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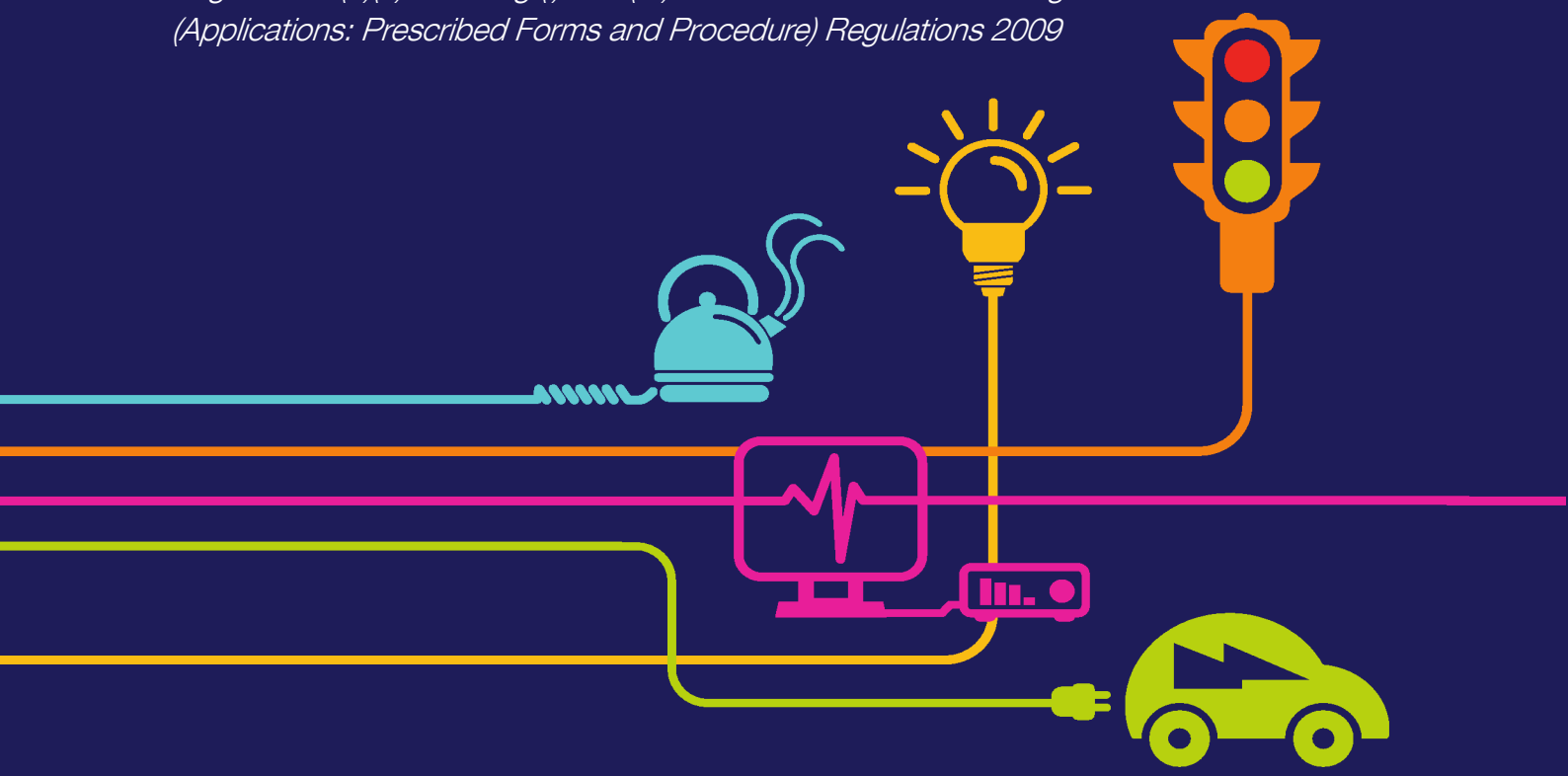
Underwater Construction Noise Modelling and Assessment Report – Effects upon Marine Mammals and Fish

Chapter 9 – Appendix 18

National Grid (North Wales Connection Project)

Regulation 5(2)(a) including (l) and (m) of the Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009



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1 Introduction

1.1.1 This Appendix presents the modelling approach and assumptions and the potential range of injury and disturbance to marine mammals and fish that could arise from the construction of the tunnel due to underwater noise arising from the tunnelling activity. The tunnel may either be constructed using a Tunnel Boring Machine (TBM) or by Drill and Blast (D&B), these methods are explained in Chapter 4, Construction, Operation, Maintenance and Decommissioning of the Proposed Development (**Document 5.4**). As the sound emissions from the explosives used in the D&B construction method would be the main mechanism of impact relative to the TBM option, and as cetaceans and fish are considered to be the most sensitive potential receptor to sound in the study area, the main focus of this assessment is the potential range of impacts on cetacean and fish species from the D&B tunnelling method, although consideration is also given to potential effects from TBM.

2 Acoustic Concepts and Terminology

2.1.1 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). Because 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 µPa, whereas airborne sound is usually referenced to a pressure of 20 µPa. To convert from a sound pressure level referenced to 20 µPa to one referenced to 1 µPa, a factor of 20 log (20/1) i.e. 26 dB has to be added to the former quantity. Thus 60 dB re 20 µPa is the same as 86 dB re 1 µPa, although differences in sound speed and densities mean that the difference in sound intensity is much more than this from air to water. All underwater sound pressure levels in this report are described in dB re 1 µPa. 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 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.

2.1.2 There are several descriptors used to characterise a sound wave. The difference between the lowest pressure variation (rarefaction) and the highest pressure variation (compression) is the peak to peak (or pk-pk) sound pressure level. The difference between the highest variation (either positive or negative) and the mean pressure is called the peak pressure level. Lastly, the root mean square (rms) sound pressure level is used as a description of the average amplitude of the variations in pressure over a specific time window. These descriptions are shown graphically in Image 2.1.

2.1.3 The rms sound pressure level (SPL) is defined as follows:

$$SPL_{rms} = 10log_{10}\left(\frac{1}{T}\int_{0}^{T}\left(\frac{p^2}{p_{ref}^2}\right)dt\right)$$

2.1.4 The magnitude of the rms sound pressure level for an impulsive sound (such as that from a seismic source array) will depend upon the integration time, T, used for the calculation (Ref 1). It has become customary to utilise the T90 time period for calculating and reporting rms sound pressure levels. This is the interval over which the cumulative energy curve rises from 5% to 95% of the total energy and therefore contains 90% of the sound energy.

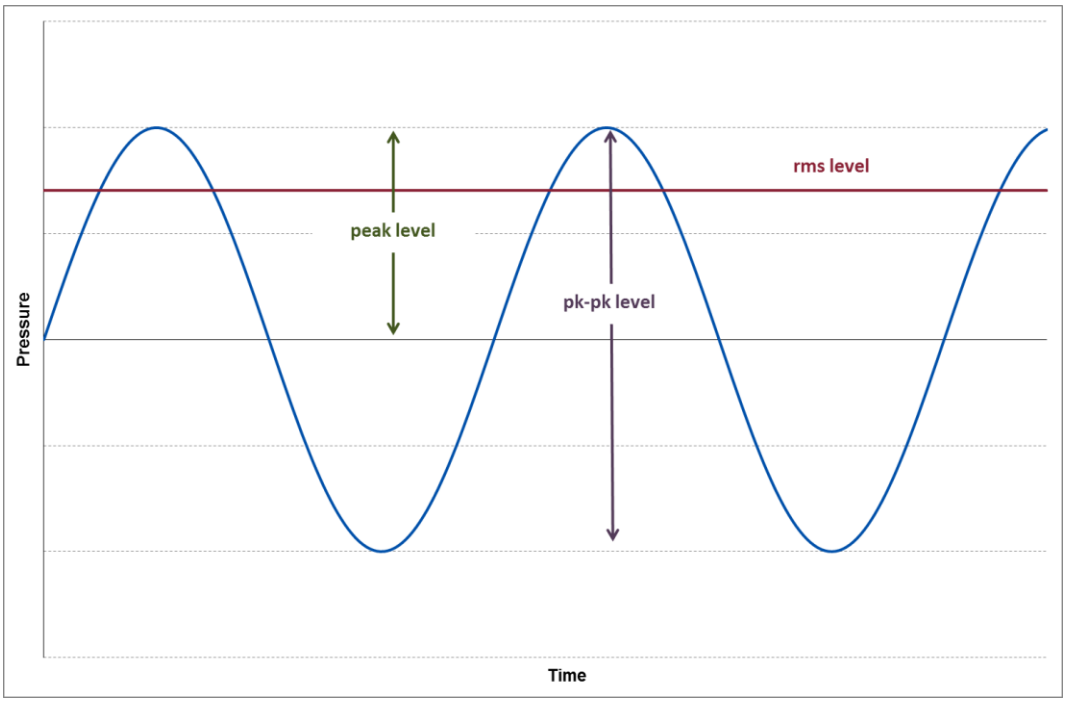

Image 2.1: Graphical representation of acoustic wave descriptors

2.1.5 Another useful measure of sound used in underwater acoustics is the Sound Exposure Level (SEL). This descriptor 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[1]. The SEL is defined as follows:

[1] Historically, use was primarily made of rms and peak sound pressure level metrics for assessing the potential effects of sound on marine life. However, the SEL is increasingly being used as it allows exposure duration and the effect of exposure to multiple events to be taken into account.

$$SEL = 10log_{10}\left(\int_0^T \left(\frac{p^2(t)}{p_{ref}^2 t_{ref}}\right) dt\right)$$

2.1.6 The frequency, or pitch, of the sound is the rate at which these oscillations occur and is measured in cycles per second, or Hertz (Hz). When sound is measured in a way which approximates to how a human would perceive it using an A-weighting filter on a sound level meter, the resulting level is described in values of dBA. However, the hearing faculty of marine mammals is not the same as humans, with marine mammals hearing over a wider range of frequencies and with a different sensitivity. It is therefore important to understand how an animal's hearing varies over the entire frequency range in order to assess the effects of sound on marine mammals. Consequently, use can be made of frequency weighting scales to determine the level of the sound in comparison with the auditory response of the animal concerned. A comparison between the typical hearing response curves for fish, humans and marine mammals is shown in Image 2.2. However, it is worth noting that hearing thresholds are sometimes shown as audiograms with sound level on the y axis rather than sensitivity, resulting in the graph shape being the inverse of the graph shown.

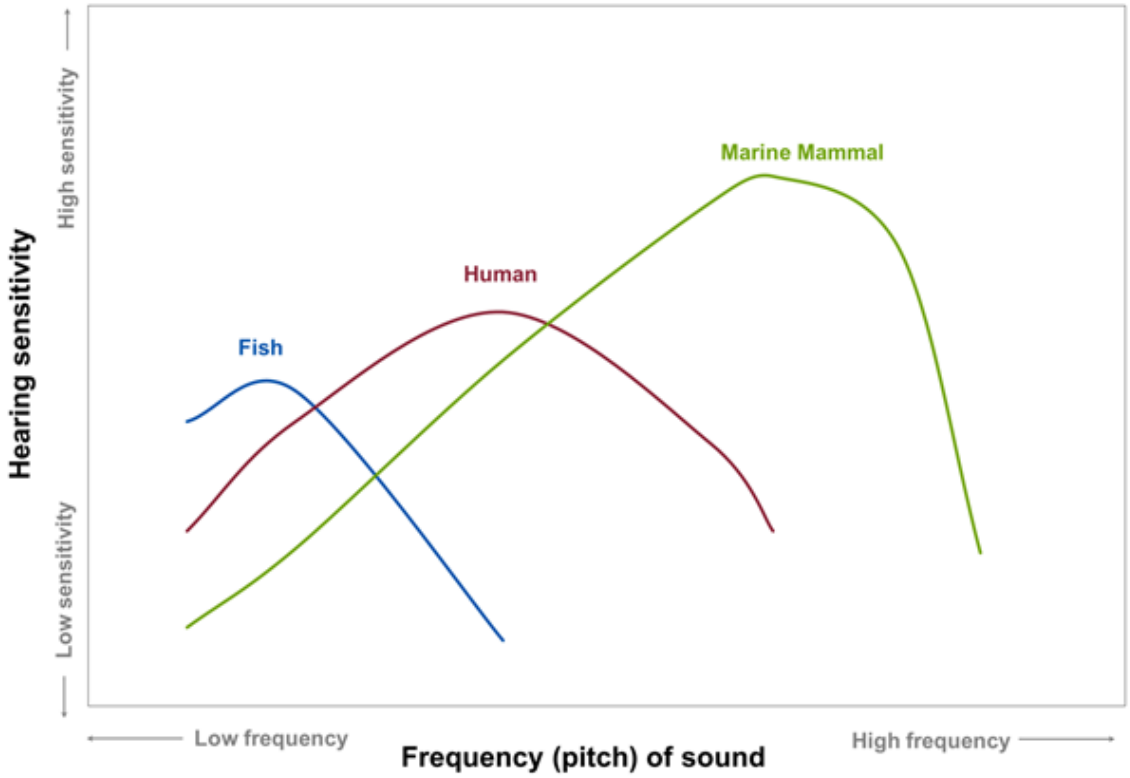

Image 2.2: Comparison between hearing thresholds of different animals

3 Acoustic Assessment Criteria

2.2 INTRODUCTION

3.1.1 Underwater noise has the potential to affect marine life in different ways depending on its noise level and characteristics. Richardson *et al.* (Ref 2) defined four zones of noise influence which vary with distance from the source and level. These are:

- the zone of audibility: this is the area within which the animal is able to detect the sound. Audibility itself does not implicitly mean that the sound will have an effect on marine mammals and fish;
- the zone of masking: This is defined as the area within which noise can interfere with detection of other sounds such as communication or echolocation clicks. This zone is very hard to estimate due to a paucity of data relating to how marine mammals and fish detect sound in relation to masking levels (for example, humans are able to hear tones well below the numeric value of the overall noise level);
- the zone of responsiveness: this is defined as the area within which the animal responds either behaviourally or physiologically. The zone of responsiveness is usually smaller than the zone of audibility because, as stated previously, audibility does not necessarily evoke a reaction; and
- the zone of injury/hearing loss: this is the area where the sound level is high enough to cause tissue damage in the ear. This can be classified as either temporary threshold shift (TTS) or permanent threshold shift (PTS). At even closer ranges, and for very high intensity sound sources (e.g. underwater explosions), physical trauma or even death are possible.

3.1.2 For this study, it is the zones of injury and disturbance (i.e. responsiveness) that are of concern (there is insufficient scientific evidence to properly evaluate masking). In order 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.

3.2 INJURY (PHYSIOLOGICAL DAMAGE) TO MAMMALS

3.2.1 Sound propagation models can be constructed to allow the received noise level at different distances from the source to be calculated. To determine the consequence of these received levels on any marine mammals which might experience such noise emissions, it is necessary to relate the levels to known or estimated impact thresholds. The injury criteria proposed by National Oceanic Atmospheric Administration (NOAA) (Ref 3) are based on a combination of linear (i.e. un-weighted) peak pressure levels and mammal hearing weighted sound exposure levels (SEL). The hearing weighting function is designed to represent the bandwidth for each group within which acoustic exposures can have auditory effects. The categories include:

- **low-frequency (LF) cetaceans** (i.e. marine mammal species such as baleen whales with an estimated functional hearing range between 7 Hz and 35 kHz);
- **mid-frequency (MF) cetaceans** (i.e. marine mammal species such as dolphins, toothed whales, beaked whales and bottlenose whales with an estimated functional hearing range between 150 Hz and 160 kHz);
- **high-frequency (HF) cetaceans** (i.e. marine mammal species such as true porpoises, Kogia, river dolphins and cephalorhynchid with an estimated functional hearing range between 275 Hz and 160 kHz);
- **phocid pinnipeds (PW)** (i.e. true seals with an estimated functional hearing range between 50 Hz and 86 kHz); and
- **otariid pinnipeds (OW)** (i.e. sea lions and fur seals with an estimated functional hearing range between 60 Hz and 39 kHz).

3.2.2 These weightings have therefore been used in this study and are shown in Image 3.1.

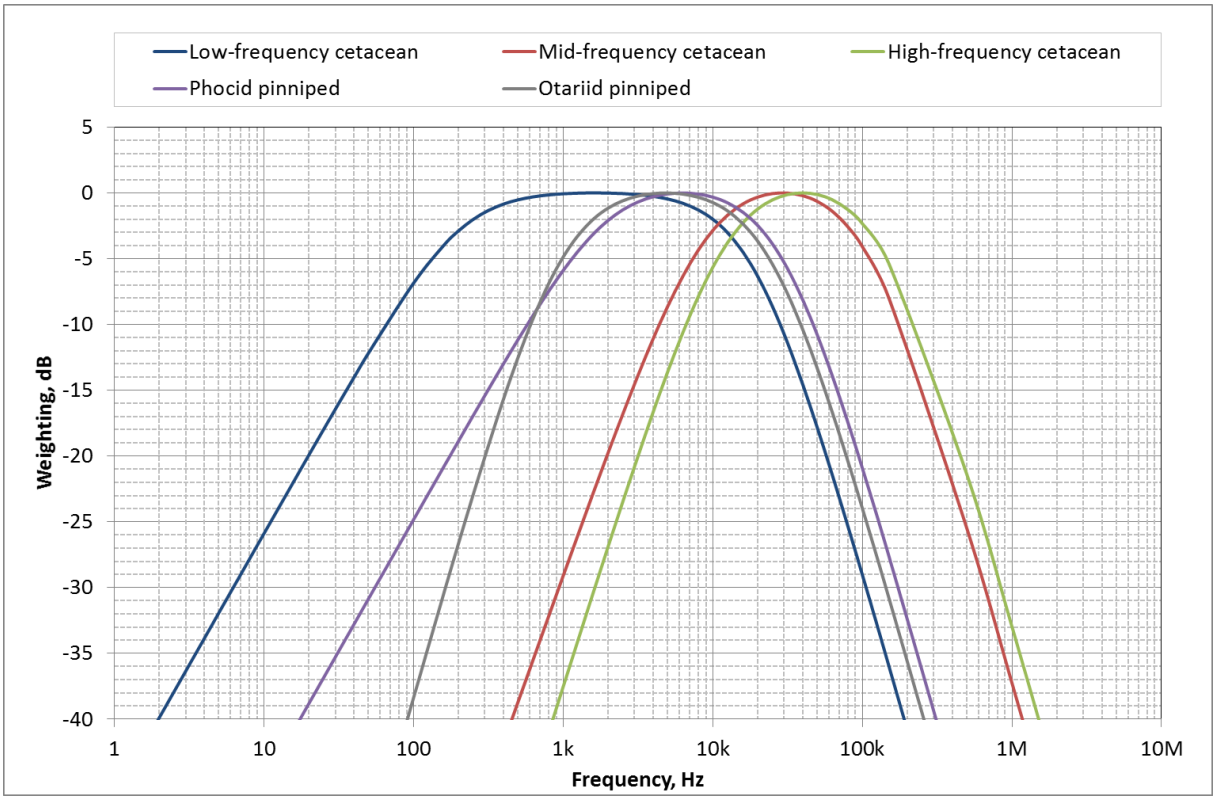

Image 3.1: Hearing weighting functions for pinnipeds and cetaceans (NOAA, 2015)

3.2.3 Injury criteria proposed by NOAA (Ref 3) are for two different types of sound as follows:

- **impulsive sounds** which are typically transient, brief (less than one second), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay (Ref 4; Ref 5; Ref 6). This category includes sound sources such as seismic surveys, impact piling and underwater explosions; and

- **non-impulsive sounds** which can be broadband, narrowband or tonal, brief or prolonged, continuous or intermittent and typically do not have a high peak sound pressure with rapid rise/decay time that impulsive sounds do (Ref 7; Ref 5). This category includes sound sources such as continuous running machinery, sonar and vessels.

3.2.4 The criteria for impulsive sound has been adopted for assessing the effects of sound due to D&B this study given the nature of the sound produced by the explosives. The criteria proposed by NOAA (Ref 3) for impulsive sounds, including the use of explosives, are as summarised in Table 3.1.

Table 3.1: Summary of PTS onset acoustic thresholds (Ref 3)			
Hearing Group	Parameter	Impulsive	Non-impulsive
Low-frequency (LF) cetaceans	Peak, unweighted	219	-
	SEL, LF weighted	183	199
Mid-frequency (MF) cetaceans	Peak, unweighted	230	-
	SEL, MF weighted	185	198
High-frequency (HF) cetaceans	Peak, unweighted	202	-
	SEL, HF weighted	155	173
Phocid pinnipeds (PW)	Peak, unweighted	218	-
	SEL, PW weighted	185	201

3.3 DISTURBANCE TO MAMMALS

3.3.1 Beyond the area in which injury may occur, the effect on marine mammal behaviour is the most important measure of impact. The Joint Nature Conservancy Council (JNCC) guidance (Ref 8) proposes that a disturbance offence may occur when there is a risk of animals incurring sustained or chronic disruption of behaviour or when animals are displaced from an area, with subsequent redistribution being significantly different from that occurring due to natural variation.

3.3.2 To consider the possibility of a disturbance offence resulting from the Proposed Development, it is necessary to consider both the likelihood that the sound could cause non-trivial disturbance and the likelihood that the sensitive receptors would be exposed to that sound.

3.3.3 For this study a precautionary approach has been adopted to assessing the potential for behavioural effects. For a single pulse, Southall *et al.* (Ref 9) recommends behavioural criteria should be based on temporary threshold shift (TTS) onset levels because TTS can deter animals from the ensonified area. This is often referred to as a 'fleeing response'. This assessment has therefore been carried out using the most recent NOAA guidelines (Ref 3) for the onset of TTS due to explosions, as shown in Table 3.2.

Table 3.2: Summary of disturbance and TTS onset acoustic thresholds (Ref 3)			
Hearing Group	Parameter	Impulsive	Non-impulsive
Low-frequency (LF) cetaceans	Peak, unweighted	213	-
	SEL, LF weighted	168	184
Mid-frequency (MF) cetaceans	Peak, unweighted	224	-
	SEL, MF weighted	170	183
High-frequency (HF) cetaceans	Peak, unweighted	196	-
	SEL, HF weighted	140	158
Phocid pinnipeds (PW)	Peak, unweighted	212	-
	SEL, PW weighted	170	186

3.4 INJURY AND DISTURBANCE TO FISH

3.4.1 The most relevant criteria for injury to fish are considered to be those contained in the recent Sound Exposure Guidelines for Fishes and Sea Turtles (Ref 10). The guidelines set out criteria for injury due to different sources of noise. Those relevant to the Proposed Development are considered to be those for injury due to explosive noise[2]. The criteria include a range of indices including SEL, rms and peak sound pressure levels. Where insufficient data exist 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). It should be noted that these qualitative criteria 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.

3.4.2 The injury criteria used in this noise assessment are given in Table 3.3.

[2] Guideline exposure criteria for seismic, piling, continuous sound and low and mid-frequency naval sonar are also presented though are not applicable to drill and blast.

Table 3.3: Criteria for injury to fish due to explosives (Ref 10)

Type of animal	Parameter	Mortality and potential mortal injury	Impairment	
			Recoverable injury	TTS
Fish: no swim bladder (particle motion detection)	Peak, dB re 1 µPa	229 - 234	(*Near*) High (*Intermediate*) Low (*Far*) Low	(*Near*) High (*Intermediate*) Moderate (*Far*) Low
Fish: where swim bladder is not involved in hearing (particle motion detection)	Peak, dB re 1 µPa	229 - 234	(*Near*) High (*Intermediate*) High (*Far*) Low	(*Near*) High (*Intermediate*) Moderate (*Far*) Low
Fish: where swim bladder is involved in hearing (primarily pressure detection)	Peak, dB re 1 µPa	229 - 234	(*Near*) High (*Intermediate*) High (*Far*) Low	(*Near*) High (*Intermediate*) High (*Far*) Low

3.4.3 The most recent criteria for disturbance are considered to be those contained in Popper *et al*. (Ref 10) which set out criteria for disturbance due to different sources of noise. As with the injury criteria, the risk of behavioural effects 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), as shown in Table 3.4.

Table 3.4: ASA criteria for disturbance to fish due to explosives (Ref 10)

Type of animal	Relative risk of behavioural effects
Fish: no swim bladder (particle motion detection)	(*Near*) High (*Intermediate*) Moderate (*Far*) Low
Fish: where swim bladder is not involved in hearing (particle motion detection)	(*Near*) High (*Intermediate*) High (*Far*) Low
Fish: where swim bladder is involved in hearing (primarily pressure detection)	(*Near*) High (*Intermediate*) High

Table 3.4: ASA criteria for disturbance to fish due to explosives (Ref 10)	
Type of animal	Relative risk of behavioural effects
	(*Far*) Low

3.4.4 It is important to note that the Popper *et al*. (Ref 10) criteria for disturbance due to sound are qualitative rather than quantitative. Consequently, a source of noise of a particular type would result in the same predicted impact, no matter the level of noise produced or the propagation characteristics.

4 Source Noise Levels and Modelling Methodology

4.1 TUNNEL BORING MACHINE

4.1.1 Transport Research Laboratory (TRL) report 429 (Ref 11) provides a summary of measured peak particle velocity (PPV) levels due to use of TBMs in a number of substrates. Thus, the maximum PPV level encountered for a TBM in rock with 10 m cover was 1.5 mm/s. Taking into account the sound power transmission coefficient from the rock formation to the sediment and water this equates to a peak sound pressure level of approximately 178 dB re 1 μPa (pk) or an rms sound pressure level of 175 dB re 1 μPa (rms) in the water column immediately adjacent to the seabed in the vicinity of the TBM.

4.1.2 Sound due to TBM would be primarily low frequency in content (<500 Hz). With reference to Image 3.1, it is clear that acoustic energy from TBM activities would fall outside the peak hearing sensitivity of mid frequency and high frequency cetaceans as well as pinnipeds. Even for low frequency cetaceans, a marine mammal would need to be located at the very bottom of the water column immediately above the TBM for a prolonged continuous period of several hours in order to be exposed to SEL levels which could cause potential injury. This is considered to be an implausible scenario.

4.1.3 Consequently, taking into account both the level and frequency of TBM noise, it is considered highly unlikely that tunnelling by TBM would result in injury or disturbance to marine life and noise from this activity has therefore not been considered further in this study.

4.2 DRILL AND BLAST

4.2.1 D&B activities involve the drilling of holes in the rock of the progressive tunnel face before charges are set, stemming placed and packed and the charges detonated. Each charge is expected to be approximately 3 to 6 kg with a total maximum weight per round of 300 kg. The equivalent charge weight per cubic meter of rock would be approximately 1.9 to 2 kg/m^3. Up to six rounds would be expected per day depending on rock quality and round length and any additional pre-grouting or pre-support requirements. Detailed assessments of the delay and blast patterns have not yet been designed and are highly dependent on contractor preference and rock quality.

- co-operating charge (charge per delay): 3 - 6 kg
- maximum total blast weight per round: 300 kg
- charge weight per m^3 rock: 1.9 - 2 kg/m^3

4.2.2 It should be noted that with poorer quality rock (which could be encountered along the tunnel alignment where there is significant fracturing) shorter blast rounds with lower charge weights would be expected. For example, it may be possible to reduce the total maximum charge weight to 200 kg. Modelling has therefore been conducted using a total maximum weight of 300 kg for rock and 200 kg for faulted rock to provide a range of the likely effects of drill and blast.

4.2.3 There is considerable literature on the peak pressures that arise due to underwater explosive operations (e.g. Ref 12; Ref 13: Ref 14; Ref 15; Ref 16). However, following an extensive literature review, it has not been possible to find any specific data relating to use of explosive charges for D&B operations for use in tunnel construction. Consequently, a series of worst-case assumptions have been made in order to estimate the likely source noise levels and propagation of sound away from the proposed operations.

4.2.4 The method used in this assessment to determine the peak pressure level is that set forward in Minerals Management Service (MMS) (Ref 17) for TNT charges buried some distance below the seabed. The expression for estimating the value of peak pressure (P_{pk}) (in Pa) for a charge buried some distance below the seabed is as follows:

$$P_{pk} = 5.24 \times 10^7 \left(\frac{W^{1/3}}{R}\right)^{\varepsilon} \left(\frac{a+b}{b}\right)^{\varepsilon-\alpha}$$

4.2.5 Where W is the TNT charge weight in kilograms and R is the range from the explosive in metres, a is the distance above the seabed, b is the charge depth below the seabed, ε is the bottom attenuation coefficient and α is the attenuation coefficient in water.

4.2.6 The only (known) reference to date that gives a specific relationship between values of underwater SEL and peak pressure is that associated with the Hay Point Coal Terminal (Ref 18). This document sets forward a best-fit curve between SEL and peak pressure for that development based upon measurements made by the University using “small explosive charges”. The specific relationship is given by the expression:

SEL = K x SPL(pk)

4.2.7 Where K = 0.8859 and SPL(pk) = peak sound pressure level in dB re 1 μPa. This reference advises the standard deviation in the estimate of K as 0.0143.

4.2.8 As the criteria for assessing physiological damage due to peak noise levels are based on un-weighted overall levels, there is no need to take the frequency content into account in this calculation. For assessing physiological damage using the NOAA weighted SEL criteria it is, however, necessary to account for frequency. For this purpose, a reference frequency spectrum has been taken from Nedwell and Howell (Ref 15) and applied to the calculated source levels. Attenuation due to molecular absorption in the water at various distances was also taken into account (this being frequency dependant).

4.2.9 As mentioned previously, the shots are not being fired in open water but are being fired inside bored holes inside the rock structure. At the closest point to the water column, the charges would be detonated in either Loggerheads Limestone Formation or Menai Strait Formation rock. Above this would be a layer of glacial till.

4.2.10 When a sound wave encounters a material with an acoustic impedance (Z) that is different to the propagation medium the sound is partially reflected. A larger difference in acoustic impedance (which is a function of density and speed of sound in the medium) between the two mediums leads to a larger proportion of the wave being reflected, and therefore a smaller proportion of the wave energy being transmitted into the other medium.

4.2.11 For plane waves, the acoustic impedance can be approximated by $Z = \rho c$ where ρ is the density of the medium and c is the speed of sound in the medium. The reflection coefficient R is given by the formula:

$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

4.2.12 Where Z_1 and Z_2 are the acoustic impendences of the two mediums. The sound power transmitted into the medium is given by $T = 1 - R^2$.

4.2.13 The reflection coefficient can also be calculated for multiple layers using formulae contained in Jensen (Ref 19), Brekhovskikh and Lysanov (Ref 20) and Kinsler *et al.* (Ref 21). Image 4.1 shows the case for three layers of differing acoustic impedance.

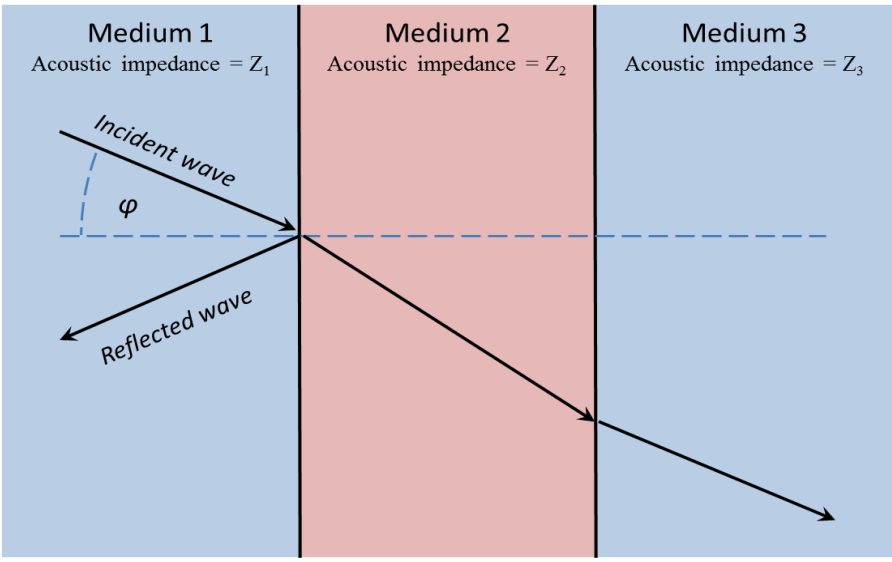

Image 4.1: Transmission of incident waves across two boundaries

4.2.14 The tunnel vertical alignment has been designed using the overwater geophysics survey. A minimum of 10 m of bedrock cover to the top of the tunnel has been designed. At the critical point, there is also an additional 1.5 to 2.5 m of marine sediment overlying bedrock. Based on the information currently available, this is the most likely critical point with respect to ground conditions. However, the following factors have also been considered in the noise model:

- overwater geophysics shows a variable thickness of superficial material (marine sediment over glacial till) overlying bedrock;
- the sediment within the Menai Strait is mobile due to the strong currents (mega-ripples of up to 1 m recorded in the area); and
- a geological fault runs through this area which may cause the rock to be weak/broken/absent to considerable depths.

4.2.15 Consequently, two different worst case ground conditions above the tunnel have been considered in the modelling, as shown in Table 4.1.

Table 4.1: Summary of ground conditions considered in noise modelling

Ground conditions (increasing depth)	Geo-acoustic properties		Layer thickness, m	
	Seismic speed, m/s	Density, kg/m^3	Scenario 1	Scenario 2
Marine Alluvium	1,650	2034	1.5	1.5

Table 4.1: Summary of ground conditions considered in noise modelling				
Ground conditions (increasing depth)	Geo-acoustic properties		Layer thickness, m	
	Seismic speed, m/s	Density, kg/m^3	Scenario 1	Scenario 2
Faulted Rock	3,200	2400	-	10
Rock[3]	3,656	2568	10	-

4.2.16 It should be noted that the "poorer" ground conditions would likely correspond with lower required charge weights (i.e. the ground is weaker, shorter excavation lengths etc.).

[3] Geo-acoustic properties for rock are based on borehole ground investigation laboratory tests for the Menai Strait Formation and Loggerheads Limestone Formation.

5 Results

5.1 ACOUSTIC MODELLING RESULTS

5.1.1 The relationship between peak pressure level and distance is shown in Image 5.1 for a 300 kg and Image 5.2 for a 200 kg charge round detonated at the shallowest point along with the peak pressure injury criteria for potential onset of permanent threshold shift in hearing. Dashed lines represent the PTS onset criteria for each marine mammal hearing group based on the NOAA (Ref 3) thresholds. Calculations based on Goertner (Ref 22) indicate that there is no likelihood of mortal injury to marine mammals at any range.

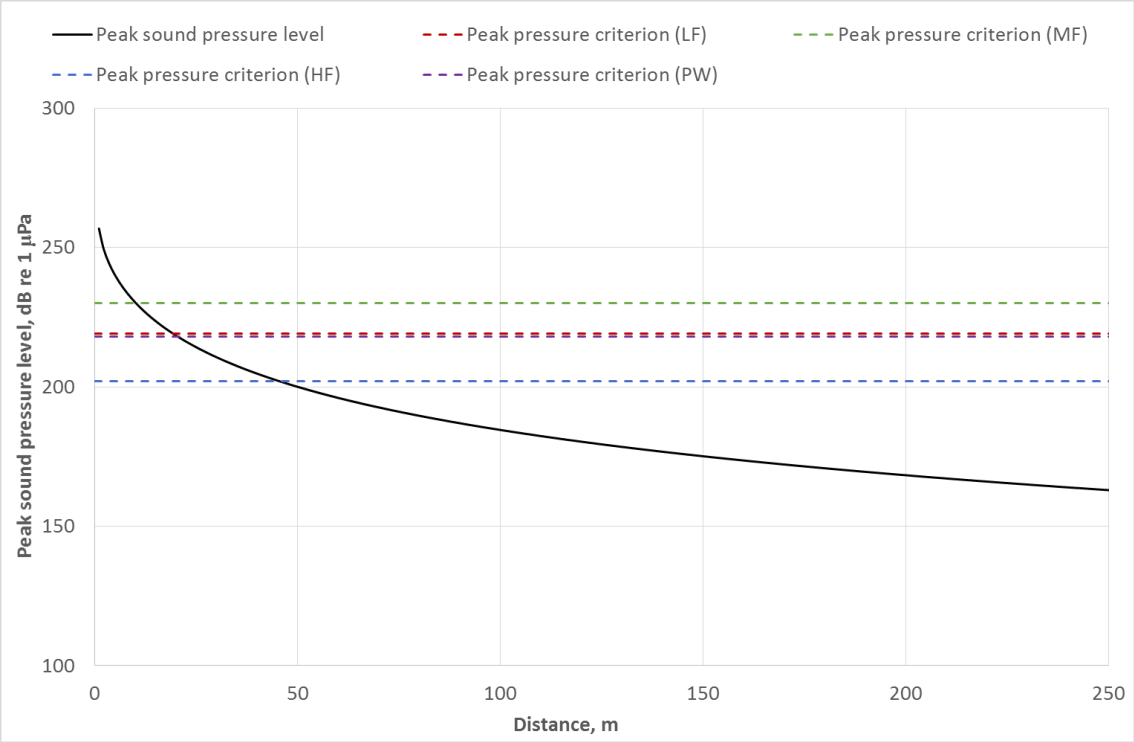

Image 5.1: Predicted ranges for onset of injury criteria due to a 300 kg charge round in rock based on peak SPL thresholds.

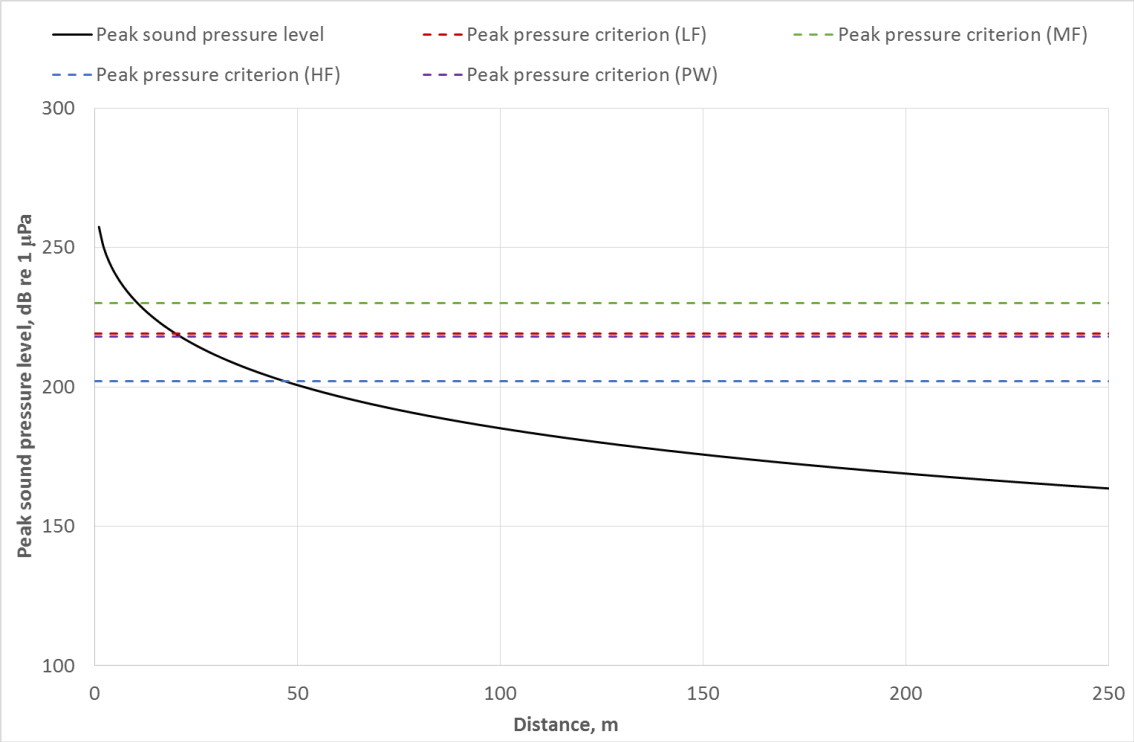

Image 5.2: Predicted ranges for onset of injury criteria due to a 200 kg charge round in faulted rock based on peak SPL thresholds.

5.1.2 The relationship between SEL and distance is shown in Images 5.3 to 5.6 along with the SEL injury criteria. Dashed lines represent the PTS onset criteria for each marine mammal hearing group based on the NOAA (Ref 3) thresholds.

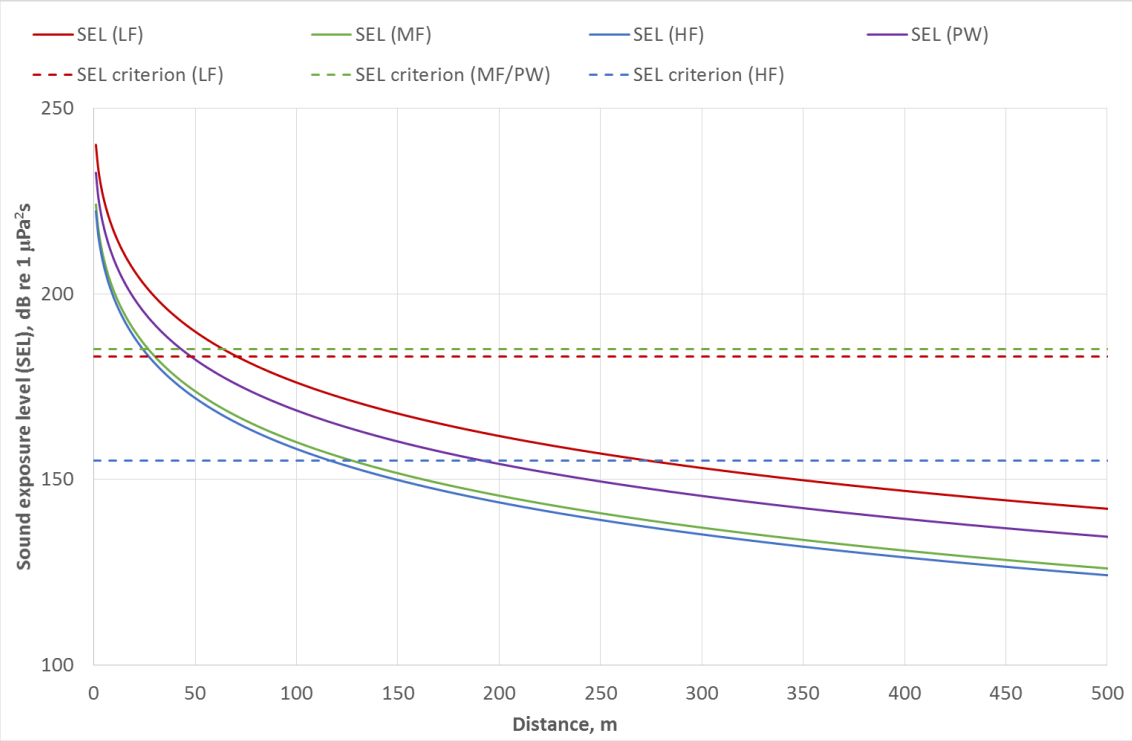

Image 5.3: Predicted ranges for onset of injury criteria due to a 300 kg charge round in rock based on SEL thresholds. (Single round)

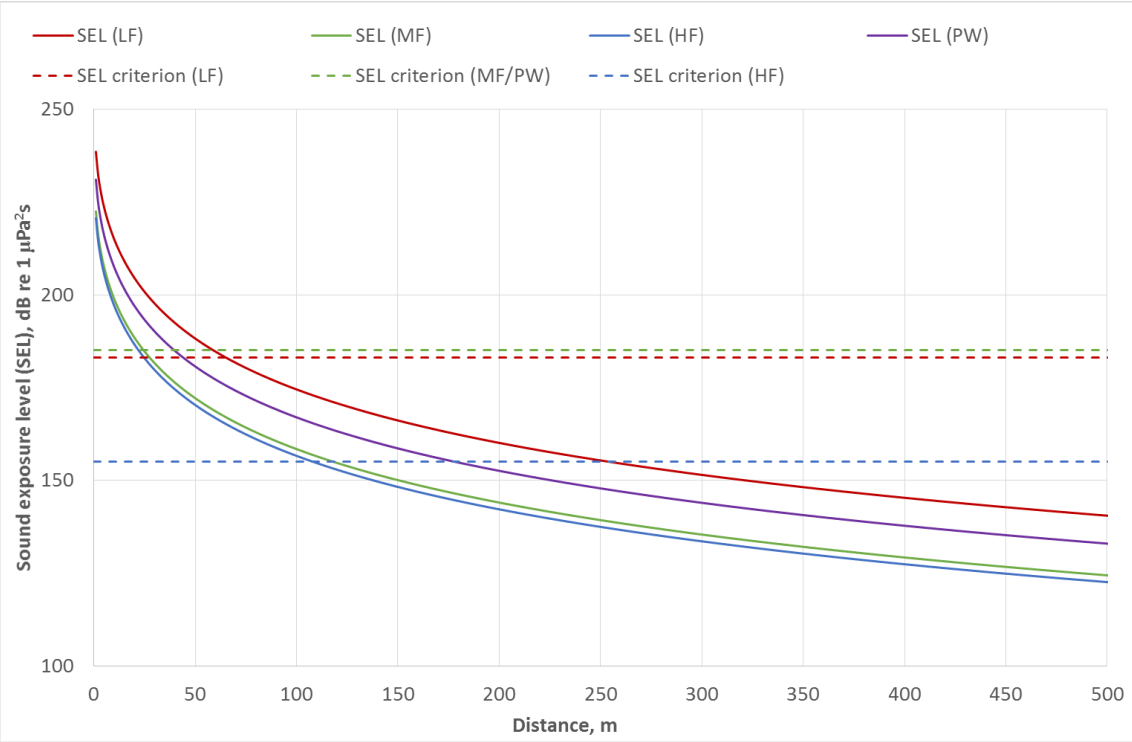

Image 5.4: Predicted ranges for onset of injury criteria due to a 300 kg charge round in rock based on SEL thresholds. (Cumulative exposure for six rounds per day)

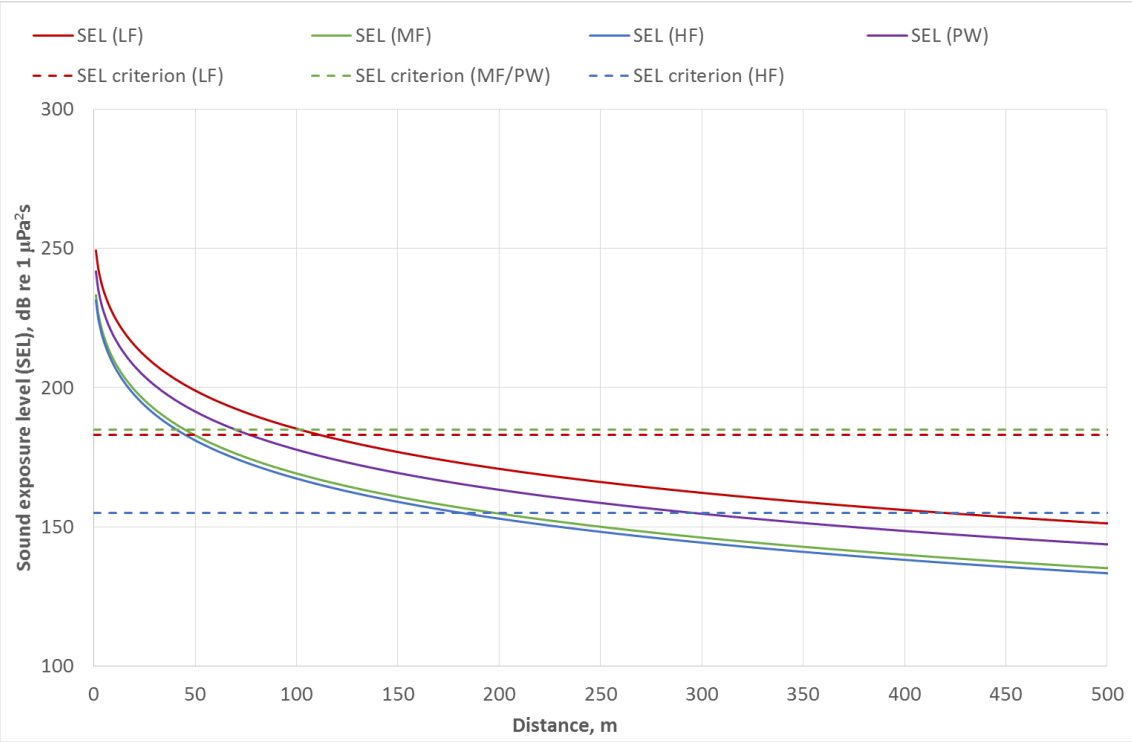

Image 5.5: Predicted ranges for onset of injury criteria due to a 200 kg charge round in faulted rock based on SEL thresholds. (Single Round)

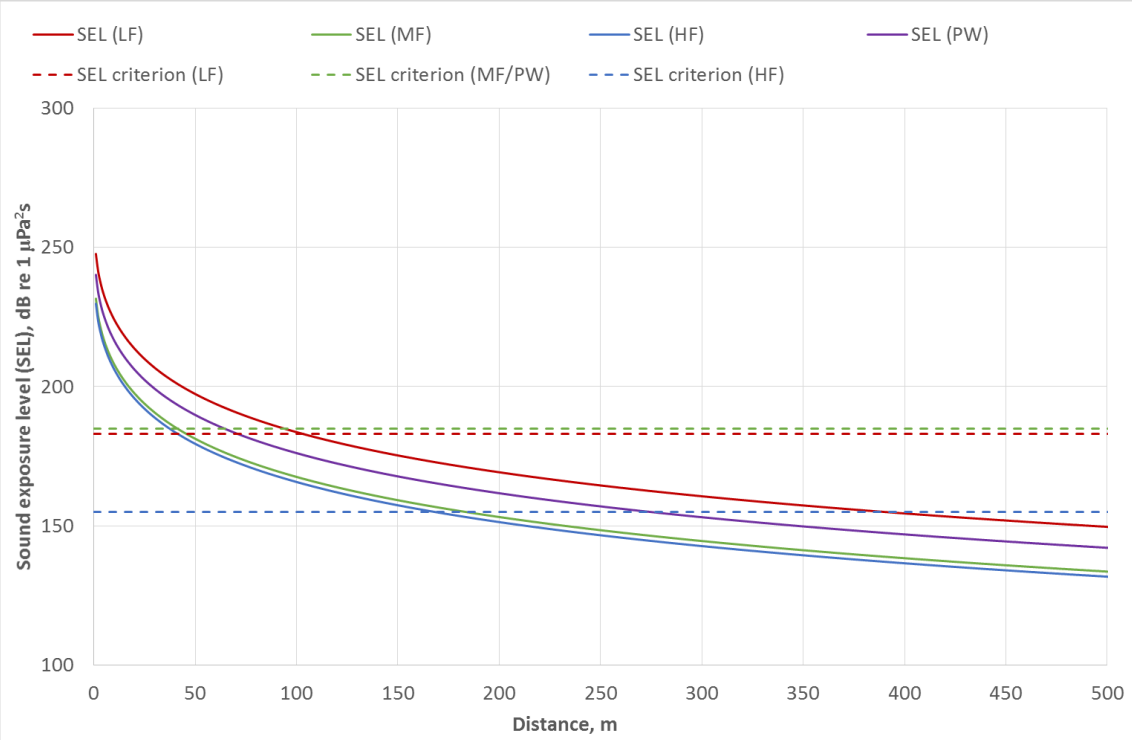

Image 5.6: Predicted ranges for onset of injury criteria due to a 200 kg charge round in faulted rock based on SEL thresholds. (Cumulative exposure for six rounds per day)

5.2 INJURY

5.2.1 The NOAA-weighted SEL and un-weighted peak pressure injury criteria ranges for the various mammal groups is summarised in Table 5.1, based on exposure to a single 300 kg or 200 kg round. The largest of the two injury ranges (SEL or peak) should be used to predict the ranges for each marine mammal group beyond which no injury would occur.

Table 5.1: Summary of maximum injury ranges due to single charge round

Hearing group	Scenario 1 (rock/300 kg)		Scenario 2 (faulted rock/200 kg)	
	Based on peak pressure	Based on SEL	Based on peak pressure	Based on SEL
Low frequency cetaceans	21 m	67 m	22 m	62 m
Mid frequency cetaceans	13 m	28 m	13 m	26 m

Table 5.1: Summary of maximum injury ranges due to single charge round				
Hearing group	Scenario 1 (rock/300 kg)		Scenario 2 (faulted rock/200 kg)	
High frequency cetaceans	44 m	109 m	45 m	101 m
Phocid pinnipeds	22 m	42 m	23 m	39 m
Fish	14 m	-	14 m	-

5.2.2 Based on the results in the table, it is estimated that the maximum possible range at which permanent threshold shift injury could occur for a single round is 109 m for high frequency cetaceans. For other marine mammal hearing groups, the predicted injury ranges are considerably smaller.

5.2.3 The injury ranges for the various mammal groups is summarised in Table 5.2 for exposure to six, 300 kg or 200 kg blast rounds in any 24 hour period. The largest of the two injury ranges (SEL or peak) should be used to predict the ranges for each marine mammal group beyond which no injury would occur. It should be noted that the peak pressure ranges will be the same as determined for a single round because the blasts would not occur at the same time (i.e. peak pressure is used to determine the range for instantaneous injury).

Table 5.2: Summary of maximum injury ranges due to six charge rounds				
Hearing group	Scenario 1 (rock/300 kg)		Scenario 2 (faulted rock/200 kg)	
	Based on peak pressure	Based on SEL	Based on peak pressure	Based on SEL
Low frequency cetaceans	21 m	104 m	22 m	96 m
Mid frequency cetaceans	13 m	43 m	13 m	40 m
High frequency cetaceans	44 m	171 m	45 m	158 m
Phocid pinnipeds	22 m	65 m	23 m	61 m
Fish	14 m	-	14 m	-

5.2.4 Based on the results in the table, it is estimated that the maximum possible range at which permanent threshold shift injury could occur for exposure to six rounds per day increases to 171 m for high frequency cetaceans. For

other marine mammal hearing groups, the predicted injury ranges are considerably smaller.

5.3 DISTURBANCE

5.3.1 The potential maximum disturbance ranges for marine mammals due to a single charge round are summarised in Table 5.3.

Table 5.3: Summary of disturbance and TTS ranges due to charge rounds

Hearing group	Scenario 1 (rock/300 kg)		Scenario 2 (faulted rock/200 kg)	
	Based on peak pressure	Based on SEL	Based on peak pressure	Based on SEL
Low frequency cetaceans	27 m	139 m	28 m	128 m
Mid frequency cetaceans	17 m	57 m	17 m	53 m
High frequency cetaceans	57 m	227 m	58 m	210 m
Phocid pinnipeds	29 m	87 m	29 m	81 m

5.3.2 As shown in Table 5.3, it can be seen that the maximum disturbance range for cetaceans (based on high frequency cetaceans) is 227 m and the maximum disturbance range for pinnipeds is 87 m.

5.3.3 Behavioural changes (e.g. disturbance, such as temporary displacement) which may occur as a result of the noise emissions, do not necessarily imply that detrimental effects would result for the animals involved (Ref 23). In addition, the explosive pulse would be a one off event lasting approximately one second, rather than a continuous sound, minimising the period over which sound is emitted to the environment.

6 Conclusions

6.1.1 Based on the results of the study, it is concluded that:

- groundborne noise due to TBM under the Menai Strait is unlikely to result in injury to marine mammals or fish;
- sound modelling conducted on a single explosive event using a 300 kg charge round predicts that the most sensitive (high frequency) cetacean species exposed to sound within 109 m could experience injury (permanent threshold shift in hearing). This range increase to 171 m for cumulative exposure, based on a maximum of six rounds per day;
- for pinnipeds, injury could occur out to 42 m for exposure to a single round increasing up to 65 m for cumulative exposure to six rounds per day;
- the period of each operation is highly restricted (i.e. approximately one second) and the noise model predicted small potential disturbance zones for all marine mammals of 227 m or less and
- injury to fish could occur out to a range of 14 m (see Image 5.7 in Appendix A for a schematic showing the indicative range of effect with blasting occurring centre channel).

6.1.2 The modelling has been conducted for the most critical location in the Menai Strait with the minimal level of rock cover (10 m). Injury and disturbance ranges will be smaller than predicted in this study if drill and blast is used in areas with deeper rock cover.

6.1.3 The acoustic modelling has been based on a theoretical treatment of sound from drill and blast activities. The real world situation will be much more complex and it is considered likely, in light of the multiple compounded worst case assumptions made in this study, that real world noise levels and impact zones are likely to be lower than predicted.

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Appendix A: Image 5.7 Schematic showing the injury zone from blasting based on a location mid channel

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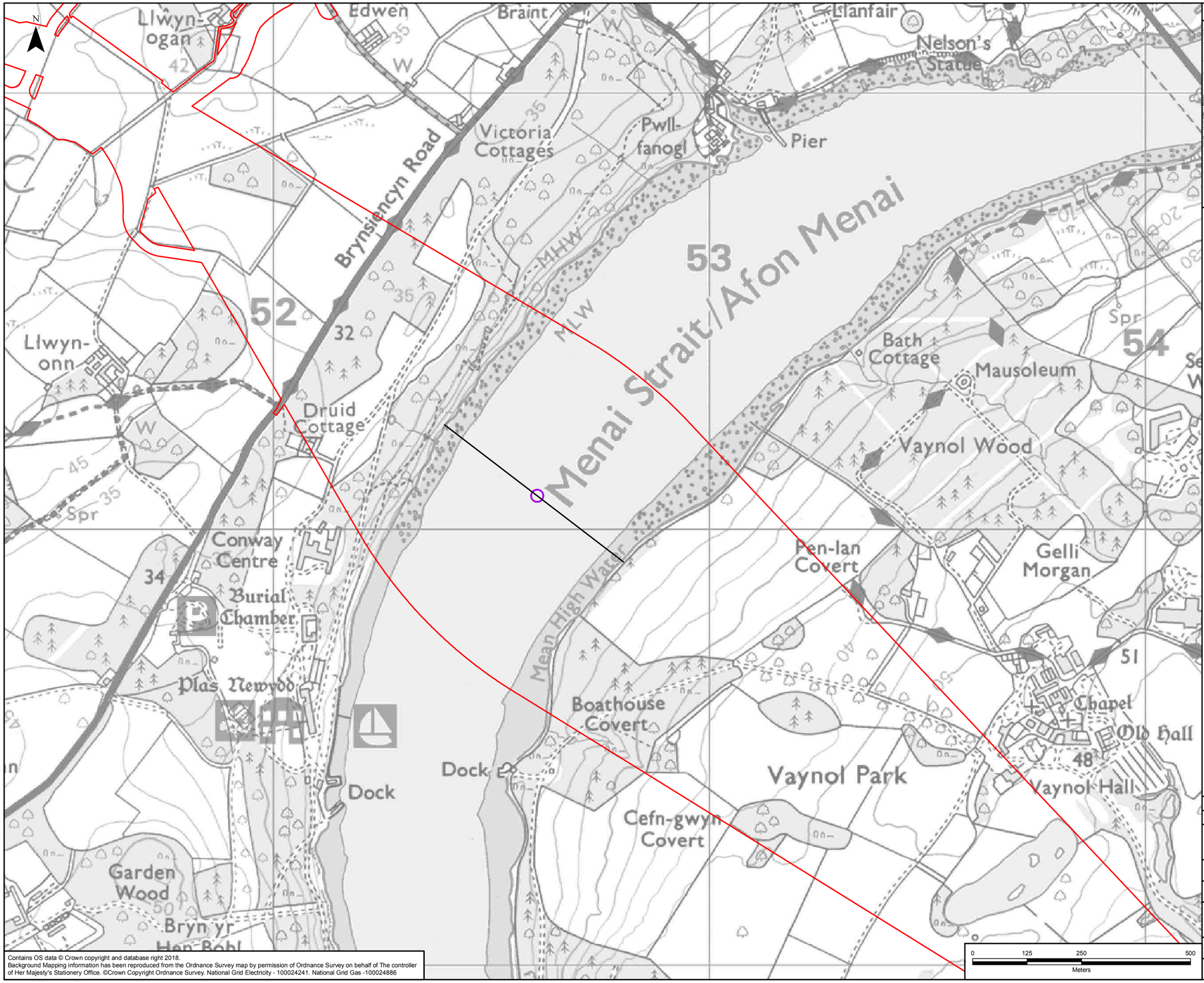
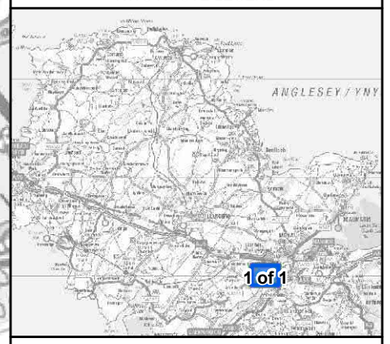


NWC ROUTE LEGEND



LEGEND

- ORDER LIMITS
- INDICATIVE TUNNEL CROSSING ROUTE
- POTENTIAL FISH INJURY ZONE

Rev	Date	Description	GIS	Chk	App
A	28/08/2018	ENVIRONMENTAL STATEMENT	AB	ILE	MR

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