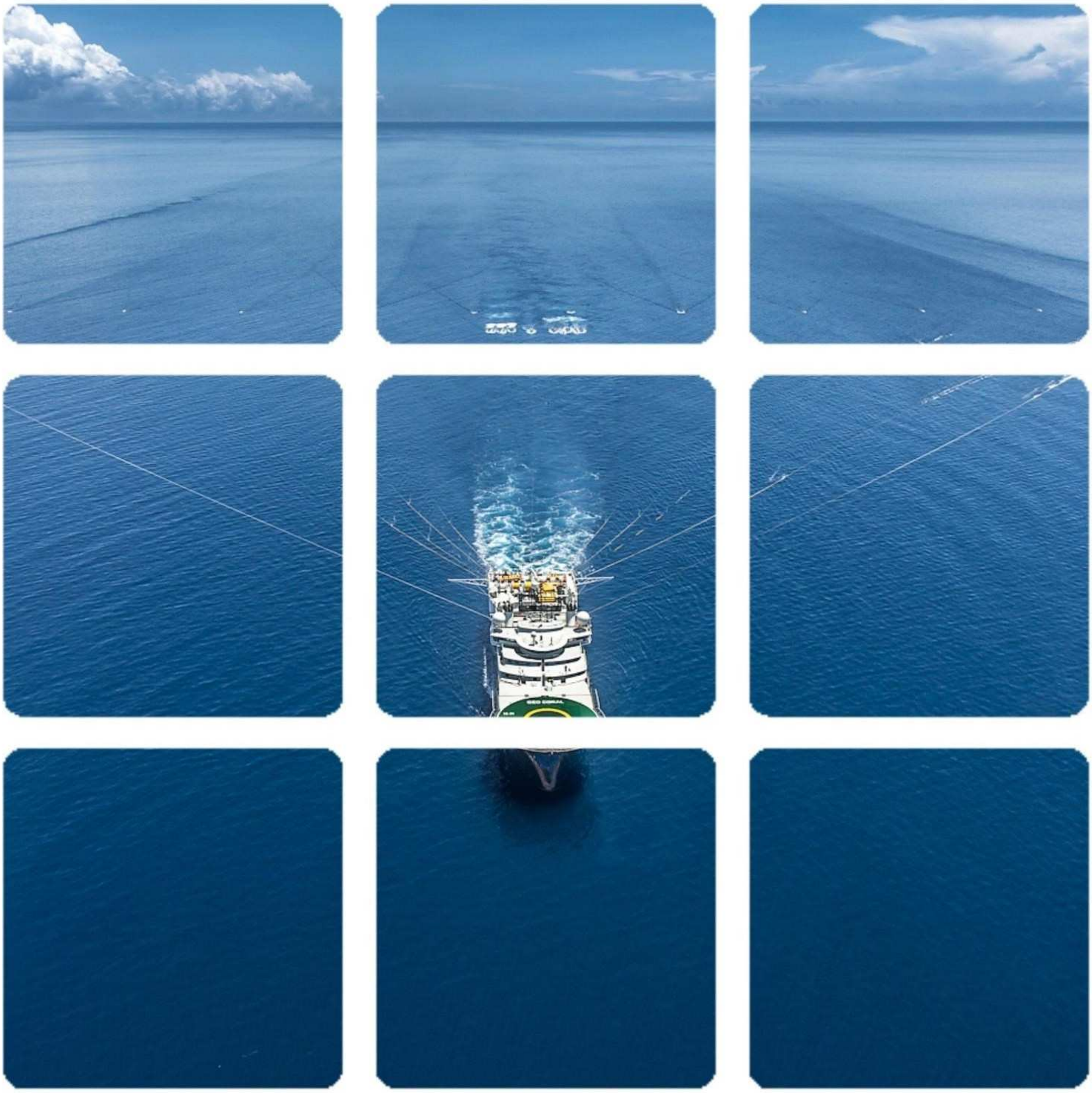
Underwater Acoustic Modelling for 3D Seismic Survey, Offshore Italy

For Proger S.P.A

Report No. JAT10348-REPT-01-R0

03 May 2018



Quality Management

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Report number:	JAT10348-REPT-01-R0		**Date of issue:**	03/05/2018

Revision History

Rev	Date	Status	Reason for revision	Additional comments
0	03/05/2018	Issued for comment	-	-

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Tables, Figures and Appendices

Tables

Figures

1 Introduction

1.1 Eni proposes to undertake a 3D seismic survey offshore in the Sicily Channel, Italy. The closest survey lines to shore are located approximately 26 km south of the Italian coast. The seismic survey areas are located in water of typically 600 to 800 m depth. The location of the survey area is illustrated in Figure 1.1.

1.2 Noise is readily transmitted underwater and there is potential for sound emissions from the survey to affect marine mammals and turtles. At long ranges the introduction of additional noise could potentially cause short-term behavioural changes, for example to the ability of cetaceans to communicate and to determine the presence of predators, food, underwater features and obstructions. At close ranges and with high noise source levels, permanent or temporary hearing damage may occur, while at very close range, gross physical trauma is possible. This report provides an overview of the potential effects due to underwater noise from the survey on the surrounding marine environment.

1.3 The primary purpose of this underwater noise study is to predict the likely range of onset for potential injury (i.e. permanent threshold shifts in hearing) and behavioural effects.

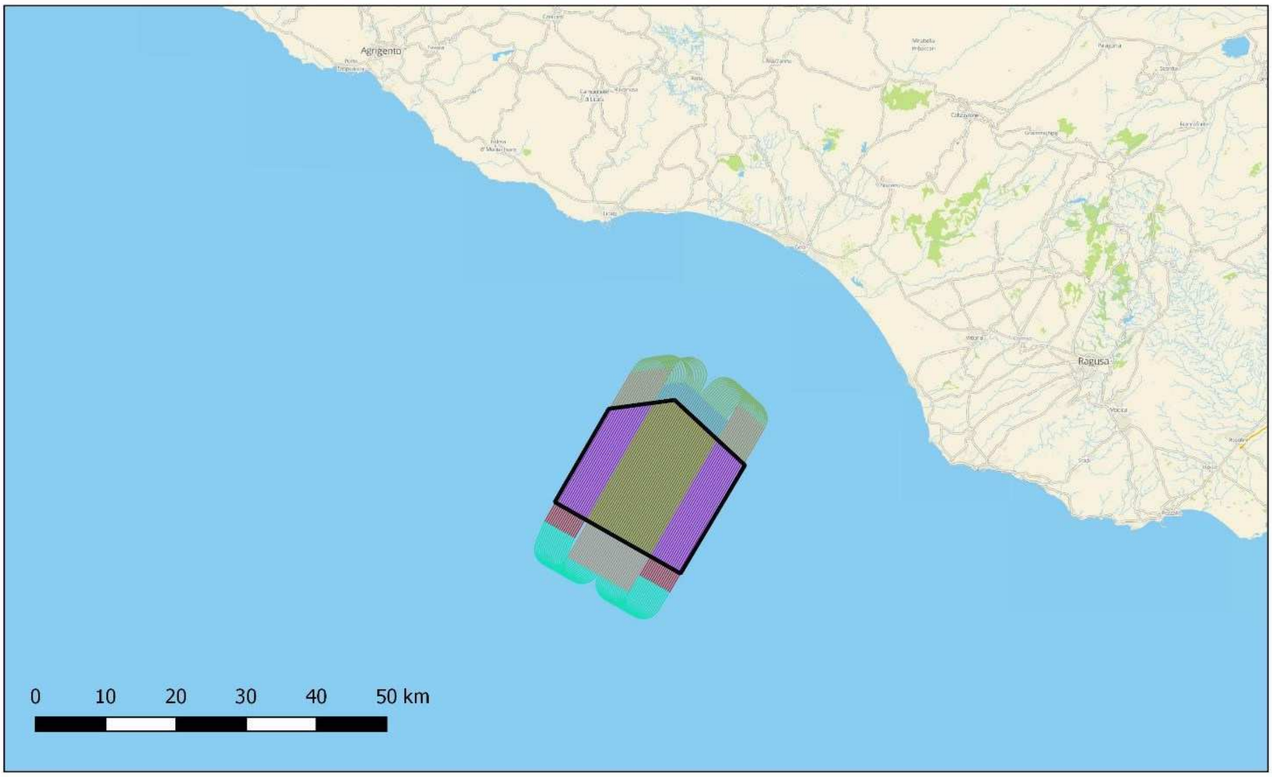


Figure 1.1 Location of survey area

2 Acoustic Concepts and Terminology

2.1 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.

2.2 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 Figure 2.1.

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

$$SPL_{rms} = 10log_{10}\left(\frac{1}{T}\int_0^T\left(\frac{p^2}{p_{ref}^2}\right)dt\right)$$

2.4 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 (Madsen 2005). 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.

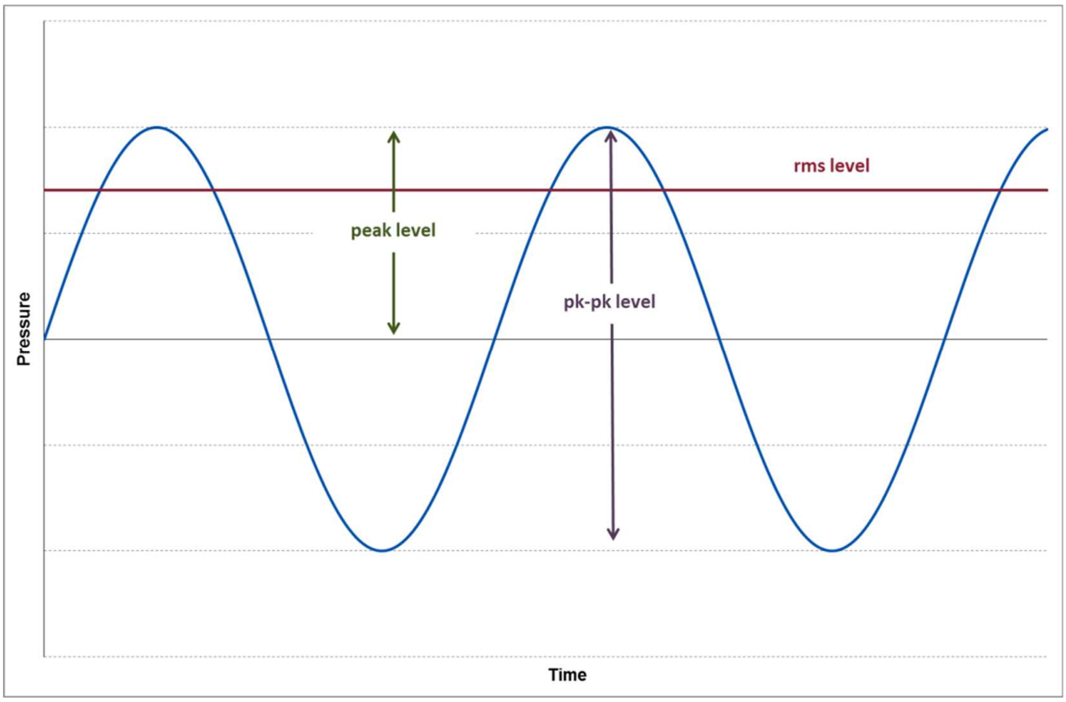


Figure 2.1 Graphical representation of acoustic wave descriptors

2.5 Another useful measure of sound used in underwater acoustics is the Sound Exposure Level, or 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:

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

2.6 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 Figure 2.2. (It is worth noting

[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.*

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.)

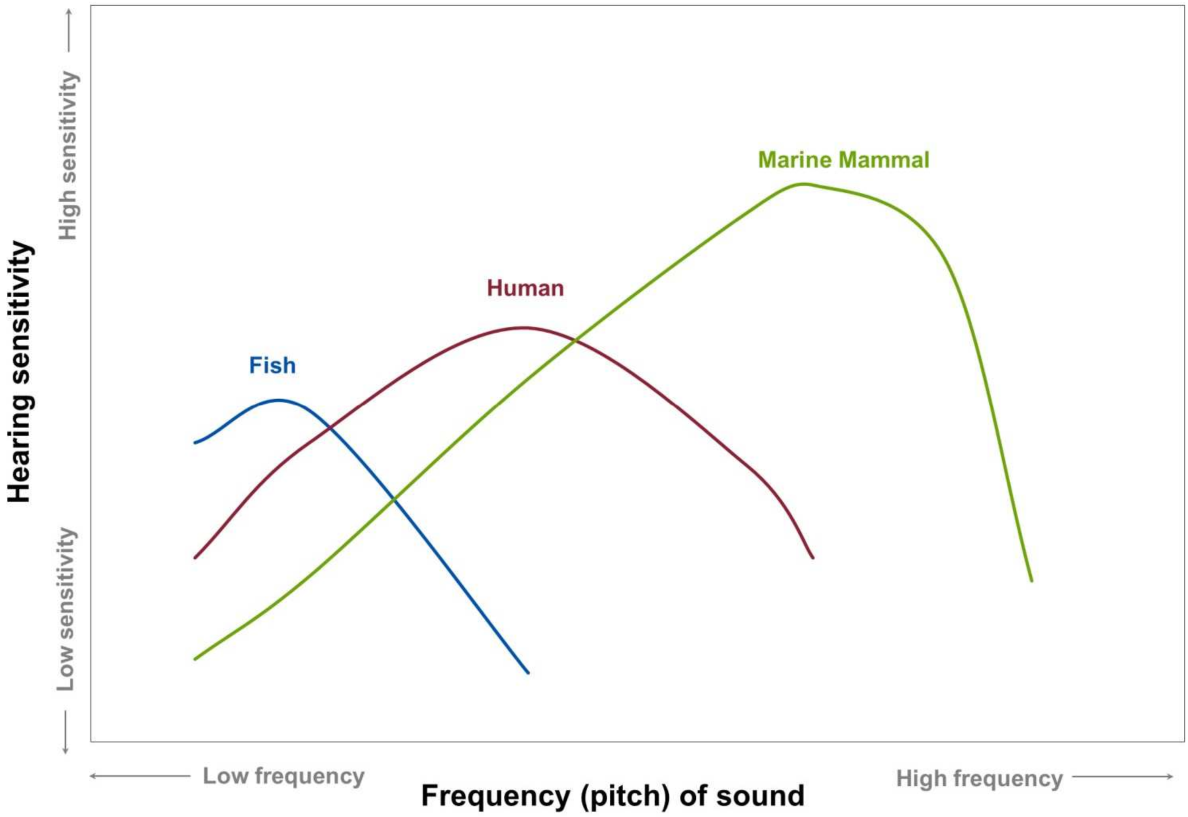


Figure 2.2 Comparison between hearing thresholds of different animals

3 Acoustic Assessment Criteria

Introduction

3.1 Underwater noise has the potential to affect marine life in different ways depending on its noise level and characteristics. Richardson *et al.* (1995) 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 the marine mammal.
- **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 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.
- **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.

3.2 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 onset of effects and describe the evidence base used to derive them.

Injury (Physiological Damage) to Mammals

3.3 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 NOAA (2016) 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 dolphons 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).

3.4 These weightings have therefore been used in this study and are shown in Figure 3.1.

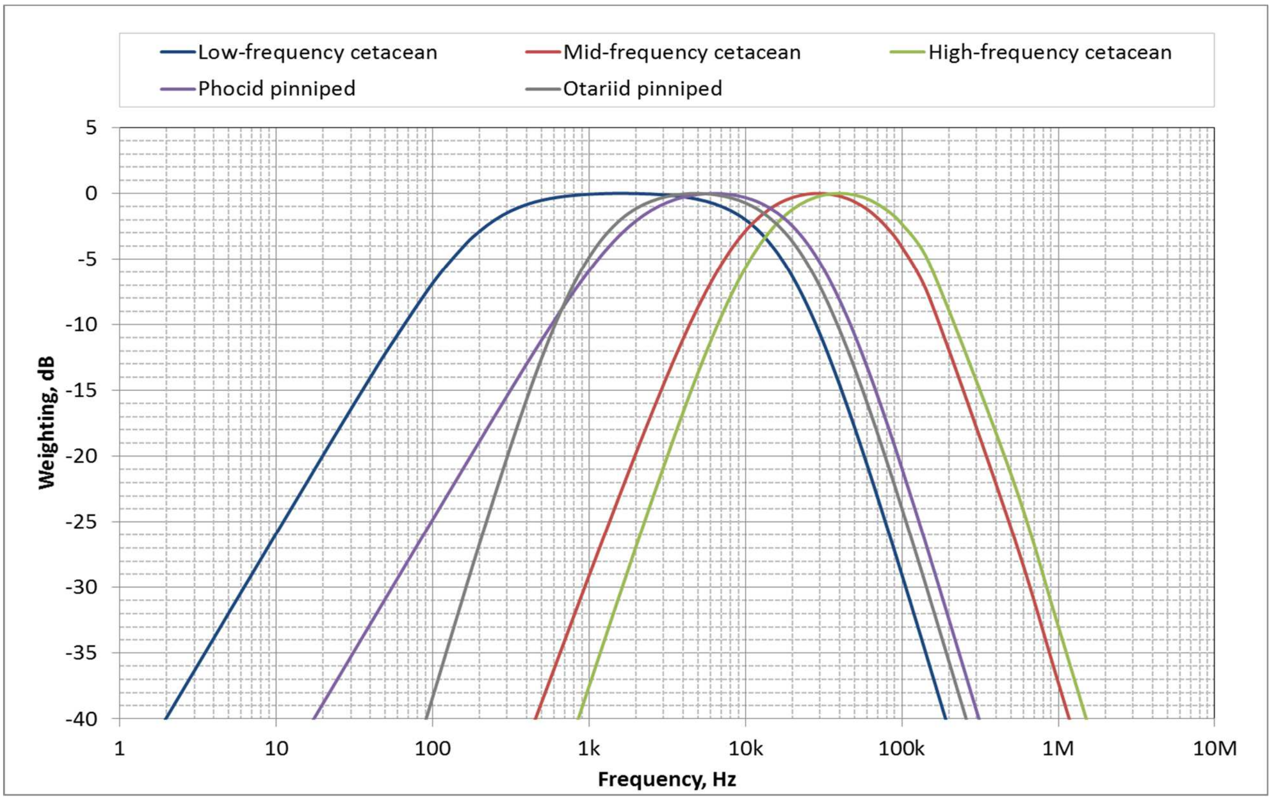


Figure 3.1 Hearing weighting functions for pinnipeds and cetaceans (NOAA, 2015)

3.5 Injury criteria are proposed in NOAA (2016) are for two different types of sound as follows:

- **Impulsive sounds** which are typically transient, brief (less than 1 second), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay (ANSI 1986; NIOSH

  1998; ANSI 2005). 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 (ANSI 1995; NIOSH 1998). This category includes sound sources such as continuous running machinery, sonar and vessels.

3.6 The criteria for impulsive sound has been adopted for this study given the nature of the sound source used during seismic surveys, where the sound source is activated at regular intervals as a seismic vessel traverses along a pre-determined data acquisition sail-line. Since noise from the vessel is of significantly lower magnitude than noise emitted by the airguns, and since the two noise sources would not act additively to result in increased noise emissions compared to the airguns themselves, noise emissions from the vessel are not considered in the modelling.

3.7 The relevant criteria proposed by NOAA (2016) are as summarised in Table 3.1.

Table 3.1 Summary of PTS onset acoustic thresholds (NOAA 2016)

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
Otariid pinnipeds (OW)	Peak, unweighted	232	-
	SEL, OW weighted	203	219

Disturbance to Mammals

3.8 Beyond the area in which injury may occur, the effect on marine mammal behaviour is the most important measure of impact. Significant disturbance may occur when there is a risk of a significant group of animals incurring sustained or chronic disruption of behaviour or when a significant group of animals are displaced from an area, with subsequent redistribution being significantly different from that occurring due to natural variation.

3.9 To consider the possibility of disturbance resulting from the proposed seismic operations, it is necessary to consider both the likelihood that the sound could cause disturbance and the likelihood that the sensitive receptors (marine mammals) will be exposed to that sound. Southall *et al*. (2007) recommended that the only currently feasible way to assess whether a specific sound could cause disturbance is to compare the circumstances of the situation with empirical studies. The more severe the response on the scale, the lower the amount of time that the animals will tolerate it before there could be significant negative effects on life functions.

3.10 Southall *et al.* (2007) present a summary of observed behavioural responses during various seismic surveys. However, although these datasets contain much relevant data for low-frequency cetaceans, there is no strong data for mid-frequency or high-frequency cetaceans. Low-frequency cetaceans other than bow-head whales were typically observed to respond significantly at a received level of 140 to 160 dB re 1 µPa (rms). Behavioural changes at these levels during multiple pulses of the source may have included visible startle response, extended cessation or modification of vocal behaviour, brief cessation of reproductive behaviour or brief / minor separation of females and dependent offspring.

3.11 The data that are available for mid-frequency cetaceans indicate that some significant response was observed at a sound pressure level of 120 - 130 dB re 1µPa (rms), however the majority of cetaceans in this category did not display behaviours of this severity until exposed to a level of 170 to 180 dB re 1µPa (rms). Furthermore, other mid-frequency cetaceans within the same study were observed to have no behavioural response even when exposed to a level of 170 – 180 dB re 1µPa (rms).

3.12 According to Southall *et al*. (2007) there is a general paucity of data relating to the effects of sound on pinnipeds in particular. One study using ringed, bearded and spotted seals (Harris *et al*., 2001) found onset of a significant response at a received sound pressure level of 160 to 170 dB re 1 µPa (rms), although larger numbers of animals showed no response at noise levels of up to 180 dB re 1 µPa (rms). It is only at much higher sound pressure levels in the range of 190 to 200 dB re 1 µPa (rms) that significant numbers of seals were found to exhibit a significant response. For non-pulsed sound, one study elicited a significant response on a single harbour seal at a received level of 100 to 110 dB re 1 µPa (rms), although other studies found no response or non-significant reactions occurred at much higher received levels of up to 140 dB re 1 µPa (rms). No data are available for higher noise levels and the low number of animals observed in the various studies means that it is difficult to make any firm conclusions from these studies.

3.13 Southall *et al*. (2007) also notes that, due to the uncertainty over whether high-frequency cetaceans may perceive certain sounds and due to paucity of data, it was not possible to present any data on responses of high frequency-cetaceans. However, Lucke *et al*. (2008) showed a single harbour porpoise consistently showed aversive behavioural reactions at received sound pressure levels above 174 dB re 1 μPa (peak-peak) or a SEL of 145 dB re 1 $\mu Pa^2 s$, equivalent to an estimated[2] rms sound pressure level of 166 dB re 1 μPa.

3.14 The High Energy Seismic Survey workshop on the effects of seismic sound on marine mammals (HESS 1997) concluded that mild behavioural disturbance would most likely occur at sound levels greater than 140 dB re 1 μPa (rms). This workshop drew on several studies but recognised that there was some degree of variability in reactions between different studies and mammal groups. This value is similar to the lowest threshold for disturbance of low-frequency cetaceans noted in Southall et al. (2007). It is, however, considered unlikely that a threshold for the onset of mild disturbance effects could be defined as significant disturbance.

3.15 Clearly, there is much intra-category and perhaps intra-species variability in behavioural response. Therefore, this assessment adopts a conservative approach and uses the US National Marine Fisheries Service (NMFS 2005) Level B harassment threshold of 160 dB re 1 μPa (rms) for impulsive sound. Level B Harassment is defined as having the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioural patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering but which does not have the potential to injure a marine mammal or marine mammal stock in the wild. This is similar to the JNCC (2010 in prep) description of non-trivial disturbance and has therefore been used as the basis for onset of behavioural change in this assessment.

3.16 It is important to understand that exposure to sound levels in excess of the behavioural change threshold stated above does not necessarily imply that the sound will result in significant disturbance. As noted previously, it is also necessary to assess the likelihood that the sensitive receptors will be exposed to that sound and whether the numbers exposed are likely to be significant at the population level.

[2] *Based on an analysis of the time history graph in Lucke et al. (2007) the T90 period is approximately 8 ms, resulting in a correction of 21 dB applied to the SEL to derive the rms T90 sound pressure level. However, the T90 was not directly reported in the paper.*

Marine Mammal Criteria Summary

3.17 The criteria used in this assessment are summarised in Table 3.2.

Table 3.2 Proposed criteria for marine mammals

Effect	Criteria		
Behavioural change	Exceedance of criteria in NMFS (2005) for impulsive sound: rms sound pressure level greater than 160 dB re 1 μPa		
Physiological damage (injury)	Exceedance of NOAA (2016) criteria for PTS due to impulsive sound:		
	Low-frequency (LF) cetaceans	peak pressure level	219 dB re 1 μPa
		SEL	183 dB re 1 $\mu Pa^2 s$
	Mid-frequency (MF) cetaceans	peak pressure level	230 dB re 1 μPa
		SEL	185 dB re 1 $\mu Pa^2 s$
	High-frequency (HF) cetaceans	peak pressure level	202 dB re 1 μPa
		SEL	155 dB re 1 $\mu Pa^2 s$
	Phocid pinnipeds (PW)	peak pressure level	218 dB re 1 μPa
		SEL	185 dB re 1 $\mu Pa^2 s$
	Otariid pinnipeds (OW)	peak pressure level	232 dB re 1 μPa
		SEL	203 dB re 1 $\mu Pa^2 s$

Injury and Disturbance to Sea Turtles

3.18 The most relevant criteria for injury are considered to be those contained in the recent Sound Exposure Guidelines for Fishes and Sea Turtles (Popper *et al*., 2014). The guidelines set out criteria for injury due to different sources of noise. Those relevant to this project are considered to be those for injury due to seismic noise[3]. 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. 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

[3] *Guideline exposure criteria for explosions, piling, continuous sound and low and mid-frequency naval sonar are also presented though are not applicable to this Project.*

considered to be a significant issue with respect to determining the potential effect of noise on fish and turtles.

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

Table 3.3 Criteria for injury to turtles due to seismic airguns (Popper *et al*., 2014)

Type of animal	Parameter	Mortality and potential mortal injury	Impairment	
			Recoverable injury	TTS
Sea turtles	SEL, dB re 1 µPa²s	210	(*Near*) High (*Intermediate*) Low (*Far*) Low	(*Near*) High (*Intermediate*) Low (*Far*) Low
	Peak, dB re 1 µPa	>207		

3.20 The most recent criteria for disturbance are considered to be those contained in Popper et al. (2014) 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 onset of behavioural effects in turtles (Popper *et al*., 2014)

Type of animal	Relative risk of behavioural effects
Sea turtles	(*Near*) High (*Intermediate*) Moderate (*Far*) Low

3.21 It is important to note that the Popper *et al*. (2014) 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 Assessment Methodology

Source Term Derivation for Seismic Source Array

4.1 Source sound levels are usually described in dB re 1 μPa at 1 m (as if measured at 1 m from the source). In practice, it is not usually possible to measure at 1 m from an active seismic source that is physically distributed over an area of typically tens of square metres, but this method allows different source levels to be compared and reported on a like-for-like basis. Far-field source modelling is typically based on the following basic assumptions:

- at some far distance from the source (typically vertically downwards) the energy from the source elements add constructively; and
- the source level is derived by back projecting a far field calculation to 1 m.

4.2 Output from the source array modelling software model of the array has been provided as source data. A key assumption is that the source data accurately reflects the source level of the array in practice, as encountered in the far field of the source. The source array modelling output is summarised as follows:

Configuration	Array size	No. of guns	Peak pressure, bar m
Minimum configuration	2965 cu in	20	44.3
Maximum configuration	4100 cu in	30	64.1

4.3 The airgun array signature is shown in Figure 4.1 for each configuration.

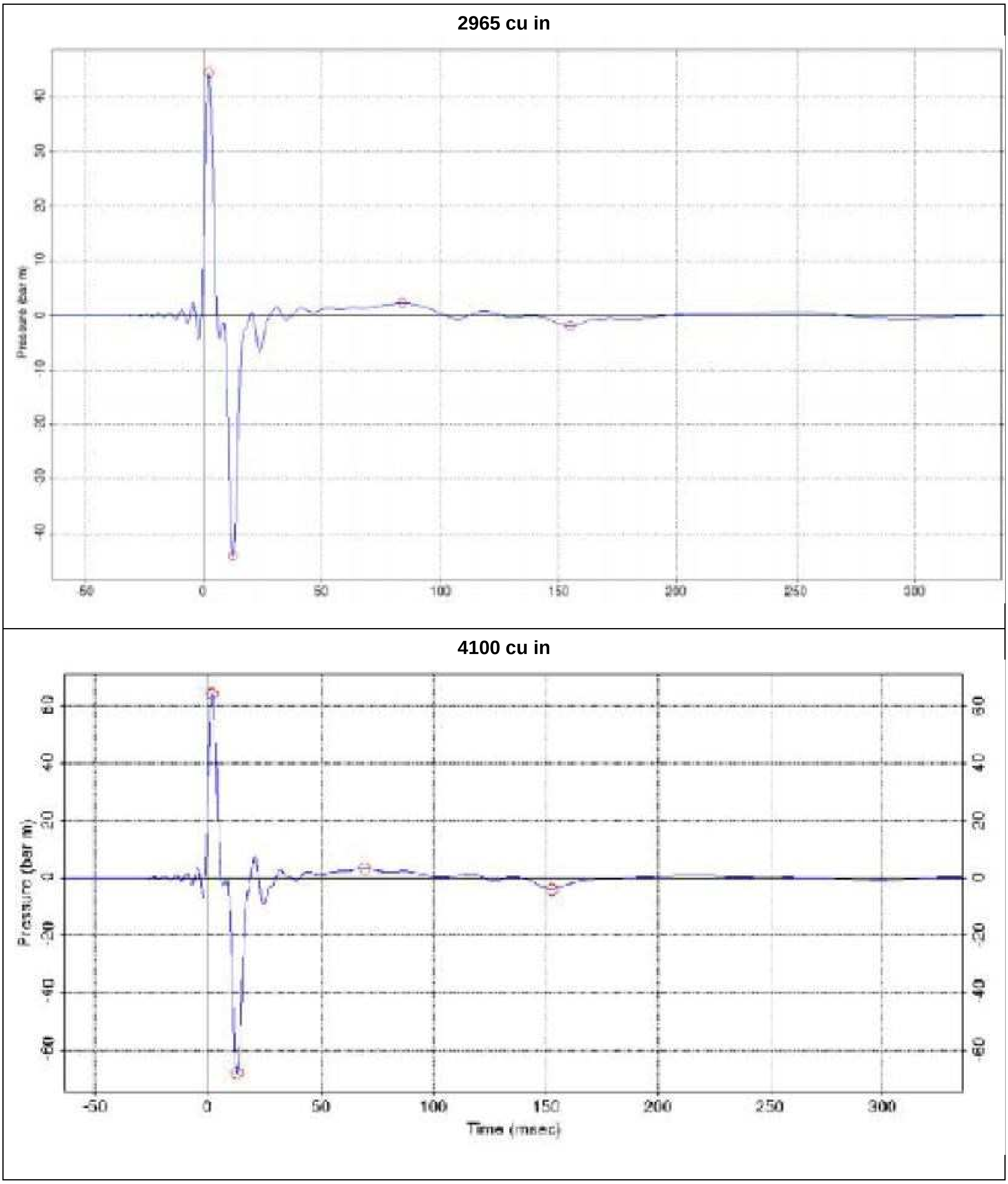


Figure 4.1 Airgun array source time signature

4.4 The supplied source data also includes information of the source frequency characteristics (Figure 4.2) but for a limited frequency range of up to 200 Hz. Although the highest sound pressure levels (in terms of un-weighted levels) are generated in this bandwidth, significant energy is also generated by seismic source arrays at much higher frequencies which are within the hearing sensitivities of marine mammals.

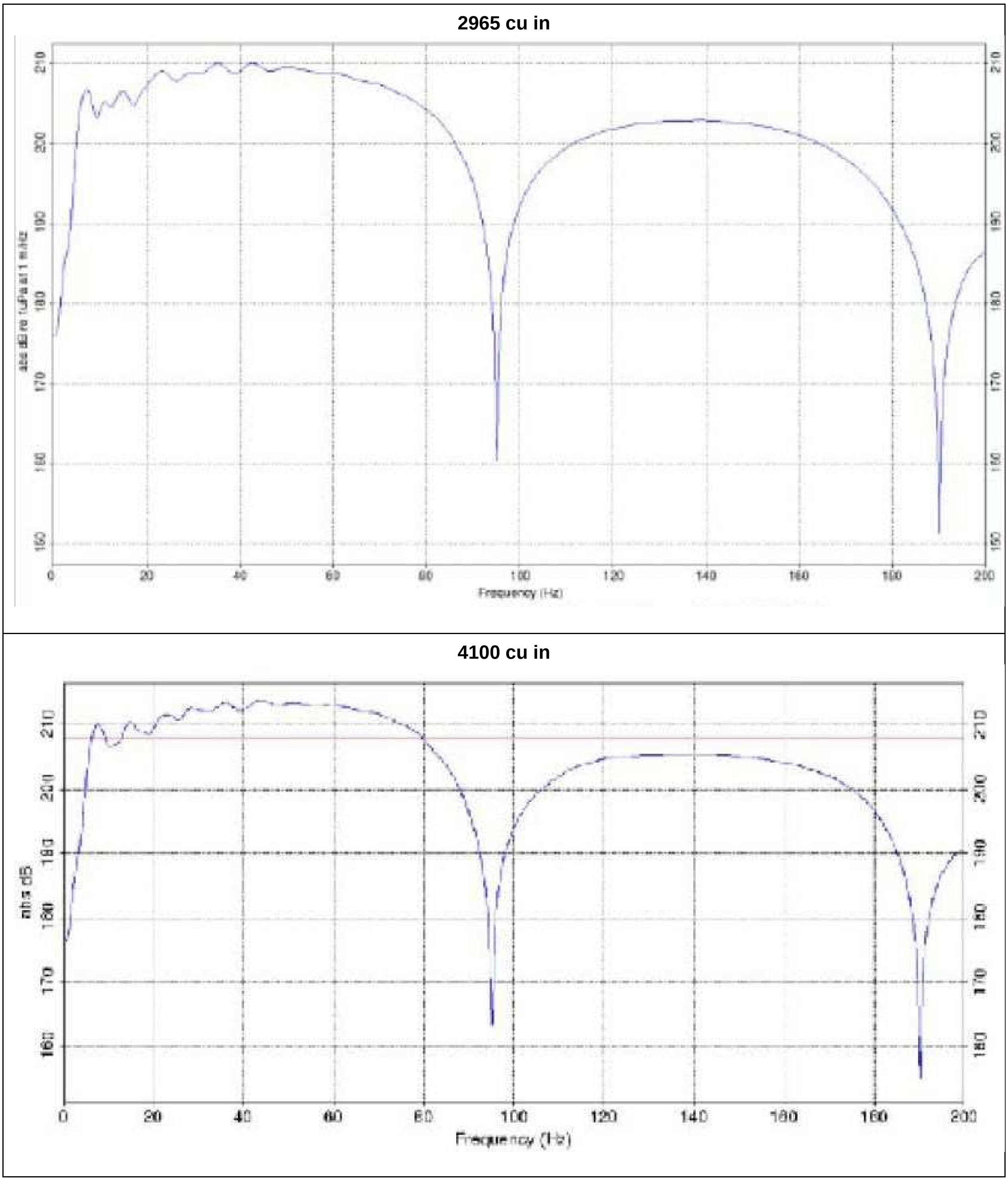


Figure 4.2 Source frequency characteristics (250 Hz low-pass filtered)

4.5 It is a common miscomprehension that seismic sound does not contain high frequency energy above a few hundred Hz. Seismic source arrays contain significant (unwanted) high frequency energy although this is often not shown in source array modelling reports due to the sampling rate of the software and the source filtering applied – this is because it is the low frequency energy content of the signature that is of interest for geophysical analysis. The miscomprehension is not helped by the way that frequency spectrum plots are often represented by use of power spectrum density. Because these plots effectively describe the power present in the signal as a function of frequency, per unit frequency, the slope of the curve can be misinterpreted as meaning that there is less high frequency content.

4.6 Inspection of the NOAA hearing weighting curves shown in Figure 3.1 shows that the majority of energy contributing to the hearing weighted SELs is well above the source modelling frequency of 200 Hz for the majority of hearing groups. Indeed, the source modelling frequency range does not cover *any* of the sound energy within the high and mid frequency cetacean weighting curves.

4.7 For this study, the source sound levels have been based on a combination of those provided by the source array model, supplemented by measured sound data from other studies over a much wider bandwidth (Breitzke et al., 2008; Tolstoy et al., 2009; Richardson et al., 1995) in order to produce low- and mid-frequency data. The low- and mid-frequency data has been extrapolated to derive the third-octave frequency spectra at higher frequencies (>200 Hz) based on the gradient of the power spectral density[4] and third-octave band plots.

4.8 The SEL represents the total energy of an event or number of events normalised to a standardised one second interval. This allows a comparison of the total energy of different sounds lasting for different time periods. As a pressure pulse from a source array propagates towards the receiver, the duration of the pulse increases. Thus the relationship between the peak sound pressure level and the SEL changes with distance. The peak level from the source array software model was converted to an SEL based on the gun signature time history graph and compared to measured data from Patterson *et al.* (2007). The single pulse SEL values have been combined for each pulse as part of the various cumulative SEL modelling scenarios.

4.9 It is important to note that the rms sound pressure level will depend upon the integration window used or, in other words, the measurement time for the rms. Using a longer duration measurement would result in a lower rms sound pressure level than using a shorter one. Therefore, the rms sound pressure source level has been calculated by scanning the source array model time history plot in order to re-calculate the rms sound pressure level using the relevant T90 time period (i.e. the interval which contains 90% of the sound energy). This integration procedure gives a more relevant and consistent value for comparison between various studies and is the suggested metric in Southall *et al.* (2007).

4.10 An additional phenomenon occurs where the seismic waveform elongates with distance from the source due to a combination of dispersion and multiple reflections. Measurements presented by Breitzke *et al*. (2008) indicate elongation of the T90 window up to approximately 800 ms at 1,000 m. This temporal "smearing" reduces the rms amplitude with distance (because the rms window is longer) and has been included within the disturbance modelling scenarios. Since the ear of most marine mammals integrates low frequency sound over a window of around 200 ms (Peter Teglberg

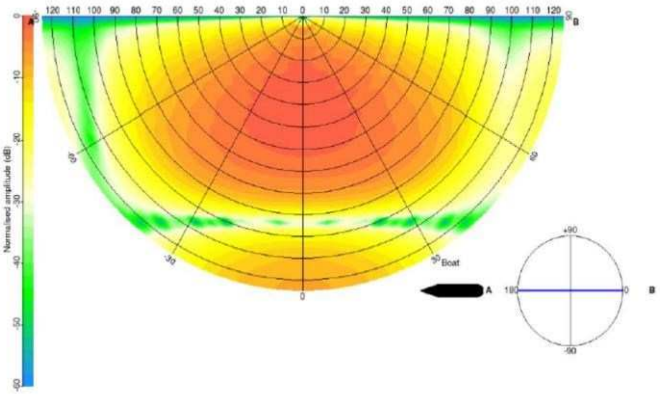
[4] *The power spectral density (PSD) is the power carried by the wave, per unit frequency of the signal.*

Madsen et al. 2006), this duration was used as a maximum integration time for the received rms sound pressure level.

4.11 The source levels stated above are likely to be overestimated in the near-field as the modelled back projection to 1 m does not consider the interaction between the source elements. This in turn overestimates near-field received levels, which are then compared to animal thresholds. In reality, near-field source sound levels will be lower than that predicted by this vertical far-field calculation.

4.12 Another important factor affecting the received sound pressure level from seismic source arrays is the source directivity characteristics. Source arrays are designed so that the majority of acoustic energy is directed downwards towards the ocean bottom. Therefore, the amount of energy emitted horizontally will be significantly less than directed downwards. The directivity plots are shown in Figure 4.3.

2965 cu in



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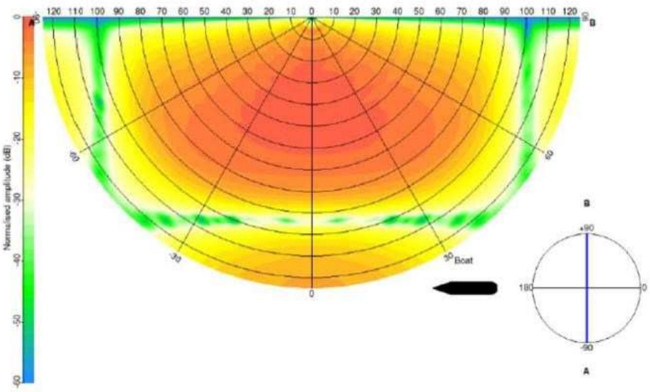

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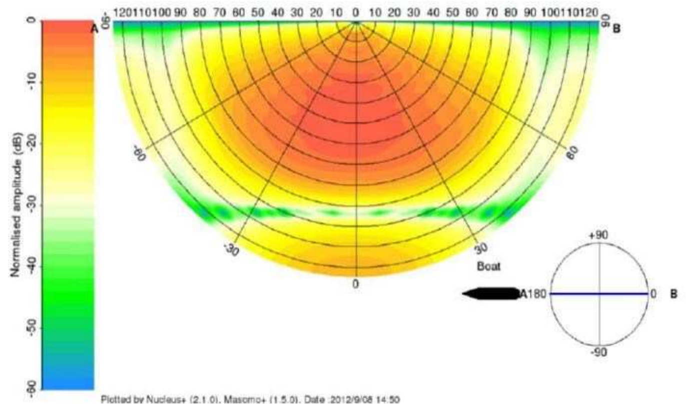
4100 cu in



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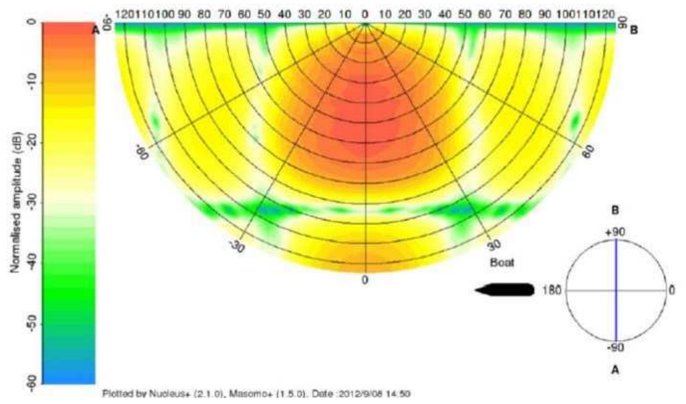

Azimuth: 90 deg

Figure 4.3 Directivity plots for source array

4.13 An example SPL plot showing this directivity effect directly under a source array is shown in Figure 4.4 (the directivity figures are for illustrative purposes only and not specific to the source array proposed for this survey). From the figure, it can clearly be seen that an animal swimming in deeper water would be subject to higher sound exposure levels than one in shallow water at the same aerial distance from the source array.

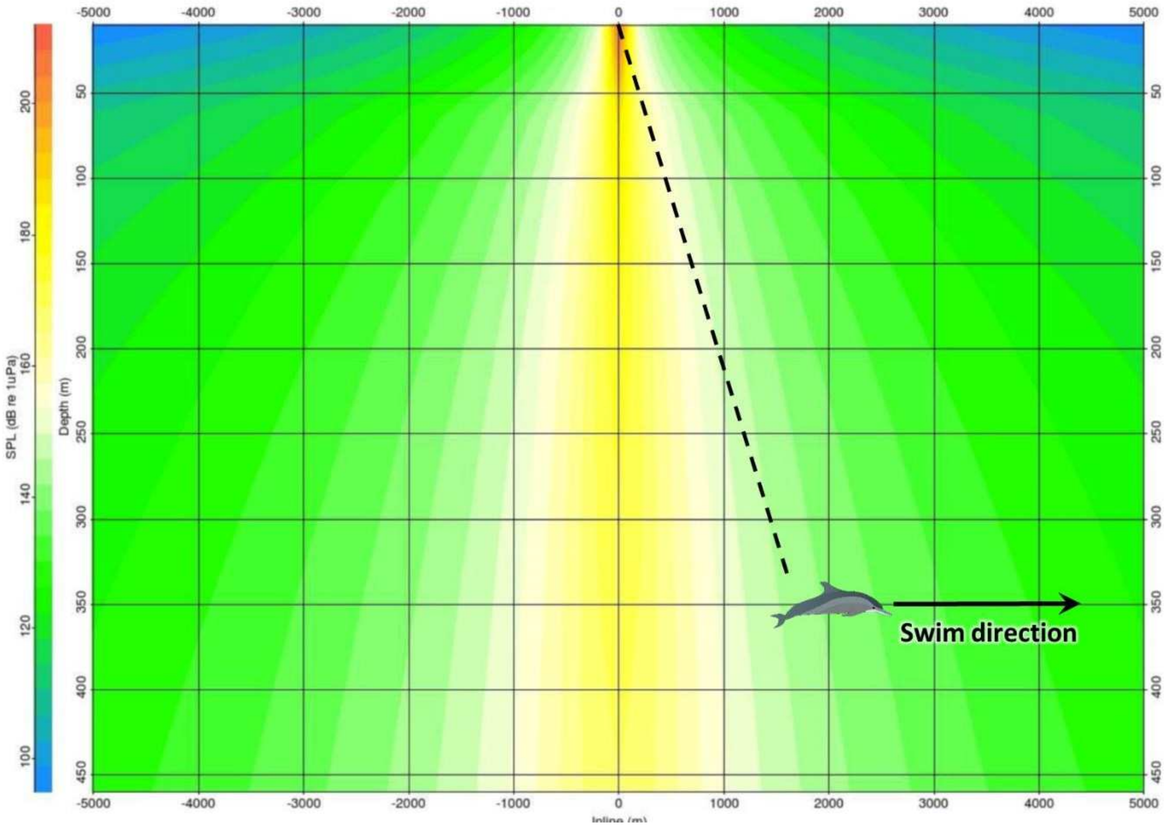

Figure 4.4 Example inline SPL showing array directivity

4.14 Directivity is a frequency dependent effect and is more pronounced at higher frequencies than at lower frequencies. Directivity corrections have been applied to the source sound level data based on supplied directivity characteristics for the proposed array. Directivity factors were derived based on source take-off angle for an animal on the bottom of the ocean, assuming that the receiver is to the side of the array (as opposed to in front of or behind the array). This results in a greater correction (reduction in level) due to directivity at distances further from the source than for receivers close to the source.

4.15 At distances closer to the source (i.e. less than the water depth), no directivity correction is made because the animal could be directly underneath the array. This scenario is shown illustratively in Figure 4.5. It should be noted that these figures and examples are illustrative and simplified scenarios in order to demonstrate the principal of take-off angles.

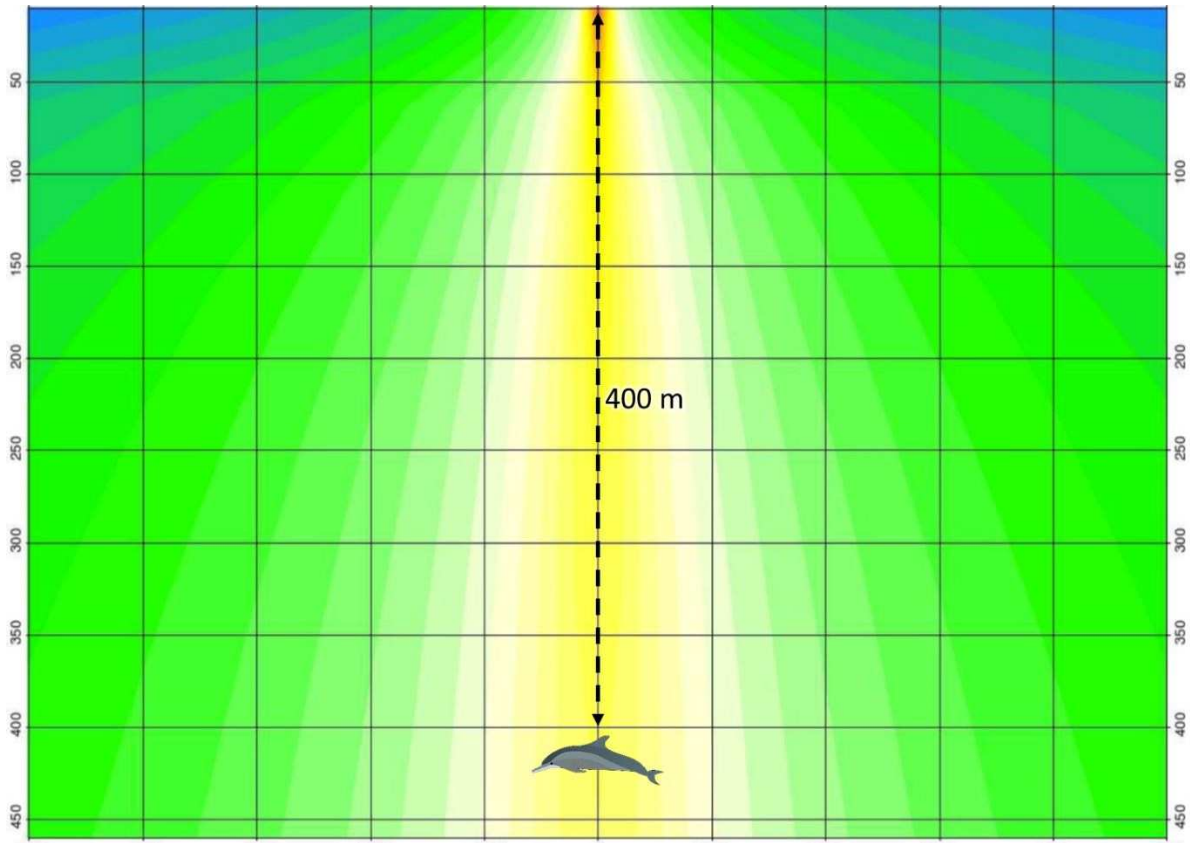

Figure 4.5 Example showing injury range less than water depth

4.16 As the injury range increases, the take-off angle between the source array and animal becomes larger. Hence, when the injury range is large in comparison to the water depth, the effects of the source array's directivity will have a much greater bearing on the received sound level. Once the injury range becomes larger than the water column depth then the array directivity effects will become increasingly important. Figure 4.6 shows an example where the injury range is slightly larger than the water column depth.

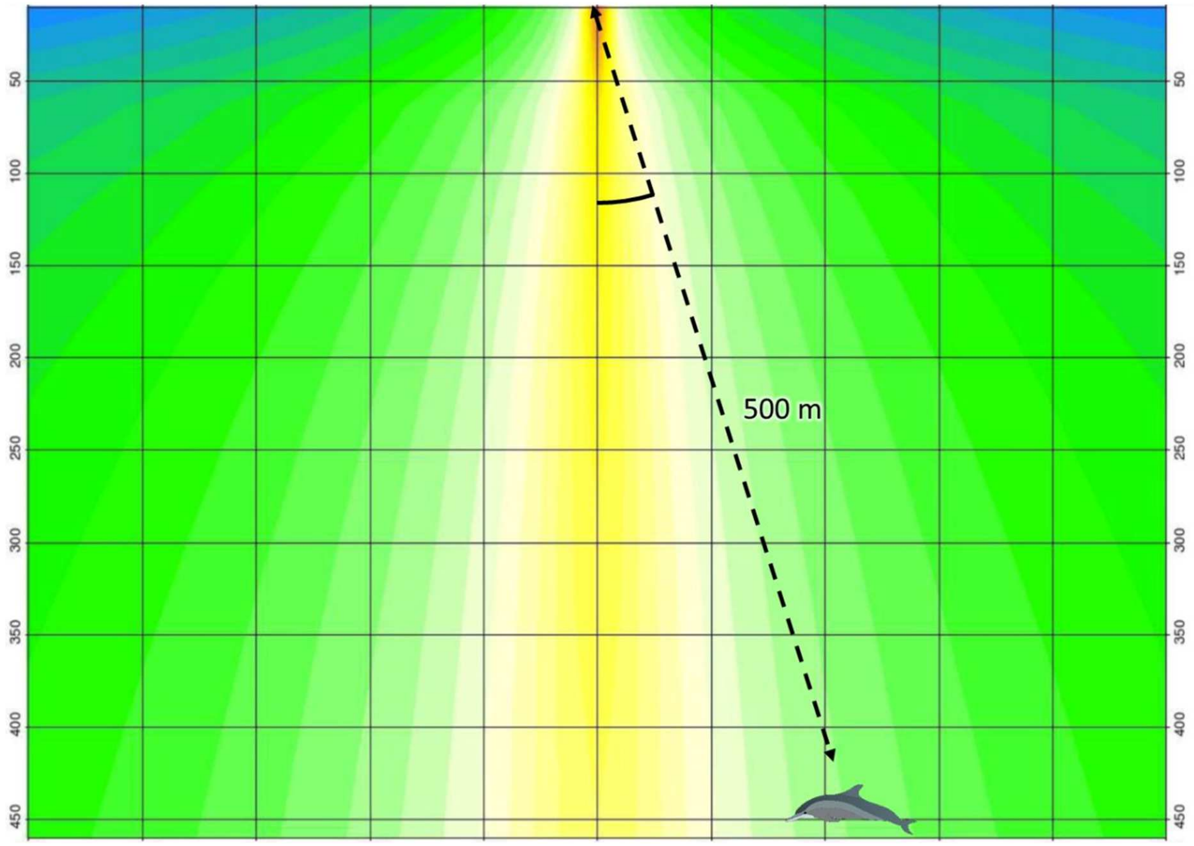

Figure 4.6 Example showing injury range slightly larger than water depth

4.17 For injury ranges which are much larger than the water column depth the effects of directivity will be much more significant. This is shown illustratively in Figure 4.7.

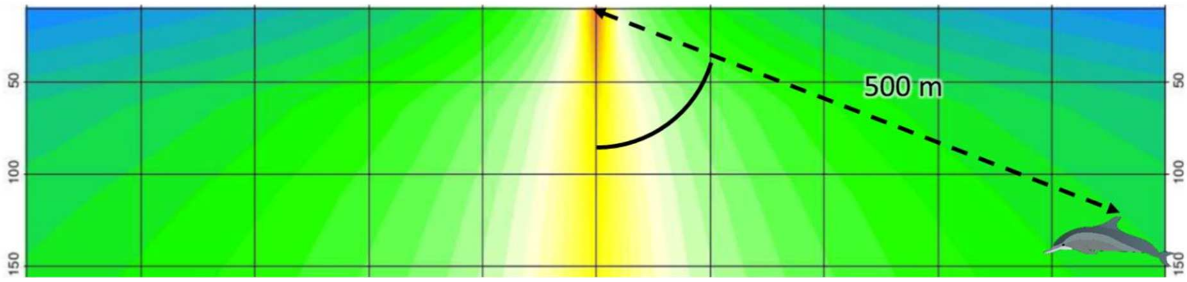

Figure 4.7 Example showing injury range much larger than water depth

Propagation Model

4.18 Increasing the distance from the sound source usually results in the level of sound becoming lower, due primarily to the spreading of the sound energy with distance, analogous to the way in which the ripples in a pond spread after a stone has been thrown in, in combination with attenuation due to absorption of sound energy by molecules in the water. This latter mechanism is more important for higher frequency sound than for lower frequencies.

4.19 The way that the sound spreads (geometrical divergence) will depend upon several factors such as water column depth, pressure, temperature gradients, salinity as well as water surface and bottom (i.e. seabed) conditions. Thus, even for a given locality, there are temporal variations to the way that sound will propagate. However, in simple terms, the sound energy may spread out in a spherical pattern (close to the source) or a cylindrical pattern (much further from the source), although other factors mean that decay in sound energy may be somewhere between these two simplistic cases.

4.20 In acoustically shallow waters[5] in particular, the propagation mechanism is coloured by multiple interactions with the seabed and the water surface (Lurton 2002; Etter 2013; Urick 1983; Brekhovskikh and Lysanov n.d.); Kinsler et al. 1999). Whereas in deeper waters, the sound will propagate further without encountering the surface or bottom of the sea, in shallower waters the sound may be reflected from either or both boundaries (potentially more than once).

4.21 At the sea surface, the majority of sound is reflected back in to the water due to the difference in acoustic impedance (i.e. sound speed and density) between air and water. However, scattering of sound at the surface of the sea can be an important factor with respect to the propagation of sound. In an ideal case (i.e. for a perfectly smooth sea surface), the majority of sound wave energy will be reflected back into the sea. However, for rough seas, much of the sound energy is scattered (e.g. Eckart 1953; Fortuin 1970; Marsh, Schulkin, and Kneale 1961; Urick and Hoover 1956). Scattering can also occur due to bubbles near the surface such as those generated by wind or fish or due to suspended solids in the water such as particulates and marine life. Scattering is more pronounced for higher frequencies than for low frequencies and is dependent on the sea state (i.e. wave height). However, the various factors affecting this mechanism are complex.

4.22 Because surface scattering results in differences in reflected sound, its effect will be more important at longer ranges from the source sound and in acoustically shallow water (i.e. where there are multiple reflections between the source and receiver). The degree of scattering will depend upon the sea state/wind speed, water depth, frequency of the sound, temperature gradient, grazing angle and range from source. It should be noted that variations in propagation due to scattering will vary temporally within an area primarily due to different sea-states / wind speeds at different times. However, over shorter ranges (e.g. several hundred meters or less) the sound will experience fewer reflections and so the effect of scattering should not be significant.

4.23 When sound waves encounter the bottom, the amount of sound reflected will depend on the geoacoustic properties of the bottom (e.g. grain size, porosity, density, sound speed, absorption coefficient and roughness) as well as the grazing angle and frequency of the sound (Cole 1965; Hamilton 1970; Mackenzie 1960; McKinney and Anderson 1964; Etter 2013; Lurton 2002; Urick 1983). Thus, bottoms comprising primarily mud or other acoustically soft sediment will reflect

[5] *Acoustically, shallow water conditions exist whenever the propagation is characterised by multiple reflections with both the sea surface and bottom (Etter 2013). Consequently, the depth at which water can be classified as acoustically deep or shallow depends upon numerous factors including the sound speed gradient, water depth, frequency of the sound and distance between the source and receiver.*

less sound than acoustically harder bottoms such as rock or sand. This will also depend on the profile of the bottom (e.g. the depth of the sediment layer and how the geoacoustic properties vary with depth below the sea floor). The effect is less pronounced at low frequencies (a few kHz and below). A scattering effect (similar to that which occurs at the surface) also occurs at the bottom (Essen 1994; Greaves and Stephen 2003; McKinney and Anderson 1964; Kuo 1992), particularly on rough substrates (e.g. pebbles).

4.24 Another phenomenon is the waveguide effect, which means that shallow water columns do not allow the propagation of low frequency sound (Urick 1983; Etter 2013). The cut-off frequency of the lowest mode in a channel can be calculated based on the water depth and knowledge of the sediment geoacoustic properties. Any sound below this frequency will not propagate far due to energy losses through multiple reflections.

4.25 Another important factor is the sound speed gradient. Changes in temperature and pressure with depth mean that the speed of sound varies throughout the water column. This can lead to significant variations in sound propagation and can also lead to sound channels, particularly for high frequency sound. Sound can propagate in a duct-like manner within these channels, effectively focussing the sound, and conversely they can also lead to shadow zones. The frequency at which this occurs depends on the characteristics of the sound channel but, for example, a 25 m thick layer would not act as a duct for frequencies below 1.5 kHz. The temperature gradient can vary throughout the year and thus there will be potential variation in sound propagation depending on the season.

4.26 Sound energy is also absorbed due to interactions at the molecular level converting the acoustic energy into heat. This is another frequency dependent effect with higher frequencies experiencing much higher losses than lower frequencies.

4.27 There are several methods available for modelling the propagation of sound between a source and receiver ranging from very simple models which simply assume spreading according to a 10 log (r) or 20 log (r) relationship (as discussed above) to full acoustic models (e.g. ray tracing, normal mode, parabolic equation, wavenumber integration and energy flux models). In addition, semiempirical models are available which lie somewhere in between these two extremes in terms of complexity.

4.28 In choosing which propagation model to employ, it is important to ensure that it is fit for purpose and produces results with a suitable degree of accuracy for the application in question, taking into account the context (as detailed in Monitoring Guidance for Underwater Noise in European Seas Part III, NPL Guidance and Farcas *et al.*, 2016). Thus, in some situations (e.g. low risk due to underwater noise, range dependent bathymetry is not an issue, non-impulsive sound) a simple (N log R) model will be sufficient, particularly where other uncertainties outweigh the uncertainties due to modelling. On the other hand, some situations (e.g. very high source levels, impulsive sound, complex source and propagation path characteristics, highly sensitive receivers and low uncertainties in assessment criteria) warrant a more complex modelling methodology.

4.29 The first step in choosing a propagation model is therefore to examine these various factors, such as set out below:

- balancing of errors / uncertainties;
- range dependant bathymetry;
- frequency dependence; and
- source characteristics.

4.30 For impulsive sound, such as that produced by a seismic survey source array, the sound propagation is rather more complex than can be modelled using a simple N log (R) relationship.

4.31 For example, the rms sound pressure level of an impulsive sound wave will depend upon the integration window used or, in other words, the measurement time for the rms. Using a longer duration measurement would result in a lower rms sound pressure level than using a shorter one. An additional phenomenon occurs where the seismic waveform elongates with distance from the source due to a combination of dispersion and multiple reflections. This temporal “smearing” can significantly affect the peak pressure level and reduces the rms amplitude with distance (because the rms window is longer). Furthermore, source levels stated in the source array modelling reports are likely to be overestimated in the near-field as the modelled back projection to 1 m does not consider the interaction between the source elements. This in turn overestimates near-field received levels, which are then compared to animal thresholds. In reality, near-field source sound levels will be lower than that predicted by this vertical far-field calculation. Another important factor affecting the received sound pressure level from seismic source arrays is the source directivity characteristics. Source arrays are designed so that the majority of acoustic energy is directed downwards towards the ocean bottom. Therefore, the amount of energy emitted horizontally will be significantly less than directed downwards. This is a frequency dependent effect and is more pronounced at higher frequencies than at lower frequencies.

4.32 Sound propagation modelling for this assessment was therefore based on an established, peer reviewed, range dependent sound propagation model which utilises the semi-empirical model developed by Rogers (1981). The model provides a robust balance between complexity and technical rigour over a wide range of frequencies, has been validated by numerous field studies, and has been benchmarked against a range of other models. The following inputs are required for the model:

- third-octave band source sound level data;
- range (distance from source to receiver);
- water column depth (input as bathymetry data grid);
- sediment type;
- sediment and water sound speed profiles and densities;
- sediment attenuation coefficient; and
- source directivity characteristics.

4.33 The propagation loss is calculated using the formula:

$$TL = 15log_{10}R + 5\log_{10}(H\beta) + \frac{\beta R \theta_L^2}{4H} - 7.18 + \alpha_w R$$

Where R is the range, H the water depth, β the bottom loss, $\theta_L$the limiting angle and α_w the absorption coefficient of sea water (α_w is a frequency dependant term which is calculated based on Ainslie and McColm, 1998).

4.34 The limiting angle, θ_L is the larger of θ_g and θ_c where θ_g is the maximum grazing angle for a skip distance and θ_c is the effective plane wave angle corresponding to the lowest propagating mode.

$$\theta_g = \sqrt{\frac{Hg}{c_w^2}} \qquad \theta_c = \frac{c_w}{2fH}$$

Where g is the sound speed gradient in water and f is the frequency.

4.35 The bottom loss β is approximated as:

$$\beta \approx \frac{0.477(\rho_w/\rho_s)(c_w/c_s)K_s}{[1-(c_w/c_s)^2]^{3/2}}$$

Where ρ_s is the density of sediment, ρ_w the density of water, c_s the sound speed in the sediment, c_w the sound speed in water and K_s is the sediment attenuation coefficient.

4.36 The propagation model also takes into account the depth dependent cut-off frequency for propagation of sound (i.e. the frequency below which sound does not propagate):

$$f_{cut-off} = \frac{c_w}{4h\sqrt{1-\frac{c_w^2}{c_s^2}}}$$

Where c_s and c_w are the sound propagation speeds in the substrate and water.

4.37 The propagation and sound exposure calculations were conducted over a range of water column depths in order to determine the likely range for injury and disturbance. It should be noted that the effect of directivity has a strong bearing on the calculated zones for injury and disturbance because a marine mammal could be directly underneath an array for greater distances in deep water compared to shallow water.

4.38 It should be borne in mind that noise levels (and associated range of effects) will vary depending on actual conditions at the time (day-to-day and season-to-season) and that the model predicts a typical worst case scenario. Taking into account factors such as animal behaviour and habituation, any injury and disturbance ranges should be viewed as indicative and probabilistic ranges to assist in understanding potential impacts on marine life rather than lines either side of which an impact definitely will or will not occur. (This is a similar approach to that adopted for airborne noise where a typical worst case is taken, though it is known that day to day levels may vary to those calculated by 5 - 10 dB depending on wind direction etc.).

4.39 The following geoacoustic parameters for the bottom have been utilised in the noise model (Hamilton 1970, 1980; Jensen 1994):

- sediment sound speed cs = 1,657 m/s
- density of sediment ρs = 2 kg/m^3
- sediment attenuation coefficient Ks = 0.459 dB/m/kHz

4.40 The bathymetry of the survey area and surrounding area is shown in Figure 4.8. Water depths in the area are generally around 600 to 800 m.

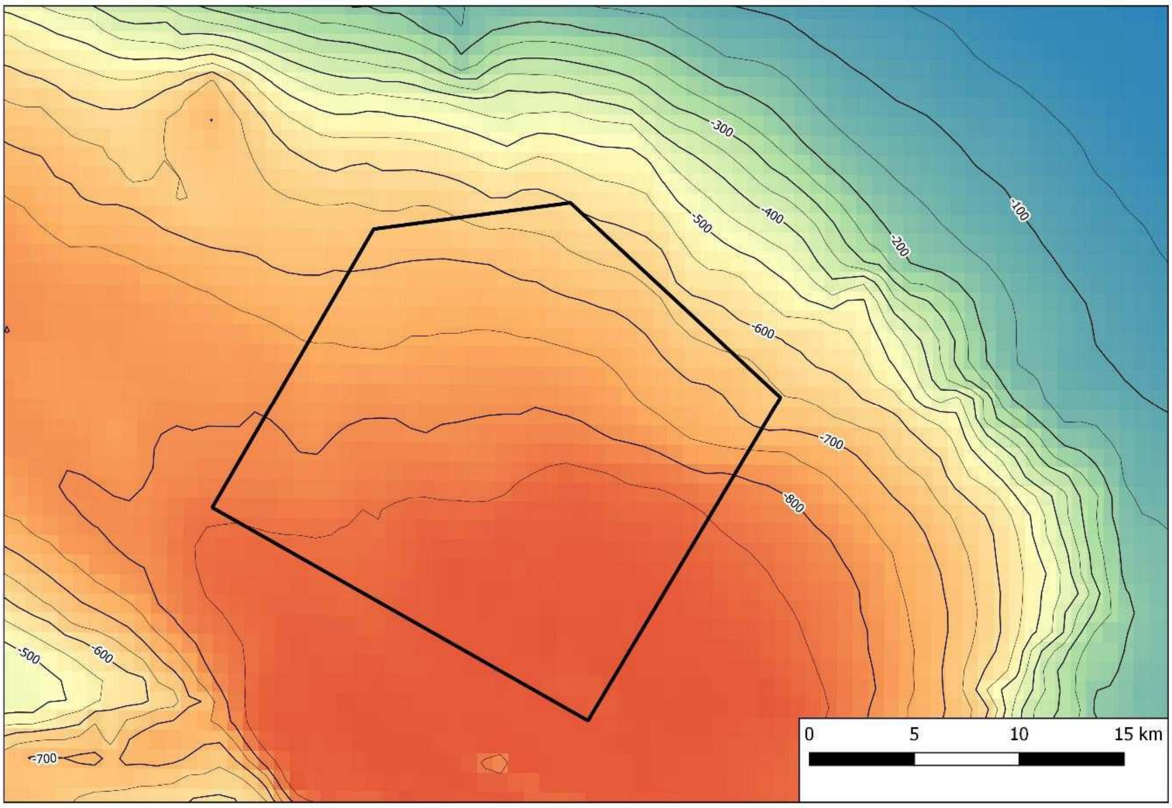

Figure 4.8 Bathymetry in the survey area

Exposure Calculations

4.41 As well as calculating the un-weighted rms and peak sound pressure levels at various distances from the source, it is also necessary to calculate the SEL for a mammal using the relevant hearing weightings described above taking into account the number of pulses to which it is exposed. For operation of the source array, the SEL sound data for a single pulse was utilised, along with the maximum number of pulses expected to be received by marine mammals in order to calculate cumulative exposure.

4.42 Exposure modelling was based on the assumption of a mammal swimming at a constant speed in a perpendicular direction away from a moving vessel (see Figure 4.9):

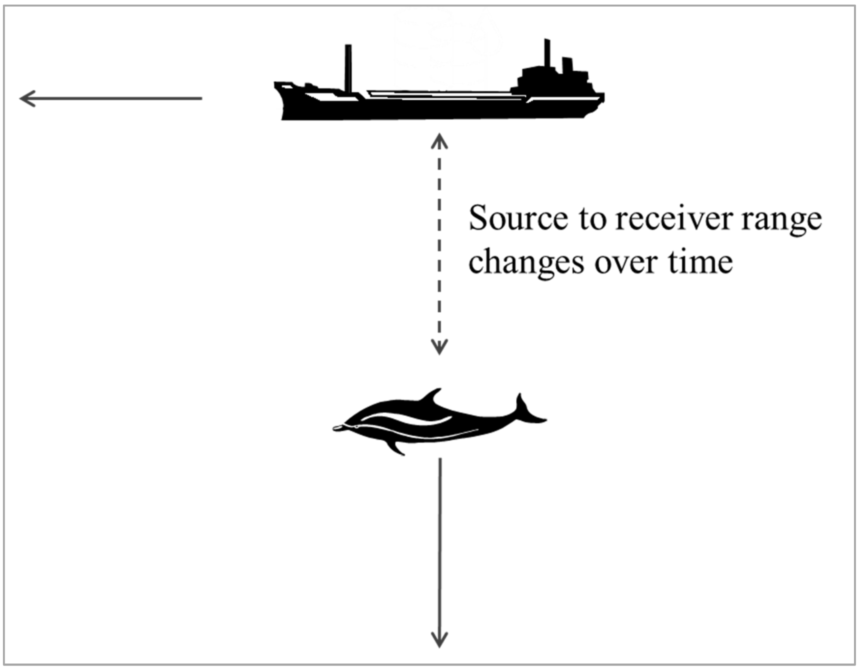

Figure 4.9 Sound exposure modelling

4.43 The above case was modelled for a range of start distances (initial or closest passing distance between the animal and vessel) in order to calculate cumulative exposure for a range of scenarios. In each case, the pulses to which the mammal is exposed in closest proximity to the vessel dominate the sound exposure. This is due to the logarithmic nature of sound energy summation.

4.44 In order to carry out the swimming mammal calculation, it has been assumed that a mammal will swim away from the noise source at an average speed of 1.5 ms^{-1}. The calculation considers each pulse to be established separately resulting in a series of discrete SEL values of decreasing magnitude (see Figure 4.10).

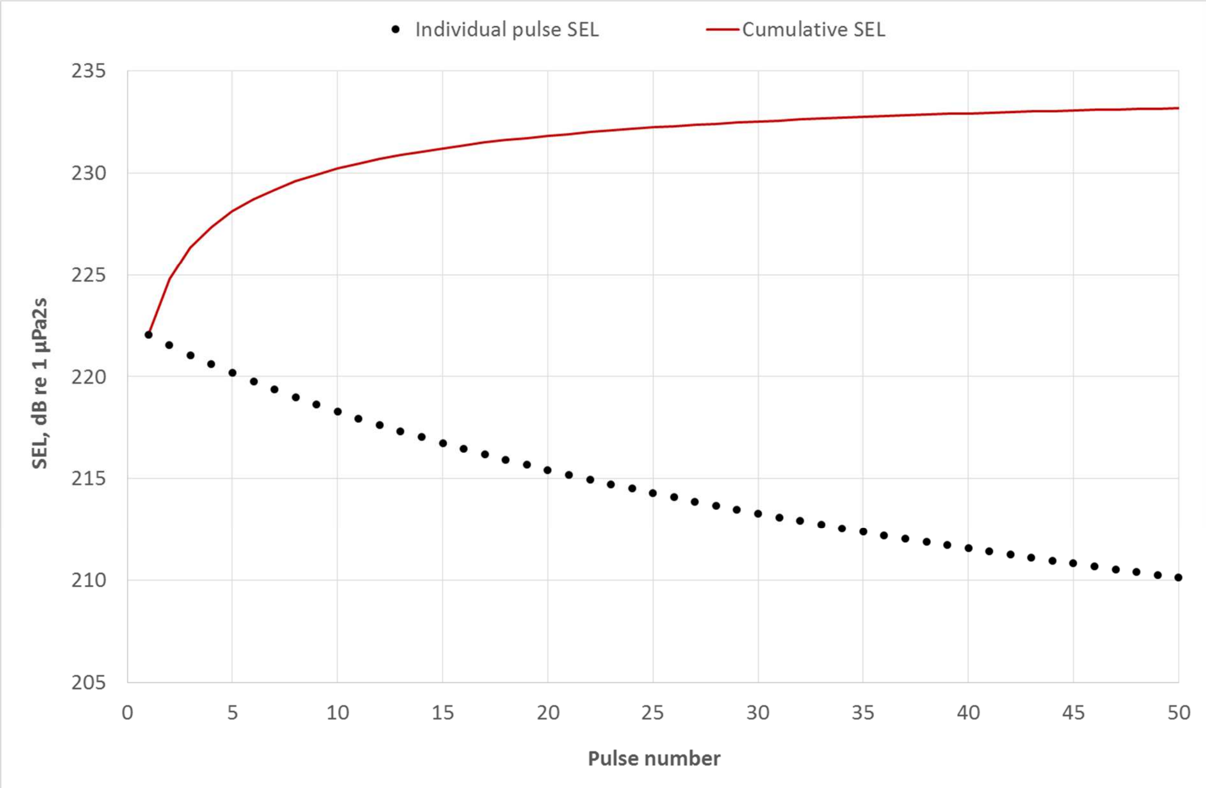

Figure 4.10 Discrete pulse SEL and cumulative SEL

4.45 As a mammal swims away from the source array, the noise will become progressively quieter; the cumulative SEL is worked out by logarithmically adding the SEL to which the mammal is exposed as it travels away from the source. 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 animal will continue to swim away at a fairly constant relative speed. The real world situation is more complex and the animal is likely to move in a more complex manner. Swim speeds of marine mammals have been shown to be up to 5 ms^{-1} (e.g. cruising minke whale 3.25 ms^{-1} (Cooper *et al.,* 2008) and harbour porpoise up to 4.3 ms^{-1} (Otani *et al.,* 2000)). The more conservative swim speed of 1.5 ms^{-1} used in this assessment allows some headroom to account for the potential that 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.

4.46 It should be noted that the sound exposure calculations are based on the simplistic assumption that the seismic source is active continuously over a 24 hour period, being activated at the same interval. The real world situation is more complex. It is understood that typically a vessel would traverse each sail-line in turn with a line-change between sail-lines when the source is not active. The SEL calculations presented in this study do not take any breaks in activity into account.

4.47 Furthermore, the multiple pulse sound criteria described in the NOAA guidelines assume that the animal does not recover hearing between each pulse or series of pulses. It is likely that both the intervals between pulses and the breaks in operations for line changes could allow some recovery from temporary hearing threshold shifts for animals exposed to the sound and, therefore, the assessment of sound exposure level is considered to be conservative. This over-estimate is, however, considered to be small because, as stated previously, the majority of sound energy to which an animal is exposed occurs when it is at the closest distance to the source, with subsequent exposure at greater ranges making an insignificant contribution to the overall exposure.

4.48 The SEL calculations described above have also been conducted to estimate the benefit of soft start operations. In this case, the individual pulse SELs are reduced in magnitude for a period of time before reverting back to the full source array values. For this assessment, it has been assumed that each pulse SEL will be attenuated by 10 dB for a period of 20 minutes during the soft start procedures. The sound modelling makes the assumption that the mammal does not re-approach the source array in the same day. As it is likely that there will be a soft-start associated with each line change, any mammals re-approaching the array will have the opportunity to swim away before commencement of full energy seismic activity.

4.49 In reality, the sound level due to a soft-start will increase over time as the soft-start is implemented (i.e. as more source elements are added). In a typical scenario, the sound pressure will be nominally 20 to 30 dB lower for the starting case of a single gun and increase in an approximately logarithmic manner until the maximum energy is reached. Consequently, the sound level to which an animal is exposed reduces (as they swim away from the source) as the energy at source slowly rises. It is considered that the assumption of a constant sound reduction over the soft start period provides a sufficiently robust and pessimistic estimate of an animal's exposure because the majority of the cumulative sound exposure level results from initial tens of pulses.

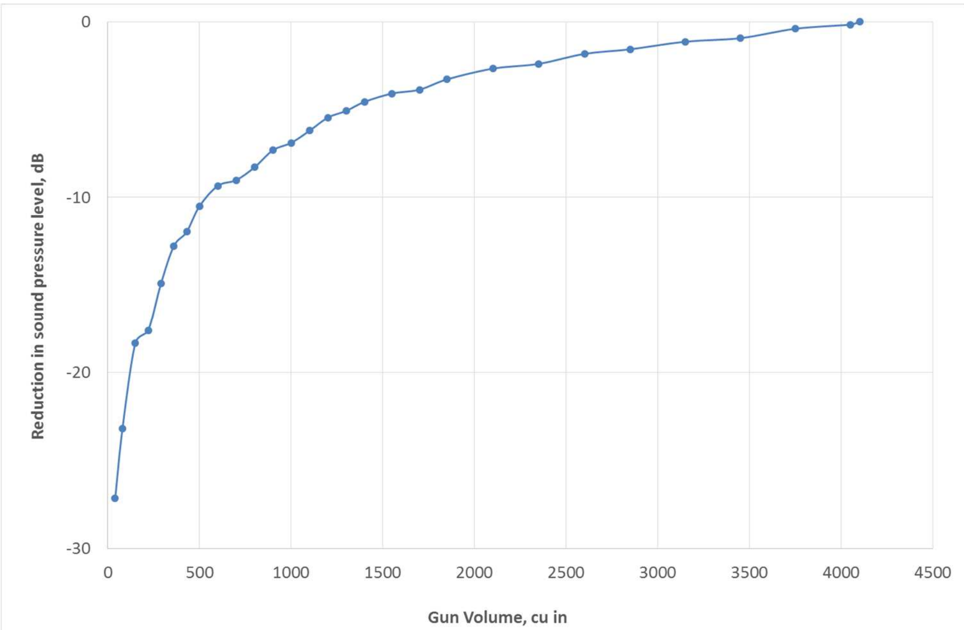

Figure 4.11 Gun volume vs reduction in sound pressure level

4.50 Sound emissions due to the survey vessel is considered negligible when compared with the source array, so has not been included for purposes of the sound exposure calculation.

5 Sound Modelling Results

Injury of Marine Mammals

5.1 Based on the results of the propagation and exposure modelling for peak pressure, the expected injury zones with and without mitigation in place are shown in Figure 5.1. It should be noted that the calculated sound pressure level in the near-field will be overestimated, as discussed in Section 4. (N/E = Criteria Not Exceeded)

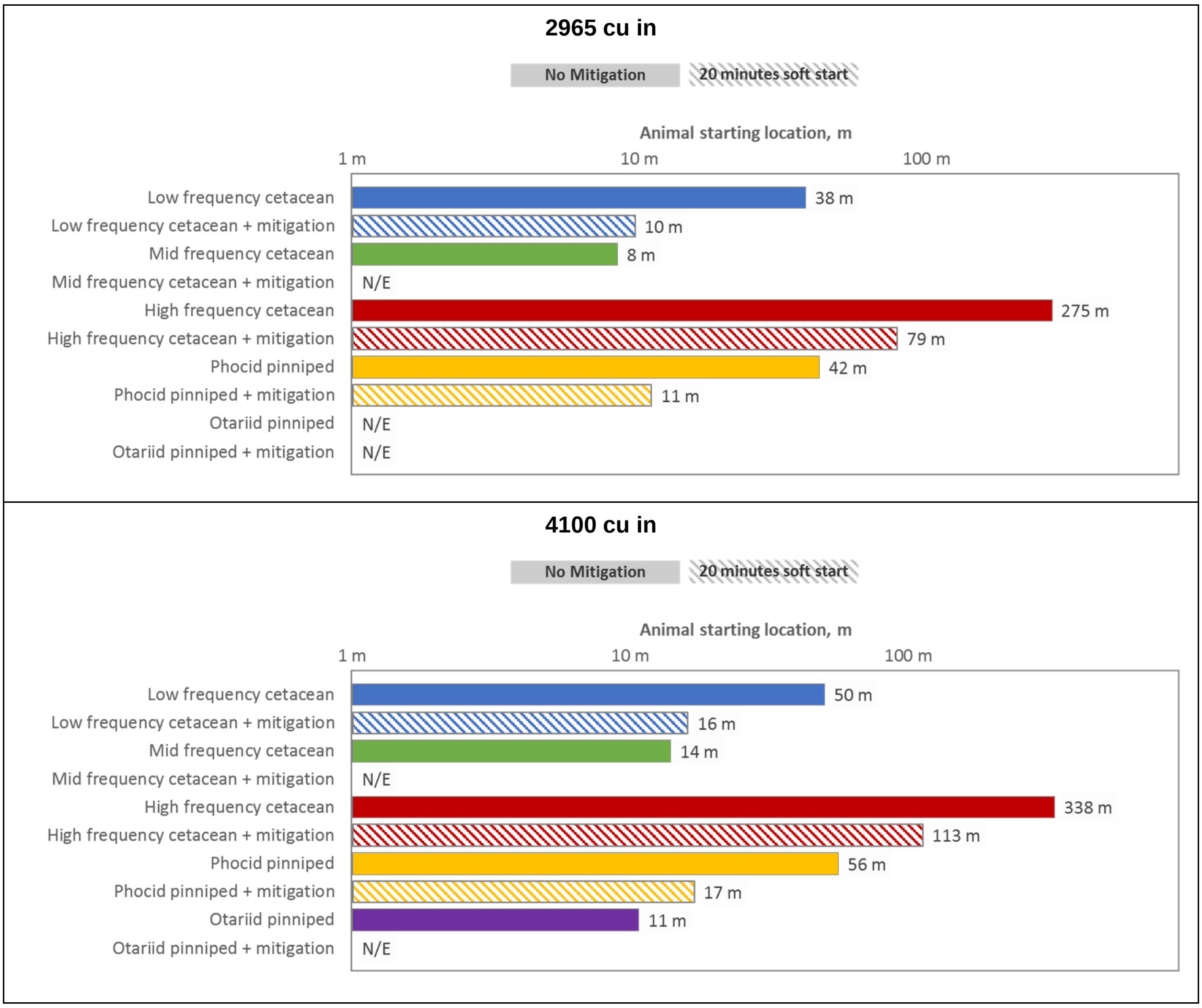

Figure 5.1 Peak pressure injury zones with and without mitigation

5.2 The results of the modelling for cumulative SEL of moving mammals is summarised in Figure 5.2.

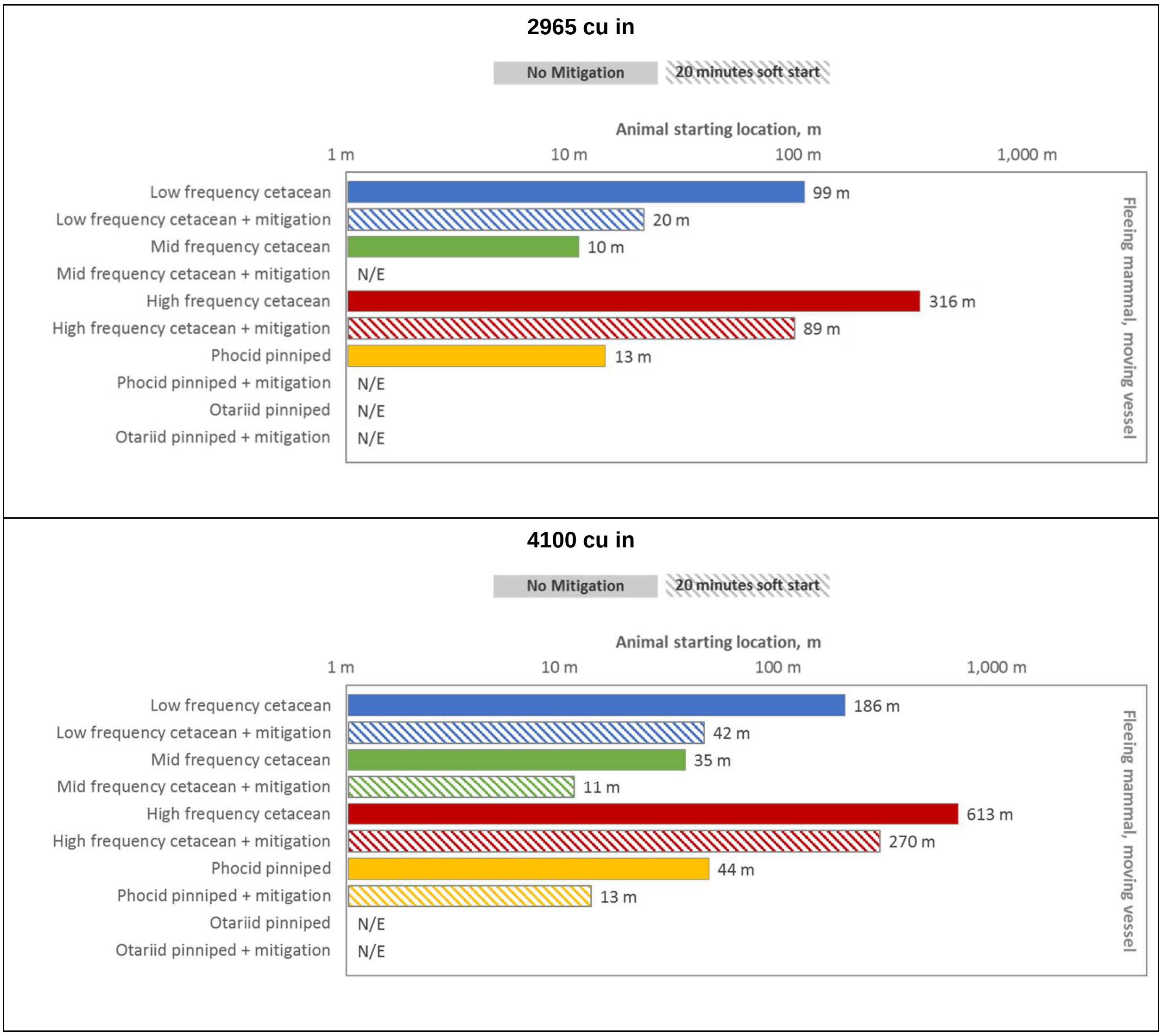

Figure 5.2 Cumulative SELs for moving animal, with and without mitigation

5.3 These same data are presented in Table 5.1 at the end of this section. The distances presented in the table and figures reflect the start point of the mammal relative to the source when the source first starts up. The mammal would then move away from the source, so the distance between the mammal and the source would increase over time.

5.4 The potential ranges presented for injury and disturbance are not a hard and fast 'line' where an impact will occur on one side and not on the other. Potential impact is more probabilistic than that; dose dependency in PTS onset, individual variations and uncertainties regarding behavioural response and swim speed/direction all mean that in reality it is much more complex than drawing a contour around a location. These ranges are designed to provide an understandable way in which a wider audience can understand the potential spatial extent of the impact.

5.5 The calculations are based on an individual mammal being exposed to sound resulting from continuous source activation which, as noted in previously, could be a simplification.

5.6 The benefit of soft start operations is greater at shorter ranges from the source than if the mammal starts further away from the source. This is because at short distances the sound level is higher and falls away at a faster rate, so an animal swimming at a constant speed will see a larger relative reduction in sound if it starts closer to the source. Care should be taken in interpreting any results within tens of meters of the source due to near-field effects potentially overestimating exposure.

Assessment of Ranges for Potential Behavioural Change for Marine Mammals

5.7 The relationship between rms sound pressure level and range from the source array is shown in Figure 5.5, plotted with the strong behavioural change criterion of 160 dB re 1 µPa (rms_{T90}). The graph shows that the radius for potential behavioural change for marine mammals is up to 730 m from the source array. It should be noted that the rms values plotted in the graph use the estimated T90 time window at various distances from the source, up to a maximum value of 200 ms.

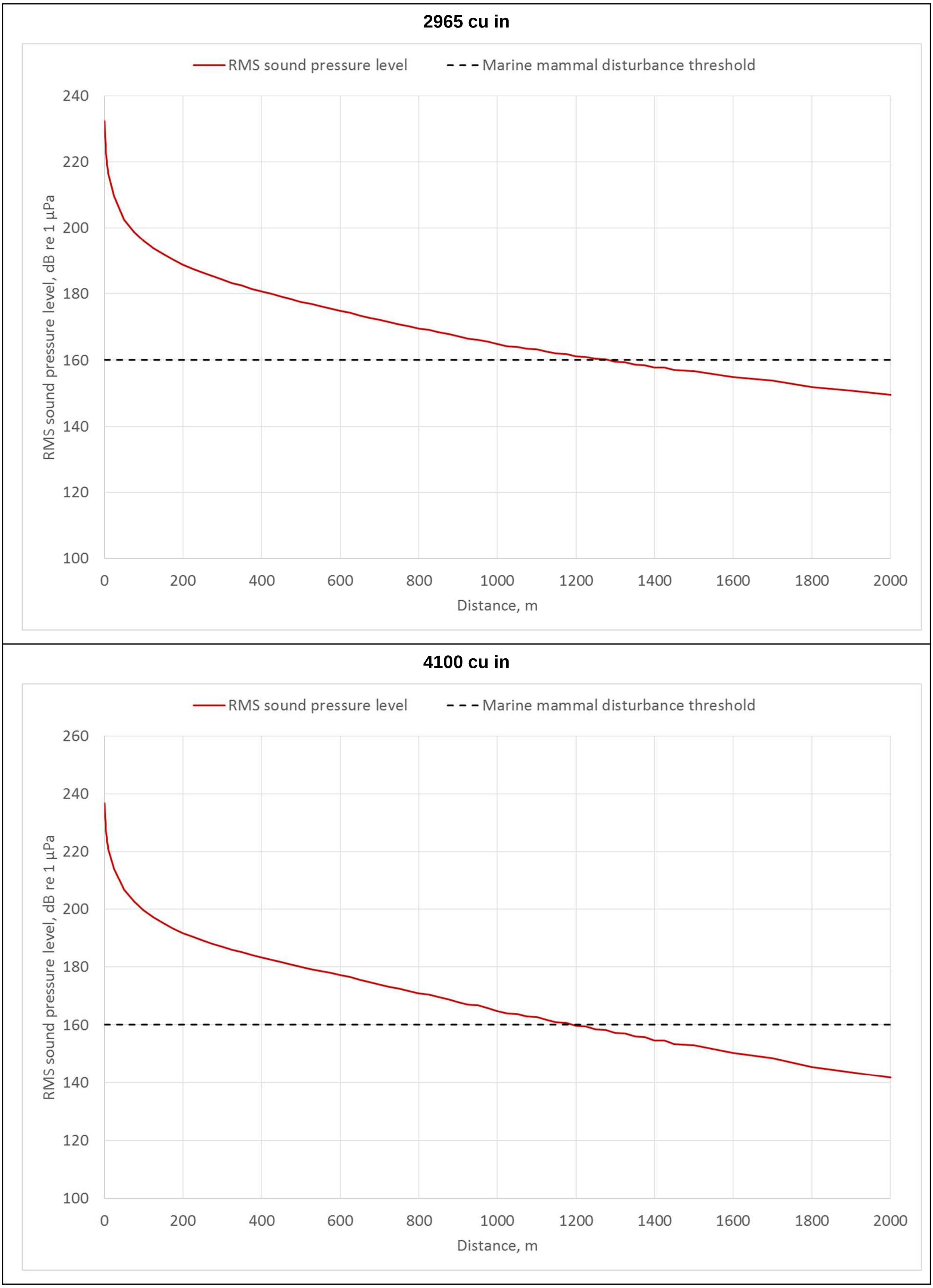

Figure 5.3 RMS$_{T90}$ sound pressure level against distance for behavioural change

5.8 Figure 5.4 shows the plotted rms T90 sound pressure level contours for a seismic source operating approximately in the centre of the survey area.

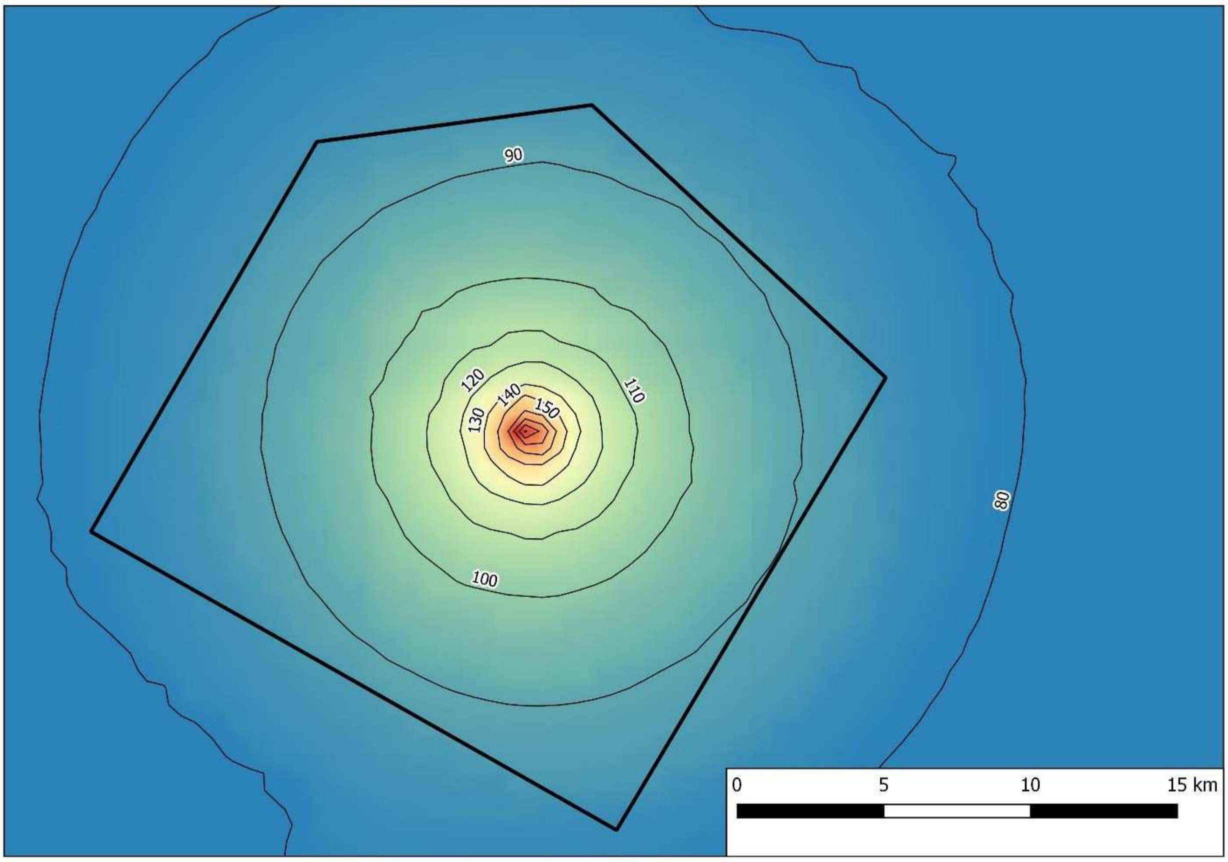

Figure 5.4 RMS_{T90} sound pressure level contour, dB re 1 µPa (rms)

Marine Mammals - Injury and Behavioural Change Zone Summary

5.9 The radius of the potential injury and disturbance zones for the different modelled situations are summarised in Table 5.1, based on a comparison of the calculated sound level at various ranges against the criteria.

Table 5.1 Summary of potential injury and disturbance zones for marine mammals

Scenario	Radius of effect			
	2965 cu in		4100 cu in	
Injury (PTS)	**SEL Fleeing Mammals:**	**Peak Mammals:**	**SEL Fleeing Mammals:**	**Peak Mammals:**
Low frequency cetacean	99 m	38 m	186 m	50 m
Low frequency cetacean + mitigation	*20 m*	*10 m*	*42 m*	*16 m*
Mid frequency cetacean	10 m	8 m	35 m	14 m
Mid frequency cetacean + mitigation	*N/E*	*N/E*	*11 m*	*N/E*
High frequency cetacean	316 m	275 m	613 m	338 m
High frequency cetacean + mitigation	*89 m*	*79 m*	*270 m*	*113 m*
Phocid pinniped	13 m	42 m	44 m	56 m
Phocid pinniped + mitigation	*N/E*	*11 m*	*13 m*	*17 m*
Otariid pinniped	N/E	N/E	N/E	11 m
Otariid pinniped + mitigation	*N/E*	*N/E*	*N/E*	*N/E*
Behavioural Change	**Radius**	**Area**	**Radius**	**Area**
NMFS 160 dB re 1 μPa	1,190 m	4.4 km^2	1,140 m	4.1 km^2

5.10 Assuming that marine mammals will swim away from the source array upon hearing start-up and with soft start procedures in place, the SEL injury zones for a swimming animal reduce to approximately 270 m for high frequency cetaceans. For low-frequency cetaceans, the injury range will be 42 m or less and the injury range for mid-frequency cetaceans will be 11 m or less. It is important to note that injury ranges are based on the worst case take-off angle between the animal and the source array. In other words, for an injury range which is less than the water depth, the assumption is that a marine mammal could be directly underneath the source array, meaning that the effects of directivity are minimal. In reality, it is more likely that the animal would be some distance away horizontally from the source array, in which case directivity effects would mean that their sound exposure would be significantly lower than predicted in this worst case modelling scenario. The scenario of a marine mammal being directly under the array during start-up is considered unlikely, even if it is theoretically possible. It can therefore be concluded that the ranges presented for injury and disturbance and very precautionary and overly pessimistic.

5.11 Strong disturbance to marine mammals could occur at distances of up to 1,190 m from the source array based on NMFS guidelines.

Sea Turtles

5.12 The spatial extent of the range of effects on turtles is summarised in Table 5.2 assuming a moderate swim speed of 0.5 m/s.

Table 5.2 Summary of potential injury and disturbance zones for fish and sea turtles

Type of animal	Parameter	Range of effect, m			
		Source array	Mortality and potential mortal injury	Recoverable injury	TTS
Sea turtles	SEL, dB re 1 μPa^{2}s	2965 cu in	2	(*Near*) High (*Intermediate*) Low (*Far*) Low	(*Near*) High (*Intermediate*) Low (*Far*) Low
		4100 cu in	4		
	Peak, dB re 1 μPa	2965 cu in	39		
		4100 cu in	185		
Predicted range of behavioural effect	(*Near*) High (*Intermediate*) Moderate (*Far*) Low				

5.13 For sea turtles, there is a high level of risk of behavioural effects within tens of meters of the seismic source, a moderate risk within hundreds of meters and a low risk within thousands of meters.

6 Mitigation

6.1 Without any mitigation measures in place, seismic survey activities have been identified as having the potential to cause injury to high frequency cetaceans at a range of up to 613 m from the source array. However, high frequency cetaceans are unlikely to be present in the survey area and the injury radius is only 35 m for mid-frequency cetaceans and 186 m for low frequency cetaceans. Disturbance to marine mammals could occur at distances of up to 1,190 m from the source array but this is based on the assumption of an animal being at the maximum possible depth in areas with deep bathymetry which, as discussed previously, is a very unlikely scenario.

6.2 Given the potential for injury (and disturbance) from the survey, it is recommended that further mitigation measures should be adopted. These include:

- **Marine Mammal Observers**
  - Provision of qualified and experienced Marine Mammal Observer (MMO) to be present for the duration of the survey to undertake cetacean visual monitoring during all daylight hours.
- **Passive Acoustic Monitoring (PAM) – if starting at night**
  - PAM comprises of a short hydrophone array station, a deck cable and data processing system which processes and stores selected data. The PAM system could be used for nighttime and low visibility shooting to detect any cetaceans within close proximity to the survey.
- **Pre-shooting search**
  - The MMO (or PAM operative) would begin observations 60 minutes before the commencement of the first use of the seismic source and the survey would be delayed if any cetaceans are detected within 1 km of the airgun array before work commences; and
  - If cetaceans are observed or detected within 1 km during this first observation, then the start of the seismic sources would be delayed until cetaceans have moved away (not sighted for at least 20 minutes).
- **Airguns**
  - To ensure that marine mammals are given the opportunity to move away from the airguns as they commence firing, energy should be slowly increased to the maximum level over a period of 20 minutes, in a process called ‘soft-start’.

6.3 Taking the effect of soft start into account, the potential injury ranges reduce further. It is therefore concluded that the injury ranges for all marine mammals are well within the 1 km MMO observation zone. This effectively reduces the risk of injury to marine mammals to negligible levels.

7 Conclusions

7.1 Based on the propagation and sound exposure modelling carried out for this assessment, it is concluded that:

- Some sea turtles could be injured at ranges of up to 185 m from the source array.
- There is potential for disturbance to marine mammals within up to 1,190 m of the source array, although this assumes that the animal is at the bottom of the water column and is considered to be an unlikely scenario. This equates to an area of approximately 4.4 km^2.
- Assuming a swimming animal, it is likely that potential injury zones for high frequency cetaceans could be up to 613 m before mitigation measures are applied. With soft start procedures in place, the potential injury zone will reduce to less than 270 m.
- It is, however, unlikely that any high-frequency cetaceans will be present in the survey area. For low-frequency cetaceans, the injury range will be 186 m or less and the injury range for mid-frequency cetaceans will be 35 m or less.
- These injury zones can effectively be monitored using MMOs during daylight or PAM at night.
- It is therefore concluded that it is unlikely that marine mammals will be injured as a result of the survey.

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