XLINKS' MOROCCO-UK POWER PROJECT

Environmental Statement

Volume 3, Appendix 4.1: Underwater Noise Technical Assessment

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1.1 Introduction

1.1.1 This document forms Volume 3, Appendix 4.1: Underwater Noise Technical Assessment of the Environmental Statement (ES) prepared for the United Kingdom (UK) elements of Xlinks' Morocco-UK Power Project (the 'Project'). For ease of reference, the UK elements of the Project are referred to as the 'Proposed Development', which is the focus of the ES. The ES presents the findings of the Environmental Impact Assessment (EIA) process for the Proposed Development.

1.1.2 This document provides an assessment of the effects of underwater noise arising from offshore works associated with the construction and operation and maintenance of the Proposed Development. Volume 1, Chapter 3: Project Description of the ES describes the Proposed Development and the associated construction activities.

1.1.3 The proposed activities associated with the construction and operation and maintenance of the UK elements of the Proposed Development will generate underwater noise. This is an impact pathway that may have potential impacts on several categories of receptor. Consequently, this report provides an assessment of the underwater noise generating activities and an initial review of the subsequent impacts on relevant marine receptors.

1.1.4 This report is intended to inform the relevant ecological impact assessment chapters of the ES (and is presented as a technical appendix to the ES).

1.1.5 This report has been structured as follows:

- **Section 1.1**: Introduction – a brief overview of the Proposed Development and need for the assessment;
- **Section 1.2**: Underwater Acoustics Principles and Terminology – an overview of the fundamental underwater acoustics principles and the metrics considered within this assessment;
- **Section 1.3**: Underwater Noise Exposure on Marine Fauna – an overview of the potential impacts of noise exposure on marine fauna and acknowledgement of the marine fauna to be assessed within this assessment;
- **Section 1.4**: Underwater Noise Assessment Criteria – a review of the auditory thresholds and subsequent impact criteria associated with the marina fauna that occur within the project zone of influence;
- **Section 1.5**: Underwater Noise Modelling Methodology - reviews the key factors influencing the propagation of underwater noise and presents the preferred underwater noise propagation model that has been applied in this assessment;
- **Section 1.6**: Project Related Noise Sources – a review of the proposed noise emitting activity and the corresponding specific acoustic characteristics of each activity;

- **Section 1.7**: Underwater Noise Modelling Results and Potential Effects – reviews the outputs of the modelling and the potential effects on the assessed marine fauna; and
- **Section 1.8**: Summary and Conclusions – presents an overview of the underwater noise assessment and conclusions and recommended mitigation considerations.
- **Section 1.9**: References

1.2 Underwater acoustics principles & terminology

1.2.1 This section comprises an overview of key underwater acoustics principles, and how they are described, classified and quantified.

1.2.2 Underwater sound is generated by the movement or vibration of any object immersed in water. The sound travels through the water as vibrations of the fluid particles in a series of pressure waves. The waves comprise a series of alternating compressions (positive pressure variations) and rarefactions (negative pressure fluctuations).

1.2.3 As sound consists of variations in pressure, the unit for measuring sound is usually referenced to a unit of pressure, the Pascal (Pa). The unit usually used to describe sound is the decibel (dB) and, in the case of underwater sound, the reference unit is taken as 1 micro pascal (µPa) (equal to 10^{-6} Pa), whereas airborne sound is usually reference to a pressure of 20 µPa. To convert from a sound pressure level reference to 20 µPa to one referenced 1 µPa, a factor of 20 log (20/1) (i.e. 26 dB) has to be added to the former quantity. Therefore, 60 dB re 20 µPa is the same as 86 dB re 1 µPa, although the difference in sound speed and densities mean that the difference in sound intensity is much greater from in-air compared to water.

1.2.4 All underwater sound pressure levels in this report are described in dB re 1 µPa.

1.2.5 In water, the 'strength' of a sound source is usually described by its sound pressure level in dB re 1 µPa, referenced back to a representative distance of 1 m from an assumed (infinitesimally small) point source. This allows for the calculation of sound levels in the far-field. For large, distributed sources, the actual sound pressure level in the near-field will be lower than predicted.

1.2.6 There are several different metrics that may be used as measures of underwater sound pressure (NPL, 2014). The key metrics that are used to characterise underwater sound pressure are as follows:

- **Peak sound pressure level (or zero-peak sound pressure), SPL_{pk}**: The maximum sound pressure during a stated time interval. A peak sound pressure may arise from a positive or negative sound pressure. This quantity is typically useful as a metric for a pulsed waveform;
- **Peak-peak sound pressure level, SPL_{pk-pk}**: The sum of the peak compressional pressure and the peak rarefactional pressure during a stated time interval. This quantity is typically most useful as a metric for a pulsed waveform; and
- **Root mean square (RMS) sound pressure level, SPL_{rms}**: The square root of the mean square pressure, where the mean square pressure is the time

integral of squared sound pressure over a specified time interval divided by the duration of the time interval.

1.2.7 **Figure 1.1** below provides a graphical representation of the above sound pressure metrics for a pulsed sound and a periodic waveform.

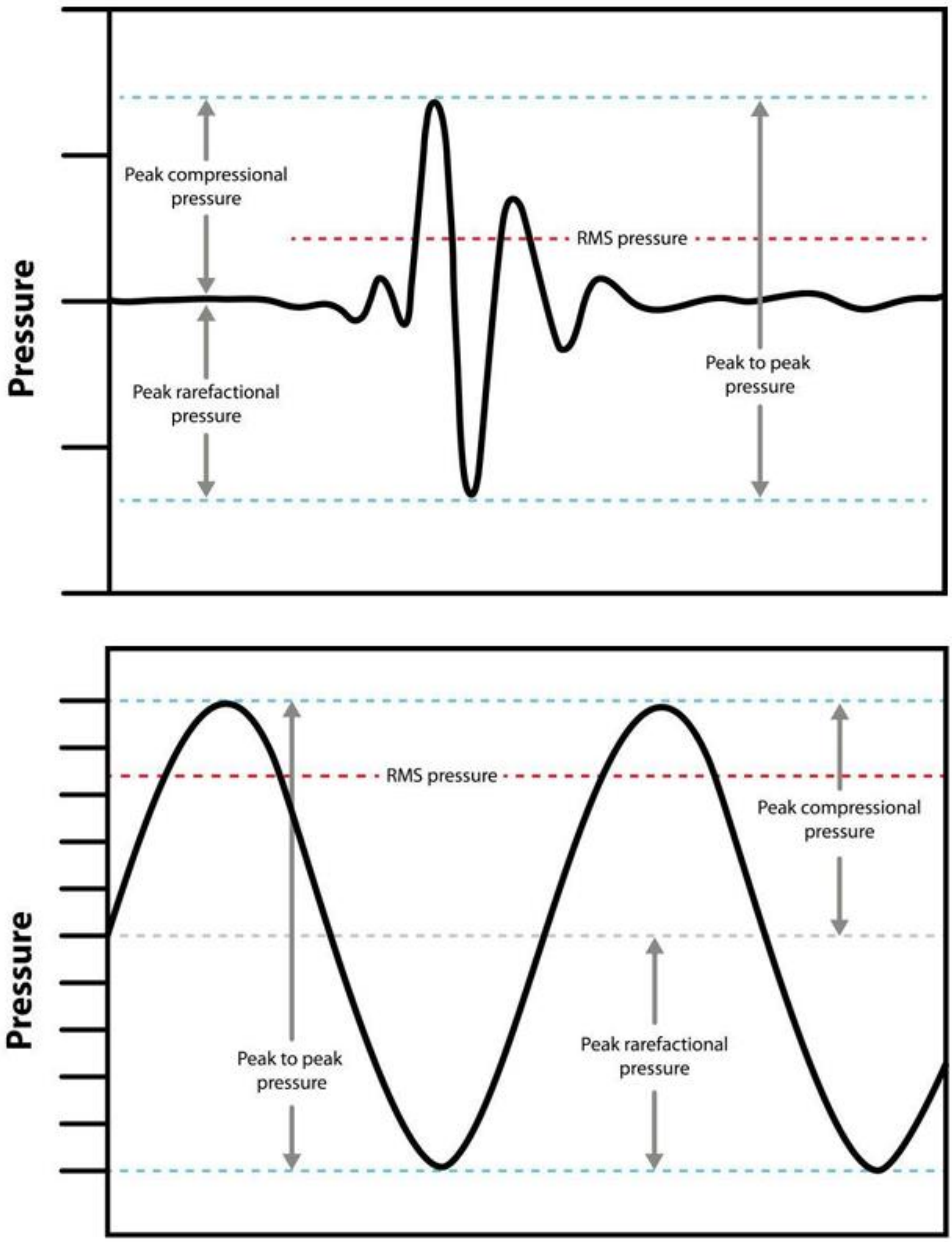

Figure 1.1: Graphical representation of sound pressure metrics for a pulsed sound (upper plot) and for a periodic waveform (lower plot) (NPL, 2014).

1.2.8 Another useful measure of sound used in underwater acoustics is the Sound Exposure Level (SEL). This metric is used as a measure of the total sound energy of an event or a number of events (e.g. over the course of a day) and is normalised to one second. This allows the total acoustic energy contained in events lasting a different amount of time to be compared on a like for like basis. It is defined as the integral of the square of the sound pressure over a stated time interval or event and is expressed in units of Pa^2s. In the context of this assessment, the SEL will be presented as a cumulative SEL (SEL_{cum}) which is representative of the total acoustic energy of a noise source taking place across the course of a day.

1.2.9 The frequency, or pitch, of sound is the rate at which pressure oscillations occur and is measured in cycles per second, or Hertz (Hz). The hearing of different species is frequency-dependent. Rather than express received sound pressures in terms of their levels over a broad bandwidth, levels can be weighted by the frequency response of hearing for the relevant animal (Popper *et al.,* 2014). When sound is measured in a way which approximates to how a human would perceive it, an A-weighting filter on a sound level meter is applied, the resulting level is described in values of dBA.

1.2.10 Southall *et al.,* (2007, 2019) developed 'M' frequency weighting functions for marine mammals to account for frequency-dependent sensitivities of several discrete hearing groups of marine mammals. These hearing weighting functions have been used to inform the assessment, and further information is provided in **Section 1.4**. It is important to note that where criteria are M-weighted, the noise source inputs to the modelling methodology also require an M-weighting, analogous to how an A-weighting is used for assessing human perception.

1.2.11 A similar attempt at frequency weighting for individual fish species and other animals was undertaken by Nedwell *et al.,* (2007). However, Popper *et al.,* (2014) discusses that whilst the general concept of weightings as proposed by Nedwell *et al.,* (2007) may have value in the context of behavioural responses by fish, its application and adoption requires further scientific validation. Consequently, weighting functions for fish in the context of this assessment have not been considered.

1.2.12 A discussion of the auditory threshold criteria for relevant species and the effects of noise on marine fauna, are provided in **Section 1.4** and **Section 1.7** respectively.

1.3 Underwater noise exposure of marine fauna

Potential Impacts

1.3.1 Potential impacts on marine fauna from underwater noise are dependent upon; the noise source characteristics (frequency (Hz) and decibels (dB)), attenuation of the noise in the specific location and the distance from the sound source from the receptor species. In addition to which, species and individual animals display variations in levels of sensitivity at different life stages and in different situations (e.g. presence of young).

1.3.2 Effects of underwater noise can be broadly classified as:

- **physical/physiological effects** (e.g., mortality, non-recoverable injury, permanent threshold shift (PTS) in hearing, temporary threshold shift (TTS) in hearing, recoverable injury), or
- **behavioural responses** (e.g., stress, changes in movements, migration, feeding, breeding, displacement, disturbance).

1.3.3 The biological significance of sound relates to how it interferes with an individual's capacity to undertake normal functional behaviours and activities, as well as their ability to grow, reproduce and survive. Sound can impact communication and / or predator / prey detection, for example, which can result in individual and population level consequences (e.g., alterations in individual fitness, abundance, and diversity) and may affect the overall viability of a species (Popper *et al.* 2014). The greater the magnitude of the sound source (i.e. the 'loudness' and the rate of distribution of sound events), and the longer the duration the receptor is exposed to the sound source, the greater the likelihood of biological impacts arising from a behavioural disturbance (Popper *et al.* 2014).

Sensitive Marine Fauna associated with the Proposed Development

1.3.4 Underwater noise-sensitive marine species are known to be present in the study area. The marine fauna hearing groups considered within this assessment are listed in **Table 1.1** below. Discussion of marine turtles is included in Volume 3, Chapter 4: Marine mammals and Turtles of the ES, noting that they are not included as a separate hearing group in this Technical Appendix. Further information on applicable auditory threshold criteria for each hearing group is provided in **Section 1.4**.

Table 1.1 Marine fauna hearing groups considered within this assessment

Marine Fauna Hearing Group	Description
Marine Mammals (Southall *et al.*, 2019)	
Very high-frequency cetaceans (VHF)	This hearing group is inclusive of harbour porpoises as well as several oceanic dolphins. The generalised hearing range considered in the literature is 275 Hz to 160 kHz.
High-frequency cetaceans (HF)	This hearing group is inclusive of most delphinid species (e.g., bottlenose dolphin, common dolphin, and pilot whale), beaked whales and sperm whales. The generalised hearing range considered in the literature is 150 Hz to 160 kHz.
Low-frequency cetaceans (LF)	This hearing group is inclusive of all the mysticetes species and are considered within the literature to have a generalised hearing range of 7 Hz to 35 kHz.
Phocid carnivores in water (PCW)	This hearing group is inclusive of harbour and grey seals. The generalised (underwater) hearing range considered in the literature is 50 Hz to 86 kHz.
Fish, Fish Eggs & Larvae (Popper *et al.*, 2014)	
Fish: Species without a swim bladder or other gas chamber	Example species are dab and other flatfish. These species are less susceptible to barotrauma[1] and only detect particle motion, not sound pressure. However, some barotrauma may result from exposure to sound pressure.
Fish: Species with a swim bladder, but without any swim bladder related hearing functionality	Example species are Atlantic salmon. These species are susceptible to barotrauma although hearing only involves particle motion not sound pressure.
Fish: Species with a swim bladder that is involved in hearing functionality	Example species are Atlantic cod, herring and relatives and Otophysi. These species are susceptible to barotrauma and detect sound pressure as well as particle motion.
Fish eggs and larvae	This hearing group considers eggs and larvae from all species.

1.4 Underwater Noise Assessment criteria

Introduction

1.4.1 Sound propagation models can be constructed to allow the received noise level at different distances from the source to be calculated. To determine the consequences of these received levels on any marine fauna which might be exposed to such noise emissions, it is necessary to relate the levels to known or estimated impact thresholds.

1.4.2 To determine the potential spatial range of injury and disturbance, a review has been undertaken of available evidence, including international guidance and scientific literature. The following sections summarise the relevant thresholds for the onset of effects and describe the evidence base used to derive them.

[1] Barotrauma is the term used to describe injuries or trauma to fish due to rapid changes in barometric pressure exposure.

1.4.3 It is important to note that underwater sound has both a sound pressure and vibration (particle motion) component. Whilst all marine mammals detect sound pressure in their auditory systems, all fish and many invertebrates also detect and use the particle motion component of underwater sound (Popper, Salmon & Horch 2001; Kaifu, Akamatsu & Segawa 2008).

1.4.4 Invertebrates are understood to be mainly sensitive to particle motion rather than sound pressure (Hawkins *et al.,* 2021). An exhaustive review of existing research on the effects of noise on invertebrates undertaken by Sole *et al.* (2023) concluded that further research and scientific validation is required to understand their auditory function. However, Sole *et al.* (2023) acknowledges that anthropogenic noise is likely to be detrimental to invertebrate species and their corresponding ecosystems.

1.4.5 For the purposes of assessment, the effects of underwater noise and vibration on invertebrates from the various aspects of the works associated with seafloor preparation, trenching and cable laying have been scoped out of assessment (see the Benthic Ecology chapter of the ES: Volume 3, Chapter 1), due to the anticipated low levels of noise and vibration associated with these activities. The potential effects of vibration in sediments due to the HDD works, however, have been scoped into assessment. This has been assessed based on information available for Peak Particle Velocity (PPV) from other HDD studies and the assessment has been undertaken in the Benthic Ecology chapter of the ES (ES Volume 3, Chapter 1).

1.4.6 There are no widely used particle motion criteria to assess against for all species. Consequently, the criteria presented in the following sections are reflective of sound pressure metrics only.

Fish, Eggs and Larvae

1.4.7 Adult fish, that are not in the immediate vicinity of noise generating activity, are generally able to vacate the area and avoid physical injury. However, larvae and eggs are not highly mobile and are therefore more likely to incur injuries from the sound energy in the immediate vicinity of the sound source, including damage to their hearing, kidneys, hearts and swim bladders. Such effects are unlikely to happen outside of the immediate vicinity of even the highest energy sound sources.

1.4.8 For fish, the most relevant criteria for injury are considered to be those contained in the Popper *et al.,* (2014). Popper *et al.* (2014) sets out criteria for impacts due to different sources of noise. Those relevant to this project are considered to be those for impacts due to continuous noise; further detail on the specific noise sources considered within the assessment are provided in **Section 1.6**.

1.4.9 For both types of noise source (i.e. impulsive and continuous), where insufficient data exists to determine a quantitative guideline value, the risk is categorised in relative terms as "high", "moderate" or "low" at three distances from the source: "near" (i.e. in the tens of metres), "intermediate" (i.e. in the hundreds of metres) or "far" (i.e. in the thousands of metres).

1.4.10 It should be noted that the qualitative criteria mentioned above cannot differentiate between exposures to different noise levels and therefore all sources of noise, no matter how noisy, would theoretically elicit the same assessment result. However, because the qualitative risks are generally qualified as "low", with the exception of a moderate risk at "near" range (i.e. within tens of metres) for some types of animal and impairment effects, this is not considered to be a significant issue with respect to determining potential effect of noise on fish.

1.4.11 **Table 1.2** below provides a summary of the assessment criteria applied in this assessment.

Table 1.2: Fish auditory threshold criteria applied in this assessment

Fish Category	Continuous Noise			
	Mortality and Potential Mortal Injury	**Recoverable Injury**	**TTS**	**Behavioural Response**
No swim bladder *(particle motion detection)*	**(N)** Low **(I)** Low **(F)** Low	**(N)** Low **(I)** Low **(F)** Low	**(N)** Moderate **(I)** Low **(F)** Low	**(N)** Moderate **(I)** Moderate **(F)** Low
Swim bladder not involved in hearing *(particle motion detection)*	**(N)** Low **(I)** Low **(F)** Low	**(N)** Low **(I)** Low **(F)** Low	**(N)** Moderate **(I)** Low **(F)** Low	**(N)** Moderate **(I)** Moderate **(F)** Low
Swim bladder involved in hearing *(primarily pressure detection)*	**(N)** Low **(I)** Low **(F)** Low	170 dB_{rms} 1µPa for 48hrs	158 dB_{rms} 1µPa for 12hrs	**(N)** High **(I)** Moderate **(F)** Low
Eggs and larvae	**(N)** Low **(I)** Low **(F)** Low	**(N)** Low **(I)** Low **(F)** Low	**(N)** Low **(I)** Low **(F)** Low	**(N)** Moderate **(I)** Moderate **(F)** Low

SPL_{rms} is referenced in dB re 1µPa.

Where insufficient data exist to make a recommendation for guidelines a subjective approach is adopted in which the relative risk of an effect is placed in order of rank at three distances from the source – near **(N)**, intermediate **(I)**, and far **(F)** (top to bottom within each cell of the table, respectively). While it would not be appropriate to ascribe distances to effects because of the many variables in making such decisions, "near" might be considered to be in the tens of meters from the source, "intermediate" in the hundreds of meters, and "far" in the thousands of meters. The rating for effects in these tables is highly subjective and represents general consensus of the Popper *et al.* (2014) working group. These ratings are not hard and fast, and they are presented as the basis for discussion.

It is important to note, that the quantifiable criteria as set out for recoverable injury and TTS are reflective of the fish receptors being stationary for the 48-hour period or 12-hour period respectively. This is not reflective of real fish habitats, as the research is based on captive fish. However, it does provide a useful quantifiable threshold level at which conservative impact ranges can be calculated.

Marine Mammals

1.4.12 The Joint Nature Conservation Committee (JNCC) guidance (JNCC, 2010) recommends using the injury criteria proposed by Southall *et al.* (2007). However, the guidance also suggests that criteria will need to be updated as and when more recent scientific studies become available. These criteria were updated in 2016 (NOAA, 2018) and most recently in 2019 (Southall *et al.* 2019). They reflect the most comprehensive and up-to-date scientific knowledge relating to the risk of auditory injury to marine mammals. Southall *et al.* (2019) divides marine mammals into Functional Hearing Groups (FHGs), with the same impact thresholds used for all species within a FHG.

1.4.13 JNCC requires the injury criteria and FHGs presented in the National Oceanic and Atmospheric Administration (NOAA) (2018) and Southall *et al.* (2019) to be used for any marine mammal noise assessment. It is worth noting that while the FHGs and thresholds are the same in these two documents, the terminology used to identify the FHGs does differ. For this assessment the terminology used in Southall *et al.* (2019) will be used. The injury criteria are based on a combination of linear (i.e. un-weighted) peak pressure levels and marine mammal hearing weighted sound exposure levels (SEL). The hearing weighting function is designed to represent the bandwidth for each FHG within which acoustic exposures can have auditory effects (Southall *et al*,. 2019).

1.4.14 The current National Marine Fisheries Service (NMFS) disturbance (onset of behavioural response) threshold for all marine mammal species is 120 dB re 1 µPa (SPL_{rms}) for non-impulsive noise (NMFS, 2023). These disturbance thresholds do not consider the overall duration of the noise or its acoustic frequency distribution to account for species dependent hearing. This is considered very conservative and not necessarily a reflection of an adverse effect, but the onset at which behavioural responses may start to occur for certain sensitive species. Furthermore, it is important to note that ambient noise levels in the areas where work is proposed could exceed this value, and hence highlights the very precautionary nature of this criterion.

1.4.15 **Table 1.3** below provides the relevant criteria for the onset of PTS and TTS as a result of exposure to non-impulsive sound sources for the relevant marine mammal FHGs considered within this assessment. Further detail on the specific noise sources considered within the assessment are provided in **Section 1.6**.

Table 1.3: Marine mammal auditory threshold criteria applied in this assessment

Marine Mammal FHG	Non-Impulsive Noise		
	PTS Onset (M-Weighted)	TTS Onset (M-Weighted)	Onset of behavioural response (Un-weighted)
Very high-frequency cetaceans (VHF)	173 dB SEL_{cum}	153 dB SEL_{cum}	120 dB SPL_{rms}
High-frequency cetaceans (HF)	198 dB SEL_{cum}	178 SEL_{cum}	
Low-frequency cetaceans (LF)	199 dB SEL_{cum}	179 SEL_{cum}	
Phocid carnivores in water (PCW)	201 dB SEL_{cum}	181 dB SEL_{cum}	
SPL_{rms} is referenced in dB re 1µPa, and SEL_{cum} is referenced in dB re 1µPa^{2}s.			

1.5 Underwater Noise Modelling Methodology

1.5.1 As discussed in **Section 1.2**, underwater sound is generated by the movement or vibration of any immersed object in water. The sound propagates through the water as vibrations of the fluid particles in a series of pressure waves. The many complexities of underwater environments influence how the sound propagates and subsequently effects how acoustic energy is lost during the process (transmission loss). These factors broadly comprise the following (NPL, 2014):

- the reduction (or attenuation) of sound away from the source due to geometrical spreading;
- absorption of the sound by the sea-water and the sea-bed;
- the interaction with the sea-surface (reflection and scattering);
- the interaction with, and transmission through, the sea-bed;
- the refraction of the sound due to the sound speed gradient;
- the bathymetry (water depth) between sound and receiver positions; and
- source and receiver depth.

1.5.2 The modelling of underwater sound propagation is an established discipline, where several modelling approaches have been developed. Each approach has differing suitability according to the project specific environmental conditions (i.e. water depth and spatial variability), the acoustic frequency range of source and receptor, and proportionate computational requirements dependent on the risk of adverse noise generating activities as well as the available source term data (Jensen *et al.,* 2011). To reduce uncertainty, field measurements of sound propagation are often used, where available, to inform theoretical and/or empirical models.

1.5.3 The *Underwater Noise Measurement Good Practice Guide* (NPL, 2014) provides a summary of the propagation models that are available for underwater noise predictions. Farcas *et al,* (2016) builds on this and provides detail on the suitability of the different modelling approaches in the context of Environmental Impact Assessments (EIA), albeit no specific modelling approach is recommended above another, as model choice is determined by the factors as discussed in **paragraph 1.5.2**.

1.5.4 The Joint Nature Conservation Committee (JNCC) provides guidance on the assessment of the significance of noise disturbance in Special Areas of Conservation (SAC) specific to Harbour Porpoise, a cetacean species particularly sensitive to underwater noise (JNCC, 2020). The guidance recommends using Effective Deterrence Ranges[2] (EDRs) based on empirical evidence as opposed to impact ranges predicted from underwater noise modelling, as an alternative approach to relying on modelling methods. However, this guidance only recommends EDRs for impulsive noise sources (e.g. impact piling, UXO clearance and geophysical surveys). The lowest presented EDR is 5 km for 'other geophysical surveys'. The proposed noise emitting activities associated with the Project are expected to generate less underwater noise compared to geophysical

[2] Defined as the radius of a circular area assumed to be disturbed.

survey activities. Consequently, the lowest 5 km EDR will be precautionary to apply in the context of the Proposed Development.

1.5.5 With reference to **Section 1.6**, the proposed noise generating activities are all non-impulsive in nature and are considered 'low-risk' (i.e. the source noise levels do not significantly exceed the auditory threshold criteria of each hearing group, and the impacts are dependent on exposure time rather than instantaneous impacts). Furthermore, there are limited proxy source term data for each of the proposed activities considered within the assessment, and hence where possible, ranges of source levels have been considered.

1.5.6 On the above basis, a proportionate modelling approach is considered to be a simple two-dimensional practical spreading loss model. This is a simplistic approach to the calculation of transmission loss and does not account for several of the factors that influence underwater noise propagation. Consequently, this approach can often over-estimate impact ranges especially in the far-field (Farcas *et al.* 2016) and is considered to provide conservative approximations of likely impact ranges. However, it is reflective of the 'low-risk' nature of the proposed noise emitting activities and the relative lack of available source term data in the literature.

1.5.7 In addition to the above, EIAs for similar offshore cable projects have utilised simplistic modelling approaches (i.e. practical spreading loss models) (GridLink, 2020; GreenLink, 2019; NorthConnect, 2018; FabLink, 2016); literature reviews of proxy data without any propagation predictions (North Sea Link, 2014); and, have scoped-out underwater noise assessments all together due to the 'low-risk' nature of the associated noise generating activities (Aquind Interconnector, 2019).

1.5.8 NOAA recommends the use of practical spreading loss model solutions to developers and has subsequently incorporated this into two separate calculation tools (NMFS, 2021; NOAA, 2021) to calculate impact ranges for fish and marine mammals for impulsive and non-impulsive underwater noise. The NMFS's Multi-Species Calculator Version 1.2 (NMFS, 2021) was modified for use for this assessment. Further details of assumptions, input values, and amendments[3] to the tools are provided in **Section 1.7**.

1.5.9 The model is a logarithmic equation that incorporates geometric spreading and absorption loss factors that is simple and efficient to provide first order calculations of the received (unweighted) levels with distance from the source. The tool considered relevant marine mammal criteria weightings where required. The formula is represented as below (Ulrick, 1983; Xavier, 2002):

$$\mathbf{TL = L_2 - L_1 = 15 \log_{10} (R_1/R_2) + \alpha R}$$

Where:

TL: is the transmission loss in dB.

L_1: sound pressure level at a given distance R_1.

L_2: measured sound pressure level at a given distance R_2.

[3] The NMFS Multi Species Pile Driving Calculator Tool (NMFS, 2021) utilises legacy impact thresholds for fish from the Fisheries Hydroacoustics Working Group (FHWG) (2008) which has since been superseded by Popper et al. (2014) and other more up-to-date research.

R_1: is the impact range in meters from the noise source at which the relevant threshold is exceeded.

R_2: is the distance from the source of the initial measurement.

αR: linear absorption and scattering loss

1.5.10 Solving for L_1 will provide the underwater sound pressure level at a given distance. To determine at what distance or range a known sound pressure level will occur, the equation must be solved for R_1:

$$R_1 = R_2 \times 10^{((L2 - L1) + \alpha R / 15)}$$

1.5.11 The linear absorption and scattering loss term is assumed to be zero. The NMFS model was used to estimate the distance from the source at which Project-related noise would attenuate to threshold noise levels. The NMFS Multi-Species Calculator considers the dominant source frequency to apply a frequency weighting. The modelling approach typically assumes that all receptors are exposed to the noise for the entire source operating time (i.e. receptors are assumed to be stationary for the duration of the proposed operational activity). This is highly precautionary and not reflective of reality where animals will generally be in transit during any sound exposure and will likely result in an over-estimation of impact ranges.

1.5.12 Consequently, marine mammal receptors in transit have been considered within the modelling calculations. It has been assumed that a receptor will swim away from the noise source at an average speed of 1.5 m/s. This swim speed was based on reported sustained swimming speeds for harbour porpoises (Otani *et al.,* 2000; Kastelein *et al.,* 2018) and is considered precautionary for other marine mammal species. For example, bottlenose dolphin and white-beaked dolphin have been recorded at a sustained swim speed of 1.52 m/s (Bailey and Thompson, 2010), minke whales at a sustained swim speed of 2.3 m/s (Boisseau *et al.,* 2010) and harbour and grey seals at a sustained swim speed of 1.8 m/s (Thompson, 2015). The calculation considers each 1-second period of exposure to be established separately, resulting in a series of discrete SEL values of decreasing magnitude, as illustrated in **Figure 1.2**. As the receptor swims away, the noise will become progressively quieter. The cumulative SEL is calculated by logarithmically adding the SEL to which the mammal is exposed as it travels away from the source.

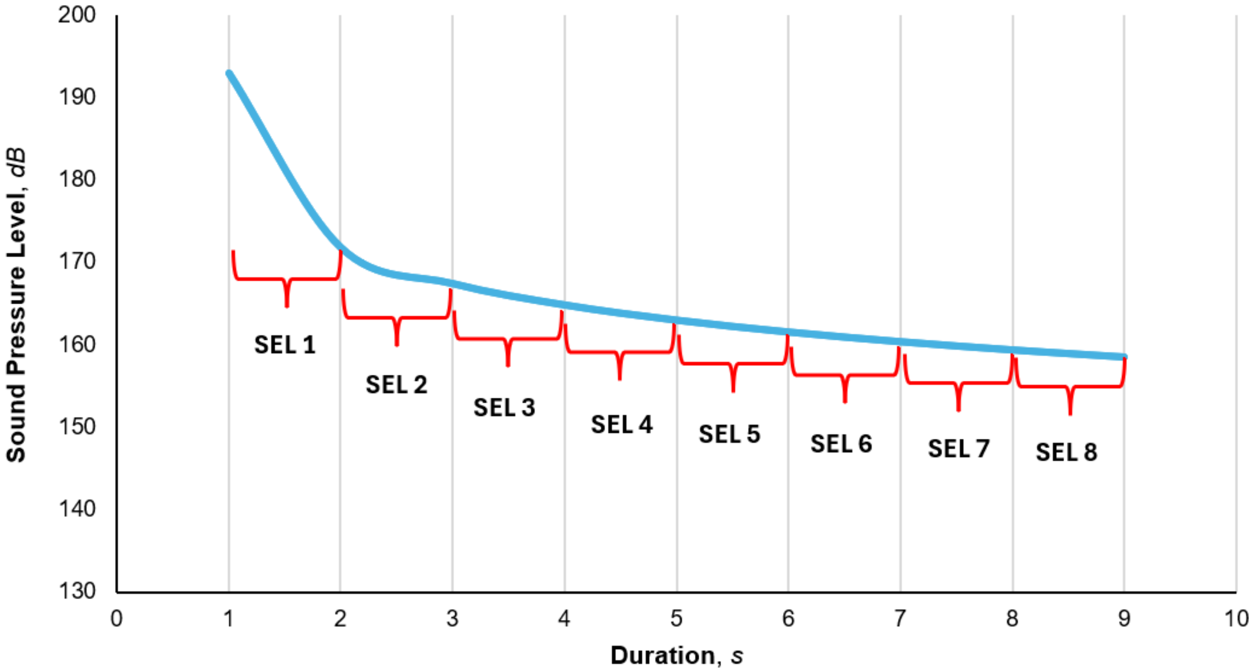

Figure 1.2: Graphical representation of the conversion of continuous noise sources into discrete 1-second windows.

1.5.13 This calculation was used to estimate the approximate minimum start distance for a marine mammal in order for it to be exposed to sufficient sound energy to result in the onset of potential injury. It should be noted that the sound exposure calculations are based on the simplistic assumption that the source is active continuously over a 24-hour period and that the animal will continue to swim away at a constant relative speed. The real-world situation is more complex, and the noise source will vary in space and time and the animal is likely to move in a more complex manner[4].

1.5.14 For fish, the same assumptions about the movement of individual animals relative to the sound source are not as well understood and are therefore not considered in the model.

1.5.15 To account for the marine mammal auditory weighting functions as provided by Southall *et al.,* (2007; 2019) within the NMFS Multi-Species Calculator, there are two options: 1) Weighting Factor Adjustments (WFA); and 2) spectrum to override the WFA outputs (NMFS, 2020).

1.5.16 The Weighting Factor Adjustment (WFA) only accounts for marine mammal auditory weighting functions via a single frequency, while relying upon a source's spectrum to override the WFA, means that multiple frequencies are considered in the application of marine mammal auditory weighting functions. The choice as to whether a single frequency or multiple frequencies are most appropriate for a sound source, depends primarily on the source's bandwidth (NMFS, 2020).

[4] Swim speeds of marine mammals have been shown to be up to 5 m/s (e.g. cruising minke whale 3.25 m/s (Cooper et al., 2008) and harbour porpoise up to 4.3 m/s (Otani et al., 2000)). The swim speed of 1.5 m/s used in this assessment is a conservative characterisation of the uncertainty of the marine mammal transit pathway (i.e. the marine mammal might not swim directly away from the source, could change direction or does not maintain a fast swim speed over a prolonged period).

1.5.17 As described in **Section 1.6**, all sources are considered broadband (i.e. sources that produce sound over a broad range of frequencies). Accounting for the weighting in terms of the source spectrum or proxy spectrum is most appropriate. However, if this is not possible, then a single frequency (i.e. a WFA) is recommended (NMFS, 2020). The sources of proxy noise data used in the assessment as provided in **Section 1.6**, do not have narrowband data available in order to over-ride the WFA. Consequently, the WFA approach has been utilised within the NMFS Multi-Species Calculator.

1.5.18 WFAs make appropriate adjustments for each marine mammal FHG based on the frequency chosen. For broadband sounds, the choice of an appropriate WFA frequency is based on the 95% frequency contour of the particular sound source, which is defined as upper frequency below which 95% of total cumulative energy is contained (NMFS, 2020). On the basis of the spread of frequencies that the various sources operate (**Table 1.4**), in addition to studies of similar non-impulsive sources considered within this assessment (Greene 1987; Blackwell et al. 2004a; Blackwell and Greene 2006), a weighting function of 2 kHz has been utilised.

1.6 Project noise sources

1.6.1 Input parameters were established for each noise source associated with the Project. Where specific noise levels were not available for project specific proposals, proxy source levels were obtained from publicly available information for similar noise sources. Note that actual source levels will depend on a number of factors including specific equipment types (dependent upon final contractors and kit availability) and bottom hardness. As the Project will involve transient activities across a range of different bed types and local environments (e.g. different water depths), many of the noise source parameters will vary along the proposed route. Thus, a range of source levels is proposed.

1.6.2 Should resultant ecological impacts be deemed to be significant, or where considerable uncertainty remains, field measurements may be considered during the Proposed Development activities, to confirm actual source levels.

1.6.3 **Table 1.4** outlines the modelling parameters associated with each source of noise, including the source level, peak operating frequency range and the operating time within a 24-hour period. It is worth noting that proxy source noise levels in **Table 1.4** are presented as root mean square (rms) sound pressure levels. Where criteria are presented as sound exposure levels, a conversion calculation dependent on the operational duration has been undertaken and input into the model as the relevant source sound pressure level. Although operations will proceed across a 24-hour period, a range or variety of noise emitting activities may be employed across that time. Therefore, the operating times assumed for the majority of noise sources presented in **Table 1.4** are worst-case assumptions and highly precautionary (i.e. 24-hour operation).

1.6.4 Source noise level data used in projects involving cable laying activities have been reviewed for this assessment (GridLink, 2020; GreenLink, 2019; NorthConnect, 2018; FabLink, 2016; White Cross, 2023). However, the source noise levels presented in **Table 1.4** are considered representative of the likely highest source noise levels associated with the proposed activities, and hence represents a precautionary assessment.

Table 1.4: Noise source parameters

Noise Source	**Operating Time** (Hours)	**Peak Operating Frequency Range** (Hz)	**Source Sound Pressure Level** (dB_{rms} re 1 µPa @ 1m)	**Literature Reference**
Seabed obstacle clearance	24	80 to 2000	178 - 183	Nedwell *et al.*, 2003
Mass flow excavation	24	80 to 2000	162 - 167	Xodus, 2017
Dredging	24	50 to 3000	183 - 188	Johansson and Andersson, 2012
Cable burial – water jetting	24	20 to 4000	188 - 193	Wyatt, 2008
Cable burial – mechanical cutter	24	50 to 3000	183 - 188	Robinson *et al.*, 2011
HDD*	24	10 to 10000	142 - 160	Erbe *et al.*, 2017
Installation of Rock protection	24	100 to 4000	188	Hannay *et al.*, 2004
Associated vessel movements – tug	24	50 to 2000	172	Richardson, 1995
Associated vessel movements – cable lay vessel	24	20 to 4000	188	Wyatt, 2008

*The available HDD source level data in the literature were measured at a nominal distance (39m) from the noise emitting activity (Nedwell *et al.,* 2012). This consequently introduces an additional level of uncertainty, as 'back-calculations' would be required to derive a proxy source level at 1m from the source, to then be input into the model.

In the absence of HDD source level data, a range of data associated with underwater geotechnical site investigation activity (including core drilling and standard penetration testing), which are considered to have greater efficacy in the context of this assessment, have been used as proxy model input data to represent the likely underwater noise emissions of HDD type activity.

1.7 Underwater noise modelling results & potential effects

Fish

1.7.1 The NMFS's Multi-Species Calculator Version 1.2 (NMFS, 2022) was utilised to predict underwater noise levels and the subsequent fish species impact ranges and relative risk due to the proposed noise emitting activities. The tool was manually updated to account for the most up-to-date impact thresholds which are considered in this assessment as provided by Popper *et al.* (2014).

1.7.2 **Table 1.5** below provides the distances at which recoverable injury and TTS impact thresholds are reached for each noise source. The Popper *et al.* (2014) relative risk of impacts as defined in **Table 1.2** are applicable to all noise sources and hence have not been presented in this section.

Table 1.5: Predicted approximate impact ranges in metres at which fish hearing response thresholds are reached due to continuous noise sources associated with the Project

Noise Source	**Recoverable Injury Isopleths** (m) *(Threshold: 170 dB_{rms} 1μPa for 48hrs)*	**TTS Isopleths** (m) *(Threshold: 158 dB_{rms} 1μPa for 12hrs)*
Seabed obstacle clearance	<10	<50
Mass flow excavation	Not Reached	<5
Dredging	<20	<100
Cable burial – water jetting	<40	<215
Cable burial – mechanical cutter	<20	<100
HDD	Not Reached	Not Reached
Installation of Rock protection	<20	<110
Associated vessel movements – tug	<10	<10
Associated vessel movements – cable lay vessel	<20	<100

1.7.3 The onset of recoverable injury in fish where swim bladders are primarily used as a pressure detection mechanism, would take place if the fish were within 40 m of the 'loudest' noise source (water-jetting for cable burial activities) for a 48-hour period.

1.7.4 The onset of TTS in fish where swim bladders are primarily used as a pressure detection mechanism, would take place if the fish were within 215 m of the 'loudest' noise source (water-jetting for cable burial activities) for a 12-hour period.

1.7.5 Overall, there is considered to be a low risk of any injury in fish as a result of the underwater noise generated by the above sources. The level of exposure will depend on the position of the fish with respect to the source, the propagation conditions, and the individual's behaviour over time. However, it is unlikely that a fish would remain in the vicinity of the proposed noise emitting activities for extended periods. Behavioural responses are anticipated to be spatially negligible in scale and fish will be able to move away and avoid the source of the noise as required.

Marine Mammals

1.7.6 The NMFS's Multi-Species Calculator Version 1.2 (NMFS, 2022) has been utilised to predict the range at which the weighted SEL_{cum} impact thresholds (Southall *et al.,* 2019) for the onset of cumulative PTS and TTS are reached. The calculator has also been used to predict the onset on behavioural response on the basis of the NMFS (2023) precautionary behavioural response criterion.

1.7.7 **Table 1.6** below provides the approximate minimum 'start-distance' for a marine mammal in order for it to be exposed to sufficient sound energy to result in the onset of PTS, when assuming the animal is swimming away from the noise source at 1.5 m/s across a 24-hour period (as described in detail in **Section 1.5**).

Table 1.6: Predicted approximate minimum 'start-distance' at which marine mammals cumulative exposure PTS thresholds are reached due to continuous noise sources associated with the Project

Noise Source	PTS Isopleths (m)			
	LF Cetaceans	**HF Cetaceans**	**VHF Cetaceans**	**PCW**
Thresholds: SEL_{24hr}, dB re 1 µPa²s	*199*	*198*	*173*	*201*
Seabed obstacle clearance	Not Reached	Not Reached	Not Reached	Not Reached
Mass flow excavation	Not Reached	Not Reached	Not Reached	Not Reached
Dredging	Not Reached	Not Reached	Not Reached	Not Reached
Cable burial – water jetting	Not Reached	Not Reached	Not Reached	Not Reached
Cable burial – mechanical cutter	Not Reached	Not Reached	Not Reached	Not Reached
HDD	Not Reached	Not Reached	Not Reached	Not Reached
Installation of Rock protection	Not Reached	Not Reached	Not Reached	Not Reached
Associated vessel movements – tug	Not Reached	Not Reached	Not Reached	Not Reached
Associated vessel movements – cable lay vessel	Not Reached	Not Reached	Not Reached	Not Reached

1.7.8 For all sources, the predicted SEL_{24hr} weighted levels of underwater noise do not exceed the relevant PTS threshold for each FHG.

1.7.9 In light of the precautionary approach to the impact range predictions as discussed in **Section 1.5**, it is considered highly unlikely that PTS impacts will take place across all FHGs during the proposed noise emitting activities.

1.7.10 **Table 1.7** below provides the approximate minimum 'start-distance' for a marine mammal in order for it to be exposed to sufficient sound energy to result in the onset of TTS, when assuming the animal is swimming away from the noise source at 1.5 m/s across a 24-hour period (as described in detail in **Section 1.5**).

Table 1.7: Predicted approximate minimum 'start-distance' at which marine mammals cumulative exposure TTS thresholds are reached due to continuous noise sources associated with the Project

Noise Source	TTS Isopleths (m)			
	LF Cetaceans	**HF Cetaceans**	**VHF Cetaceans**	**PCW**
Thresholds: *SEL$_{24hr}$, dB re 1 µPa^{2}s*	*179*	*178*	*153*	*181*
Seabed obstacle clearance	<20	Not Reached	Not Reached	Not Reached
Mass flow excavation	Not Reached	Not Reached	Not Reached	Not Reached
Dredging	<110	Not Reached	Not Reached	<20
Cable burial – water jetting	<940	Not Reached	Not Reached	<160
Cable burial – mechanical cutter	<110	Not Reached	Not Reached	<20
HDD	Not Reached	Not Reached	Not Reached	Not Reached
Installation of Rock protection	<110	Not Reached	Not Reached	<20
Associated vessel movements – tug	Not Reached	Not Reached	Not Reached	Not Reached
Associated vessel movements – cable lay vessel	<110	Not Reached	Not Reached	<20

1.7.11 The maximum approximate distance at which the predicted SEL_{24hr} weighted levels of underwater noise exceeds the TTS threshold for the most sensitive FHG (LF cetaceans, such as minke whales) and the 'loudest' noise source (water-jetting for cable burial activities) is **940m**.

1.2 Consequently, TTS impacts have the potential to take place for species within the LF cetacean FHG if they are within 940m of the 'loudest' noise source when the proposed activity commences. TTS impacts have the potential to take place for species within the PCW FHG if they are within 160m of the 'loudest' noise source when the proposed activity commences. For species within the HF cetacean and VHF cetacean FHGs, TTS thresholds are not reached and hence TTS impacts are considered highly unlikely.

1.7.1 **Table 1.8** below provides the distances at which the onset of behavioural response may take place for each noise source. It is worth reiterating that this is a very precautionary criterion and does not necessarily represent an adverse effect.

Table 1.8: Predicted approximate impact ranges in metres at which marine mammals onset of behavioural response thresholds are reached due to continuous noise sources associated with the Project

Noise Source	Onset of Behavioural Response Isopleth (m) *(Threshold: 120 dB$_{rms}$ 1µPa)*
Seabed obstacle clearance	<16,900
Mass flow excavation	<1,400
Dredging	<34,200
Cable burial – water jetting	<73,600
Cable burial – mechanical cutter	<34,200
HDD	<470
Installation of Rock protection	<36,400
Associated vessel movements – tug	<3,000
Associated vessel movements – cable lay vessel	<34,200

1.7.2 The maximum approximate distance at which the predicted SPL$_{rms}$ levels of underwater noise exceeds the onset of behavioural response threshold for all heading groups for the 'loudest' noise source (water-jetting for cable burial activities) is 73.6km. With reference to paragraph 4.3.3, this is a very precautionary criterion which does not necessarily represent the onset of an adverse behavioural response. It is likely that the onset of any adverse behavioural responses will take place at a significantly smaller range from the source, and only for certain highly sensitive species. Furthermore, it is important to note that ambient noise levels in the areas where work is proposed could exceed this value, and hence highlights the very precautionary nature of this criterion.

1.7.3 On the above basis, all receptors are considered to be at low risk of any adverse behavioural responses during the proposed noise emitting activities. However, the onset of behavioural response may take place in some particularly sensitive species during the proposed noise emitting activities.

1.8 Summary and conclusions

1.8.1 This report presents the results of the underwater noise modelling and subsequent initial analysis of the impacts on the relevant marine fauna within the zone of influence of the proposed development. This report is intended to inform the relevant ecological impact assessment chapters of the ES (and is presented as a technical appendix to the ES).

1.8.2 With reference to **Section 1.5**, a simple logarithmic practical spreading loss model has been selected to predict the propagation of underwater sound. This is considered a proportionate modelling approach due to the following: the noise emissions from the proposed activities are considered 'low-risk' (i.e. the source noise levels do not significantly exceed the auditory threshold criteria of each hearing group, and the impacts are dependent on exposure time rather than instantaneous impacts); and, several existing interconnectors within UK waters have used this approach (e.g. GridLink, 2020; GreenLink, 2019; NorthConnect, 2018; FabLink, 2016).

1.8.3 The predicted levels of underwater noise have been compared against peer-reviewed noise exposure criteria to determine the potential risk of impact on marine fauna (Popper *et al.,* 2014; NOAA, 2018; Southall *et al.,* 2019).

Fish

1.8.4 **Table 1.9** below provides a summary of the worst-case impact ranges for fish receptors when considering the 'loudest' noise source. The onset of recoverable injury in fish is predicted to take place within 40 m from the 'loudest' noise source, and the onset of TTS in fish is predicted to take place within 215 m from the 'loudest' noise source. However, these effects will only likely take place if the fish receptor is within the predicted impact ranges for a 48-hour period, and a 12-hour period respectively. It is unlikely that a fish would remain in the vicinity of the proposed noise emitting activities for extended periods, and therefore there is considered to be low risk of any injury in fish. Behavioural responses are anticipated to be spatially negligible in scale and fish will be able to move away and avoid the source of the noise as required.

Table 1.9 Summary of the worst-case predicted impact ranges for the most sensitive fish hearing group

'Loudest' Noise Source	**Recoverable Injury Isopleths** (m) *(Threshold: 170 dB_{rms} 1µPa for 48hrs)*	**TTS Isopleths** (m) *(Threshold: 158 dB_{rms} 1µPa for 12hrs)*
Cable burial – water jetting	<40	<215

Marine Mammals

1.8.5 **Table 1.10** and **Table 1.11** below provides a summary of the worst-case impact ranges for the most-sensitive marine mammal receptors considering the 'loudest' noise source.

Table 1.10: Summary of the worst-case predicted minimum 'starting-distances' for impact thresholds to be exceeded for the most sensitive marine mammal FHG

'Loudest' Noise Source	Most affected FHG	Cumulative PTS Isopleth	Cumulative TTS Isopleth
Thresholds		***199 dB SEL$_{cum}$***	***179 SEL$_{cum}$***
Cable burial – water jetting	LF cetaceans (such as minke whales)	Not Reached	<940 m

1.8.6 PTS impact thresholds are predicted to not be exceeded for any FHG, for any proposed noise source, across a 24-hour period.

1.8.7 TTS impact thresholds are predicted to be exceeded, with a worst-case 'starting-distance' of **940m** when considering the 'loudest' noise source (water jetting) and the most sensitive FHG (LF cetaceans, such as minke whales).

1.8.8 With reference to **Table 1.7**, TTS impacts have the potential to take place for species within the PCW FHG if they are within 160m of the 'loudest' noise source when the proposed activity commences. For species within the HF cetacean and VHF cetacean FHGs, TTS thresholds are not reached and hence TTS impacts are considered highly unlikely.

Table 1.11: Summary of the worst-case predicted impact range at which the onset of behavioural response may take place for the most sensitive marine mammal FHG

'Loudest' Noise Source	Most affected FHG	Onset of Behavioural Response Isopleth
Thresholds		***120 dB SPL$_{rms}$***
Cable burial – water jetting	LF cetaceans (such as minke whales)	<73600 m

1.8.9 With reference to **paragraph 1.4.14**, the onset of behavioural response threshold for all marine mammal species is 120 dB re 1 µPa (SPL$_{rms}$) for non-impulsive noise (NMFS, 2023). These disturbance thresholds do not consider the overall duration of the noise or its acoustic frequency distribution to account for species dependent hearing. This is considered very conservative and not necessarily a reflection of an adverse effect, but the onset at which behavioural responses may start to occur for certain sensitive species.

1.8.10 Furthermore, it is important to note that ambient noise levels in the areas where work is proposed could exceed this value (as discussed in Volume 3, Chapter 4: Marine mammals and Turtles of the ES) and hence highlights the very precautionary nature of this criterion. On this basis, all receptors are considered to be at low risk of any adverse behavioural responses during the proposed noise emitting activities.

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