp for coastal waters.

Figure 2: Levels and frequencies of anthropogenic and naturally occurring sound sources in the marine environment (from https://www.ospar.org/work-areas/eiha/noise). Natural physical noise sources represented in blue; marine fauna noise sources in green; human noise sources in orange

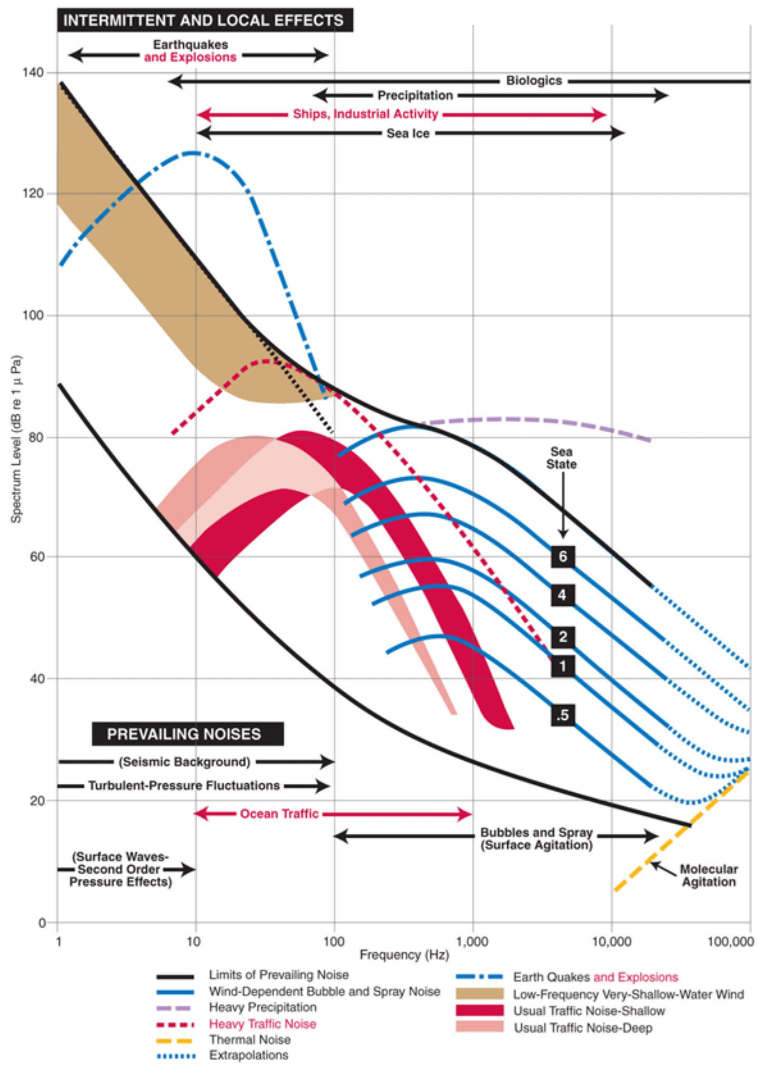


A summary of the spectra of various ambient noise sources based on a review study undertaken by Wenz (1962) is shown in **Figure 3**. It should be noted that although the spectral curves in the figure are based on average levels from reviewed references primarily for the North Atlantic Ocean, they are regarded as representative in general for respective ocean ambient noise spectral components.

Overall ambient noise levels typically range from approximately:

- As low as 80 dB re 1 µPa for the frequency range 10 – 10 kHz for light surrounding shipping movements and calm sea surface conditions, to;
- Up to 120 dB re 1 µPa for the 10 – 10 kHz frequency range for moderate to heavy remote shipping traffic and medium to high wind conditions.

Figure 3: Spectra and frequency distribution of ocean sound sources based on the Wenz curves (Miksis-Olds et al. 2013, adapted from Wenz (1962))

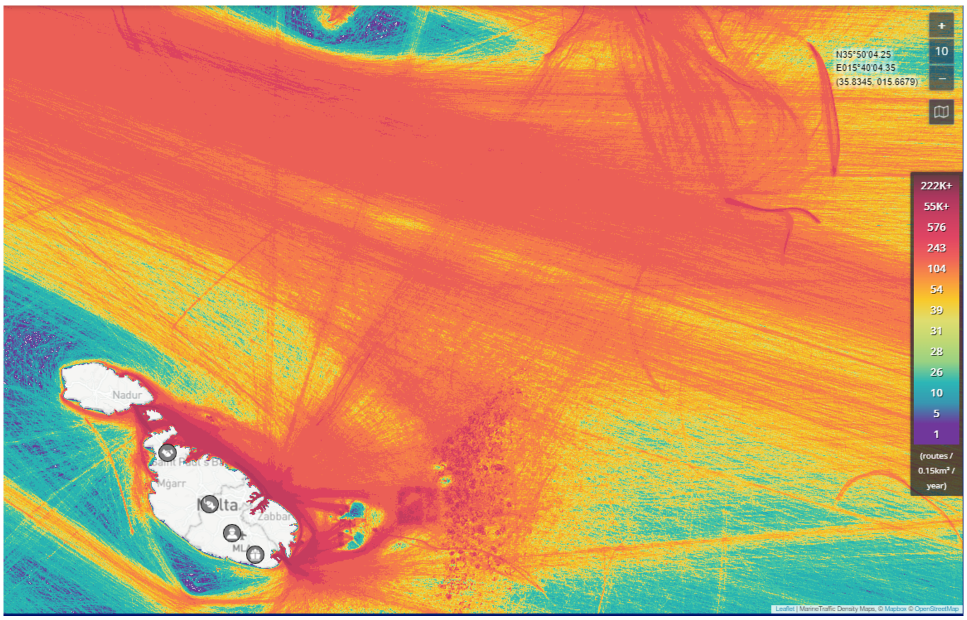


3.2 Shipping Traffic Offshore Malta

Shipping traffic density offshore Malta is shown in **Figure 4**. Major shipping routes are along the Malta coastline, connecting several points of the island. The figure shows that the site area has high shipping traffic density over the project area, particularly nearshore to Malta.

As such, the shipping noise component of the ambient noise environment is expected to be significant nearshore Malta and moderate offshore.

Figure 4: Shipping traffic density offshore Malta region (Source: http://www.marinetraffic.com/, accessed 16th February 2023)



3.3 Metocean conditions offshore Malta

A comprehensive metocean study has been performed for the design of the proposed submarine pipeline, including the wind distribution analysis based on long-term historical data for the Malta Channel derived from KNMI (The Royal Netherlands Meteorological Institute) observations from 1960 to 1980, hindcasted wind data during the period 1998 – 2017 at four DICCA (Dipartimento di Ingegneria Civile, Chimica e Ambientale) positions surrounding the pipeline route, as well as the long-term measurement data at one offshore monitoring location east of the pipeline route: Vega – a platform with a meteo-marine monitoring system installed (De Filippi 2019).

The annual wind rose from historical data in Malta Channel and long-term measurements at Vega indicate that the yearly prevailing wind directions are westerly to north-westerly, as shown in **Figure 5**. The frequency distributions of the wind speed vs incoming direction for the historical data based on KNMI observations from 1960 to 1980 are shown in **Table 2**. For yearly frequency distribution, wind speeds are below the speed of 6 m/s (i.e., Beaufort scale around 3) over 50% of the one-year period, over 15% of the period, the wind speeds within the range of 6 – 8 m/s (i.e., Beaufort scale around 4), and over 2% of wind speeds within the range of 16 – 20 m/s (i.e., Beaufort scale around 7 - 8).

Compared with generic ambient noise spectra in Wenz's curve in **Figure 3**, it illustrates that the offshore area surrounding the proposed IC2 route has generally calm sea state conditions and has a mid-range of wind-induced ambient noise spectral components.

Figure 5: Annual wind rose from historical data (1960 - 1980) in Malta Channel (left) and long-term measurements (2002 - 2017) at Vega (right).

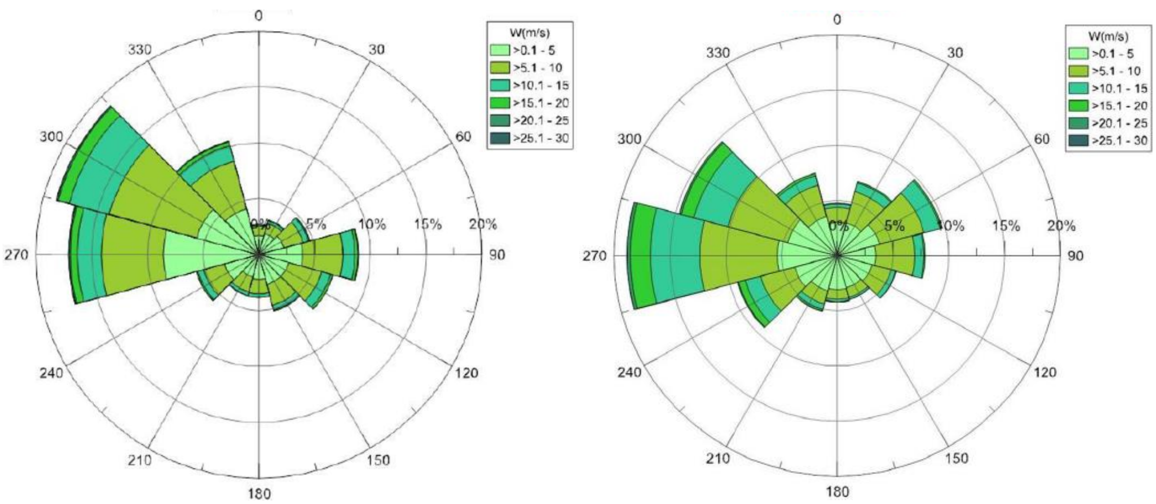


Table 2: Frequency distribution (%) of wind speed vs incoming direction for historical data in Malta Channel (KNMI Observation 1960 - 1980)

DIRECTION (°N)	WIND SPEED (m/s)											
	4	6	8	10	12	14	16	18	20	22	24	>24	TOTAL
0	5.29	1.09	.58	.35	.11	.74	.04	.00	.01	.00	.00	.00	8.21
30	1.34	.87	.41	.26	.13	.07	.08	.02	.01	.01	.00	.00	3.19
60	1.54	1.20	.85	.48	.23	.20	.10	.05	.02	.01	.01	.00	4.69
90	2.68	1.99	1.64	1.12	.57	.40	.26	.09	.06	.01	.01	.00	8.82
120	1.81	1.71	1.35	.90	.50	.28	.15	.06	.04	.01	.00	.00	6.81
150	1.92	1.34	.88	.50	.24	.16	.08	.02	.01	.00	.00	.00	5.17
180	1.54	.97	.59	.38	.15	.12	.02	.01	.00	.00	.00	.00	3.78
210	1.47	.95	.64	.36	.18	.12	.03	.01	.00	.00	.00	.00	3.77
240	2.26	1.44	.82	.56	.27	.25	.08	.04	.02	.01	.00	.01	5.75
270	3.90	2.81	2.43	1.92	1.08	.87	.53	.17	.11	.08	.05	.02	13.96
300	3.64	3.62	3.35	3.13	1.81	1.64	.79	.33	.17	.08	.06	.02	18.64
330	2.63	2.49	2.02	1.43	.69	.63	.27	.10	.06	.03	.03	.02	10.39
TOTAL	30.02	20.49	15.56	11.40	5.96	5.47	2.43	.90	.51	.23	.15	.07	93.18
CALM:	6.82												

Given the high density of shipping traffic and moderate metocean conditions specific to the adjacent area surrounding offshore Malta (as described in the following relevant sections), the ambient noise levels are expected to be at least 10 dB higher than the lowest level, within the higher range of the typical ambient noise levels, i.e., 90 - 130 dB re 1 µPa for the frequency range 10 – 10 kHz.

4.0 Underwater Noise Impact Assessment Criteria

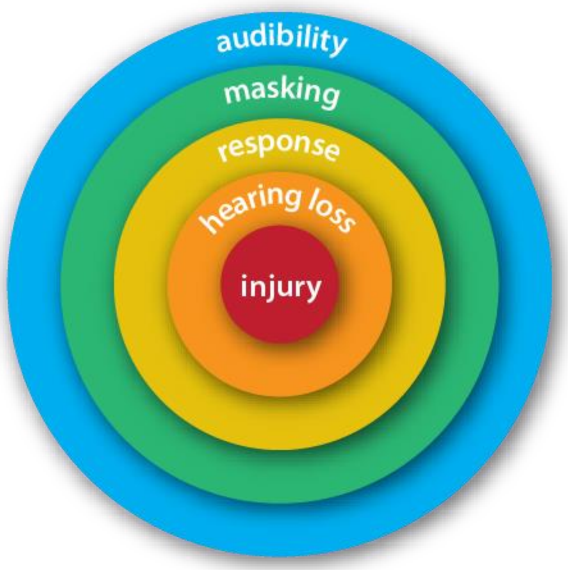
Malta has no specific national legislation or regulatory guidelines for assessing underwater noise impacts on marine fauna species. Therefore, the assessment has been undertaken considering current industry best practices applied internationally and being consistent with impact studies undertaken for other similar major offshore development projects elsewhere globally.

4.1 Impact of Noise on Marine Fauna Species

The effects of noise and the range over which these effects take place depend on the acoustic characteristics of the noise (e.g., source level, spectral content, temporal characteristics[1], directionality, etc.), the sound propagation environment, as well as the hearing ability and physical reaction of individual marine fauna species. The potential impacts of noise on marine fauna species include audibility/detection, masking of communication and other biologically important sounds, behavioural responses and physiological impacts, which generally include discomfort, hearing loss, physical injury, and mortality (Richardson et al. 2013; Erbe et al. 2018; Popper and Hawkins 2019).

Physical injuries can occur when the animal is close to the acoustic source. As the animal moves further away from the source, the impacts are expected to decrease gradually to a point where the impacts are negligible. The theoretical zones of noise influence, according to Richardson et al. (2013), based on the severity of the noise impact are illustrated in **Figure 6**.

Figure 6: Theoretical zones of noise influence (adapted from Richardson et al. 2013)



4.1.1 Audibility / Sound Detection

A sound is audible when the receiver is able to perceive it over background noise. The audibility is also determined by the threshold of hearing that varies with frequency. The frequency dependant hearing

[1] Impulsive noise is typically very short (with seconds) and intermittent with rapid time and decay back to ambient levels (e.g., noise from pile driving, seismic airguns and seabed survey sonar signals).

sensitivity is expressed in the form of a hearing curve (i.e., audiogram). In general, marine mammals and fish species usually have U-shaped audiograms, meaning that within their respective hearing ranges, they are more sensitive to the sound energy component in the mid-frequency range and less sensitive to the energy components in the lower and upper-frequency ranges (Finneran 2016; Southall et al. 2019; Popper et al. 2019).

For fish species, their sound detection is based on the response of the auditory portion of their ears (i.e., the otolithic organs) to the particle motion of the surrounding fluid (Popper and Hawkins 2018). Some fish species can detect sound pressure via gas-filled structures near the ear and/or extensions of the swim bladder that functionally affect the ear, in addition to purely the fluid particle motion, which as a result, increases hearing sensitivity and broaden the hearing bandwidth (Nedelec et al. 2016; Popper and Hawkins 2018).

4.1.2 Masking

Masking occurs when the noise is high enough to impair the detection of biologically relevant sound signals, such as communication signals, echolocation clicks and passive detection cues that are used for navigation and finding prey. The zone of masking is defined by the range at which sound levels from the noise source are received above the threshold within the 'critical band'[2] centred on the signal (Richardson et al. 2013) and, therefore, strongly dependent on the background noise environment.

The potential for masking can be reduced due to an animal's frequency and temporal discrimination ability, directional hearing, co-modulation masking release (if noise is amplitude modulated over a number of frequency bands) and multiple looks (if the noise has gaps or the signal is repetitive), as well as anti-masking strategies (increasing call level, shifting frequency, repetition, etc.) (Erbe 2016).

4.1.3 Behavioural Response

Responses to noise include changes in vocalization, resting, diving and breathing patterns, changes in mother-infant relationships, and avoidance of the noise sources. For behavioural responses to occur, a sound would mostly have to be significantly above ambient levels and the animal's audiogram.

The behavioural response effects can be very difficult to measure and depend on a wide variety of factors such as the physical characteristics of the signal, the behavioural and motivational state of the receiver, its age, sex and social status and many others. Therefore, the extent of behavioural disturbance for any given signal can vary within a population and within the same individual. Behavioural reactions can vary significantly, ranging from very subtle changes in behaviour to strong avoidance reactions (Ellison et al. 2012; Richardson et al. 2013).

4.1.4 Hearing loss / Discomfort

The physiological effects of underwater noise are primarily associated with the auditory system, which is likely to be most sensitive to noise. Therefore, the exposure of the auditory system to a high level of noise for a specific duration can cause a reduction in the animal's hearing sensitivity or increase the range to the threshold (Finneran 2016; Popper and Hawkins 2019; Southall et al. 2019).

If the noise exposure is below some critical sound energy level, the hearing loss is generally only temporary, and this effect is called temporary hearing threshold shift (TTS). However, if the noise

[2] In biological hearing systems, noise is integrated over several frequency filters, called the critical bands.

exposure exceeds the critical sound energy level, the hearing loss can be permanent, and this effect is called permanent hearing threshold shift (PTS).

4.1.5 Physical Injury

In a broader sense, physiological impacts also include non-auditory physiological effects. Other physiological systems of marine animals potentially affected by noise include the vestibular system, reproductive system, nervous system, liver or organs with high levels of dissolved gas concentrations and gas-filled spaces. Noise at high levels may cause concussive effects, physical damage to tissues and organs, cavitation, or result in the rapid formation of bubbles in the venous system due to massive oscillations of pressure (Groton 1998).

From an adverse impact assessment perspective, among the potential noise impacts above, physiological impacts are deemed the primary adverse impact, and behavioural responses are the secondary adverse impact. The following sub-sections outline the corresponding impact assessment criteria for marine mammals, fish and sea turtle species, and human divers and swimmers based on a review of relevant guidelines and/or literature published.

4.2 Marine Mammals, Fish and Sea Turtles

There have been extensive scientific studies and research efforts to develop quantitative links between marine noise and impacts on marine mammal species, fish, and sea turtles. For example, Southall et al. (2019) have proposed noise exposure criteria associated with various sound types, including impulsive noise (e.g., seismic airgun and sonar noise) and non-impulsive noise (e.g., vessel and dredging noise) for certain marine mammal species (i.e., cetaceans, and carnivores), based on a review of expanding literature on marine mammal hearing and physiological and behavioural responses to anthropogenic sounds. Popper et al. (2014) and Popper and Hawkins (2019) proposed sound exposure guidelines for fish, considering the diversity of fish, the different ways they detect sound, as well as various sound sources and their acoustic characteristics. Finneran et al. (2017) presented a revision of the thresholds for sea turtle injury and hearing impairment (TTS and PTS).

The following subsection provides the noise exposure levels above which adverse effects could be expected on various groups of marine mammals, fish, and sea turtles. The latter is based on all available relevant data and published literature (i.e., the state of current knowledge). For more details, see Appendix C.

4.2.1 Noise Impact Criteria for Marine Mammals

The newly updated scientific recommendations in marine mammal noise exposure criteria (Southall et al. 2019) propose PTS-onset and TTS-onset criteria for impulsive noise events.

- The PTS-onset and TTS-onset criteria for impulsive noise are outlined in **Table 3**, which incorporate a single-criteria approach based on peak sound pressure level (SPL).
- The PTS-onset and TTS-onset criteria for non-impulsive noise, as outlined in
- Table 4, are based on cumulative SEL within a 24-hour period (SEL_{24hr}).

For behavioural changes, the widely used assessment criterion for the onset of possible behavioural disruption in marine mammals is root-mean-square (RMS) SPL of 160 dB re 1 µPa for impulsive noise and 120 dB re 1 µPa for non-impulsive noise, as shown in

Table 5.

Table 3: PTS and TTS threshold levels for individual marine mammals exposed to impulsive noise events (Southall et al. 2019)

Marine mammal hearing group	PTS and TTS threshold levels – impulsive noise events	
	Injury (PTS) onset	TTS onset
	Pk SPL, dB re 1µPa	Pk SPL, dB re 1µPa
Low-frequency cetaceans (LF)	219	213
High-frequency cetaceans (HF)	230	224
Very-high-frequency cetaceans (VHF)	202	196
Phocid carnivores in water (PCW)	218	212
Other marine carnivores in water (OCW)	232	226

Table 4: PTS- and TTS-onset threshold levels for individual marine mammals exposed to non-impulsive noise (Southall et al. 2019)

Marine mammal hearing group	PTS and TTS threshold levels – non-impulsive noise events	
	Injury (PTS) onset	TTS onset
	Weighted SEL_{24hr}, dB re 1µPa^2·S	Weighted SEL_{24hr}, dB re 1µPa^2·S
Low-frequency cetaceans (LF)	199	179
High-frequency cetaceans (HF)	198	178
Very-high-frequency cetaceans (VHF)	173	153
Phocid carnivores in water (PCW)	201	181
Other marine carnivores in water (OCW)	219	199

Table 5: Behavioural disruption threshold levels for individual marine mammals – impulsive and non-impulsive noise (NOAA 2019)

Marine mammal hearing group	Behavioural disruption threshold levels, RMS SPL, dB re 1µPa	
	Impulsive noise	Non-impulsive noise
All hearing groups	160	120

4.2.2 Noise Criteria for Fish

In general, limited scientific data regarding sound effects on fish are available. As such, assessment procedures and subsequent regulatory and mitigation measures are often severely limited in relevance and efficacy. To reduce regulatory uncertainty for all stakeholders by replacing precaution with scientific facts, the U.S. National Oceanic and Atmospheric Administration (NOAA) convened an international panel of experts to develop noise exposure criteria for fish and sea turtles in 2004, primarily based on published scientific data in the peer-reviewed literature. The panel was organized as a Working Group (WG) under the ANSI-Accredited Standards Committee S3/SC 1, Animal Bioacoustics, which the Acoustical Society of America sponsors.

The outcomes of the WG are broadly applicable to sound exposure guidelines for fish, fish eggs and larvae (Popper et al. 2014, Popper and Hawkins 2019), considering the diversity of fish and the different ways they detect sound, as well as various sound sources and their acoustic characteristics.

High-frequency active sonar sources (above 10 kHz), such as SBES sources, are not expected to cause an adverse hearing impact on fish species due to the low-frequency hearing ranges of these animals (from below 100 Hz to up to a few kHz) (Popper et al. 2014). However, high-frequency sonar could potentially generate behavioural responses in some species (e.g., American shad and Gulf menhaden) that can detect ultrasound (up to 180 kHz) (Mann et al. 2001).

Currently, there is no direct evidence of mortality or potential mortal injury to fish from non-impulsive noise sources such as shipping noise or dredging activities (Popper et al. 2014). However, continuous noise of any level that is detectable by fish can mask signal detection and impact their behaviour (Popper and Hawkins 2019). Increased noise levels may affect a wide range of behaviour patterns over the long term. For example, anthropogenic sounds can interfere with foraging behaviour by masking the relevant sounds or resembling sounds that prey may generate. Similarly, fish might avoid predators by listening to sounds that predators make deliberately or inadvertently (Popper and Hawkins 2019).

For behavioural disruption threshold levels for all fish species, the National Marine Fisheries Services (NMFS) uses the U.S. Navy Phase III criteria for all noise thresholds (Navy 2017). As of December 2021, potential effects on endangered listed fish species may occur when impulsive or non-impulsive activities produce sounds that exceed the thresholds, according to Table 6.

Table 6: Exposure criteria for behavioural disruption - all fish species (Navy 2017)

Type of animal	Behavioural disruption threshold levels, RMS SPL, dB re 1μPa	
	Impulsive noise	Non-impulsive noise
Fish	150	150

4.2.3 Noise Criteria for Sea Turtles

Popper et al. (2014) suggested threshold levels for the occurrence of mortality and potential mortal injuries (PTS) of sea turtles. However, these adopted levels were extrapolated from other animal groups, such as fish, based on the logic that the hearing range of turtles is much closer to that of poorly hearing fish. More recently, Finneran et al. (2017) revised the sea turtle thresholds (PTS) by reviewing individual references from at least five different species (see Appendix C) to construct their composite audiograms and provide thresholds for the onset of temporary hearing impairment (TTS). Finneran et al. (2017) agreed that even within their best hearing range, sea turtles have low sensitivity with audiograms more similar to those of fish without specialized hearing adaptations for high frequency, like some marine mammals.

No data on sea turtles and their response to high-frequency sonar is available. However, since turtles detect sound below 1 kHz, any effect would only be in response to low-frequency sonar (Popper et al. 2014).

The revised thresholds for sea turtles relevant to the non-impulsive noise from shipping and other sources, such as dredging, are presented in Table 7. Additionally, 175 re 1 µPa SPL RMS is expected to be the received sound level at which sea turtles would actively avoid exposure to non-impulsive noise activities, such as shipping and dredging operations, as shown in

Table 8 (Finneran et al. 2017).

Table 7: PTS threshold levels for sea turtles exposed to non-impulsive noise events (Navy 2017)

Type of animal	PTS threshold levels – non-impulsive noise events
	Injury (PTS) onset
	Criteria - Weighted SEL_{24hr}, dB re 1µPa^2·S
Sea turtles	220

Table 8: The behavioural disruption threshold level for individual sea turtles to non-impulsive noise (Finneran et al. 2017)

Type of animal	Behavioural disruption threshold levels, RMS SPL, dB re 1µPa
	Non-impulsive noise
Sea turtles	175

4.3 Zones of Bioacoustics Impact

Received noise levels can be predicted using known source levels in combination with models of sound propagation transmission loss between the source and the receiver locations. Zones of impact can then be determined by comparison of the predicted received levels to the noise exposure criteria for the marine fauna species of concern.

It is expected that the noise generated by the major cable laying sources and dredging operation activities can be significantly higher than the natural ambient noise levels (90 - 130 dB re 1 µPa as described in **Section 3.0** above).

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

In all cases, zones of impact are conservatively determined by using the maximum predicted noise level across the water column to determine the zone of impact. Since noise levels vary with depth at any location, areas in the water column within the identified zone of impact will be exposed to lower noise levels than implied by the identified zones of impact, representing worst-case scenarios.

5.0 Underwater Noise Modelling Predictions

5.1 Underwater Noise Assessment Scenarios and Source Levels

A list of modelling scenarios with relevant major noise-generating equipment is developed based on relevant operation activities information provided and the general project description as in Section 2.0. Broadband source levels (SL) and their spectra have been sourced from relevant literature. These scenarios and relevant noise sources are summarised in Table 9.

For non-impulsive noise, it is assumed that the source SEL levels are equivalent to their corresponding RMS SPL source levels, considering the consistency and longer durations of the typical continuous noise emissions.

Table 9: Operational activities and sources to be assessed with relevant broadband noise SLs

Operational Activity	Major Noise Source	Broadband SL (dB re 1µPa @ 1 m)
Sonar survey	Single-beam echo-sounder (SBES) – (40 kHz and 200 kHz)	233*
Trench Dredging	Cutter Suction Dredger (CSD) vessel – Athena or Al Mahaar (Zykov 2013)	184
Cable Laying	Cable Laying Vessel (CLV) with DPS - *Castorone* (Nedwell and Edwards 2004)	192
	Anchor Handling Tug (AHT) - *Katun* (Hannay et al. 2004)	189
	Offshore Supporting Vessel (OSV) - *Setouchi Surveyor* (Hannay et al. 2004)	184
	Combined cable laying effort	194
*Peak to peak SPL (dB re 1µPa @ 1 m)		

5.1.1 Single-beam echo-sounder (SBES)

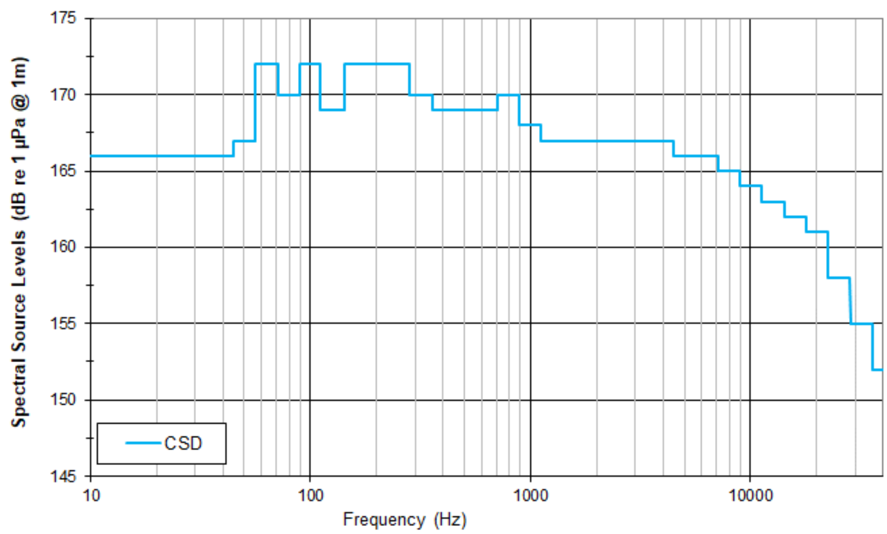
The sonar devices for seafloor mapping mid to high frequency (a few kHz to hundreds of kHz) impulsive (tens of milli-seconds) signals, and their noise emissions are highly directional towards the seabed. As a result, less energy propagates horizontally. Therefore, noise impact from these sources is expected to be predominantly near-field and immediate rather than cumulative over time at far-field distances. Spherical spreading loss is assumed to be the transmission loss estimate for the near-field sonar noise propagation.

An extensive review of existing data on the underwater sound produced by the Oil and Gas Industry (Wyatt 2008) has shown that seabed survey sonar devices generate impulsive signals with Pk-Pk SPL ranging 200 dB re 1µPa @ 1 m to 233 dB re 1µPa @ 1 m. Therefore, based on a worst-case consideration, it is assumed that the sonar devices to be used for the pre-laying survey have the Pk-Pk SPL of 233 dB re 1µPa @ 1 m.

5.1.2 Cutter Suction Dredger (CSD)

The one-third octave spectral source levels for the CSD vessel are used based on the field measurements undertaken by SLR during a port development in Northern Queensland, Australia, for the large-sized CSD Athena and Al Mahaar (total installed power 11,224 KW) under their full operation conditions (Zykov 2013). The spectral source levels with an overall SL of 184.0 dB re 1µPa @ 1 m is shown in Figure 6.

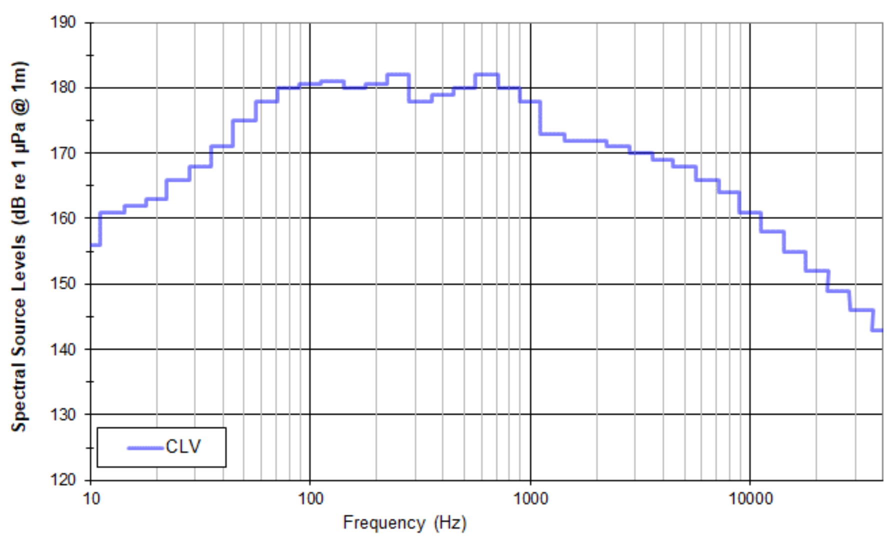
Figure 7 One-third octave band spectral SLs for the CSD vessel *Athena* (Zykov 2013)



5.1.3 Cable Laying Vessel (CLV)

Underwater noise emissions from the CLV are predominantly from propulsion operations. For deep water operations, noise emissions are also generated by the thrusters from the operation of the DP system. The spectral source levels with an overall SL of 192 dB re 1µPa @ 1 m for the cable laying vessel, as shown in Figure 8, are assumed to be similar to the *Castorone* barge with a propulsion power of 67,000 kW (Nedwell and Edwards 2004).

Figure 8: One-third octave band spectral SLs for the CLV Castorone (Nedwell and Edwards 2004).

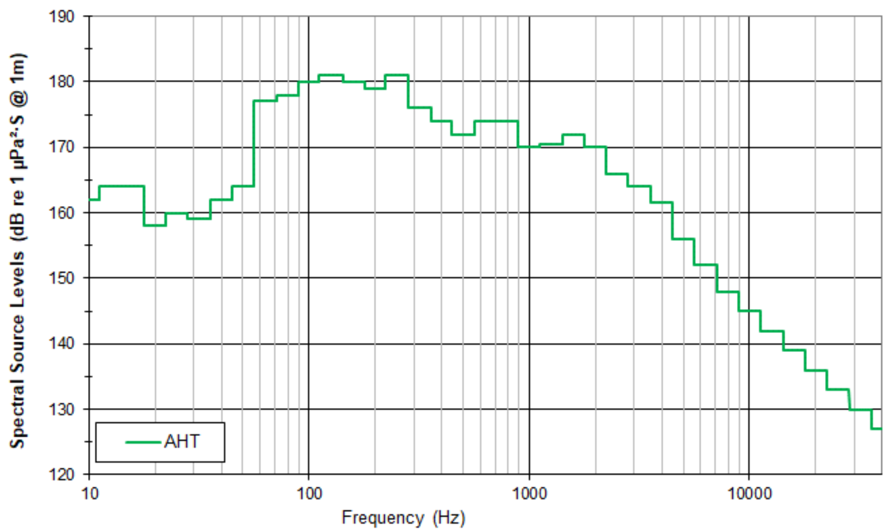


5.1.4 Anchor Handling Tug (AHT)

The major noise emissions from the AHT operations are expected to be from the cavitation noise generated by propellers and thrusters, with energy predominantly below 1 - 2 kHz.

The spectral source levels with an overall SL of 189 dB re 1µPa @ 1 m for the AHT, as shown in **Figure 9**, are assumed to be similar to the barge Katun with a propulsion power of 9,000 kW (Hannay et al. 2004) under transiting operations.

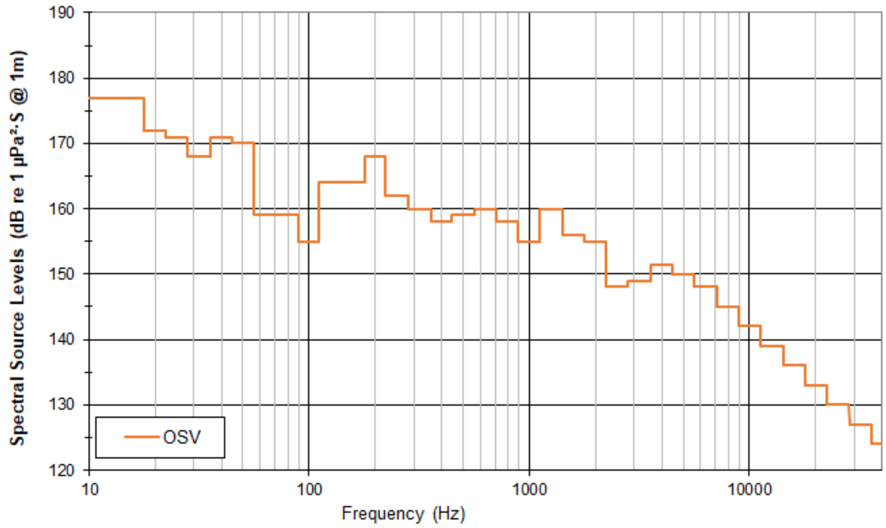
Figure 9 One-third octave band spectral SLs for the AHT Katun (Hannay et al. 2004)



5.1.5 Offshore Supporting Vessel (OSV)

The source spectral levels for OSV were assumed to be similar to those of the *Setouchi Surveyor* (Hannay et al. 2004), as shown in Figure 10, with an overall SL of 184 dB re 1µPa @ 1 m. The offshore supporting vessel *Setouchi Surveyor* is 64.8 m long with an 11.3 m beam, with a propulsion power of 3,400 kW.

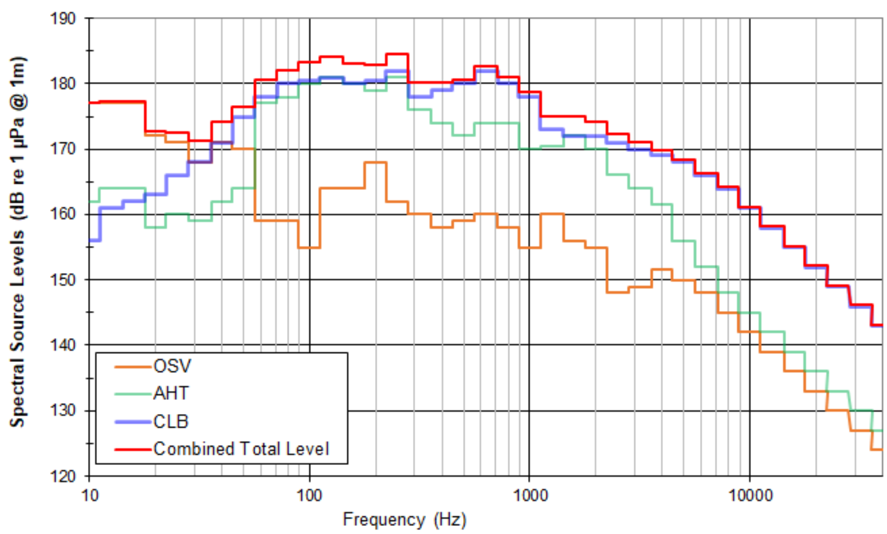
Figure 10 One-third octave band spectral SLs for the OSV *Setouchi Surveyor* (Hannay et al. 2004)



5.1.6 Combined Cable Laying Sources

The overall noise level from combined noise emissions from the CLV, AHT and OSV is approximately 194 dB re 1 µPa @ 1 m (or dB re 1 µPa^2·S @ 1 m). The one-third octave spectral levels for each source and combined total levels are shown in **Figure 11**. For the purposes of the cumulative noise modelling, it was assumed that cable laying activities would be continuous and may occur on a 24-hour schedule.

Figure 11: One-third octave spectral SLs for the combined cable laying sources



5.2 Modelling Methodology and Procedure

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

$$RL = SL - TL \qquad (1)$$

5.2.1 Trench Dredging and Cable Laying

The parabolic equation is range-dependant and accepts variable bathymetry and water/sediment environmental inputs. The PE is suitable for low-frequency problems. The input to the solver is configured so that the sediment layer is extended down to 2 times the depth of the water column, with the attenuation rapidly increasing at the lowest depths. The intention is to remove energy that would be reflected from the very bottom of the sediment layer. The sea surface is a pressure-release interface. As sharp discontinuities in density cause incorrect calculation results, the density is smoothed between water and seabed and between seabed layers by means of a hyperbolic tangent function.

The ray tracer forms a solution by tracing rays from the source out into the sound field. Many rays leave the source covering a range of angles, and the sound level at each point in the receiving field is calculated by combining the components from each ray. It is often useful to set this number very low as a fast initial 'checking' solve before increasing the number of rays and running a full solution which may take some time. The overlying space is modelled as a vacuum. The ray tracer is suitable for high-frequency problems.

When multiple seafloor layers are present, rays are not split and traced into the seafloor. A complex reflection coefficient is calculated, which is representative of the underlying layers, and this coefficient is applied to the ray at the point of seafloor reflection. The reflection coefficient calculation follows Computational Ocean Acoustics, Jensen et al. Springer 2011. The ray tracer is used for time domain calculations. Instead of returning a transmission loss at each point in the slice, a list of ray arrivals is returned (with separate entries for each frequency). These arrivals lists can be used to calculate the effective time series at each point in the slice, which is then used to calculate peak, peak-to-peak, and frequency band SEL levels. These calculation methods are extensively documented in Computational Ocean Acoustics (Jensen et al., Springer, 2011).

Dredging is modelled as a stationary continuous source for a duration of 24 hours. Cable laying and combined sources are modelled as continuous moving sources for 24 hours or 7 km of cable lay.

5.2.2 Sonar Survey

For the purposes of the high-level prediction of SBES, sound propagation is assumed from a stationary single-pulse exposure (i.e., impulsive noise) with spherical spreading loss and a Pk-Pk SPL of 233 dB re 1µPa @ 1 m.

A spreadsheet tool from the National Marine Fisheries Service (NMFS) it was used as means to estimate distances (i.e., isopleths) where PTS thresholds may be exceeded (NMFS 2018). Results provided in this report do not represent the entirety of the comprehensive effects but rather serve as a tool to help evaluate the effects of a proposed action on marine mammal hearing and behavioural response on marine mammals and fish.

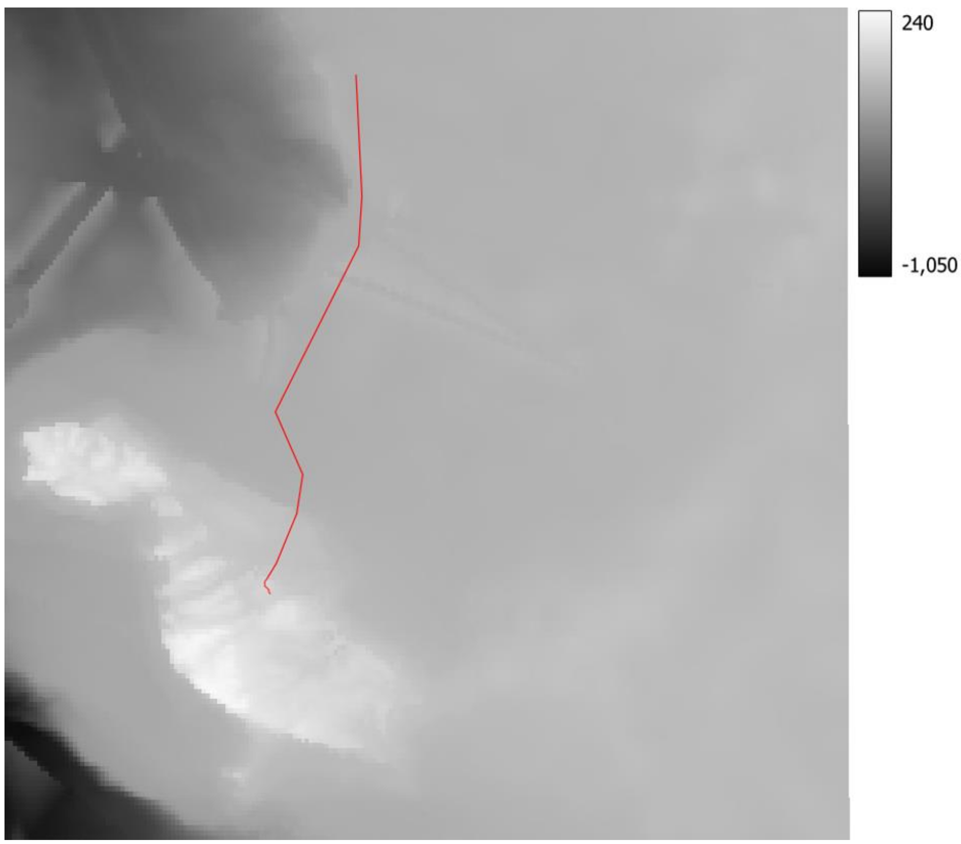
5.3 Modelling Input Parameters

5.3.1 Bathymetry

The bathymetry data used for the sound propagation modelling were obtained from the General Bathymetric Chart of the Oceans (GEBCO) dataset grid (GEBCO 2022). This is the fourth GEBCO grid developed through the Nippon Foundation-GEBCO 'Seabed 2030 Project' (https://seabed2030.org).

The bathymetric imagery within and surrounding the proposed IC2 route is presented in **Figure 12**.

Figure 12: The bathymetric imagery (m) within and surrounding the project area. The coordinate system is based on WGS 84 Zone 5 North. The red line shows the proposed cable lay route.



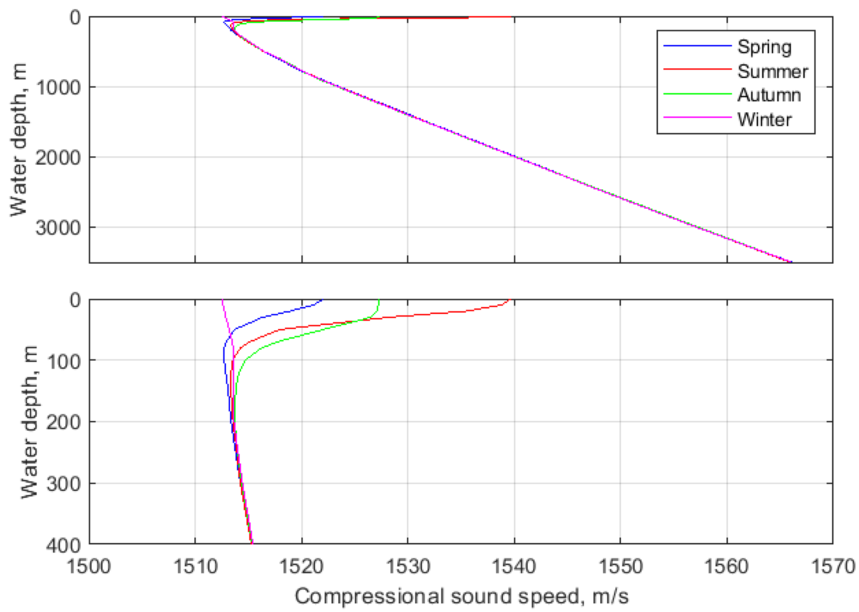
5.3.2 Sound Speed Profile

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

Figure 13 presents the typical sound speed profiles of four seasons around the proposed IC2 route. The figure demonstrates that the most significant distinctions for the profiles of the four seasons occur within the mixed layer near the surface. In the upper layers, propagation is characterized by upward refraction in winter and an acoustic channel in summer. It is also noticed that the sound speed profiles differ from those in temperature zones of the open oceans. This is due to the vertical thermal structure of the Mediterranean Sea, characterized by a reduced or absent permanent thermocline and by warmer deep waters (Salon et al. 2003).

Due to the upward refraction within the profile, the winter season is expected to favour the propagation of sound from a near-surface acoustic source.

Figure 13: Typical sound speed profiles within deep (top) and shallow (bottom) water regions surrounding the proposed gas pipeline route for different northern atmosphere seasons.



5.3.3 Seafloor Geoacoustic Model

The seafloor geoacoustic model for the modelling area is developed based on a habitat mapping study carried out for the continental shelves off Malta's northwest coast and the Maltese Islands' east coasts (Prampolini et al. 2017).

The study reveals that for the coastal areas off Malta's northwest coast and the Maltese Islands' east coasts, the seabed sediments range from sand and rock (moraine) at the nearshore areas to fine to sand clay and fine silty sand at areas further offshore. Therefore, the seafloor geoacoustic model is proposed to be divided into two areas: nearshore and offshore, as detailed in Table 10. The geoacoustic properties of sandy sediments are described in Hamilton (1980) and Jensen et al. (2011). The elastic properties are treated as negligible.

Table 10: Geoacoustic parameters for the proposed seafloor model (Nearshore)

Seafloor Materials	Depth Range, m	Density, ρ, (kg.m^{-3})	Compressional Wave	
			Speed, c_p, (m.s^{-1})	Attenuation, α_p, (dB/λ)
Sand	5	1900	1650	0.8
Rock (Moraine)	∞	2100	1950	0.4

Table 11: Geoacoustic parameters for the proposed seafloor model (Offshore)

Seafloor Materials	Depth Range, m	Density, ρ, (kg.m^{-3})	Compressional Wave	
			Speed, c_p, (m.s^{-1})	Attenuation, α_p, (dB/λ)
Sandy Clay	20	1500	1500	0.2
Silty Fine Sand	∞	1700	1575	1

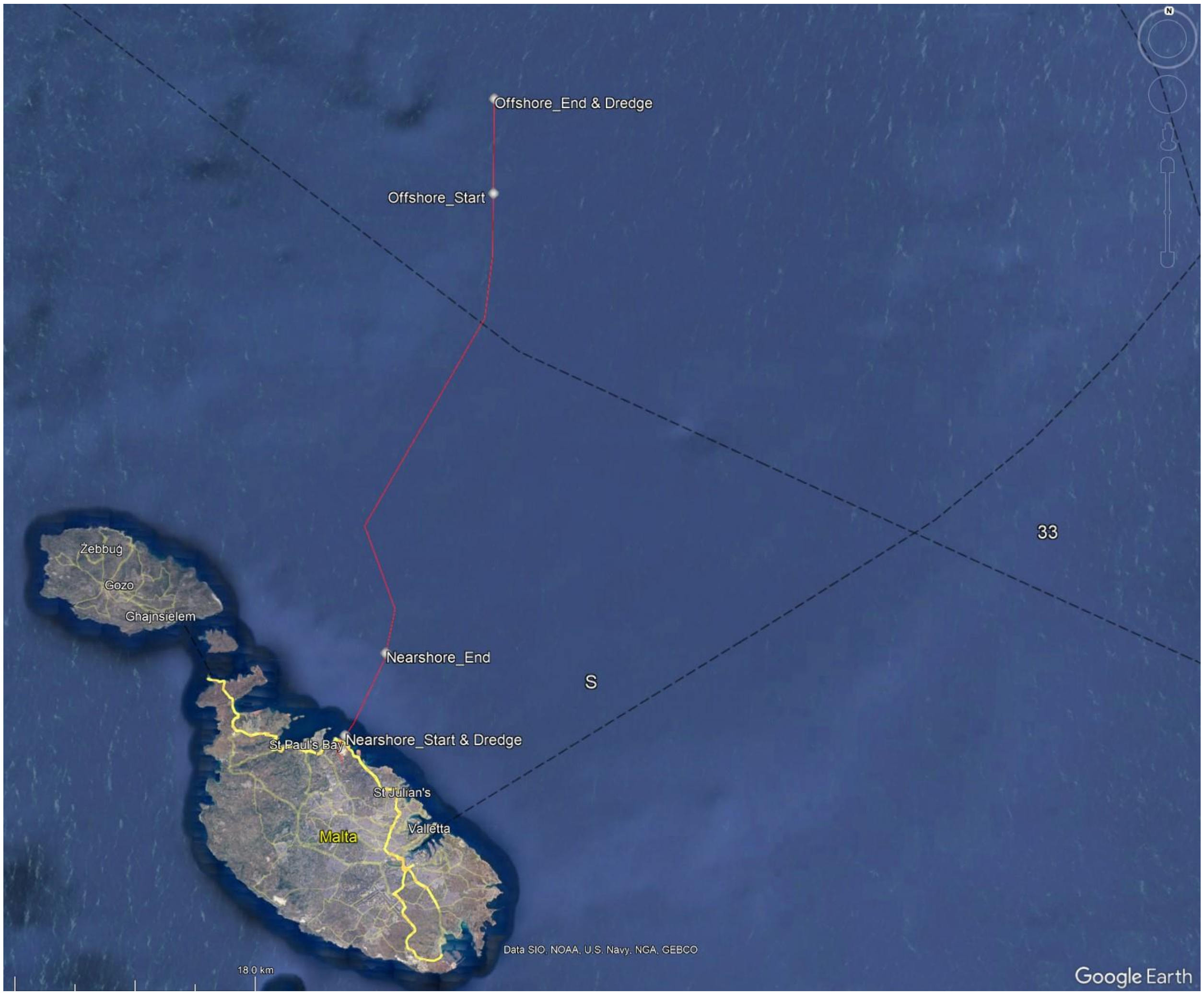
5.4 Modelling Source Locations

Noise modelling locations for the exploration programme are consistent with the proposed operation areas, as indicated in Figure 14, and further detailed in Table 12 below with their corresponding coordinates, water depths and localities.

Table 12: Details of the two selected source locations for noise modelling

Source Location	Water Depth, m	Coordinates [Easting, Northing]	Locality
Nearshore Cable Lay Start & Dredge	20	[449 676, 3 979 214]]	Nearshore, shallow water location
Nearshore Cable Lay End	98	[452 298, 3 985 658]	Nearshore, shallow water location
Offshore Cable Lay Start	152	[458 110, 4 019 219]	Offshore, deep water location
Offshore Cable End & Dredge	155	[457 782, 4 026 249]	Offshore, deep water location

Figure 14: The selected source locations are indicated as white dots. The red line indicates the proposed cable lay route. The cable lay distance between the Nearshore and Offshore start/stop points is 7 km.



6.0 STLM Results and Zones of Impact

The weighted SEL modelling results for different marine mammal hearing groups (**Appendix B**) are based on weighted SEL source level inputs which are derived by applying relevant auditory hearing functions to the unweighted SEL source levels as presented in **Appendix C**.

The modelling noise contour figures for the trench dredging and cable laying activities are presented in **Appendix D**. The contour figures are the modelling results based on unweighted SEL source level inputs in dB re 1 μPa^2·s for non-impulsive noise of 1-second duration as given in **Section 5.1**.

For cumulative SEL estimates of cable laying, and dredging noise, the following cumulative factor (*CF*) is applied:

$$CF = 10 \times \log10\,(T) \qquad (2)$$

Where *T* is the exposure duration for the cable laying and dredging noise sources, respectively.

For non-impulsive noise, the root-mean-square sound pressure levels (RMS SPLs) are equivalent to the sound exposure levels (SELs) of 1-second duration.

The Pk SPL is relevant to the impact assessment for impulsive noise, such as the signal from a stationary single pulse sonar survey.

The predicted noise levels of all considered modelling scenarios were compared with relevant threshold criteria as listed in **Section 4.0**. The zones of different levels of noise impact for marine mammals and fish and sea turtle species were calculated, and all results are presented in **Table 13** to **Table 21**, including:

- Impact zones from an SBES noise source with impulsive noise emissions are shown in **Table 13** regarding the immediate impact on marine mammals. **Table 14** shows the impact zones regarding behavioural disturbance for marine mammals and fish;
- Impact zones from trench dredging activities with non-impulsive noise emissions are shown in **Table 15** and
- **Table** 16 regarding the immediate impact for marine mammals under two continuous exposure scenarios (i.e., 24-hour exposure nearshore and offshore). **Table 17** shows the impact zones regarding behavioural disturbance for fish, marine mammals, and sea turtles; and
- Impact zones from the combined cable laying sources with non-impulsive noise emissions are shown in **Table 18** to **Table 20** regarding cumulative impact for marine mammals and sea turtles under two continuous exposure scenarios (i.e., 24-hour exposure nearshore and offshore), respectively. **Table 21** shows the impact zones regarding behavioural disturbance for marine mammals, fish, and sea turtles.

The estimated impact zones are presented as a single maximum threshold distance to the source and as the ensonified area (km^2) for each source scenario (i.e., nearshore and offshore).

Based on noise modelling prediction results and relevant post-processing analysis as described above, the zones of impact for marine fauna species assessed from all modelling scenarios are detailed in the following sections.

6.1 Zones of Impact – Immediate Exposure from an SBES pulse

6.1.1 Marine Mammals

SBES sources have extremely narrow source directivity along the cross-track direction. Thus, marine mammals are predicted to experience PTS at very close proximity to the sonar sources due to the immediate exposure to individual pulses. Based on zones of impact estimated Pk-SPL metric criteria as provided in Table 13, marine mammals of all hearing groups except very-high-frequency cetaceans are predicted to experience the PTS effect within less than 6 m from the sonar source. The maximum zones of the PTS effect for very-high-frequency cetaceans are predicted to be within 35.5 m from the sonar source.

The zones of TTS due to a single pulse exposure for marine mammals of all hearing groups except very-high-frequency cetaceans are predicted to be within less than 12 m from the sonar source. The maximum zones of the TTS effect for very high-frequency cetaceans are predicted to be within 70.8 m from the sonar source.

Table 13: Zones of immediate impact from a SBES pulse for PTS and TTS - marine mammals

Marine mammal hearing group	Zones of impact – maximum horizontal distances from source to peak impact threshold levels			
	Injury (PTS) onset		TTS onset	
	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m	Criteria - Pk SPL dB re 1µPa	Maximum threshold distance, m
Low-frequency cetaceans (LF)	219	5.0	213	10.0
High-frequency cetaceans (HF)	230	1.4	224	2.8
Very-high-frequency cetaceans (VHF)	202	35.5	196	70.8
Phocid carnivores in water (PCW)	218	5.6	212	11.2
Other marine carnivores in water (OCW)	232	1.1	226	2.2

6.1.2 Fish and Sea Turtles

As stated in Section 0, high-frequency from SBES sources is not expected to cause an adverse hearing impact on fish species due to the low-frequency hearing ranges of these animals. Likewise, since turtles detect sound below 1 kHz, any effect would only be in response to low-frequency sonar. Thus, a PTS/TTS-onset zone in sea turtles is not expected from SBES sources.

6.1.3 Behavioural Responses

The zones of behavioural disturbance for marine mammals caused by the immediate exposure to individual sonar pulses for sonar surveys are presented in Table 14. The modelling results show that the maximum impact distance for the behavioural disturbance caused by the immediate exposure to individual sonar pulses is predicted to reach 4.46 km from the source for marine mammals of all hearing groups.

Table 14: Zones of immediate impact from an SBES pulse for behavioural disturbance – marine mammals

Type of animal	Zones of impact – maximum horizontal distances from the source to impact threshold levels	
	Behavioural disturbance	
	Criteria - RMS SPL, dB re 1µPa	Maximum threshold distance, m
Marine mammals	120	4,460

As stated in Section 0 and Section 0, fish species and sea turtles are not sensitive to high-frequency sonar.

6.2 Zones of Impact - Cumulative Trench Dredging Activities

6.2.1 Marine Mammals

Table 15 and

Table 16 below present the zones of cumulative impact based on cumulative SELs from stationary dredging operation activities with the highest non-impulsive noise emissions (i.e., CSD vessel) for marine mammals.

For the worst-case consideration (i.e., the cutting dredging operations are continuous and affected marine animals stay at the fixed location over the entire 24-hour period), LF cetaceans are the only hearing group with PTS-onset and has the highest TTS-onset impact zones among all marine mammal hearing groups. From Table 15, the PTS-onset zone for LF cetaceans is up to 80 m, and the TTS-onset zone is up to 690 m for the nearshore scenario.

The zones of impact will at least double for the offshore scenario, as shown in

Table 16. For example, the PTS-onset zone is predicted to be within 175 m from the noise source, and the TTS-onset zone is within up to 1,455 m for LF cetaceans. For other cetacean groups, no PTS-onset is predicted, and TTS-onset is predicted to occur only within less than 560 m from the noise source.

6.2.2 Fish and Sea Turtles

As stated in Section 0, non-impulsive noise sources such as dredging (i.e., cutting/trenching) are not expected to cause mortality or potential mortal injury to fish species. There would thus also be no cumulative impact from the non-impulsive dredging noise sources expected on fish species.

Unlike the combined cable lay noise sources, the higher noise emissions from dredging are not sufficient to generate cumulative impact zones for sea turtles based on the cumulative SELs of the two dredging operation scenarios (nearshore/offshore). Therefore, a PTS-onset zone in sea turtles is not expected.

Table 15: Zones of cumulative impact from trench dredging noise for marine mammals –nearshore

Marine mammal hearing group	Zones of impact – maximum horizontal distances from source to cumulative impact threshold levels					
	Injury (PTS) onset			TTS onset		
	Criteria – Weighted SEL_{24hr} dB re 1 μPa²·s	Maximum threshold distance, m	Ensonified Area (m²)	Criteria – Weighted SEL_{24hr} dB re 1 μPa²·s	Maximum threshold distance, m	Ensonified Area (m²)
Low-frequency cetaceans (LF)	**199**	80	30	**179**	690	1,870
High-frequency cetaceans (HF)	**198**	-	-	**178**	-	-
Very-high-frequency cetaceans (VHF)	**173**	-	-	**153**	325	470
Phocid carnivores in water (PCW)	**201**	-	-	**181**	470	1,010
Other marine carnivores in water (OCW)	**219**	-	-	**199**	-	-

Table 16: Zones of cumulative impact from trench dredging noise for marine mammals –offshore

Marine mammal hearing group	Zones of impact – maximum horizontal distances from source to cumulative impact threshold levels					
	Injury (PTS) onset			TTS onset		
	Criteria – Weighted SEL_{24hr} dB re 1 μPa²·s	Maximum threshold distance, m	Ensonified Area (m²)	Criteria – Weighted SEL_{24hr} dB re 1 μPa²·s	Maximum threshold distance, m	Ensonified Area (m²)
Low-frequency cetaceans (LF)	**199**	175	70	**179**	1,455	6,860
High-frequency cetaceans (HF)	**198**	-	-	**178**	-	-
Very-high-frequency cetaceans (VHF)	**173**	-	-	**153**	560	990
Phocid carnivores in water (PCW)	**201**	-	-	**181**	525	770
Other marine carnivores in water (OCW)	**219**	-	-	**199**	-	-

6.2.3 Behavioural Responses

Table 17 below presents the distances to potential behavioural disturbance from the non-impulsive noise emissions from dredging activities for marine mammals, fish, and sea turtles. The predicted zones of impact to occur for marine mammals of all hearing groups are up to 82.91 km from the assessed nearshore scenario and up to 28.11 km from the assessed offshore scenario.

For fish species, the predicted maximum zones of immediate impact from non-impulsive dredging noise emissions are expected to occur within 1.87 km and 1.45 km from the noise source, respectively, for the nearshore and offshore scenarios.

The potential behavioural disturbance from the non-impulsive dredging activities for sea turtles is predicted to occur within less than 10 m from both assessed scenarios.

Table 17: Zones of immediate impact from trench dredging noise for behavioural disturbance – marine mammals, fish, and sea turtles

Type of animal	Zones of impact – maximum horizontal distances from the source to impact threshold levels		
	Behavioural disturbance		
	Criteria - RMS SPL, dB re 1µPa	nearshore	offshore
		Maximum threshold distance, m	Maximum threshold distance, m
Marine mammals	120	82,910	28,110
Fish	150	1,870	1,450
Sea Turtles	175	<10	<10

6.3 Zones of Impact - Cumulative Combined Cable Laying Sources

6.3.1 Marine Mammals

Table 18 and

Table 19 below present the zones of cumulative impact based on cumulative SELs from the combined cable laying sources with the highest non-impulsive noise emissions (i.e., cable laying barge, anchor handling tug and offshore supporting vessel) for marine mammals.

For the worst-case consideration (i.e., the cable laying operations are continuous and affected marine animals stay at the fixed location over the entire 24-hour period), LF cetaceans and PCW have the highest PTS-onset and TTS-onset impact zones among all marine mammal hearing groups. From Table 18, the PTS-onset zone for LF cetaceans and PCW is up to 775 m and 380 m, and the TTS-onset zones are up to 2.35 km and 2 km, respectively.

In the offshore scenario, the zones of impact will increase significantly, especially for the LF cetaceans, as shown in

Table 19. For example, the PTS-onset zone is predicted to be within 1.63 km from the noise source, and the TTS-onset zone is within 12.23 km for LF cetaceans. For other cetacean groups, no PTS-onset is predicted, and TTS-onset is predicted to occur only within less than 2 km from the noise source. For the PCW, the TTS-onset zone will double up to 4.19 km.

Table 18: Zones of cumulative impact from cable laying noise for marine mammals –nearshore

Marine mammal hearing group	Zones of impact – maximum horizontal distances from source to cumulative impact threshold levels					
	Injury (PTS) onset			TTS onset		
	Criteria – Weighted SEL_{24hr} dB re 1 µPa²·s	Maximum threshold distance, m	Ensonified Area (m²)	Criteria – Weighted SEL_{24hr} dB re 1 µPa²·s	Maximum threshold distance, m	Ensonified Area (m²)
Low-frequency cetaceans (LF)	**199**	775	13,510	**179**	2,350	28,480
High-frequency cetaceans (HF)	**198**	-	-	**178**	360	3,140
Very-high-frequency cetaceans (VHF)	**173**	<10	<40	**153**	615	6,890
Phocid carnivores in water (PCW)	**201**	380	5,050	**181**	2,000	23,690
Other marine carnivores in water (OCW)	**219**	-	-	**199**	610	6,760

Table 19: Zones of cumulative impact from cable laying noise for marine mammals –offshore

Marine mammal hearing group	Zones of impact – maximum horizontal distances from source to cumulative impact threshold levels					
	Injury (PTS) onset			TTS onset		
	Criteria – Weighted SEL_{24hr} dB re 1 µPa²·s	Maximum threshold distance, m	Ensonified Area (m²)	Criteria – Weighted SEL_{24hr} dB re 1 µPa²·s	Maximum threshold distance, m	Ensonified Area (m²)
Low-frequency cetaceans (LF)	**199**	1,630	25,110	**179**	12,230	241,560
High-frequency cetaceans (HF)	**198**	-	-	**178**	125	1,290
Very-high-frequency cetaceans (VHF)	**173**	-	-	**153**	1,930	31,420
Phocid carnivores in water (PCW)	**201**	55	790	**181**	4,190	52,970
Other marine carnivores in water (OCW)	**219**	-	-	**199**	155	2,180

6.3.2 Fish and Sea Turtles

As stated in Section 0, non-impulsive noise sources, such as those from cable laying, are not expected to cause mortality or potential mortal injury to fish species. Thus, there would be no cumulative impact from the non-impulsive cable lying noise sources expected on fish species.

Table 20 below presents the zones of cumulative impact for sea turtles based on cumulative SELs from two cable laying operation scenarios (nearshore and offshore) with the combined non-impulsive noise emissions. The PTS-onset zone for the nearshore scenario is within 120 m distance from the source location and 40 m for the offshore scenario.

Table 20: Zones of cumulative impact from cable laying noise for sea turtles –nearshore & offshore

Type of animal	Zones of impact – maximum horizontal distances from the source to cumulative impact threshold levels				
	Injury (PTS) onset				
	Criteria – Weighted SEL_{24hr} dB re 1 μPa²·s	nearshore		offshore	
		Maximum threshold distance, m	Ensonified Area (m²)	Maximum threshold distance, m	Ensonified Area (m²)
Sea turtles	**220**	120	840	40	530

6.3.3 Behavioural Responses

Table 21 below presents the distances to potential behavioural disturbance from the non-impulsive noise emissions from cable laying operations for marine mammals, fish, and sea turtles. The predicted zones of impact to occur for marine mammals of all hearing groups are up to 102.8 km from the assessed nearshore scenario and up to 30.1 km from the assessed offshore scenario.

For fish species, the predicted maximum zones of immediate impact from non-impulsive combined cable laying noise emissions are expected to occur within 5.1 km and 2.8 km distance from the noise source, respectively, for the nearshore and offshore scenarios.

The potential behavioural disturbance from the non-impulsive cable laying operations for sea turtles is predicted to occur up to 180 m from both assessed scenarios.

Table 21: Zones of immediate impact from cable laying noise for behavioural disturbance –marine mammals, fish, and sea turtles

Type of animal	Zones of impact – maximum horizontal distances from the source to impact threshold levels		
	Behavioural disturbance		
	Criteria - RMS SPL, dB re 1μPa	nearshore	offshore
		Maximum threshold distance, m	Maximum threshold distance, m
Marine mammals	**120**	102,800	30,100
Fish	**150**	5,110	2,800
Sea Turtles	**175**	180	160

7.0 Discussion and Summary

As detailed in **Section 4.0**, dual metric criteria (i.e., per-pulse impact criteria Pk SPL and cumulative exposure impact criteria SEL_{24hr}) are applied to assess PTS and TTS impact for marine mammals and sea turtles. The metric criteria of RMS SPL are applied to assess the behavioural response of marine mammals, fish, and sea turtles. The combined threshold distance for each impact effect is considered as the maximum threshold distance (i.e., the worst-case scenario) estimated from either metric criterion being applied.

The estimated maximum zones of impact for all operational activities (e.g., sonar survey, trench dredging and combined cable laying) are summarised in Table 22 below, based on the STLM results, prediction sheet and the zones of impact estimated as detailed in the above sub-sections within Section 0.

Table 22: Summary of the maximum zones of impact for marine mammals, fish, and sea turtles

Type of Animal	Operational Activities & Scenarios		Maximum threshold distances, m		
			Cumulative impact		Immediate Impact
			PTS onset	TTS onset	Behavioural disturbance
Marine mammals	SBES Sonar	Nearshore	35	70	4,460
		Offshore			
	Trench Dredging	Nearshore	80	690	82,910
		Offshore	175	1,455	28,110
	Cable Laying	Nearshore	775	2,350	102,800
		Offshore	1,630	12,230	30,100
Fish	Trench Dredging	Nearshore	-	-	1,870
		Offshore			1,450
	Cable Laying	Nearshore	-	-	5,110
		Offshore			2,800
Sea Turtles	Trench Dredging	Nearshore	-	-	<10
		Offshore			<10
	Cable Laying	Nearshore	120	-	180
		Offshore	40	-	160
Note: A dash indicates the threshold is not applicable.					

For general marine mammal species, low physiological impact, particularly the PTS impact, is predicted from impulsive sonar survey for the nearshore and offshore scenarios. The only marine mammal hearing group with a higher impact is the VHF cetaceans due to their higher hearing sensitivity to high frequencies. Those animals' behavioural responses could reach up to some kilometers from the noise source. SBES sources are not expected to cause an adverse hearing impact on fish species and sea turtles due to the low-frequency hearing ranges of these animals.

For all non-impulsive activities (e.g., cable laying and trench dredging), the cumulative exposure level at both scenarios was modelled based on the assumption that the marine animals are constantly exposed to the source at a fixed location over the entire operational period (up to 24 hours for continuous non-impulsive noise). However, marine fauna species, such as marine mammals and sea turtles, would not (under realistic circumstances) stay in the same location for the entire period unless the individual animals were attached to a specific feeding/breeding area. Therefore, the zones of impact assessed for marine mammals and sea turtles represent the worst-case consideration.

Among all identified non-impulsive noise emissions during the construction and operation of the IC2 development, the combined cable-lay vessel sources are predicted to have the highest noise impact (PTS and TTS), particularly for low-frequency cetaceans.

For general fish species, mortality or potential mortal injury is not expected to occur from non-impulsive noise emissions associated with operational activities. Therefore, the overall adverse impact on fish species relates to behavioural disturbance only. For Sea turtles, low physiological impact (only PTS) is predicted to occur at close distances from the noise source.

It should be noted that this modelling study is undertaken without detailed specifications of relevant equipment to be used for major noise-generating activities assessed. It is therefore recommended that detailed specifications be reviewed for major noise-generating equipment to be used once they are available. In addition, characterization of the source noise emissions and noise model validations via field measurements are also recommended for consideration.

A summary of residual effects due to anthropogenic activities is shown below in **Table 23**.

Table 23: Summary of residual effects due to anthropogenic activities

Impact Type and Source			Impact Receptor		Effect & Scale							Probability of Impact Occurring (Inevitable, Likely, Unlikely, Remote, Uncertain)	Overall Impact Significance	Proposed Mitigation Measures	Residual Impact Significance	Other Requirements (monitoring, authorisations, etc.)
Specific Intervention Leading to Impact	**Project Phase** (Construction / Operation / Decommissioning)	**Impact Type**	**Receptor Type**	**Sensitivity Toward Impact**	**Direct / Indirect / Cumulative**	**Beneficial / Adverse**	**Severity**	**Physical / Geographic Extent of Impact**	**Short- / Medium- / Long-Term**	**Temporary** (indicate duration) / **Permanent**	**Reversible** (indicate ease of reversibility) / **Irreversible**					
Immediate exposure from an SBES pulse	Construction	Injury PTS onset	Marine mammals	High	Direct	Adverse	High	Local	Short	Temporary	Irreversible	Remote	Slight	NA	NA	NA
		TTS onset		Mild			Mild				Reversible	Likely	Slight/Moderate		Minimum and for a short time	
		Behavioural response		Slight			Slight	Maximum zone of 4.4 km				Likely				
Cumulative trench dredging activities	Construction	Injury PTS onset	Marine mammals	High	Cumulative	Adverse	High	Local	Short	Temporary	Irreversible	Unlikely	Moderate	NA	NA	NA
		TTS onset		Mild			Mild				Reversible	Likely			Minimum and for a short time	
		Behavioural response		Slight	Direct		Slight	Maximum zone of 28.1 km				Likely	Slight/Moderate			
		Behavioural response	Fish	Mild			Mild	Maximum zone of 1.4 km				Likely				
		Behavioural response	Sea Turtles	Slight			Almost null	Less than 10 m				Remote	Slight			
Cumulative combined cable laying sources	Construction	Injury PTS onset	Marine mammals	High	Cumulative	Adverse	High	Local	Short	Temporary	Irreversible	Unlikely	Moderate	NA	NA	NA
		TTS onset		Mild			Mild				Reversible	Likely			Minimum and for a short time	
		Behavioural response		Slight	Direct		Slight	Maximum zone of 30.1 km				Likely	Slight/Moderate			
		Behavioural response	Fish	Mild			Mild	Maximum zone of 2.8 km				Likely				
		Injury PTS onset	Sea Turtles	High			High	Local				Unlikely	Moderate		NA	
		Behavioural response		Slight			Slight	Maximum zone of 160 m				Likely	Slight		Minimum and for a short time	

Dual metric criteria (i.e., per-pulse impact criteria Pk SPL and cumulative exposure impact criteria SEL_{24hr}) are applied to assess PTS and TTS impact for marine mammals and sea turtles. The metric criteria of RMS SPL are applied to assess the behavioural response of marine mammals, fish, and sea turtles. For all non-impulsive activities (e.g., cable laying and trench dredging), the cumulative exposure level at both scenarios was modelled based on the assumption that the marine animals are constantly exposed to the source at a fixed location over the entire operational period (up to 24 hours for continuous non-impulsive noise). However, marine fauna species, such as marine mammals and sea turtles, would not (under realistic circumstances) stay in the same location for the entire period unless the individual animals were attached to a specific feeding/breeding area. Therefore, the zones of impact assessed for marine mammals and sea turtles represent the worst-case consideration.

8.0 Statement of Limitations

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Appendix A Acoustic Terminology

Underwater Sound Transmission Loss Modelling Study

Malta-Italy Second Electrical Interconnector

AIS Environment

SLR Project No. 201.099039.00001

April 6, 2023

Acoustic Terminology

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

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Appendix B Marine Mammal Hearing Classification

Underwater Sound Transmission Loss Modelling Study

Malta-Italy Second Electrical Interconnector

AIS Environment

SLR Project No. 201.099039.00001

April 6, 2023

Marine Mammal Hearing Classification

The following appendix gives a summary of marine mammal hearing group classification and sea turtles. Not all animals listed in **Table B.1** are expected to be found in the vicinity of the project area.

Table B.1: Summary of marine mammal classification

Hearing Classification	Common Name	Scientific Name
Low frequency cetaceans (extracted from Appendix 1 Southall et al. (2019))	Bowhead whale	*Balaena mysticetus*
	Southern right whale	*Eubalaena australias*
	North Atlantic right whale	*Eubalaena glacialis*
	North Pacific right whale	*Eubalaena japonica*
	Common minke whale	*Balaenoptera acutorostrata*
	Antarctic minke whale	*Balaenoptera bonaerensis*
	Sei whale	*Balaenoptera borealis*
	Bryde's whale	*Balaenoptera edeni*
	Omura's whale	*Balaenoptera omurai*
	Fin whale	*Balaenoptera physalus*
	Humpback whale	*Megaptera novaeangliae*
	Pygmy right whale	*Caperea marginate*
	Gray whale	*Eschrichtius robustus*
High frequency cetaceans (extracted from Appendix 2 Southall et al. (2019))	Sperm whale	*Physeter macrocephalus*
	Arnoux' beaked whale	*Berardius arnuxii*
	Baird's beaked whale	*Berardius bairdii*
	Northern bottlenose whale	*Hyperoodon ampullatus*
	Southern bottlenose whale	*Hyperoodon planifrons*
	Tropical bottlenose whale	*Indopacetus pacificus*
	Sowerby's beaked whale	*Mesoplodon bidens*
	Andrews' beaked whale	*Mesoplodon bowdoini*
	Hubb's beaked whale	*Mesoplodon carlbubbsi*
	Blainville's beaked whale	*Mesoplodon densirostris*
	Gervais' beaked whale	*Mesoplodon europaeus*
	Ginkgo-toothed beaked whale	*Mesoplodon ginkgodens*
	Gray's beaked whale	*Mesoplodon grayi*

Hearing Classification	Common Name	Scientific Name
	Hector's beaked whale	*Mesoplodon hectori*
	Deraniyagala's beaked whale	*Mesoplodon hotaula*
	Layard's beaked whale	*Mesoplodon layardii*
	True's beaked whale	*Mesoplodon mirus*
	Perrin's beaked whale	*Mesoplodon perrini*
	Pygmy beaked whale	*Mesoplodon peruvianus*
	Stejneger's beaked whale	*Mesoplodon stejnegeri*
	Spade-toothed whale	*Mesoplodon traversii*
	Tasman beaked whale	*Tasmacetus shepherdi*
	Cuvier's beaked whale	*Ziphius cavirostris*
	Killer whale	*Orcinus orca*
	Beluga	*Delphinapterus leucas*
	Narwhal	*Monodon monoceros*
	Short- and long-beaked common dolphins	*Delphinus delphis*
	Pygmy killer whale	*Feresa attenuata*
	Short-finned pilot whale	*Globicephala macrorhynchus*
	Long-finned pilot whale	*Globicephala melas*
	Risso's dolphin	*Grampus griseus*
	Fraser's dolphin	*Lagenodelphis hosei*
	Atlantic white-sided dolphin	*Lagenorhynchus acutus*
	White-beaked dolphin	*Lagenorhynchus albirostris*
	Pacific white-sided dolphin	*Lagenorhynchus obliquidens*
	Dusky dolphin	*Lagenorhynchus obscurus*
	Northern right whale dolphin	*Lissodelphis borealis*
	Southern right whale dolphin	*Lissodelphis peronii*
	Irrawaddy dolphin	*Orcaella brevirostris*
	Australian snubfin dolphin	*Orcaella heinsohni*
	Melon-headed whale	*Peponocephala electra*
	False killer whale	*Pseudorca crassidens*
	Indo-Pacific humpback dolphin	*Sousa chinensis*
	Indian Ocean humpback dolphin	*Sousa plumbea*

Hearing Classification	Common Name	Scientific Name
	Australian humpback dolphin	*Sousa sahulensis*
	Atlantic humpback dolphin	*Sousa teuszii*
	Tucuxi	*Sotalia fluviatilis*
	Guiana dolphin	*Sotalia guianensis*
	Pantropical spotted dolphin	*Stenella attenuata*
	Clymene dolphin	*Stenella clymene*
	Striped dolphin	*Stenella coeruleoalba*
	Atlantic spotted dolphin	*Stenella frontalis*
	Spinner dolphin	*Stenella longirostris*
	Rough-toothed dolphin	*Steno bredanensis*
	Indo-Pacific bottlenose dolphin	*Tursiops aduncus*
	Common bottlenose dolphin	*Tursiops truncatus*
	South Asian river dolphin	*Platanista gangetica*
Very high frequency cetaceans (extracted from Appendix 3 Southall et al. (2019))	Peale's dolphin	*Lagenorhynchus australis*
	Hourglass dolphin	*Lagenorhynchus cruciger*
	Commerson's dolphin	*Cephalorhynchus commersonii*
	Chilean dolphin	*Cephalorhynchus eutropia*
	Heaviside's dolphin	*Cephalorhynchus heavisidii*
	Hector's dolphin	*Cephalorhynchus hectori*
	Narrow-ridged finless porpoise	*Neophocaena asiaeorientalis*
	Indo-Pacific finless porpoise	*Neophocaena phocaenoides*
	Spectacled porpoise	*Phocoena dioptrica*
	Harbor porpoise	*Phocoena phocoena*
	Vaquita	*Phocoena sinus*
	Burmeister's porpoise	*Phocoena spinipinnis*
	Dall's porpoise	*Phocoenoides dalli*
	Amazon river dolphin	*Inia geoffrensis*
	Yangtze river dolphin	*Lipotes vexillifer*
	Franciscana	*Pontoporia blainvillei*
	Pygmy sperm whale	*Kogia breviceps*
	Dwarf sperm whale	*Kogia sima*

Hearing Classification	Common Name	Scientific Name
Sirenians (extracted from Appendix 4 Southall et al. (2019))	Amazonian manatee	*Trichechus inunguis*
	West Indian manatee	*Trichechus manatus*
	West African manatee	*Trichechus senegalensis*
	Dugong	*Dugong dugon*
Phocid carnivores (extracted from Appendix 5 Southall et al. (2019))	West Indian manatee	*Trichechus manatus*
	West African manatee	*Trichechus senegalensis*
	Dugong	*Dugong dugon*
	Ribbon seal	*Histriophoca fasciata*
	Leopard seal	*Hydrurga leptonyx*
	Weddell seal	*Leptonychotes weddellii*
	Crabeater seal	*Lobodon carcinophaga*
	Northern elephant seal	*Mirounga angustirostris*
	Southern elephant seal	*Mirounga leonina*
	Mediterranean monk seal	*Monachus monachus*
	Hawaiian monk seal	*Neomonachus schauinslandi*
	Ross seal	*Ommatophoca rossii*
	Harp seal	*Pagophilus groenlandicus*
	Spotted seal	*Phoca largha*
	Harbor seal	*Phoca vitulina*
	Caspian seal	*Pusa caspica*
	Ringed seal	*Pusa hispida*
	Baikal seal	*Pusa sibirica*

Hearing Classification	Common Name	Scientific Name
Other marine carnivores (extracted from Appendix 6 Southall et al. (2019))	Walrus	*Odobenus rosmarus*
	South American fur seal	*Arctocephalus australis*
	New Zealand fur seal	*Arctocephalus forsteri*
	Galapagos fur seal	*Arctocephalus galapagoensis*
	Antarctic fur seal	*Arctocephalus gazella*
	Juan Fernandez fur seal	*Arctocephalus philippii*
	Cape fur seal	*Arctocephalus pusillus*
	Subantarctic fur seal	*Arctocephalus tropicalis*
	Northern fur seal	*Callorhinus ursinus*
	Steller sea lion	*Eumetopias jubatus*
	Australian sea lion	*Neophoca cinerea*
	South American sea lion	*Otaria byronia*
	Hooker's sea lion	*Phocarctos hookeri*
	California sea lion	*Zalophus californianus*
	Galapagos sea lion	*Zalophus wollebaeki*
	Polar bear	*Ursus maritimus*
	Sea otter	*Enhydra lutris*
	Marine otter	*Lontra feline*
Sea Turtles (extracted from Finneran et al. 2017)	Green sea turtle	*Chelonia mydas*
	Kemp's ridley sea turtle	*Lepidochelys kempii*
	Loggerhead sea turtle	*Caretta*
	Leatherback sea turtle	*Dermochelys coriacea*
	Hawksbill sea turtle	*Eretmochelys imbricata*

Appendix C Auditory Weighting Functions

Underwater Sound Transmission Loss Modelling Study

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Auditory Weighting Functions

This appendix provides the recommended frequency-weighting functions for use in assessing the effects of relatively intense sounds on hearing. This information is derived based on all available relevant data and published literature (i.e., the state of current knowledge).

Marine animals do not hear equally well at all frequencies within their functional hearing range. Based on the hearing range and sensitivities, Southall et al. (2019) have categorised marine mammal species (i.e., cetaceans and pinnipeds) into six underwater hearing groups: low-frequency (LF), high-frequency (HF), very high-frequency (VHF) cetaceans, Sirenians (SI), Phocid carnivores in water (PCW) and Other marine carnivores in water (OCW). For each specific marine mammal species, refer to **Error! Reference source not found.** of this document for their corresponding hearing groups.

The potential noise effects on animals depend on how well the animals can hear the noise. Frequency weighting is a method of quantitatively compensating for the differential frequency response of sensory systems (Southall et al. 2019).

When developing updated scientific recommendations in marine mammal noise exposure criteria, Southall et al. (2019) adopted the auditory weighting functions as expressed in the equation below, which are based on the quantitative method by Finneran (2016) and are consistent with the U.S. National Oceanic and Atmospheric Administration (NOAA) technical guidance (NMFS 2016, 2018). Finneran et al. (2017) revised the auditory-weighting functions for sea turtle (TU). Audiogram slopes were calculated across a frequency range of one octave for five sea turtle species (refer to **Appendix B**) with composite audiograms based on experimental data.

$$W(f) = C + 10log10\left\{\frac{(f/f_1)^{2a}}{[1+(f/f_1)^2]^a[1+(f/f_2)^2]^b}\right\} \qquad (C.1)$$

Where:

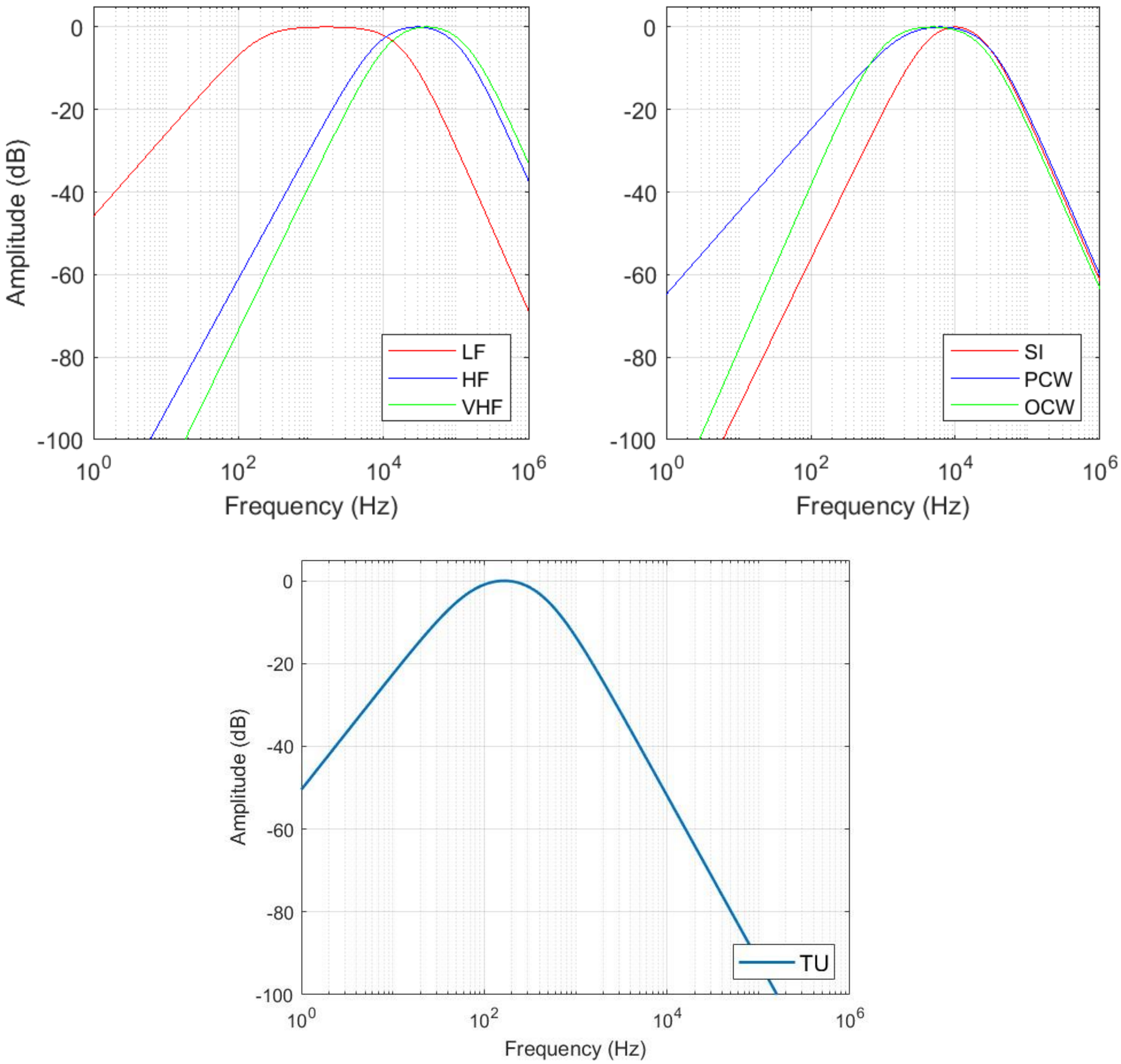
- ***W(f)*** is the weighting function amplitude (in dB) at frequency f (in kHz).
- f_1 represents LF transition value (in kHz), i.e., the lower frequency at which the function amplitude begins to change from the flat, central portion of the curve.
- f_2 represents HF transition value (in kHz), i.e., the upper frequency at which the function amplitude begins to change from the flat, central portion of the curve.
- a represents the LF exponent value (dimensionless) which defines the rate of decline of the weighting function amplitude at low frequencies. The change in weighting function amplitude with frequency at low frequencies (the LF slope) is 20a dB/decade.
- b represents the HF exponent value (dimensionless) which defines the rate of decline of weighting function amplitude at high frequencies, becoming linear with the logarithm of frequency. The change in weighting function amplitude with frequency at high frequencies (the HF slope) is -20b dB/decade.
- C is the constant that defines the vertical position of the curve. It is defined so that the maximum amplitude of the weighting function equals 0 dB (with all other values being negative).

Table C.1 lists the auditory weighting parameters as defined above for the seven hearing groups. The corresponding auditory weighting functions for all hearing groups are presented in **Figure C.1.**

Table C.1: Auditory weighting functions - parameters (Southall et al. 2019; Finneran et al. 2017)

Marine mammal hearing group	*a*	*b*	*f1 (kHz)*	*f2 (kHz)*	*C (dB)*
Low-frequency cetaceans (LF)	1.0	2	0.20	19	0.13
High-frequency cetaceans (HF)	1.6	2	8.8	110	1.20
Very-high-frequency cetaceans (VHF)	1.8	2	12	140	1.36
Sirenians (SI)	1.8	2	4.3	25	2.62
Phocid carnivores in water (PCW)	1.0	2	1.9	30	0.75
Other marine carnivores in water (OCW)	2.0	2	0.94	25	0.64
Sea turtles (TU)	1.4	2	0.077	0.44	2.35

Figure C.1: Auditory weighting functions – spectral plots (Southall et al. 2019; Finneran et al. 2017)



Appendix D Noise Modelling Contour Figures

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Figure D.1: Modelled nearshore maximum SEL24hr (maximum level across water column) contours for combined continuous sources from cable laying operation.

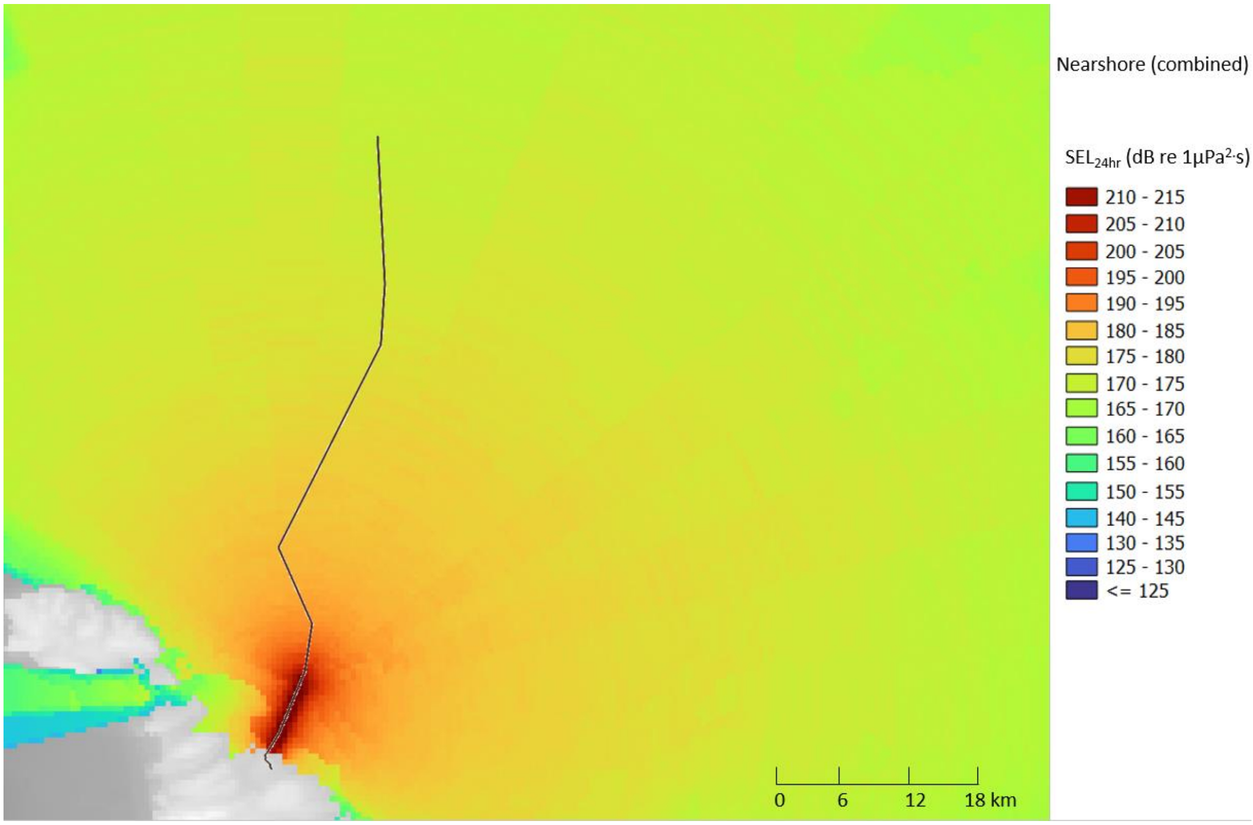

Figure D.2: Modelled offshore maximum SEL24hr (maximum level across water column) contours for combined continuous sources from cable laying operation.

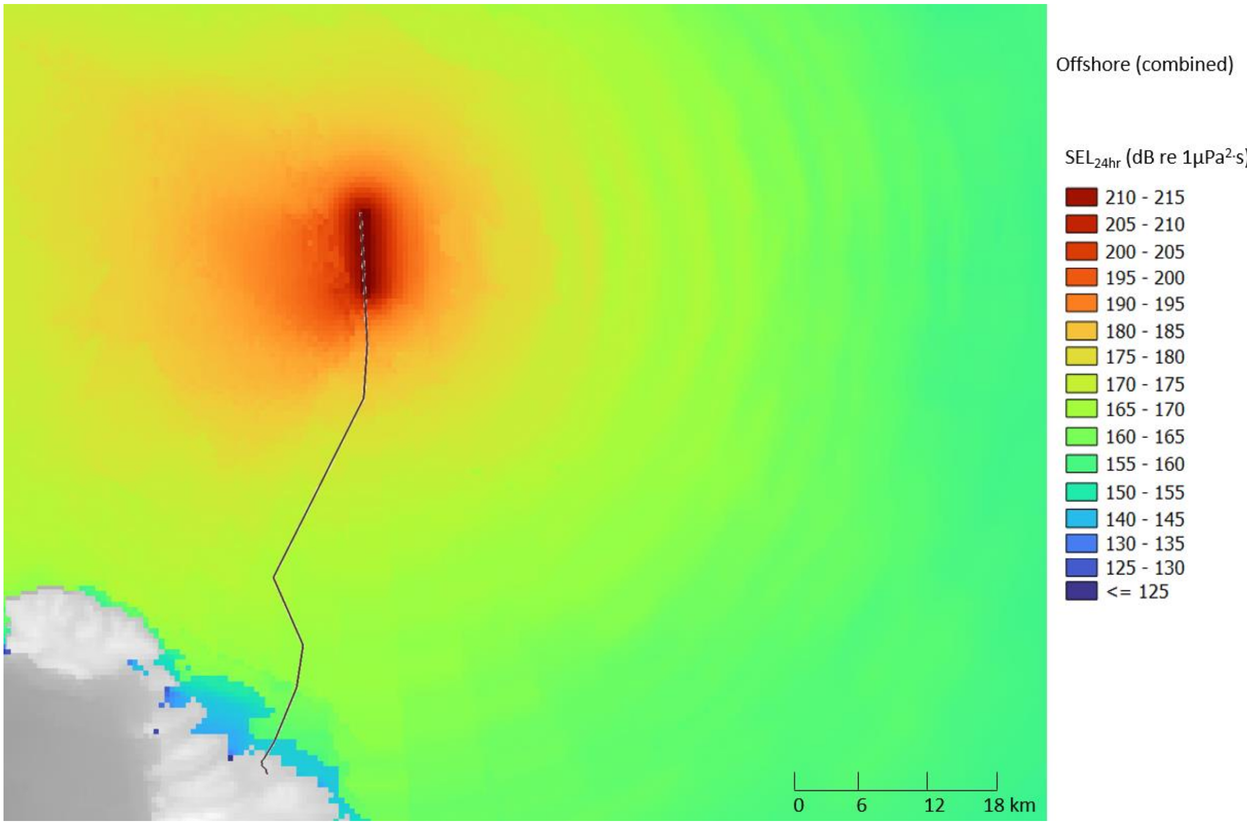

Figure D.3: Modelled nearshore maximum SEL24hr (maximum level across water column) contours for Cable Laying Vessel (CLV).

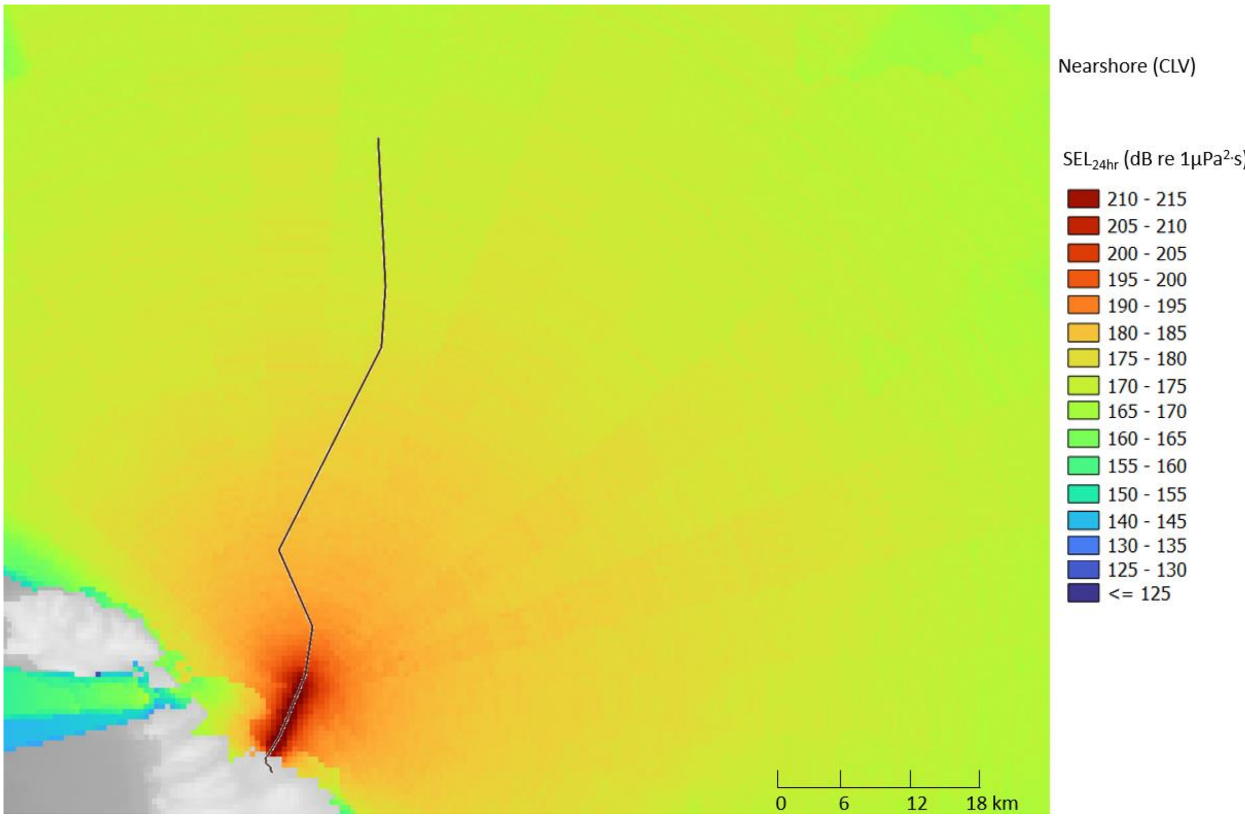

Figure D.4: Modelled offshore maximum SEL24hr (maximum level across water column) contours for Cable Laying Vessel (CLV).

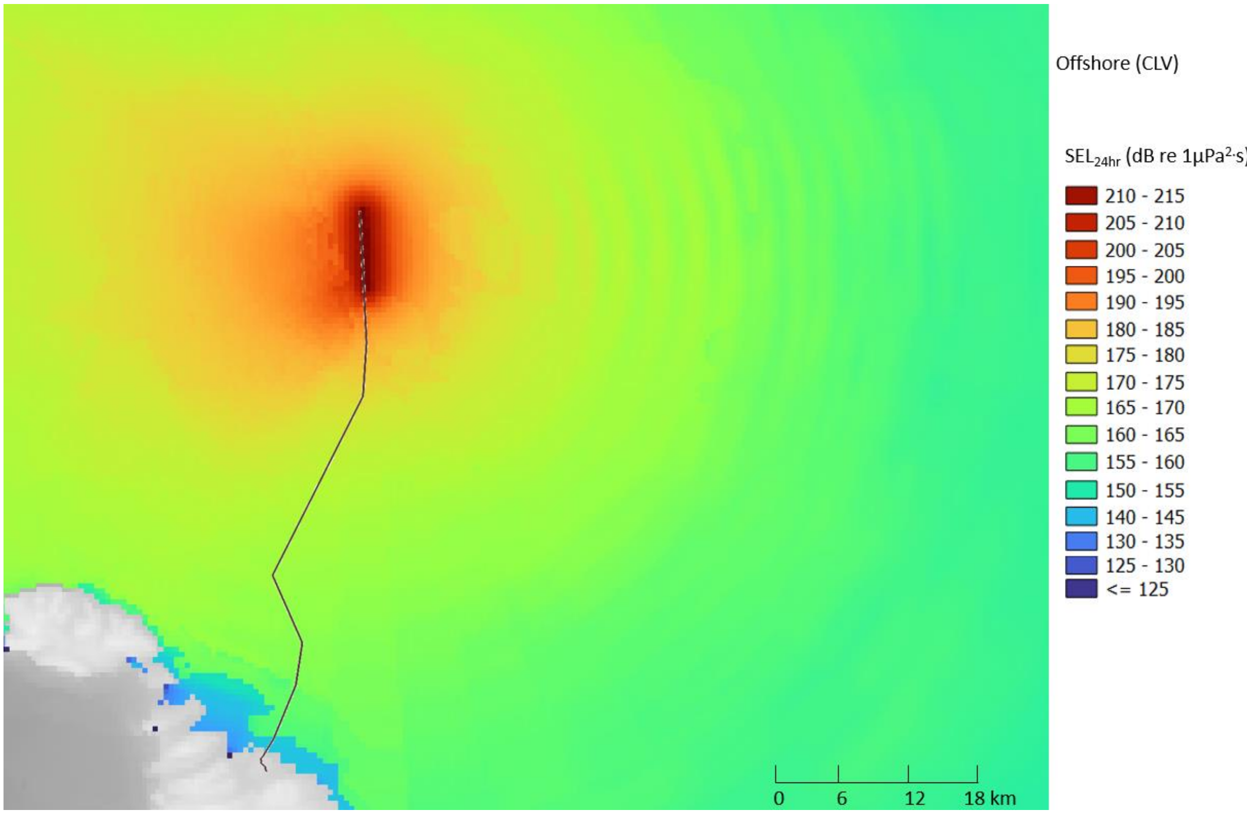

Figure D.5: Modelled nearshore maximum SEL24hr (maximum level across water column) contours for Offshore Support Vessel (OSV).

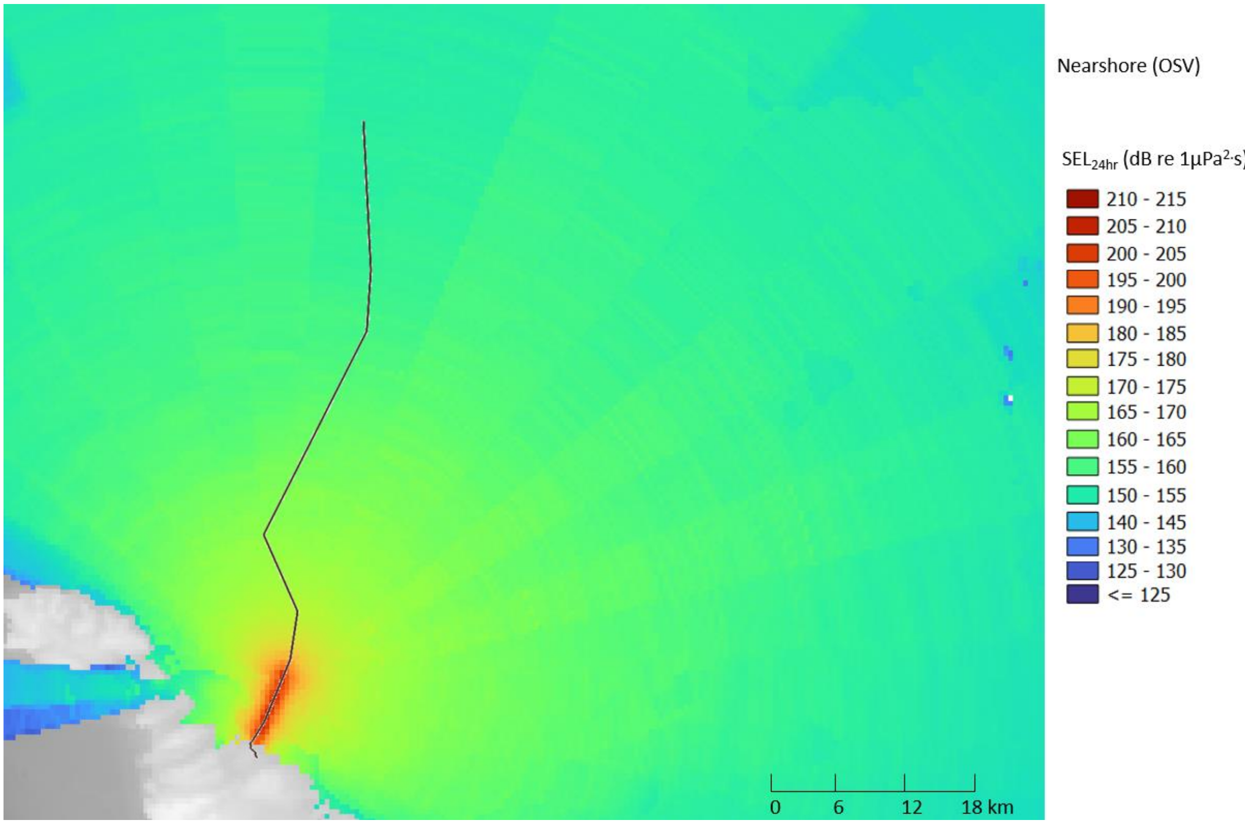

Figure D.6: Modelled offshore maximum SEL24hr (maximum level across water column) contours for Offshore Support Vessel (OSV).

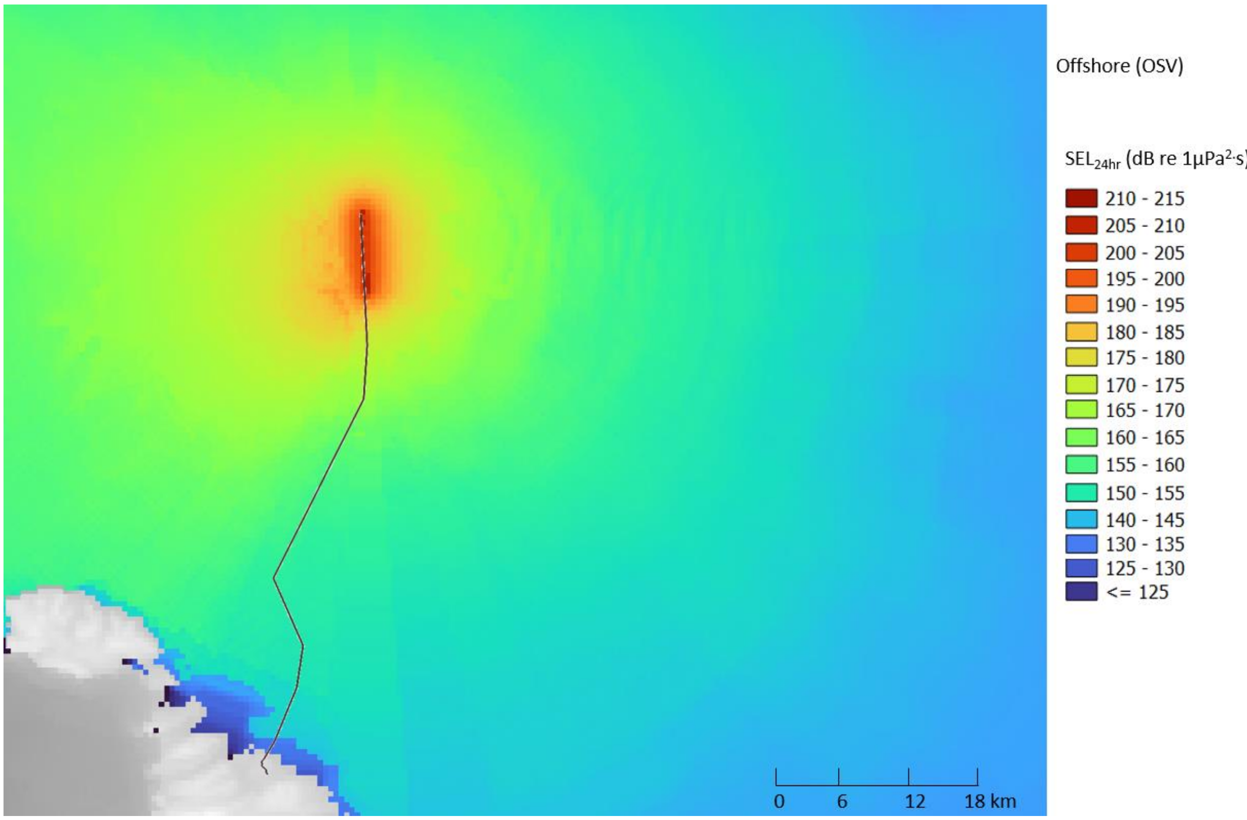

Figure D.7: Modelled nearshore maximum SEL24hr (maximum level across water column) contours for Anchor Handling Tug (AHT).

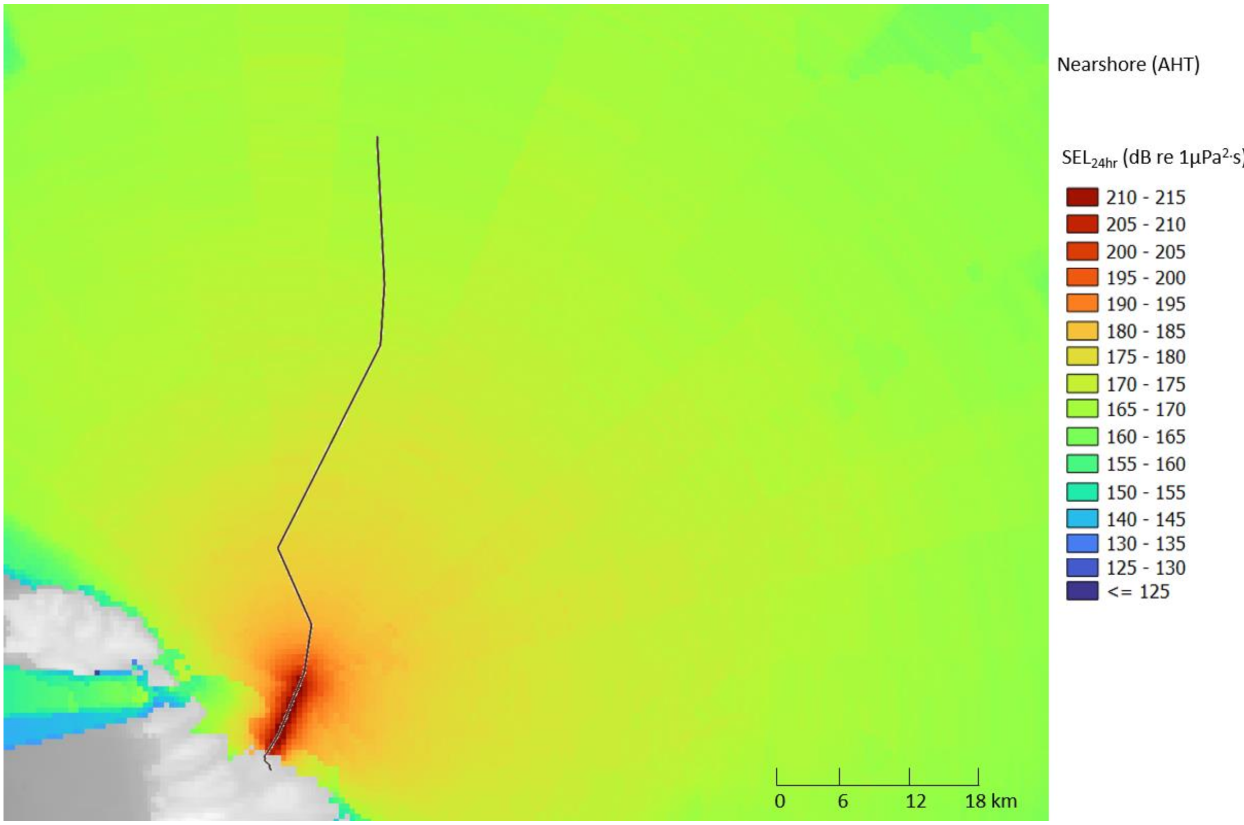

Figure D.8: Modelled offshore maximum SEL24hr (maximum level across water column) contours for Anchor Handling Tug (AHT).

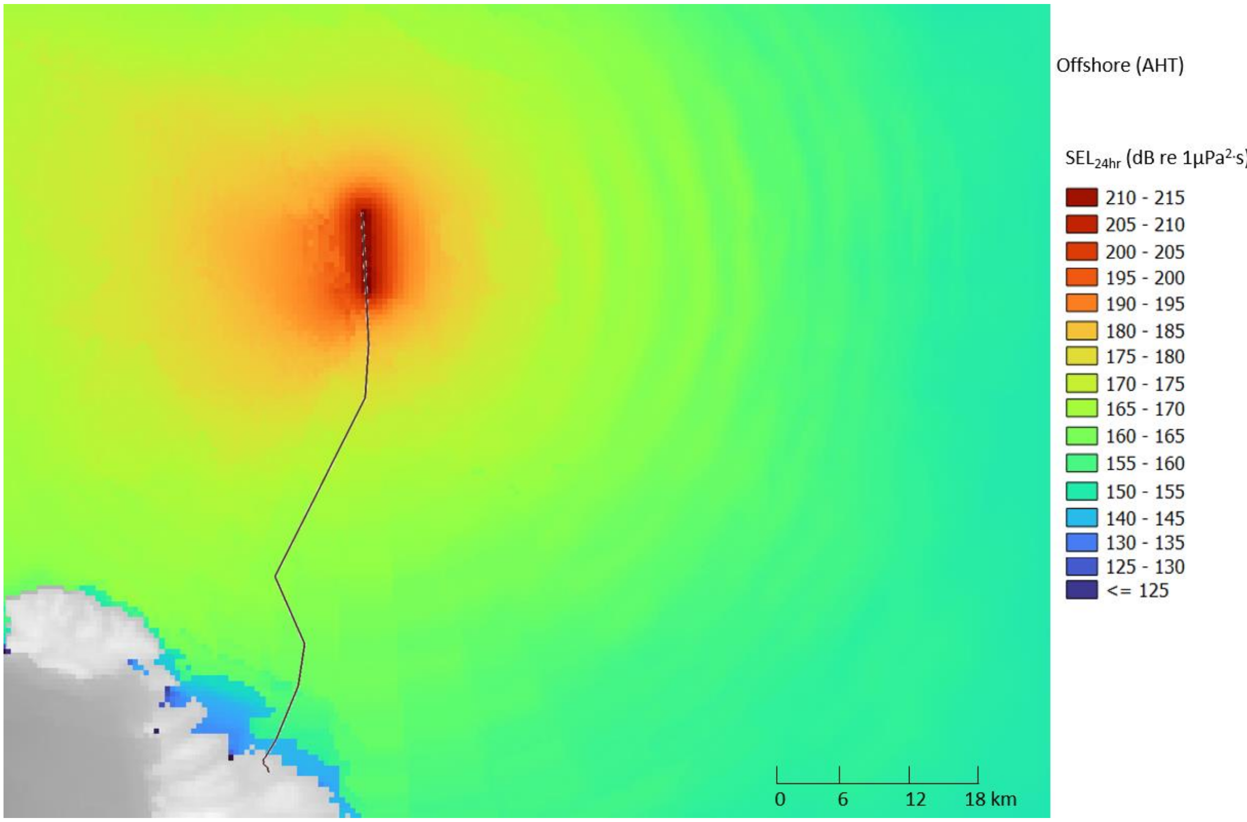

Figure D.9: Modelled (stationary) nearshore maximum SEL24hr (maximum level across water column) contours for Dredging (CSD).

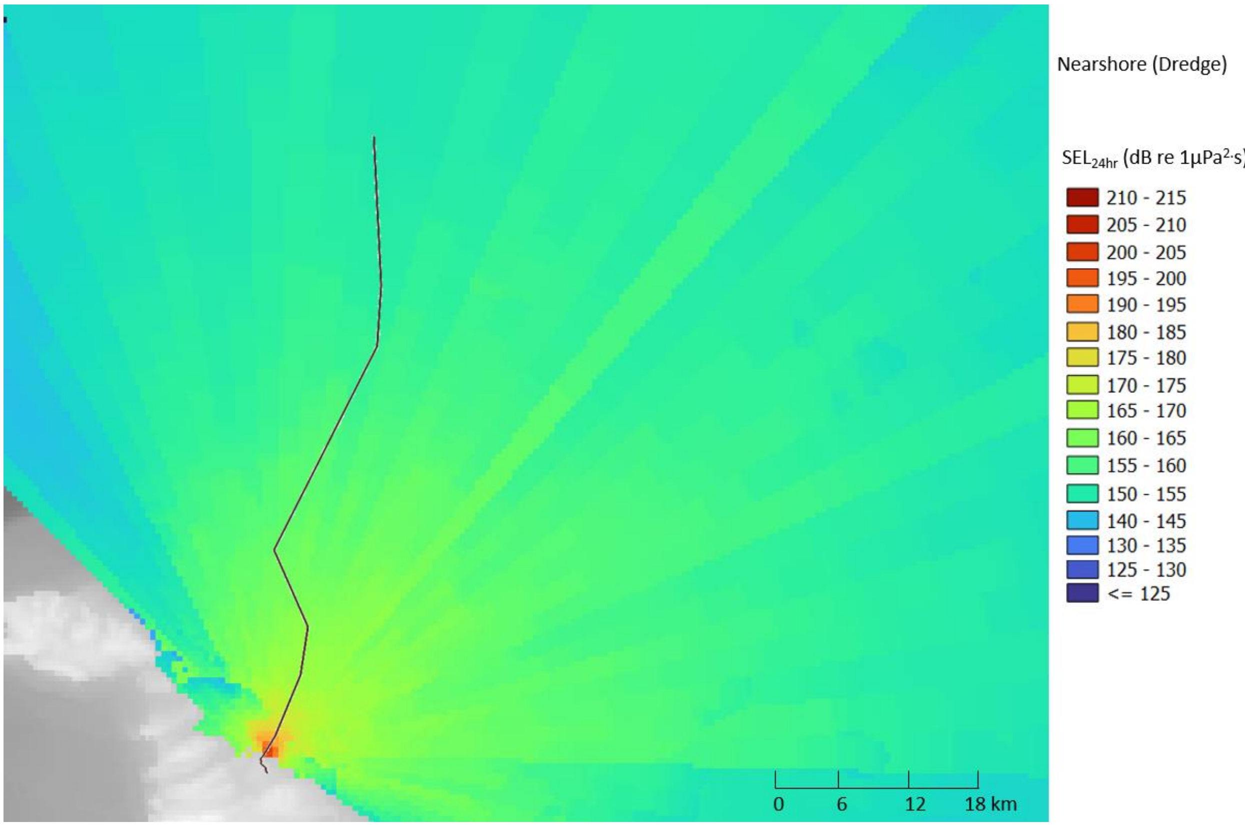

Figure D.10: Modelled (stationary) nearshore maximum SEL24hr (maximum level across water column) contours for Dredging (CSD).