MARINE ENERGY WALES

MARINE ENERGY TEST AREA (META)

Environmental Impact Assessment

Chapter 6:

Underwater Noise

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Prepared by:	Prepared for:
RPS Energy Ltd.	**Marine Energy Wales**

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Glossary

Term	Definition
ABPmer	Consultancy providing NRW with advice on underwater noise.
Ambient noise	The total noise environment due to a combination of all sources including naturally occurring sound (e.g. marine mammal vocalisations, wave noise, tidal noise) and man-made noise (e.g. shipping).
Bathymetry	The measurement of water depth in oceans, seas and lakes.
OpenHydro	Tidal stream device developer
Oyster 800 project	An oscillating wave surge converter
pH	How acid Acid or Alkali a solution is
Power spectral density	A measure of the frequency content (spectrum) of noise per unit of frequency.
Sea State	The degree of turbulence at sea measures on a scale of 0 to 9 according to the average wave height.
Sound Exposure Level	A measure of the total sound energy of an event or a number of events (e.g. over the course of a day), normalised to one second.
Sound Pressure Level	A logarithmic measure of the effective pressure of a sound relative to a reference value.

Acronyms

Acronym	Description
ANSI	American National Standards Institute
ASA	Acoustical Society of America
DP	Dynamically Positioned
EIA	Environmental Impact Assessment
EMEC	European Marine Energy Centre
EPS	European Protected Species
HF	High-frequency hearing weighting (cetacean)
LNG	Liquified Natural Gas
LF	Low-frequency hearing weighting (cetacean)
MEW	Marine Energy Wales
META	Marine Energy Test Areas
MF	Mid-frequency hearing weighting (cetacean)
MHWS	Mean High Water Springs
MMO	Marine Mammal Observer
NIOSH	National Institute for Occupational Safety and Health
NMFS	National Marine Fisheries Service
NRW	Natural Resources Wales
OW	Ottariid hearing weighting
Pa	Pascal
pk	Peak
pk-pk	Peak to peak
PSD	Power spectral density
PTS	Permanent Threshold Shift
PW	Pinniped hearing weighting
RIAA	Report to inform Appropriate Assessment
rms	Root mean square
ROV	Remotely Operated Vehicle
SAC	Special Area of Conservation
SEL	Sound Exposure Level
SPL	Sound Pressure Level
T90	Period that contains 90% of the total cumulative sound energy
TTS	Temporary Threshold Shift
UK	United Kingdom
US	United States
WSDOT	Washington State Department of Transport

Units

Unit	Description
dB	deciBel
dBA	A-weighted deciBel
dB_{ht}	Hearing threshold weighted deciBel
Hz	Hertz
kHz	Kilohertz
km	Kilometre
kW	Kilowatt
m	Metre
ms	Millisecond
Pa	Pascal
pk	Peak
pk-pk	Peak to peak
Ppt	Parts per thousand
rms	Root mean square
rpm	Revolutions per minute
s	Second

Unit	Description
T90	Period that contains 90% of the total cumulative sound energy
$\mu\text{Pa}^2\text{Hz}^{-1}$	Micro Pascal squared seconds per Hertz (power spectral density reference unit)
$\mu\text{Pa}^2\text{s}$	Micro Pascal squared seconds (sound exposure level reference unit)
μPa	Micro Pascal (sound pressure level reference unit)

6. UNDERWATER NOISE

6.1 Consultation

6.1.1.1 A summary of the key issues raised during consultation specific to underwater noise is outlined below in Table 6.1, together with how these issues have been considered in the production of this Environmental Statement chapter. Natural Resources Wales (NRW) received advice from ABPmer to inform their Scoping Opinion on underwater noise.

Table 6.1: Summary of key consultation issues raised during consultation activities undertaken for the META project relevant to underwater noise.

Date	Consultee and type of response	Issues raised	Response to issue raised and/or where considered in this chapter
28 March 2019	NRW – scoping response	In summary, the Scoping Report has identified some of the potential issues that are relevant in relation to underwater noise and vibration and that should be scoped into the Environmental Impact Assessment (EIA). There are some inconsistencies and key gaps, however, including the need to apply appropriate acoustic models and relevant response thresholds that follow good practice. Recommendations for addressing these gaps are provided in our scoping advice note.	General comment - no action needed
28 March 2019	NRW – scoping response	According to the marine mammal section of the Scoping Report (Section 6.4), potential effects on marine mammals from the noise generated during the installation and decommissioning of devices are proposed to be scoped out of the EIA on the basis that the expected sound pressures levels of drilled piling (which are lower than expected from miscellaneous small vessels) are unlikely to result in injury to marine mammals. Potential effects on marine mammals during the operation of tidal turbines are also proposed to be scoped out on the basis that available data suggest the levels of noise generated by these devices is low and, in the context of existing high levels of baseline noise present within the Waterway, are unlikely to be a significant issue. This does not correspond with the underwater noise section of the Scoping Report (Section 6.7) which presents a proposed approach to assessing the effects of the installation and operation of devices on marine mammals (see Section 3.4 below).	Noise assessment has been undertaken for installation and operational noise. Assessment presented in relevant topic chapters.
28 March 2019	NRW – scoping response	The further assessment work that is proposed to be undertaken as part of the EIA will comprise a desk-based review of publicly available underwater noise levels from the installation, operation, maintenance and decommissioning activities, including drilled piling. The potential range of injury and disturbance in fish and marine mammals for these different activities will then be predicted. The most recent published exposure criteria or acoustic thresholds for effects on fish[4] and marine mammals[5] will be used to inform the assessment. The potential impacts on benthic ecology will also be considered, with a particular focus on Special Area of Conservation (SAC) qualifying habitat features.	Fish and marine mammals have been included. The assessments are presented in chapter 8: Fish and Shellfish and chapter 9: Marine Mammals. The assessments presented are informed by the assessment presented in chapter 6: Underwater Noise.
28 March 2019	NRW – scoping response	The underwater noise assessment will need to follow the latest guiding principles for assessing the impact of underwater noise[6]. This includes applying an appropriate acoustic model, and relevant noise sources and model input data[7]. The limitations and constraints of any approach should be clearly set out. The acoustic thresholds that are referenced in the Scoping Report consider potential injury effects only and there will be a need to consider available published criteria or indicators of behavioural responses in marine mammals[8] and fish[9].	Detailed modelling was not undertaken but rather a high-level assessment was conducted. The most recent thresholds for injury and disturbance have been included and are set out in this chapter – chapter 6: Underwater Noise. The assessment techniques are appropriate to the scale and relative risks of the project.
28 March 2019	NRW – scoping response	The underwater noise assessment should also include a desk-based review of the latest available scientific evidence of the observed responses of marine fauna (namely fish, marine mammals and benthic invertebrates) to different types of underwater sounds, for context. Although scientific research on the potential effects of underwater noise on invertebrates is relatively underdeveloped[10], there is increasing evidence to suggest that invertebrates are sensitive to noise, in particular particle motion [11,12,13].	A detailed review of literature in relation to marine mammal and fish response to underwater sound is covered in the relevant technical chapters (chapter 8: Fish and Shellfish and chapter 9: Marine Mammals). No assessment in relation to invertebrates has been undertaken as the potential for impact is deemed to be negligible because there are no impulsive sound sources associated with the META project. Noise from pile drilling and other sources will be similar to the existing sources such as tankers, ships and vessels which are already in the area. The references provided are in relation to pile-driving which has the potential for greater impact, including on benthic invertebrates than the drilled pin piling proposed at the META project.
28 March 2019	NRW – scoping response	The cumulative impacts of the META Project with the MOD firing range located to the south of East Pickard Bay will be considered as part of the underwater noise assessment and feed into the EIA topic specific chapters, including Fish and Shellfish, and Marine Mammals. The potential cumulative underwater noise effects from other activities (e.g. shipping) and projects that might generate underwater noise should also be considered as part of the EIA.	Modelling potential noise emissions from other developments has not been carried out as this is not deemed to be proportionate to the potential impact from the META project. CIA is of other plans and projects has been carried out in the relevant technical chapters (chapter 8: Fish and Shellfish, and chapter 9: Marine Mammals).

6.2 Introduction

6.2.1.1 Marine Energy Wales (MEW) aims to provide a suite of offshore marine energy test sites within, and in proximity to, the Milford Haven Waterway (subsequently referred to as the Waterway); to facilitate the testing and development of marine energy projects. This will allow developers to test devices, subassemblies and components, and monitoring equipment, thereby de-risking marine energy projects prior to larger scale or array deployments. This proposal, known as the Marine Energy Test Areas (META) project will provide marine renewable energy device developers with pre-consented testing sites, which will reduce the consenting burden on device developers. The aim of META is therefore to provide a series of pre-consented, non-grid connected, marine energy test areas that will allow for the deployment and testing of devices, components and subassemblies, and ancillary activities and equipment, in support of marine energy testing.

6.2.1.2 This report presents the results of a desktop study addressing the potential impacts due to underwater noise from the proposed META project on the surrounding marine environment. It is considered that the key issues will be the effects of underwater noise on marine mammals and fish from the following project activities:

- Device installation noise, in particular noise due to pin pile drilling and installation of devices a; and
- Operational noise due to testing of marine energy devices.

6.2.1.3 Noise is readily transmitted underwater and there is potential for sound emissions from the installation and operation of the project to affect marine mammals and fish. There are likely to be noise impacts due to the operational testing of marine energy test devices as well as installation activities such as marine energy device installation and use of vessels.

6.2.1.4 This report provides an overview of the potential effects due to underwater noise from the META project on the surrounding marine environment. Because the exact type, size and installation method for the potential test devices is unknown at this stage, this report presents an overview of likely impacts due to underwater noise from a typical range of marine energy devices and installation methodologies. As such, no detailed underwater noise modelling has been conducted.

6.2.1.5 The results from this high-level underwater noise review will be used to inform the marine mammal (chapter 9: Marine Mammals) and fish and shellfish ecology (chapter 8: Fish and Shellfish) impact assessments of the EIA in order to determine the potential impact of underwater noise on marine life. Consequently, the primary purpose of the underwater noise study is to predict the likely range of onset for potential physiological and behavioural effects due to increased anthropogenic noise due to the installation, operation and maintenance, or decommissioning phases of the META project. The sensitivity of species, magnitude of impact and significance of impact from underwater noise associated with the META project are dealt with in the relevant Environmental Statement chapters.

6.2.1.6 As this chapter is a partial step in the process of assessing the potential impacts of underwater noise on marine ecological receptor species, it is set out differently to the other chapters in this Environmental Statement. This chapter will be used to inform the following assessments:

- Chapter 8 – Fish and Shellfish; and
- Chapter 9 – Marine Mammals, Basking Shark and Otter.

6.3 Acoustic concepts and terminology

6.3.1.1 Sound travels through 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, a sound pressure of 60 dB re 20 μPa is the same as 86 dB re 1 μPa, although care also needs to be taken when converting from in air noise to in water noise levels due to the different sound speeds and densities of the two mediums resulting in a conversion factor of 62 dB. All underwater sound pressure levels in this report are described in dB re 1 μPa. In water, the sound source strength is defined 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.

6.3.1.2 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 ambient 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 6.1.

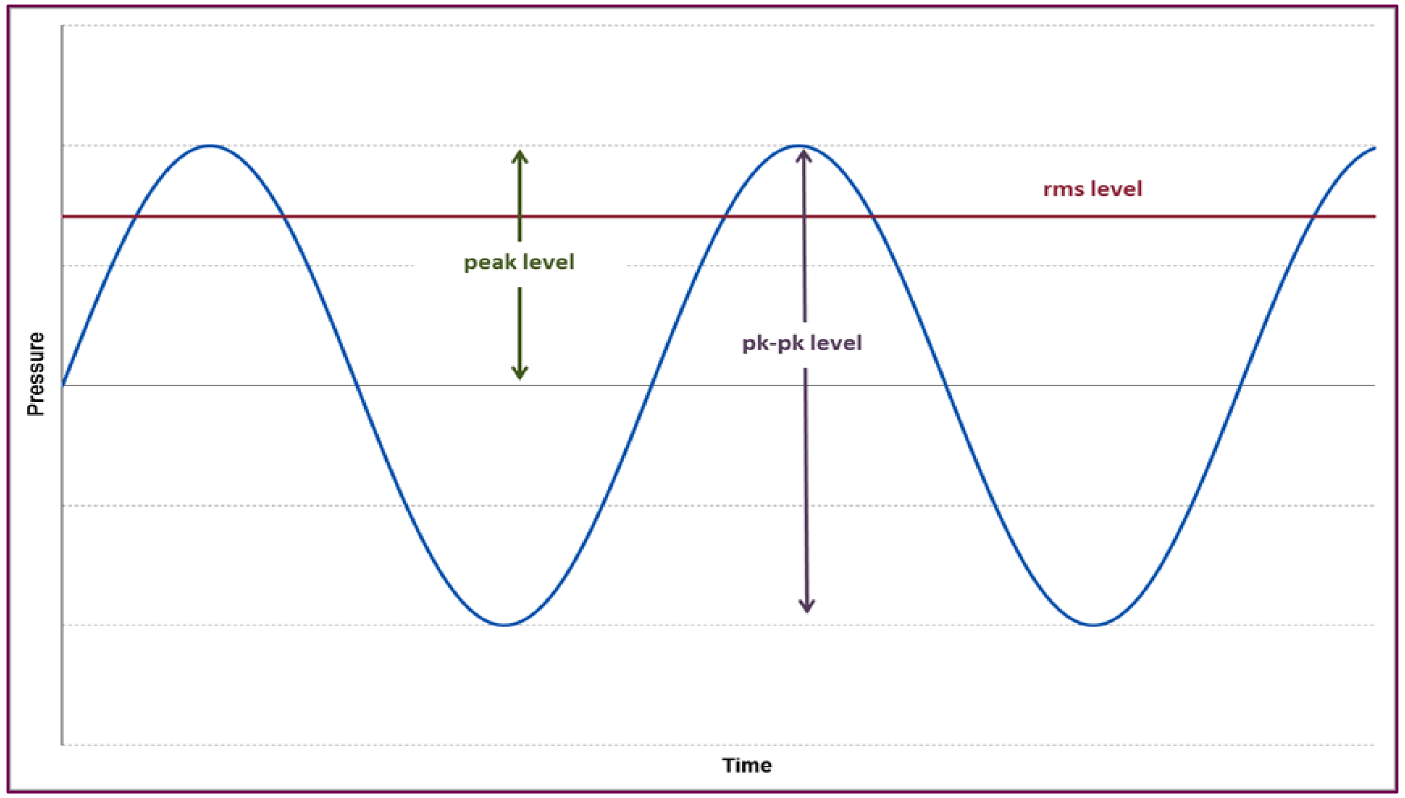

Figure 6.1: Graphical representation of acoustic wave descriptors.

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

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

6.3.1.4 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. 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 over a 24-hour period to be taken into account. The SEL is defined as follows:

$$SEL = 10log_{10}\left(\int_{0}^{T}\left(\frac{p^2(t)}{p_{ref}^2 t_{ref}}\right)dt\right)$$

6.3.1.5 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 faculties of marine mammals and fish are not the same as humans, with marine mammals hearing over a wider range of frequencies, fish over a typically smaller range of frequencies and both with different sensitivities. 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 life. 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 6.2. 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. It is also worth noting that some fish are sensitive to particle velocity rather than pressure, although paucity of data relating to particle velocity levels for anthropogenic noise sources means that it is often not possible to quantify this effect.

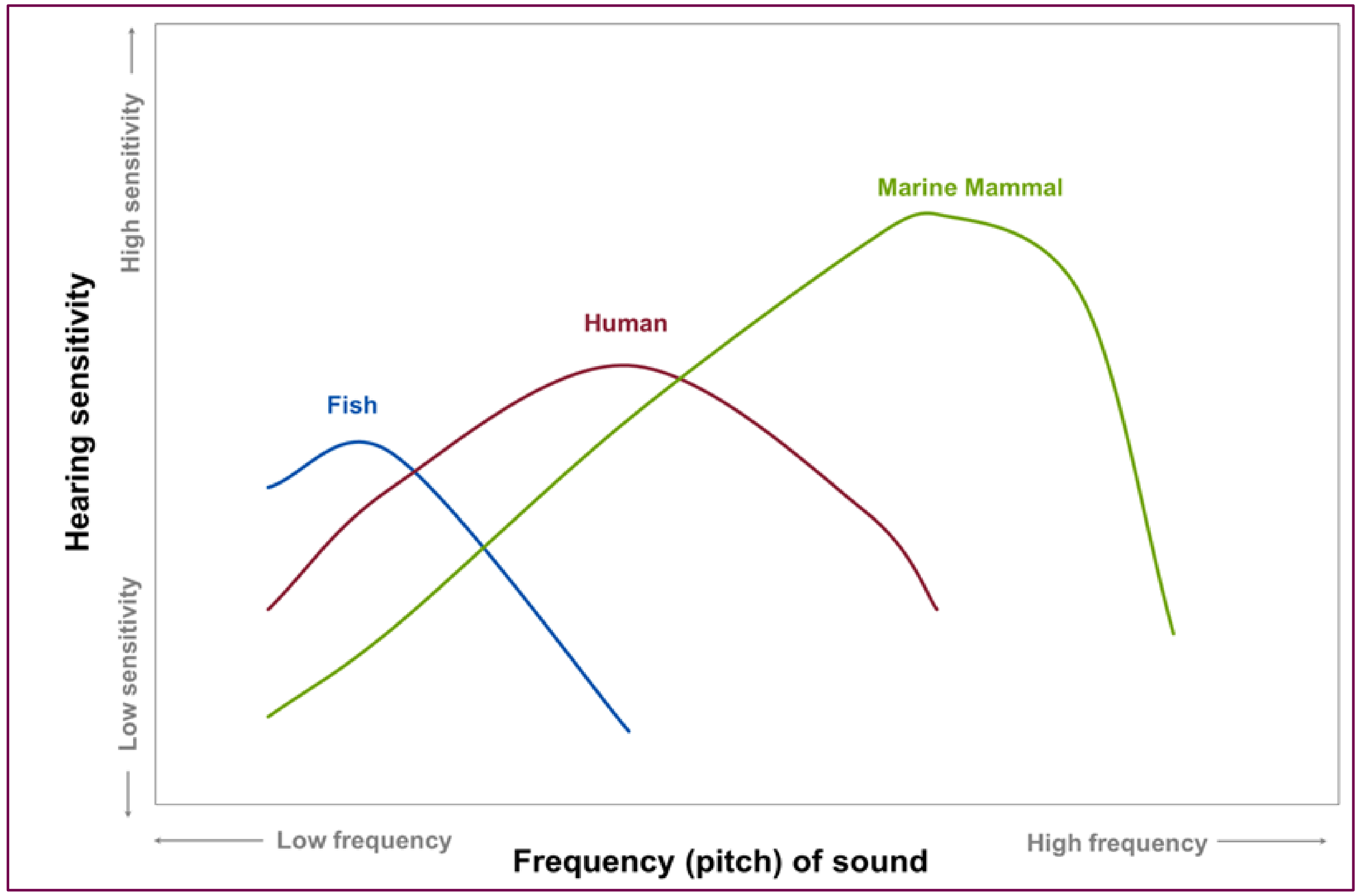

Figure 6.2: Comparison between hearing thresholds of different marine animals and humans.

6.4 Underwater noise assessment methodology

6.4.1 Assessment criteria

General

6.4.1.1 In order to determine the potential spatial range of injury and disturbance, assessment criteria have been developed based on a review of available evidence including national and international guidance and scientific literature. The following sections summarise the relevant criteria and describe the evidence base used to derive them.

6.4.1.2 Underwater noise has the potential to affect marine life in different ways depending on its noise level and characteristics. Assessment criteria generally separate sound into two distinct types, 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 (ANSI 1986; NIOSH 1998; ANSI 2005). This category includes sound sources such as seismic surveys, impact piling and underwater explosions; and
- **Non-impulsive (continuous) 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.

6.4.1.3 The proposed project does not include any potential sources of impulsive sound. Consequently, only the non-impulsive (continuous) sound criteria are of relevance.

6.4.1.4 The acoustic assessment criteria for marine mammals and fish in this report has followed the latest International guidance, (based on the best available scientific information), that are widely accepted for assessments in the UK, Europe and worldwide.

Marine mammals

6.4.1.5 Richardson *et al*. (Richardson and Thomson 1995) defined four zones of noise influence which vary with distance from the source and level as follows:

- Injury/hearing loss;
- Responsiveness;
- Masking; and
- Audibility.

6.4.1.6 For this study, it is the zones of injury and responsiveness (i.e. behavioural effects) that are of concern; there is insufficient evidence to properly evaluate masking.

6.4.1.7 The zone of injury in this study is classified as the distance over which a marine mammal can suffer a Permanent Threshold Shift (PTS) leading to non-reversible auditory injury. Injury thresholds are based on a dual criteria approach using both linear (i.e. un-weighted) peak SPL and marine mammal hearing-weighted SELs. 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); and
- **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).[1].

6.4.1.8 Beyond the area in which injury may occur, the effect on marine mammal behaviour is the most important measure of impact. Significant (i.e. non-trivial) disturbance 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.

6.4.1.9 To consider the possibility of significant disturbance resulting from the project, it is therefore necessary to consider the likelihood that the sound could cause non-trivial disturbance, the likelihood that the sensitive receptors will be exposed to that sound and whether the number of animals exposed are likely to be significant at the population level. Assessing this is however a very difficult task due to the complex and variable nature of sound propagation, the variability of documented animal responses to similar levels of sound, and the availability of population estimates, and regional density estimates for all marine mammal species.

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1. As no sea lions or fur seals are predicted to occur within the marine mammal regional study area, this category is provided for information only.

6.4.1.10 Southall *et al*. (2007) recommended that the only currently feasible way to assess whether a specific non-impulsive 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, which would constitute a disturbance under the relevant regulations. The Southall scale is shown in Table 6.2.

Table 6.2: Southall *et al*. (2007) behavioural disturbance scale.

Response Score	Corresponding Behaviours in free-ranging subjects
0	No observable response
1	Brief orientation response (investigation / visual orientation)
2	Moderate or multiple orientation behaviours Brief or minor cessation/modification of vocal behaviour Brief or minor change in respiration rates
3	Prolonged orientation behaviour Individual alert behaviour Minor changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source Moderate change in respiration rate Minor cessation or modification of vocal behaviour (duration < duration of source operation)
4	Moderate changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source Brief, minor shift in group distribution Moderate cessation or modification of vocal behaviour (duration more or less equal to the duration of source operation)
5	Extensive or prolonged changes in locomotion speed, direction, and/or dive profile but no avoidance of sound source Moderate shift in group distribution Change in inter-animal distance and/or group size (aggregation or separation) Prolonged cessation or modification of vocal behaviour (duration > duration of source operation)
6	Minor or moderate individual and/or group avoidance of sound source Brief or minor separation of females and dependent offspring Aggressive behaviour related to noise exposure (e.g. tail/flipper slapping, fluke display, jaw clapping/gnashing teeth, abrupt directed movement, bubble clouds) Extended cessation or modification of vocal behaviour Visible startle response Brief cessation of reproductive behaviour
7	Extensive or prolonged aggressive behaviour Moderate separation of females and dependent offspring Clear anti-predator response Sever and/or sustained avoidance of sound source Moderate cessation of reproductive behaviour
8	Obvious aversion and/or progressive sensitization Prolonged or significant separation of females and dependent offspring with disruption of acoustic reunion mechanisms Long-term avoidance of area (> source operation) Prolonged cessation of reproductive behaviour
9	Outright panic, flight, stampede, attack of conspecifics, or stranding events Avoidance behaviour related to predator detection.

6.4.1.11 For non-pulsed sound, the lowest sound pressure level at which a score of five or more occurs for low frequency cetaceans is 90 - 100 dB re 1 µPa (rms). However, this relates to a study involving migrating grey whales. A study for minke whales showed a response score of three at a received level of 100 – 110 dB re 1 µPa (rms), with no higher severity score encountered for this species. For mid frequency cetaceans, a response score of eight was encountered at a received level of 90 - 100 dB re 1 µPa (rms), but this was for one mammal (a sperm whale) and might not be applicable for the species likely to be encountered near the META project. For high frequency cetaceans, a number of individual responses with a response score of six are noted ranging from 80 dB re 1 µPa (rms) and upwards. There is a significant increase in the number of mammals responding at a response score of six once the received sound pressure level is greater than 140 dB re 1 µPa (rms).

6.4.1.12 Clearly, there is much intra-category and perhaps intra-species variability in behavioural response. As such, a conservative approach should be taken to ensure that the most sensitive marine mammals remain protected.

6.4.1.13 This assessment therefore adopts a conservative approach and uses the US National Marine Fisheries Service (NMFS, 2005) Level B harassment thresholds for non-impulsive sounds. 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 description of non-trivial disturbance has therefore been used as the basis for onset of behavioural change in this assessment.

6.4.1.14 The (NMFS, 2005) guidance sets the marine mammal level B harassment threshold for continuous noise at 120 dB re 1 µPa (rms). This value sits approximately mid-way between the range of values identified in Southall *et al*. (2007) for continuous sound but is lower than the value at which the majority of mammals responded at a response score of six (i.e. once the received rms sound pressure level is greater than 140 dB re 1 µPa). Taking into account the paucity and high-level variation of data relating to onset of behavioural effects due to continuous sound, it is recommended that any ranges predicted using this number are viewed as probabilistic and potentially over-precautionary.

6.4.1.15 The relevant criteria for marine mammals are summarised in Table 6.3. This includes the thresholds for non-impulsive sound based on the relevant guidelines (NMFS 2018, NMFS 2005). In Table 6.3 SELs are expressed as dB re 1 µPa^{2}s (cumulative over a 24-hour period) and RMS sound pressure levels are in dB re 1 µPa (rms).

Table 6.3: Summary of acoustic thresholds for marine mammals for non-impulsive sound.

Hearing group	Parameter	PTS	TTS	Disturbance
Low-frequency (LF) cetaceans	SEL, LF weighted dB re 1 µPa^{2}s	199	179	-
	RMS$_{T90}$ dB re 1 µPa (rms)	-	-	120
Mid-frequency (MF) cetaceans	SEL, MF weighted dB re 1 µPa^{2}s	198	178	-
	RMS$_{T90}$ dB re 1 µPa (rms)	-	-	120
High-frequency (HF) cetaceans	SEL, HF weighted dB re 1 µPa^{2}s	173	153	-
	RMS$_{T90}$ dB re 1 µPa (rms)	-	-	120
Phocid pinnipeds (PW)	SEL, PW weighted dB re 1 µPa^{2}s	201	181	-
	RMS$_{T90}$ dB re 1 µPa (rms)	-	-	120
Otariid pinnipeds (OW)	SEL, OW weighted dB re 1 µPa^{2}s	219	-	-
	RMS$_{T90}$ dB re 1 µPa (rms)	-	-	120

Fish

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

6.4.1.17 For fish, the most relevant criteria for injury are considered to be those contained in ASA S3/SC1.4 TR-2014, Sound Exposure Guidelines for Fishes and Sea Turtles (Popper *et al.* 2014) (Table 6.4). 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 continuous noise (which are applicable for vessels, drilled pin piling activities and operational noise from devices). The criteria include a mixture of indices including SEL, rms and peak sound pressure levels. Where insufficient data exists to determine a quantitative guideline value the risk is categorised in relative terms as “high”, “moderate” or “low” at three distances from the source: “near” (i.e. in the tens of metres), “intermediate” (i.e. in the hundreds of metres) or “far” (i.e. in the thousands of metres). 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 meters) for some types of animal and impairment effects, this is not considered to be a significant issue with respect to determining the potential effect of noise on fish.

Table 6.4: ASA guideline criteria for injury in fish due to non-impulsive sound.

Type of animal	Mortality and potential mortal injury	Impairment	
		Recoverable injury	TTS
Fish: no swim bladder (particle motion detection)	(Near) Low (Intermediate) Low (Far) Low	(Near) Low (Intermediate) Low (Far) Low	(Near) Moderate (Intermediate) Low (Far) Low
Fish: where swim bladder is not involved in hearing (particle motion detection)	(Near) Low (Intermediate) Low (Far) Low	(Near) Low (Intermediate) Low (Far) Low	(Near) Moderate (Intermediate) Low (Far) Low
Fish: where swim bladder is involved in hearing (primarily pressure detection)	(Near) Low (Intermediate) Low (Far) Low	170 dB re 1 µPa (rms) for 48 hours	158 dB re 1 µPa (rms) for 12 hours
Eggs and larvae	(Near) Low (Intermediate) Low (Far) Low	(Near) Low (Intermediate) Low (Far) Low	(Near) Low (Intermediate) Low (Far) Low

Notes:
Range of effect classified as Near = tens of meters / Intermediate= hundreds of meters / Far = thousands of meters
Relative risk classified as high, moderate or low

6.4.1.18 Behavioural reactions of fish to sound has been found to vary between species based on their hearing sensitivity. Typically, fish sense sound via particle motion in the inner ear which is detected from sound-induced motions in the fish’s body. The detection of sound pressure is restricted to those fish which have air filled swim bladders; however, particle motion (induced by sound) can be detected by fish without swim bladders.

6.4.1.19 Highly sensitive species such as herring have elaborate specialisations of their auditory apparatus, known as an otic bulla - a gas-filled sphere connected to the swim bladder which enhances hearing ability. The gas filled swim bladder in species such as cod and salmon may be involved in their hearing capabilities, so although there is no direct link to the inner ear, these species are able to detect lower sound frequencies and as such are considered to be of medium sensitivity to noise. Flat fish and elasmobranchs have no swim bladders and as such are considered to be relatively less sensitive to sound pressure.

6.4.1.20 The most recent criteria for disturbance are considered to be those contained in ASA S3/SC1.4 TR-2014, Sound Exposure Guidelines for Fishes and Sea Turtles (Popper *et al.,* 2014) which set out criteria for disturbance due to different sources of noise (Table 6.5). 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).

Table 6.5: ASA guideline criteria for onset of behavioural effects in fish due to non-impulsive sound.

Type of Animal	Relative Risk of Behavioural Effects
Fish: no swim bladder (particle motion detection)	(Near) Moderate (Intermediate) Moderate (Far) Low
Fish: where swim bladder is not involved in hearing (particle motion detection)	(Near) Moderate (Intermediate) Moderate (Far) Low
Fish: where swim bladder is involved in hearing (primarily pressure detection)	(Near) High (Intermediate) Moderate (Far) Low
Eggs and larvae	(Near) Moderate (Intermediate) Moderate (Far) Low

6.4.1.21 It is important to note that the ASA criteria for disturbance due to sound are qualitative rather than quantitative criteria. Consequently, a source of noise of a particular type (e.g. drilled pin piling or sound from vessels etc.) would result in the same predicted impact, no matter the level of noise produced or the propagation characteristics. Consequently, it is also proposed to use the criteria presented in the Washington State Department of Transport Biological Assessment Preparation for Transport Projects Advanced Training Manual (WSDOT 2011). The manual suggests an un-weighted sound pressure level of 150 dB re 1 µPa (rms) as the criterion for onset of behavioural effects, based on work by Hastings (2002). Sound pressure levels in excess of 150 dB re 1 µPa (rms) are expected to cause temporary behavioural changes, such as elicitation of a startle response, disruption of feeding, or avoidance of an area. The document notes that levels exceeding this threshold are not expected to cause direct permanent injury but may indirectly affect the individual fish (such as by impairing predator detection). It is important to note that this threshold is for onset of potential effects, and not necessarily an ‘adverse effect’ threshold. Whilst this criterion is rather generic and uses relatively old studies, it is used in this study as a way of benchmarking possible ranges of disturbance in conjunction with the ASA qualitative criteria.

6.4.2 Noise modelling methodology

6.4.2.1 Sound propagation modelling for this assessment was 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.

6.4.2.2 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 maximum 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). Taking into account the relatively low risk associated with noise from the proposed development (no impulsive sound), it is considered that potential errors due to paucity of information on marine mammal and fish criteria thresholds and uncertainties in source data are likely to be greater that the uncertainties inherent in the high-level acoustic modelling.

6.5 Baseline noise

6.5.1.1 Background or “ambient” underwater noise is generated by a number of natural sources, such as rain, breaking waves, wind at the surface, seismic noise, biological noise and thermal noise. Biological sources include marine mammals (which use sound to communicate, build up an image of their environment and detect prey and predators) as well as certain fish and shrimp. Anthropogenic sources also add to the background noise, such as fishing boats, ships, industrial noise, seismic surveys and leisure activities. Generalised ambient noise spectra (Wenz, 1962) attributable to various noise sources including both natural and anthropogenic sources are shown in Figure 6.3.

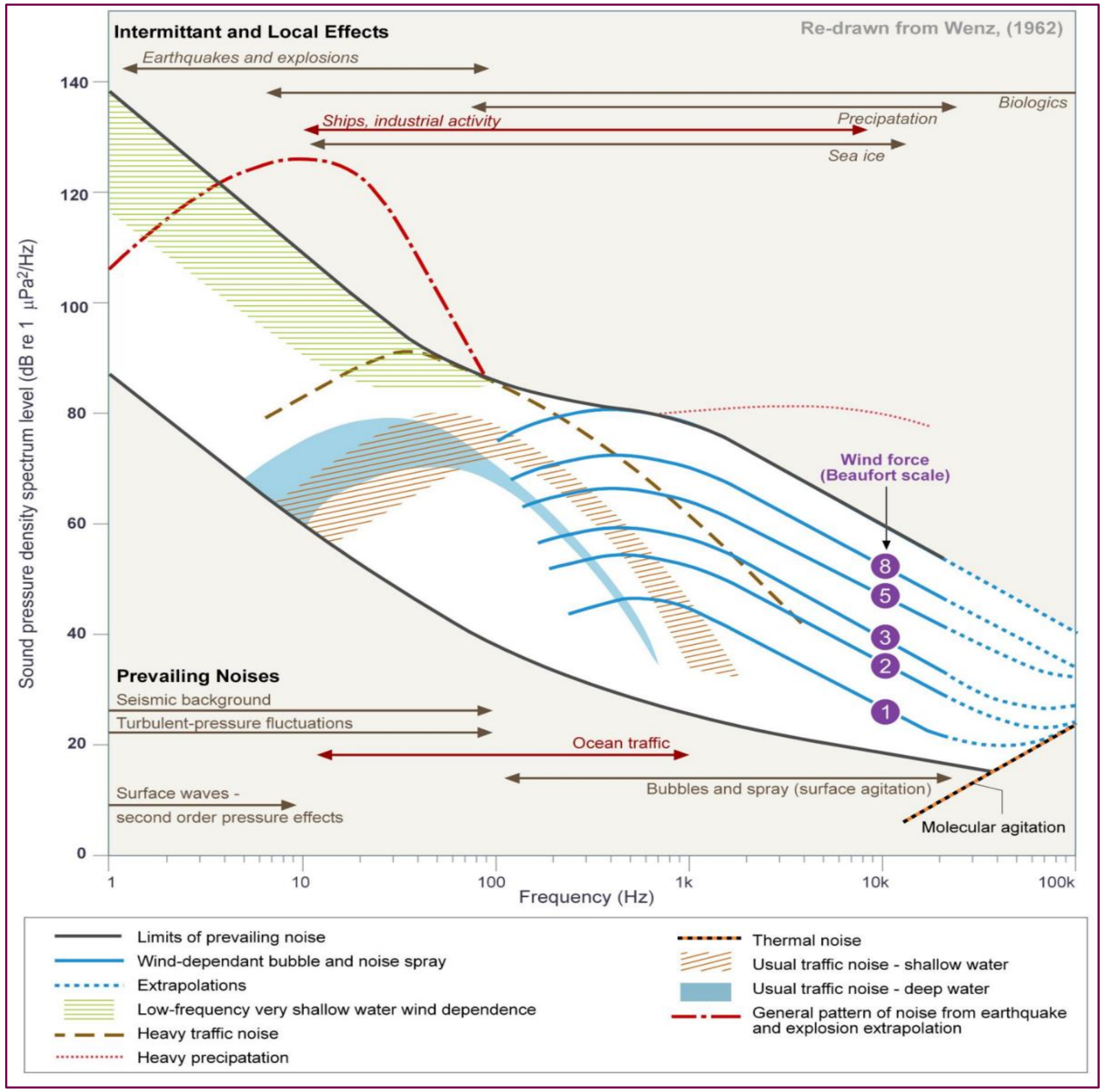

Figure 6.3: Generalised ambient noise spectra attributable to various noise sources (Wenz 1962).

6.5.1.2 The vast majority of research relating to both physiological effects and behavioural disturbance due to noise on marine species is based on determining the absolute noise level for the onset of that effect. As a result, criteria for assessing the effects of noise on marine mammals and fish tend to be based on the absolute noise criteria, as opposed to the difference between the baseline noise level and the specific noise being assessed (e.g. Southall *et al.*, 2007). Given the lack of evidence-based studies investigating the effects of noise relative to background on marine wildlife, the value of establishing the precise baseline noise level is somewhat diminished. It is important to understand that baseline noise levels will vary significantly depending on, amongst other factors, seasonal variations and different sea states, meaning that the usefulness of establishing such a value would be very limited. Nevertheless, it can be useful (though not essential) when undertaking an assessment of underwater noise, to have an understanding of the range of noise levels likely to be prevailing in the area, so that any noise predictions can be placed in the context of the baseline. It is important to note however, that even if an accurate baseline noise level could be determined, there is a paucity of scientific understanding regarding how various species distinguish anthropogenic sound relative to masking noise.

6.5.1.3 An animal's perception of sound is likely to depend on numerous factors including the hearing integration time, the character of the sound, and hearing sensitivity. It is not known for example, to what extent marine mammals and fish can detect tones of lower magnitude than the background masking noise, or how they distinguish time varying sound. Therefore, it is necessary to exercise considerable caution if attempting any comparison between noise from the proposed development and the baseline noise level. For example, it does not follow that because the broadband sound pressure level due to the source being considered is below the numeric value of the baseline level, that this means that marine mammals or fish cannot detect that sound. This is particularly true where the background noise is dominated by low frequency sound which is outside the animal's range of best hearing acuity. Until such a time as further research is conducted to determine a dose response relationship between the "signal-to-noise" level and behavioural response, a precautionary approach should be adopted.

6.5.1.4 For the reasons given above, and due to the relatively low risk of impulsive marine sound due to lack of impulsive piling for this project, it was considered that it would be disproportionate and unnecessary to undertake baseline noise measurements as part of this study. Alternatively, as detailed below, RPS has reviewed baseline noise studies carried out in UK waters for other projects in order to determine the likely magnitude of noise encountered in such waters.

6.5.1.5 A review of noise data relating to other sites in UK waters was undertaken for the Beatrice Wind Farm including a review of baseline underwater noise measurements in UK coastal waters (Brooker *et al.*, 2012). These noise data are summarised in Table 6.6 and power spectral density levels are shown graphically in Figure 6.4 (Sea State 1) and Figure 6.5 (Sea State 3).

Table 6.6: Summary of average background levels of noise around the UK coast (Brooker *et al.*, 2012).

	Overall (Un-Weighted) Average Background Noise Levels, dB re 1 µPa (rms)	
	Sea State 1	Sea State 3
Minimum	92	94
Maximum	126	132
Mean	111	112

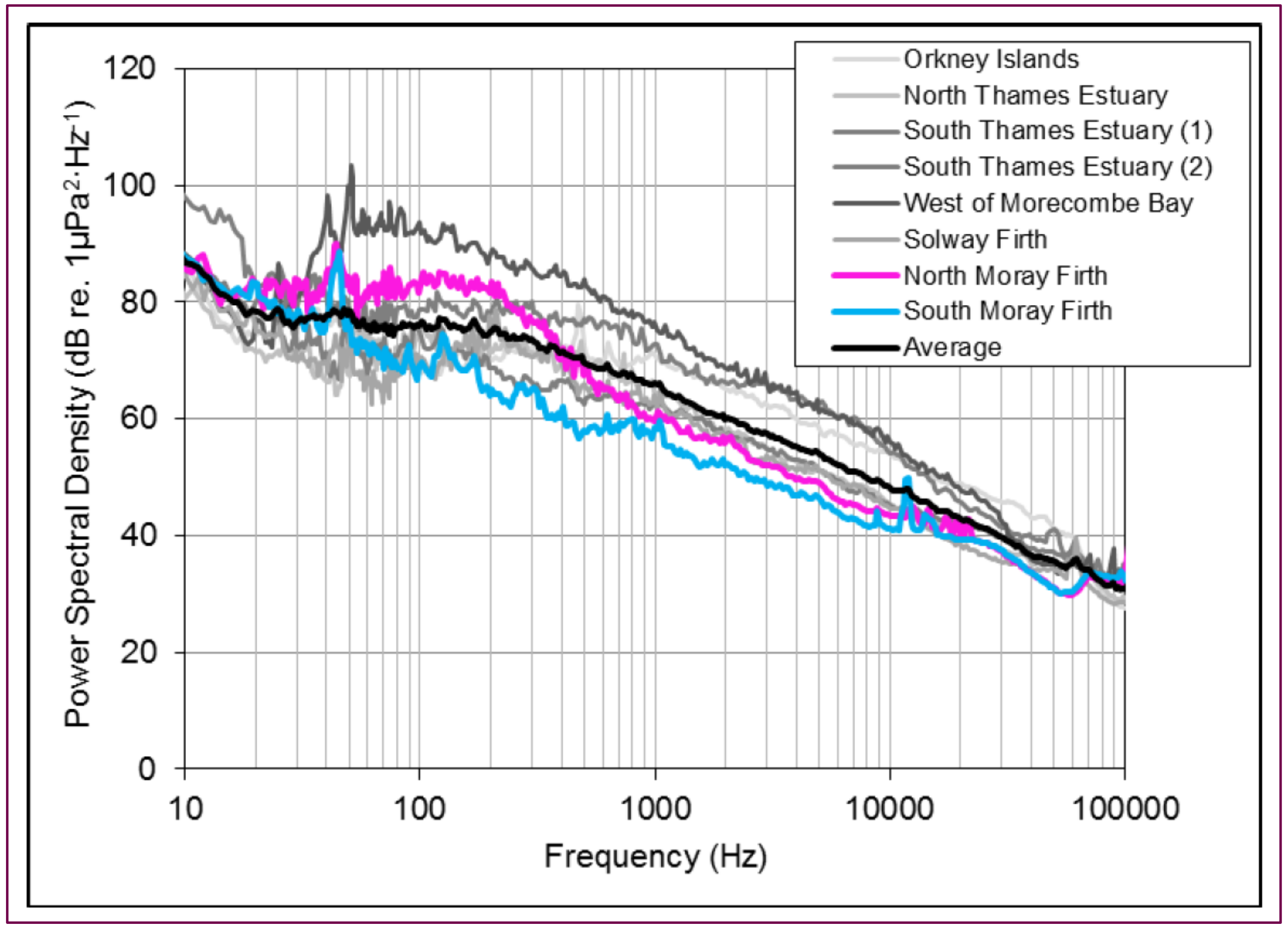

Figure 6.4: Summary of Power Spectral Density levels of background underwater noise at Sea State 1 at sites around the UK coast (Brooker, Barham, and Mason 2012).

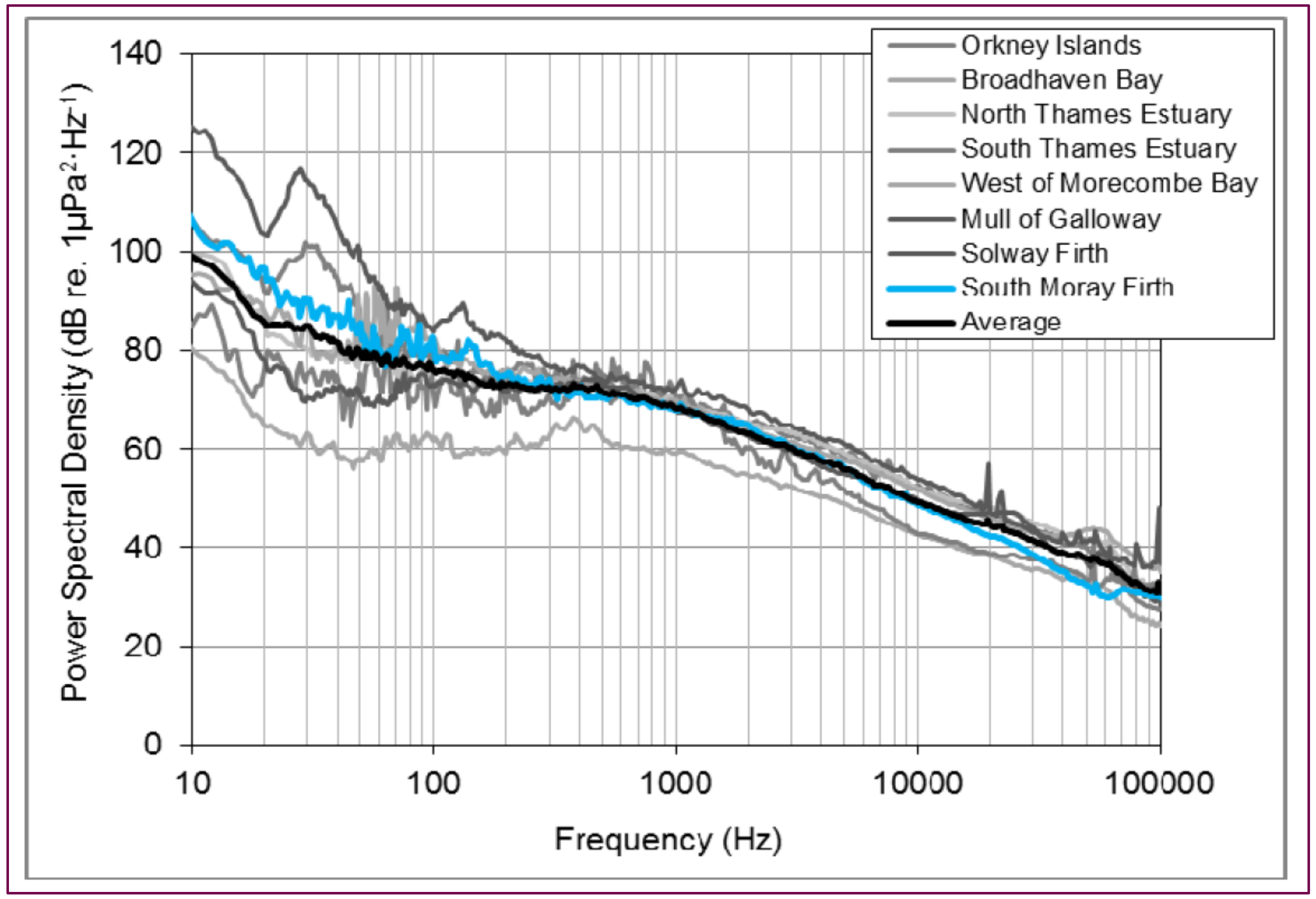

Figure 6.5: Summary of Power Spectral Density levels of background underwater noise at Sea State 3 at sites around the UK coast (Brooker *et al.*, 2012).

6.5.1.6 The measured power spectral density levels (maximum values in red, mean values in black and minimum values in green, in dB re 1 µPa^{2}Hz^{-1}) and third octave band sound pressure levels (light blue, in dB re 1 µPa) are shown in Figure 6.6 taken from Kongsberg (2012).

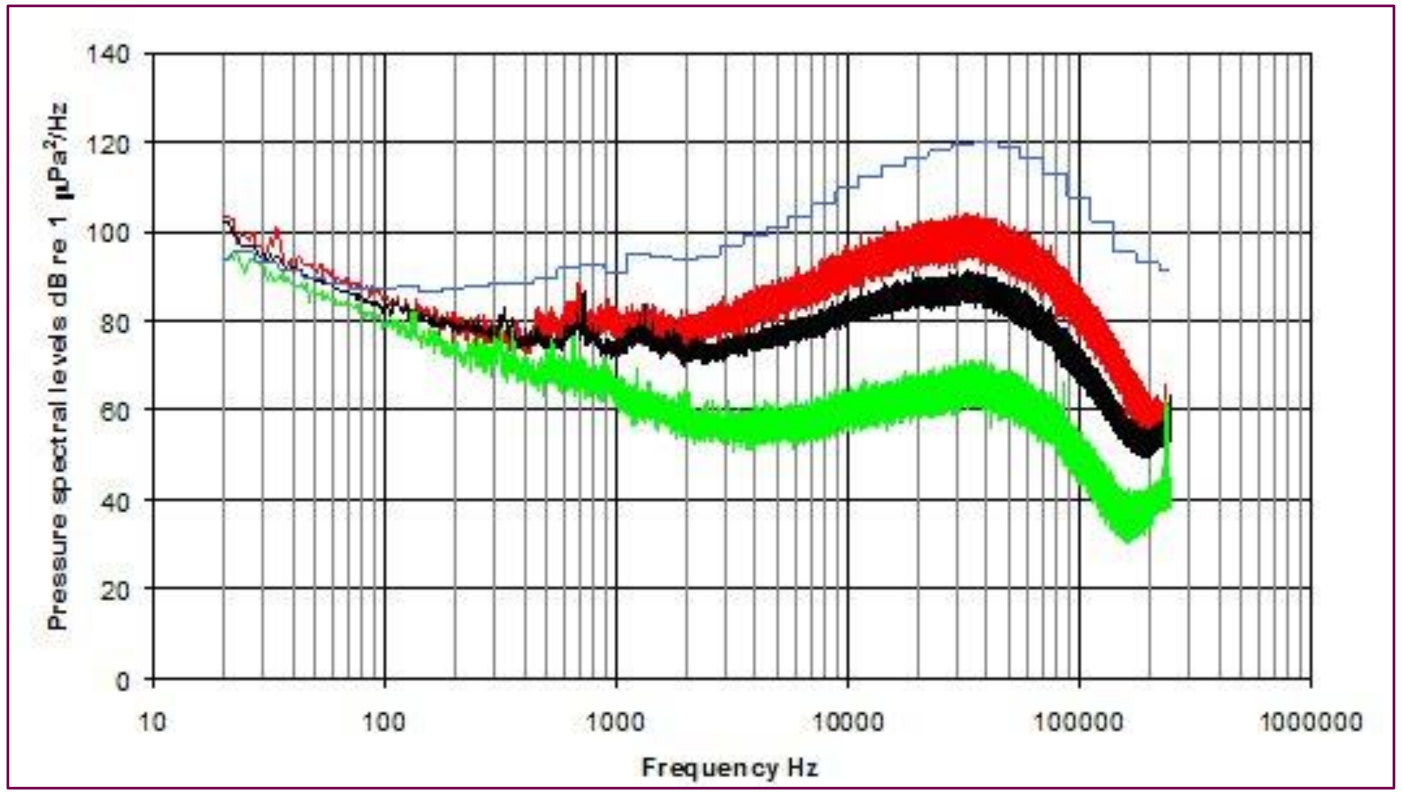

Figure 6.6: Summary of power spectral density levels and third octave band sound pressure levels of background underwater noise measured in the Inner Sound (Meygen), August 2011 (Kongsberg, 2012).

6.5.1.7 A “drifting-buoy” style assessment of background noise was undertaken by the Low Carbon Research Institute (LCRI) marine division in July 2014. Over an eleven-hour period, noise levels at the Inner Sound site were seen to vary from 91 dB re 1µPa during periods of low tidal flow speed to 121 dB re 1µPa at high tidal flow speeds.

6.5.1.8 Based on the review, it is concluded that baseline underwater noise levels in high-tidal, coastal areas are likely to be in the range 91 to 121 dB re 1 µPa (rms). Baseline noise is likely to be at its highest during periods of high tidal flow, which is also when proposed tidal energy devices at Warrior Way (site 6) are likely to produce the greatest amount of noise. Likewise, ambient noise will be elevated during high sea states which is also when the wave energy devices will produce the greatest noise (Dale Roads (site 7) and East Pickard Bay (site 8). Consequently, it is likely that noise from natural sources will be elevated during periods when the devices produce the greatest noise, meaning that noise from the devices will be afforded more masking during their peak operating modes.

6.5.1.9 In addition to natural ambient noise sources, the META project is within the vicinity of a heavily trafficked area. Significant vessel traffic occurs due to the hydrocarbon berths (South Hook Liquified Natural Gas (LNG), Valero refinery on the south bank, and Valero Oil Terminal & Dragon LNG), Milford Haven Dock and Pembroke Dock. Consequently, the area will already experience elevated levels of anthropogenic noise in addition to elevated natural ambient noise.

6.6 Review of sound propagation concepts

6.6.1.1 Increasing the distance from the noise source usually results in the level of noise getting 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.

6.6.1.2 The way that the noise spreads will depend upon several factors such as water column depth, pressure, and temperature gradients, salinity as well as water surface and 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.

6.6.1.3 In acoustically shallow waters[2] 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 2003, 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).

6.6.1.4 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 is an important factor with respect to the propagation of sound from a source. 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 waters, much of the sound energy is scattered (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.

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[2] Acoustically, shallow water conditions exist whenever the propagation is characterised by multiple reflections with both the sea surface and seabed (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.

6.6.1.5 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 water surface smoothness / wind speed, water depth, frequency of the sound, temperature gradient, grazing angle and range from source. Depending upon variations in the aforementioned factors, significant scattering could occur at sea state 3 or more for higher frequencies (e.g. 15 kHz or more). It should be noted that variations in propagation due to scattering will vary temporally (primarily due to different sea-states / wind speeds at different times) and that more sheltered areas (which are more likely to experience calmer waters) could experience surface scattering to a lesser extent and less frequently than less sheltered areas which are likely to encounter rougher waters. However, over shorter ranges (e.g. a few hundred meters or less) the sound will experience fewer reflections and so the effect of scattering should not be significant. Consequently, taking into account the sheltered location and likely distances over which injury will occur, this effect is unlikely to significantly affect the injury ranges presented in this report, although it is possible that disturbance ranges could vary depending on local and seasonal conditions.

6.6.1.6 When sound waves encounter the seabed, the amount of sound reflected will depend on the geoacoustic properties of the seabed (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, seabeds comprising primarily mud or other acoustically soft sediment will reflect less sound than acoustically harder seabeds such as rock or sand. This will also depend on the profile of the seabed (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) and so might not be a significant factor to take into account with respect to drilled pin piling noise (where most of the acoustic energy is at frequencies of a few hundred Hz). A scattering effect (similar to that which occurs at the surface) also occurs at the seabed (Essen, 1994; Greaves and Stephen, 2003; McKinney and Anderson, 1964; Kuo, 1992), particularly on rough substrates (e.g. pebbles).

6.6.1.7 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. The cut-off frequency as a function of water depth is shown in Figure 6.7 for a range of seabed types. Thus, for a water depth of 10 m (i.e. shallow waters typical of coastal areas) the cut-off frequency would be approximately 70 Hz for sand, 100 Hz for silt, 140 Hz for clayey silt and 40 Hz for bedrock.

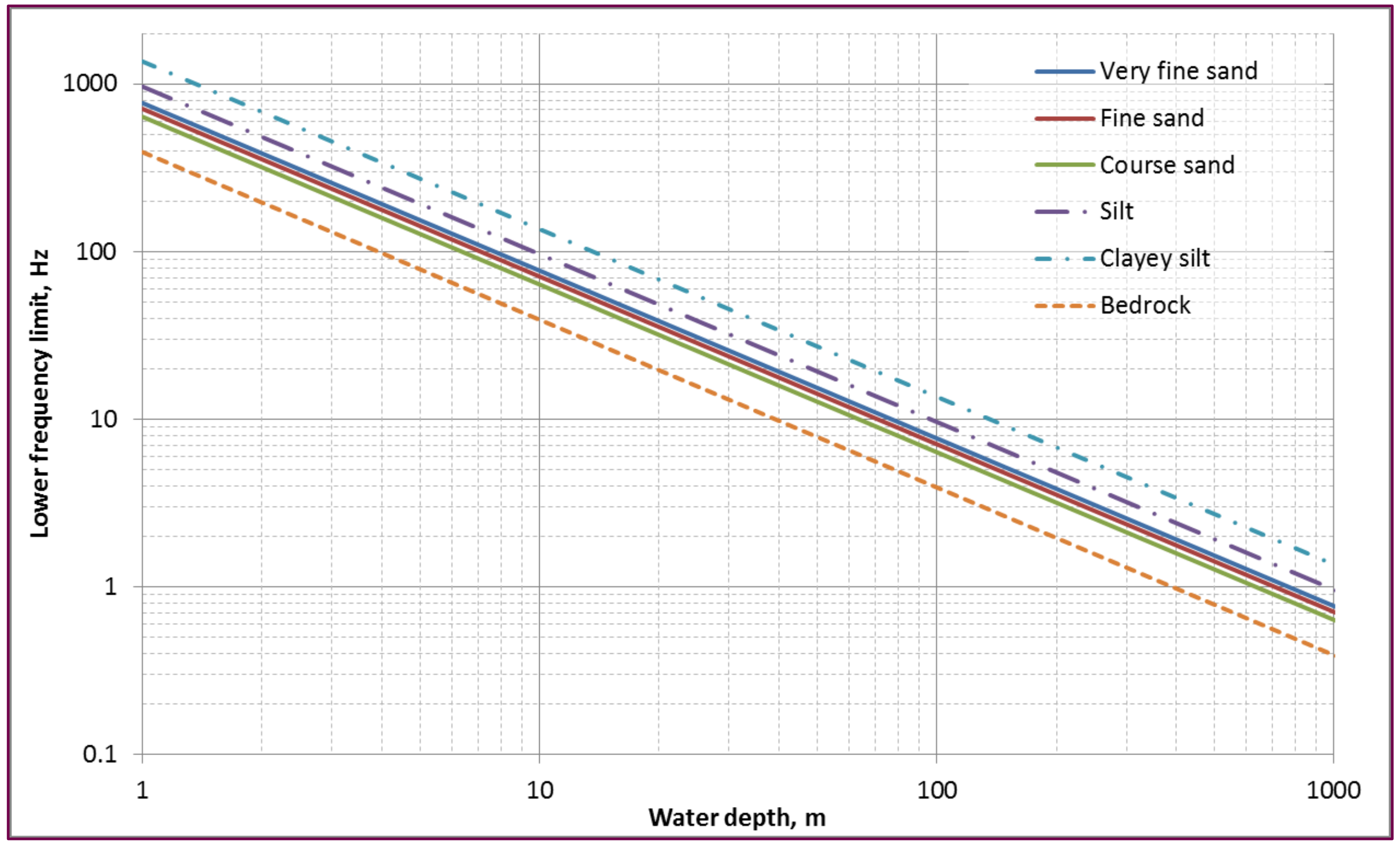

Figure 6.7: Lower cut-off frequency as a function of depth for a range of seabed types.

6.6.1.8 Sound energy can also be 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. This is shown in Figure 6.8. Although the effect of this absorption will be higher in cold water and with higher levels of MgSO4, these variations are relatively insignificant. As can be seen from Figure 6.8, the molecular absorption effect is only significant at high frequencies so is unlikely to be a significant factor for drilled pin piling noise.

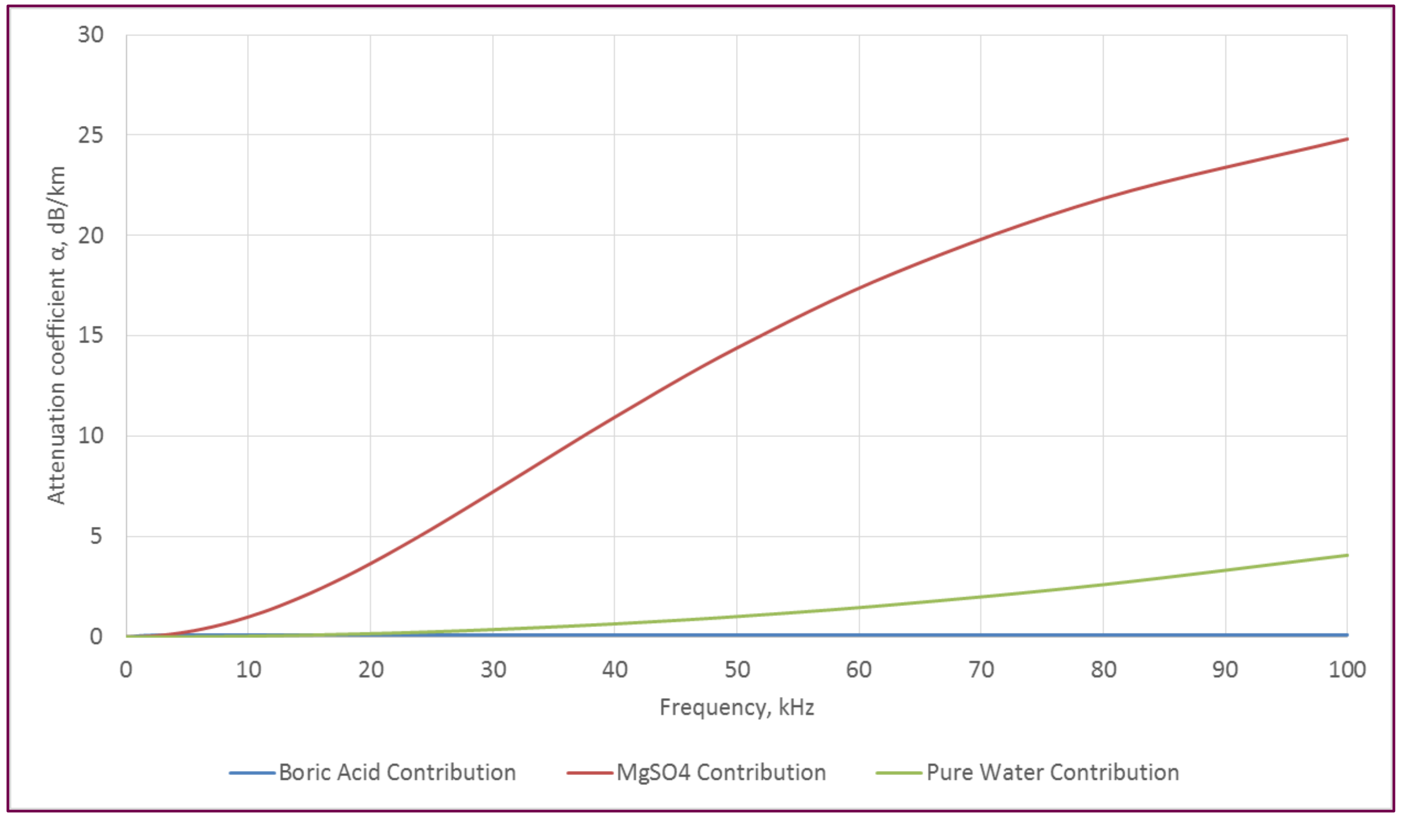

Figure 6.8: Absorption loss coefficient (α), dB/km (pH 8, 5 ºC, salinity 35 ppt).

6.7 Assessment of noise

6.7.1 Installation

6.7.1.1 There is potential for installation vessels, drilled pin piling and other equipment to produce noise during installation of the energy devices.

6.7.1.2 The design of the marine energy device support structures or anchoring will vary according to the different types being tested and method of attachment to the seabed (see chapter 2: Project Description). The following options are considered in this review:

- **Gravity base structure** - Installation requires use of installation vessels with heavy lifting capacity or specialist deployment barge; and
- **Drilled pin pile** - Installation of drilled pin piles require the use of specialist drilling equipment (e.g. drilling unit that sits on the seabed) and multi-stage operations to grout the piles into their socket.

6.7.1.3 Other installation activities or device mooring options are not considered to have the potential to result in an increase in underwater noise.

6.7.1.4 For the pin pile drilling, noise will be transmitted into the water through the interface between the bedrock and drill bit directly via ground borne noise, and also directly from the drill bit into the water. Source noise levels have been based on noise measurements undertaken during drilling activities for the Oyster 800 project at the EMEC test site at Billia Croo, Orkney (Kongsberg, 2011).

6.7.1.5 Once the sub-structures are in place, the turbines will be transported to the deployment area either on a deployment barge or similar heavy lifting vessel. Devices with built in buoyancy would be towed to site using standard support (such as a multicat) vessels. Once the devices are at site they will be lowered (or pulled down for buoyant turbines) by a winch to the top of the support structure. Remotely Operated Vehicles (ROVs) may then be used to guide the turbines into place for attachment to the substructure. The turbines will then be mechanically secured in place.

6.7.1.6 The noise emissions from the types of vessels that may be used in the META Project are quantified in Table 6.8, based on a review of publicly available data. Data are also presented for underwater pin pile drilling. SELs have been estimated for each source based on 24 hours continuous operation. This is likely to be an overestimation of duration. Source noise levels for vessels depend on the vessel size and speed as well as propeller design and other factors. There can be considerable variation in noise magnitude and character between vessels even within the same class. Therefore, source data for this project has been based largely on maximum scenario assumptions (i.e. using noise data toward the higher end of the scale for the relevant class of vessel as a proxy).

6.7.1.7 It is important to note that it is highly unlikely that any marine mammal or fish would stay at a stationary location or within a fixed radius of a vessel (or any other noise source) for 24 hours. Consequently, any resulting injury zones should be treated as a very pessimistic, maximum scenario. To put this into context, if an animal spent one hour instead of 24 hours being exposed to sound, this would result in a SEL 13 dB lower than predicted in this study which, in very ballpark terms, equates a potential injury radius of approximately a quarter of the size (and a reduction in the potential area over which injury might occur by one sixteenth). Taking into account the various precautionary assumptions made in derivation of injury criteria as well as the potential overestimate in sound exposure due to use of 24-hour SEL values, any estimated injury zones in this report should be treated as being precautionary over-estimates.

Table 6.7: Source noise data for installation vessels.

Item	Description/assumptions	Data source	Source sound pressure level at 1 m Rms, dB re 1 µPa	SEL (24h), dB re 1 µPa^{2}s
Anchor handling vessel	Tug used as proxy	Richardson (1995)	172	221
Installation vessel (using DP)	DP drilling rig used as proxy	McCauley (1998)	183	232
Support vessel / tug	Tug used as proxy	Richardson (1995)	172	221
Pin pile drilling	Pile drilling for Oyster 800 project	Kongsberg (2011)	163	212

6.7.1.8 An assessment of the distance to onset of injury from each vessel category is presented in Table 6.8 based on the SEL cumulative exposure criterion, along with an assessment of potential disturbance zones. As noted previously, the potential radii for injury are based on exposure levels over a 24-hour period. Thus, for example, a seal would need to stay within 20 m of support vessel/tug operations for a period of 24 hours to experience any injury. This is considered to be an unrealistically pessimistic scenario and therefore it is not thought likely that any marine mammals will be injured as a result of installation activities. Table 6.8 also presents the potential radius of disturbance for marine mammals based on the conservative 120 dB re 1 µPa (rms) criterion. It is important to bear in mind when viewing these potential disturbance radii that the 120 dB re 1 µPa (rms) criterion is very precautionary and that ambient noise levels could well exceed this value, particularly during periods with high tidal flow.

Table 6.8: Calculated effects of continuous vessel / installation noise on marine mammal receptors.

Activity / vessel	Radius of potential injury zone (assuming continuous exposure within that radius over 24-hour period)					Radius of potential disturbance
	LF	MF	HF	PW	OW	
Anchor handling vessel	20 m	2 m	46 m	7 m	0 m	2 km
Installation vessel (using DP)	88 m	0 m	3 m	8 m	0 m	12 km
Support vessel / tug	20 m	2 m	46 m	7 m	0 m	2 km
Pin pile drilling	5 m	2 m	45 m	3 m	0 m	0.5 km

6.7.1.9 The potential for injury and disturbance to fish is shown in the Table 6.9 and Table 6.10. Table 6.9 shows the qualitative risk of injury and disturbance to different fish types of potential installation activities, depending on range and in accordance with ASA guidance.

Table 6.9: Effects of continuous installation noise based on ASA qualitative criteria.

Range:	Qualitative risk due to exposure to continuous noise Near (10s of metres)	Intermediate (100s of metres)	Far (1,000s of metres)
ASA qualitative risk of potential injury:			
Fish: no swim bladder	Low	Low	Low
Fish: swim bladder not involved in hearing	Low	Low	Low
Fish: swim bladder involved in hearing	N/A – see Table 6.10		
Eggs and larvae	Low	Low	Low
ASA qualitative risk of potential disturbance:			
Fish: no swim bladder	Moderate	Moderate	Low
Fish: swim bladder not involved in hearing	Moderate	Low	Low
Fish: swim bladder involved in hearing	High	Moderate	Low
Eggs and larvae	Moderate	Moderate	Low

6.7.1.10 Table 6.10 shows the calculated ranges of injury to fish with swim bladders in line with ASA guidelines, based on exceedance of 170 dB re 1 µPa (rms) over 48 hours continuous exposure, and the potential disturbance radius to fish based on the WSDOT criterion of 150 dB re 1 µPa (rms).

Table 6.10: Calculated effects of continuous vessel noise on fish receptors.

Activity / vessel	ASA Radius of potential recoverable injury zone (assuming continuous exposure within that radius over 48-hour period)	Radius of potential disturbance zone (based on WSDOT criteria)
	Fish: swim bladder involved in hearing	All fish
Anchor handling vessel	1 m	23 m
Installation vessel (using DP)	6 m	37 m
Support vessel / tug	1 m	7 m
Pin pile drilling	0 m	6 m

6.7.1.11 The potential ranges presented for injury and disturbance are not a hard and fast 'line' where an impact will occur on one side of the line and not on the other side. 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 a way in which a wider audience can understand the potential spatial extent of the impact.

6.7.2 Operational noise

6.7.2.1 The proposed project is technology neutral on the basis that Marine Energy Wales does not know the exact devices that will be tested. The Pentland Firth and Enabling Actions Report (Robinson and Lepper 2013) presents a review of underwater noise emissions from tidal energy devices. The review identified 17 studies which report the absolute level of noise radiated from wave and tidal energy devices, as summarised in Table 6.11.

Table 6.11: Summary of publicly available measured data for energy devices.

Project	Measurements
SeaFlow (MCT) Lynmouth	Broadband "effective radiated noise level" of 166 dB re 1 µPa referred to 1 m
SeaGen (MCT) Strangford Lough	Broadband received level of 141 dB re 1 µPa (SPL) at a range of 311 m. Broadband "effective radiated noise level" of 174 dB re 1µPa referred to 1m
OpenHydro, Fall of Warness, EMEC	Broadband SPL received levels ranged from 116 to 127 dB re 1 µPa
Cobscook Bay Tidal Energy	Broadband received level at range of 10 m: <100 dB re 1 µPa^{2}/Hz
Andritz Hydro Hammerfest (HS300) Kvalsund, Western Finnmark, Norwa	Third octave SPLs received levels ranged from 130 to 150 dB re 1 µPa
East River, New York	145 dB re 1 µPa received level measured at 1 m
Admiralty Inlet, Puget Sound 2 x 6 m Openhydro	"Estimated maximum noise level" of 172 dB re 1 µPa
Pelamis P2 Billia Croo, EMEC, UK	Broadband Source Level 120 dB re 1 µPa^{2}/Hz referred to 1 m in low sea state Broadband Source Level 180 dB re 1 µPa^{2}/Hz referred to 1 m in high sea state
Wave Energy Pico Plant, Algarve, Portugal	SPL Received Levels did not exceed 126 dB re 1 µPa measured at 10 m.
SeaRay, West Point, Puget Sound, USA	SPL Received Level of 126 dB re 1 µPa observed
L12 Lykesil, WESA project, Uppsala University, Norway	Received levels SPL at 20 m from a WEC was 133 dB re 1 µPa (max SPL value) and 129 dB re 1 µPa (average SPL value). Peak amplitude was found at 145 Hz with "an average value" of 126 dB re 1 µPa.
Wavestar A/S, Hastholm, Denmark. Aarhus University, Denmark	Median SPL Received Level of 106-109 dB re. 1 µPa in the range 125-250 Hz A more powerful tone at 150 Hz (SPL of 121-125 dB re 1 µPa) occurred during start-up and shut-down.

6.7.2.2 The authors of the Pentland Firth and Enabling Actions Report noted that all values and units quoted in Table 6.11 are as stated in the original reports as far as possible and that direct comparison of values is difficult due to the varying methodologies, metrics and notations that have been used by different authors. Furthermore, the lack of frequency data in the reports for the turbine devices makes these data of limited usefulness for this study[3]. Therefore, based on the aforementioned data quality issues, the noise modelling for this study has been undertaken based on noise measurements of an OpenHydro tidal turbine at the EMEC facility in Orkney (Parvin and Brooker 2008) and the Pelamis P2 measured at Billia Croo (Lepper and Robinson 2016). Whilst it would be preferable to carry out modelling for a wider range of potential devices, the ability to do so is limited by the lack of sufficient data reported in the available literature. The noise source data used in the modelling is summarised in Table 6.12. It should be noted that the maximum diameter of tidal turbines likely to be used at Warrior Way is 5 m and therefore it is considered likely that source noise levels will be at the lower end of the scale. Consequently, it is considered that the range of source noise levels modelled (162 to 180 dB re 1 µPa at 1 m) is representative of the maximum noise output from renewable energy convertors that might be used.

Table 6.12: Source noise data for example operational devices.

Item	Description/assumptions	Data source	Source sound pressure level at 1 m	
			RMS, dB re 1 µPa	SEL(24h), dB re 1 µPa^{2}s
OpenHydro tidal turbine	EMEC facility in Orkney	Parvin and Brooker (2008)	162	212
Pelamis P2 WEC	EMEC facility in Orkney	Lepper *et al.* (2012)	180	229

6.7.2.3 An assessment of the distance to onset of injury from each vessel category is presented in Table 6.13 based on the SEL cumulative exposure criterion, along with an assessment of potential disturbance zones. As noted previously, the potential radii for injury are based on exposure levels over a 24-hour period. In reality, an animal is highly unlikely to spend 24 hours within a short range of an operating device and the radii can therefore be considered as a maximum scenario, highly precautionary zone.

Table 6.13: Calculated effects of continuous operational device noise on marine mammal receptors.

Activity / vessel	Radius of potential injury zone (assuming continuous exposure within that radius over 24-hour period)					Radius of potential disturbance
	LF	MF	HF	PW	OW	
OpenHydro tidal turbine	3 m	0 m	2 m	0 m	0 m	0.5 km
Pelamis P2 WEC	76 m	1 m	18 m	23 m	2 m	7 km

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[3] The Robinson and Lepper report does not reproduce PSD or third octave data for any of the devices, although it is likely that these data do exist, albeit not currently reproduced in publicly available literature.

6.7.2.4 On the basis of the above and taking into account the very low likelihood of an animal being exposed to noise from a device within the injury radii over a 24-hour period, it is considered highly unlikely that injury would occur to any marine mammal as a result of operational noise from test devices.

6.7.2.5 The potential range of injury and disturbance on fish is summarised in Table 6.14.

Table 6.14: Calculated effects of continuous operational device noise on fish receptors.

Activity / vessel	ASA Radius of potential recoverable injury zone (assuming continuous exposure within that radius over 48-hour period)	Radius of potential disturbance zone (based on WSDOT criteria)
	Fish: swim bladder involved in hearing	All fish
OpenHydro tidal turbine	4 m	78 m
Pelamis P2 WEC	0 m	6 m

6.7.2.6 Based on the ASA guideline criterion for potential injury to fish with swim bladders involved in hearing of 170 dB re 1 µPa (for 48 hours exposure), it is not expected that any fish will experience injury as a result of exposure to noise from the operation of marine energy devices. The disturbance zone for fish is likely to be less than 80 m around each device, although this is based on the upper range of noise levels expected.

6.7.2.7 Vessels may be utilised for some activities during the operation and maintenance phase of the project. Impacts associated with operation and maintenance vessels will be the same as for installation vessels.

6.8 Conclusions

6.8.1.1 A high-level review has been undertaken to understand the potential impacts due to underwater noise from the META project. Based on the study it is concluded that:

- Baseline noise levels will be highest during periods when the marine energy test devices are likely to be at their maximum noise output (due to elevated wave and tidal noise);
- There is potential for vessels and drilled pin piling to cause noise during the installation and decommissioning phase;
- There is potential for some installation activities to cause injury to marine mammals within an 88 m radius of the installation vessel, but this assumes that the marine mammal will stay within this radius for a 24-hour period, which is a highly unlikely scenario;
- Potential disturbance to marine mammals could occur within 12 km of the installation activities, although in reality it is likely that baseline ambient noise will mask this thus reducing the likelihood of disturbance occurring;
- There is a low risk of injury to fish during the installation phase – even the most sensitive fish would need to stay within a distance of less than 6 m from vessels for a 48-hour period to experience injury. This is considered highly unlikely;
- Disturbance to fish is only likely with 37 m or less from installation vessels;
- Injury could occur to marine mammals within 76 m of an operational marine energy device, although this assumes that the animal will stay within this range for a 24-hour period, which is considered highly unlikely;
- Disturbance to marine mammals could occur within 7 km of a marine energy device based on the highest noise output device modelled, although this would only be during periods of very high wave power – consequently ambient noise levels would also be elevated, and it is likely that noise from the devices would be masked;
- Although it is theoretically possible that fish could be injured within 4 m of an operational marine energy device if they stay within this radius for a period of 48 hours, this is considered a highly unlikely scenario; and
- Disturbance to fish could occur at up to 78 m of the highest noise output marine energy device, although this would only occur under very high wave heights;
- The significance of the above effects is examined separately in the marine mammal and fish chapters as well as the report to inform Appropriate Assessment (RIAA).

6.8.1.2 Based on the results of the high-level review, it is therefore concluded that it is highly unlikely that injury will occur for any marine mammal or fish species as a result of the META project.

6.9 References

ANSI. 2005. “ANSI S1.13-2005 Measurement of Sound Pressure Levels in Air.” American National Standards Institute.

ANSI. 1995. “ANSI S3.20-1995 Bioacoustical Terminology.” American National Standards Institute.

ANSI. 1986. “S12.7-1986 Method for Measurement of Impulse Noise.”

Brekhovskikh, Leonid Maksimovich, and I͡Uriĭ Lysanov. 2003. Fundamentals of Ocean Acoustics.

Brooker, A., R. Barham, and T. Mason. 2012. “Underwater Noise Modelling Technical Report.” E287R0919. Subacoustech Ltd.

Cole, B. F. 1965. “Marine Sediment Attenuation and Ocean-Bottom-Reflected Sound.” The Journal of the Acoustical Society of America 38 (2): 291–297.

Eckart, Carl. 1953. “The Scattering of Sound from the Sea Surface.” The Journal of the Acoustical Society of America 25 (3): 566–570.

Essen, H.-H. 1994. “Scattering from a Rough Sedimental Seafloor Containing Shear and Layering.” The Journal of the Acoustical Society of America 95 (3): 1299–1310.

Etter, Paul C. 2013. Underwater Acoustic Modeling and Simulation. CRC Press.

Fortuin, Leonard. 1970. “Survey of Literature on Reflection and Scattering of Sound Waves at the Sea Surface.” The Journal of the Acoustical Society of America 47 (5B): 1209–1228.

Greaves, Robert J., and Ralph A. Stephen. 2003. “The Influence of Large-Scale Seafloor Slope and Average Bottom Sound Speed on Low-Grazing-Angle Monostatic Acoustic Scattering.” The Journal of the Acoustical Society of America 113 (5): 2548–2561.

Hamilton, Edwin L. 1970. “Reflection Coefficients and Bottom Losses at Normal Incidence Computed from Pacific Sediment Properties.” Geophysics 35 (6): 995–1004.

Hastings, M. C. 2002. “Clarification of the Meaning of Sound Pressure Levels & the Known Effects of Sound on Fish.”

Kinsler, Lawrence E., Austin R. Frey, Alan B. Coppens, and James V. Sanders. 1999. “Fundamentals of Acoustics.” Fundamentals of Acoustics, 4th Edition, by Lawrence E. Kinsler, Austin R. Frey, Alan B. Coppens, James V. Sanders, Pp. 560. ISBN 0-471-84789-5. Wiley-VCH, December 1999. 1.

Kongsberg. 2011. “Measurement of Underwater Noise during Installation of 2.4MW Oyster Array at EMEC Wave Test Site, Billia Croo, Orkney.” 250121-TR-0001.

Kongsberg. 2012. “Underwater Noise Impact Study for Tidal Turbine Development in Inner Sound, Pentland Firth.” 250123-TR-0003-V3.

Kuo, Edward YT. 1992. “Acoustic Wave Scattering from Two Solid Boundaries at the Ocean Bottom: Reflection Loss.” Oceanic Engineering, IEEE Journal Of 17 (1): 159–170.

Lepper, Paul A., and Stephen P. Robinson. 2016. “Measurement of Underwater Operational Noise Emitted by Wave and Tidal Stream Energy Devices.” In The Effects of Noise on Aquatic Life II, 615–622. Springer.

Lurton, Xavier. 2002. An Introduction to Underwater Acoustics: Principles and Applications. Springer Science & Business Media.

Mackenzie, K. V. 1960. “Reflection of Sound from Coastal Bottoms.” The Journal of the Acoustical Society of America 32 (2): 221–231.

Marsh, H. Wysor, M. Schulkin, and S. G. Kneale. 1961. “Scattering of Underwater Sound by the Sea Surface.” The Journal of the Acoustical Society of America 33 (3): 334–340.

McCauley, Rob. 1998. “Radiated Underwater Noise Measured From the Drilling Rig Ocean General, Rig Tenders Pacific Ariki and Pacific Frontier, Fishing Vessel Reef Venture and Natural Sources in the Timor Sea, Northern Australia.” C98-20. Centre for Marine Science and Technology, Curtin University of Technology.

McKinney, C. Mo, and C. D. Anderson. 1964. “Measurements of Backscattering of Sound from the Ocean Bottom.” The Journal of The Acoustical Society of America 36 (1): 158–163.

NIOSH. 1998. “Criteria for a Recommended Standard: Occupational Noise Exposure.” National Institute for Occupational Safety and Health.

NMFS. 2005. “Scoping Report for NMFS EIS for the National Acoustic Guidelines on Marine Mammals.” National Marine Fisheries Service.

NMFS. 2018. “2018 Revision to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0).” NOAA Technical Memorandum NMFS-OPR-59. National Oceanic and Atmospheric Administration.

Parvin, S. J., and A. G. Brooker. 2008. “Measurement and Assessment of Underwater Noise from Crest Energy / OpenHydro Tidal Turbine at the EMEC Facility, Orkney.” 812R0101. Subacoustech Ltd.

Popper, Arthur N., Anthony D. Hawkins, Richard R. Fay, David A. Mann, Soraya Bartol, Thomas J. Carlson, Sheryl Coombs, *et al*. 2014. ASA S3/SC1.4 TR-2014 Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report Prepared by ANSI-Accredited Standards Committee S3/SC1 and Registered with ANSI. Springer.

Richardson, William John, and Denis H. Thomson. 1995. Marine Mammals and Noise. San Diego; Toronto: Academic Press.

Richardson, William John. 1995. Marine Mammals and Noise. San Diego, Calif.; Toronto: Academic Press.

Robinson, S. P., and P. A. Lepper. 2013. “Pentland Firth and Orkney Waters Enabling Actions Report - Review of Current Knowledge of Underwater Noise Emissions from Wave and Tidal Stream Energy Devices.” The Crown Estate.

Rogers, P. H. 1981. “Onboard Prediction of Propagation Loss in Shallow Water.” DTIC Document.

Southall, Brandon L., Ann E. Bowles, William T. Ellison, James J. Finneran, Roger L. Gentry, Charles R. Greene Jr, David Kastak, *et al*. 2007. “Marine Mammal Noise-Exposure Criteria: Initial Scientific Recommendations.” Aquatic Mammals 33 (4): 411–521.

Urick, Robert J. 1983. Principles of Underwater Sound. McGraw-Hill.

Urick, Robert J., and Robert M. Hoover. 1956. “Backscattering of Sound from the Sea Surface: Its Measurement, Causes, and Application to the Prediction of Reverberation Levels.” The Journal of the Acoustical Society of America 28 (6): 1038–1042.

Wenz, Gordon M. 1962. “Acoustic Ambient Noise in the Ocean: Spectra and Sources.” The Journal of the Acoustical Society of America 34 (12): 1936–1956.

WSDOT. 2011. “Biological Assessment Preparation for Transport Projects - Advanced Training Manual.” Washington State Department of Transport.