Brims Underwater Noise Assessment

Underwater Noise Assessment Report

SSE Renewables Developments (UK) Ltd

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EXECUTIVE SUMMARY

BTAL proposes to develop a tidal energy array to the south of the island of Hoy, off the Brims Ness headland, Orkney. It is anticipated that the Brims project will consist of:

- Offshore tidal generators and support;
- Inter-array cables;
- Potential for offshore hubs; and
- Export cable corridor and landfall location works.

The project is being progressed based on two phases of development. The offshore tidal array will comprise of between 15 and 30 tidal turbines for Phase 1 of the project with a maximum total installed capacity of 30 MW. Phase 2 of the project will have a maximum total installed capacity of 200 MW (Phases 1 and 2 combined) with between 100 and 200 tidal turbines in total. The total number of turbines installed will depend on the rating of the selected turbine, for example, a 1 MW device would result in 200 tidal turbines for the Phase 1 and 2 combined capacity of 200 MW. Inter-array and export cables will be used to transmit electricity generated by the turbines to shore. It is intended that subsea cable connection hubs will be used to collect inter-array cables for connection into the export cables. The export cables are likely to come ashore at one of three possible landfalls; Sheep Skerry, Moodies Eddy or Aith Hope.

The project is being developed on an open technology basis. To generate electricity the turbines will convert kinetic energy from the flow of water into electrical energy via the turbine blades turning the generator. The turbines being considered are either mono or bi-directional. Some turbines may also have independent blade pitching which can be modified to optimise tidal flows in different directions.

Noise is readily transmitted underwater and there is potential for sound emissions from construction and operation of the project to affect marine mammals and fish. At long ranges the introduction of additional noise could potentially cause short-term behavioural changes, for example avoidance of the area or cause changes 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 might occur, while at very close range, gross physical trauma is possible. This report describes the methodology, results and assessment of the potential range of effects due to underwater noise from Phases 1 and 2 of the Brims development combined.

The objectives of the underwater noise assessment were to:

- Establish the level of noise likely to result from construction, operation and decommissioning of the development;
- Undertake noise modelling to determine the propagation of noise away from the development site and cable corridor;
- Assess the spatial range of effects of noise on marine mammals and fish (including basking sharks) using established criteria for input to the marine mammal and fish EIA studies; and
- Make recommendations, if appropriate, to minimise the effects of noise from the development including possible mitigation and post consent monitoring requirements.

This technical report has been prepared based on the results of the study to inform the fish and marine mammal impact assessments. It is important to understand that the impacts on marine mammal and fish species (including population level and temporal effects) will be addressed in the respective EIA chapters and do not form part of this underwater noise technical study.

An extensive review was undertaken of available evidence, including national and international guidance and scientific literature, in order to determine the potential spatial range of injury and disturbance. Because there will be no impulsive sound (e.g. pile driving) associated with this development, the criteria for injury and disturbance only took into account exposure to continuous sound.

A noise model was developed to take into account both the propagation of underwater sound away from a source and also taking into account exposure of animals, including the likely swim speed of marine mammals. Noise sources modelled included construction activities (including vessels, pile drilling and a jack up rig), operational noise (including Phase 1 and Phases 1 and 2 combined) and decommissioning (which included use of vessels). Based on the results of the modelling and assessment it was concluded that:

> Assuming an animal swimming at an average speed of 1.5 ms^{-1} from the sources of construction and decommissioning noise, the noise modelling shows that injury to marine mammals is *unlikely* to occur for any of the vessels.

> The estimated ranges for onset of disturbance effects due construction and decommissioning vessels are likely to range from 1.4 to 14 km, although this is a worst case assessment. Actual disturbance ranges are likely to be smaller due to both masking by background noise and because animals in the area are already used to regular vessel traffic. It is worth noting that these noise sources are temporary and transitory. Effects due to construction are likely to be similar for Phases 1 and 2.

> Injury zones for fish will be less than 10 m and the disturbance zone will be up to 185 m for larger construction and decommissioning vessels.

> Drilled piling is unlikely to result in injury to marine mammals or fish and the disturbance zone will be up to 375 m for marine mammals and 5 m for fish.

> For operational turbine noise, the SEL injury criteria will not be exceeded for cetaceans and pinnipeds even if they were to spend 24 hours immediately adjacent to a turbine. Likewise, the peak injury criteria are not exceeded at any location, even immediately adjacent to the turbines.

> For Phase 1 the extent of the potential disturbance zone for marine mammals for the operational tidal array is a radius of approximately 1 km from the centre of the array, equating to an area of approximately 2.8 km^2.

> For Phase 2, the extent of the potential disturbance zone will be 2 to 4 km and covers an area of approximately 30 km^2.

> It is unlikely that fish will experience any injury or disturbance due to the operating turbines.

ABBREVIATIONS

dB	deciBel
dBA	A-weighted deciBel
dB_{ht}	Hearing threshold weighted deciBel
DP	Dynamically Positioned
EPS	European Protected Species
HF	High-frequency hearing weighting (cetacean)
Hz	Hertz
JNCC	Joint Nature Conservation Committee
kHz	Kilohertz
km	Kilometre
LF	Low-frequency hearing weighting (cetacean)
MF	Mid-frequency hearing weighting (cetacean)
MMO	Marine Mammal Observer
Pa	Pascal
PAM	Passive Acoustic Monitoring
pk	Peak (zero-to-peak)
pk-pk	Peak to peak
PTS	Permanent Threshold Shift
rms	Root mean square
rpm	Revolutions per minute
SEL	Sound Exposure Level
SPL	Sound Pressure Level
TTS	Temporary Threshold Shift
WSDOT	Washington State Department of Transport
μPa^2s	Micro Pascal squared seconds
µPa	Micro Pascal

1 INTRODUCTION

Brims Tidal Array Limited (BTAL) proposes to develop a tidal energy array to the south of the island of Hoy, off the Brims Ness headland, Orkney.

Noise is readily transmitted underwater and there is potential for sound emissions from construction and operation of the project to affect marine mammals and fish. At long ranges the introduction of additional noise could potentially cause short-term behavioural changes, for example avoidance of the area or cause changes 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 might occur, while at very close range, gross physical trauma is possible. However, it should be noted that noise assessments for other tidal developments such as SeaGen, MeyGen and Fall of Warness tidal energy test site (e.g. MeyGen, 2012 Keenan *et al.*, 2011 and Harland, 2013) show that marine mammals are unlikely to be significantly affected by noise from tidal energy development.

This document describes the methodology, results and assessment of the potential range of effects due to underwater noise from Phases 1 and 2 of the Brims development combined.

The objectives of the underwater noise assessment within this technical report are to:

> Establish the level of noise likely to result from construction, operation and decommissioning of the development;

> Undertake noise modelling to determine the propagation of noise away from the development site and cable corridor;

> Assess the spatial range of effects of noise on marine mammals and fish (including basking sharks) using established criteria for input to the marine mammal and fish EIA studies; and

> Make recommendations, if appropriate, to minimise the effects of noise from the development including possible mitigation and post consent monitoring requirements.

The underwater noise assessment was undertaken by Xodus Group. This technical report has been prepared based on the results of the study to inform the fish and marine mammal impact assessments. It is important to understand that the impacts on marine mammal and fish species (including population level and temporal effects) will be addressed in the respective EIA chapters and do not form part of the underwater noise technical study.

A quantified assessment of the effect of underwater noise on diving birds has been scoped out of the underwater noise study for the following reasons:

> There is a complete absence of measured data on the underwater hearing of birds;

> It is not known how birds use sound underwater (e.g. for communication, foraging, predator detection etc.);

> It is speculated (based on comparisons to human hearing underwater and an understanding of avian hearing physiology) that hearing is not a useful mechanism for birds underwater.

No high intensity sound sources (e.g. impact or vibratory pile driving) are required for this project so the effects of underwater noise on humans has also been scoped out of the study.

2 PROJECT DESCRIPTION

2.1 Study area

The Brims Tidal Array Area for Lease (AfL) was identified as part of the Pentland Firth and Orkney Waters (PFOW) Leasing Round. The proposed development is located to the south of the island of Hoy, off Brims Ness headland. The water depth in the area ranges between 60 and 100 m.

It is anticipated that the Brims project will consist of:

- Offshore tidal generators and support structures;
- Inter-array cables;
- Potential for offshore hubs; and
- Export cable corridor and landfall location works.

The location of the AfL and export cable route is shown in Figure 2.1, with the AfL area shown in red and the Area of Search (AoS) for export cable corridors shown in green.

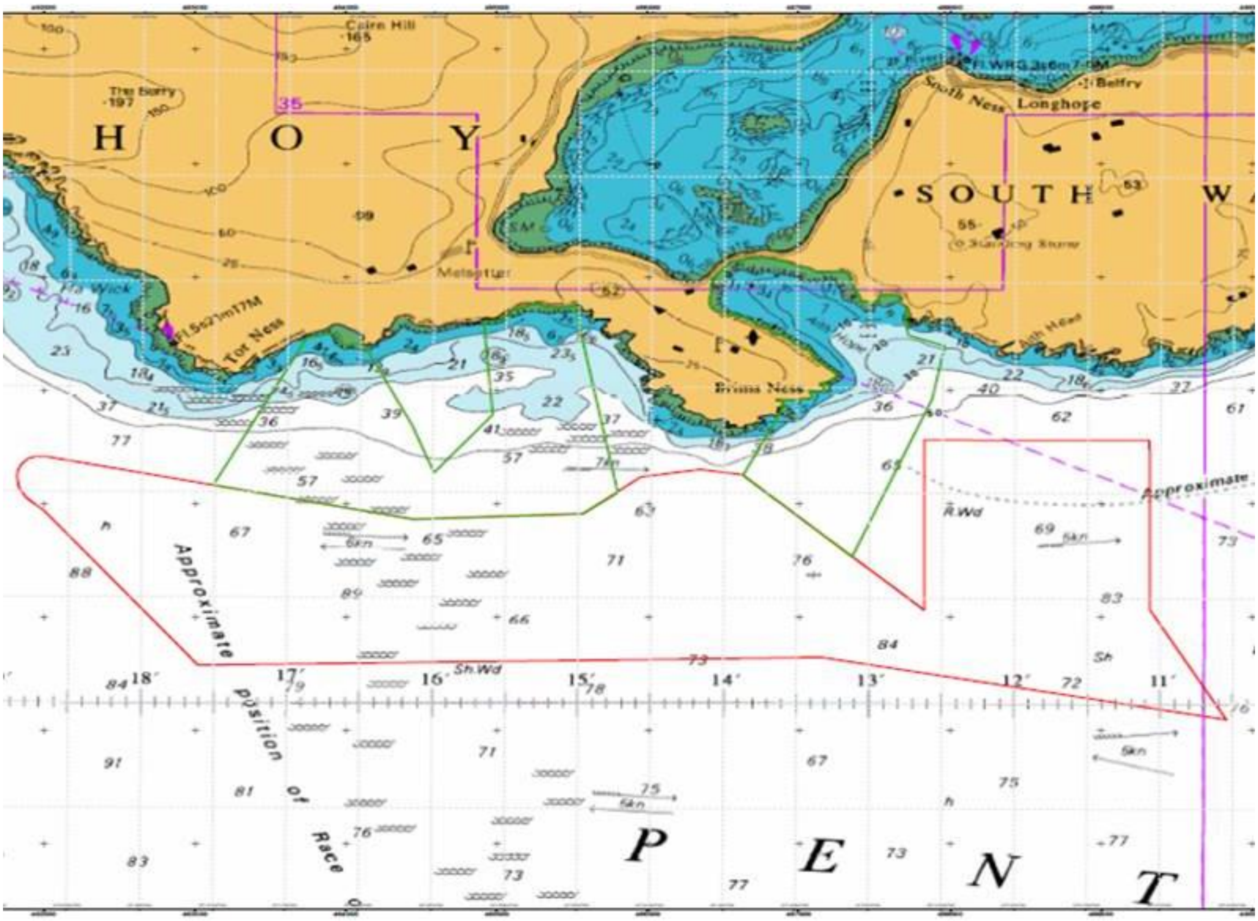

Figure 2.1 Brims AfL area (red) and proposed subsea cable route corridors (green and blue)

The project is being progressed based on two phases of development, although the consent is being sought for the full scheme. The offshore tidal array will comprise of between 15 and 30 tidal turbines for Phase 1 of the project with a maximum total installed capacity of 30 MW. Phase 2 will have a maximum total installed capacity of 200 MW (Phases 1 and 2 combined) with between 100 and 200 tidal turbines in total. The total number of turbines installed will depend on the rating of the selected turbine, for example, a 1MW device would result in 200 tidal turbines for the Phase 1 and 2 combined capacity of 200 MW. Exact turbine locations will be defined based on tidal flow and water depths; the optimum turbine locations may vary depending on the technology to be installed. An indicative turbine layout is shown in Figure 2.2.

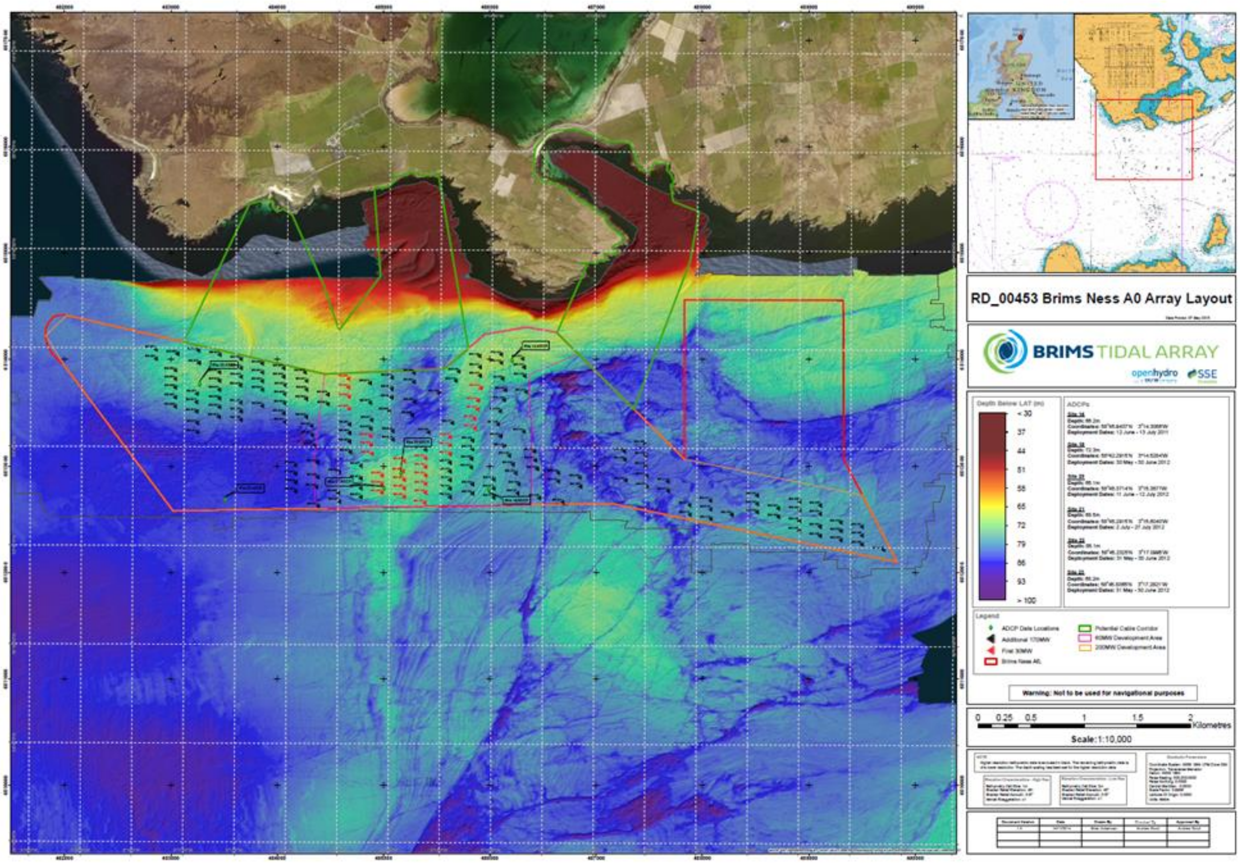

Figure 2.2 Indicative turbine layout

Inter-array and export cables will be used to transmit electricity generated by the turbines to shore. The total number of inter-array cables required will depend on the number of turbines required for a 200 MW array.. It is intended that subsea cable connection hubs will be used to collect inter-array cables for connection into the export cables. The export cables are likely to come ashore at one of three possible landfalls; Sheep Skerry, Moodies Eddy or Aith Hope.

The project is being developed on an open technology basis. To generate electricity the turbines will convert kinetic energy from the flow of water into electrical energy via the turbine blades turning the generator. The turbines being considered are either mono or bi-directional:

- Mono-directional: Uses a yaw system to re-orientate rotor blades during slack tide in order to optimise tidal flow from both ebb and flood tides; and
- Bi-directional: has fixed pitch blades which generate energy from flows in both directions (ebb and flood tides).

Some turbines may also have independent blade pitching which can be modified to optimise tidal flows in different directions.

The rated power output of the turbines depends on a number of factors including technological developments, site conditions and array layout. For the purpose of this assessment, it is assumed that all turbines will have a rated power output of at least 1 MW. Given that the maximum capacity of the AfL area is 200 MW, the total number of turbines required for the Project will decrease as the rated power of the tidal turbines increases. For example, if the turbines have a rated power output of 2 MW only 100 turbines will be required. This assessment is based on the worst-case scenario that 200 turbines will be required.

There may be a requirement for subsea hubs as part of the project. There will be two subsea hubs required for Phase 1 and six for Phase 2 (8 in total). The offshore hubs are a point where inter array cables can be gathered for conversion into an export cable. Since there will be no transforming of voltage or operating machinery at these hubs it is considered highly unlikely that they will produce any noise and they have therefore been scoped out of this study.

2.2 Design envelope considerations

Table 2.1 presents of the maximum 'worst case' project parameters that the underwater noise study considers.

Table 2.1 Design envelope parameters for underwater noise assessment

Project parameter relevant to the assessment	Maximum Project parameter for impact assessment	Explanation of maximum Project parameters
Number of turbines (phase 1)	30	Dependent on rated output of selected turbines. 30 turbines is a worst case scenario
Number of turbines (phase 1 & 2)	200	Dependent on rated output of selected turbines. 200 turbines is a worst case scenario.
Minimum cross flow spacing	80 m	Cross flow spacing depends on selected turbine, but there will be a minimum spacing between turbines of 80m.
Minimum down flow spacing	150 m	Minimum down flow spacing between turbines will be 150m.
Turbine noise level	152 dB re 1 Pa (rms)	Based on measurements on 2.2 MW, 16 m diameter device
Turbine sub-structure	Potential for Gravity Base Structure (GBS) including sub-sea bases (SSBs), drilled monopole or pin pile tripods	Drilled piling has been assumed as a worst case.
Vessels (construction)	Potential for various vessels during construction including:	Calculations performed for all potential vessels using proxy data

Project parameter relevant to the assessment	Maximum Project parameter for impact assessment	Explanation of maximum Project parameters
	Anchor handling vessel Installation / construction vessel (using DP) Support vessel Rock placement vessel Cable lay vessel Misc. small vessels (e.g. tugs, vessels carrying ROVs, crew transfer vessels, dive boats and RIBs)	where no specific data exists.
Cable installation	Cable trenching / cutting using DP vessel	Estimated maximum sound pressure levels used for cable trenching / cutting following literature review.
Cable landfall installation	Horizontal Directional Drilling - 1 off jack-up barge assumed as worst case	Estimated maximum sound pressure levels used for jack up barge following literature review

3 LEGISLATIVE FRAMEWORK AND POLICY CONTEXT

The following legislation and guidance is relevant to underwater noise for this project:

> **EC Habitats Directive** (92/43/EEC): this Directive lists all cetaceans in Annex IV (making them European Protected Species; EPS) and lists harbour porpoise, bottlenose dolphins and grey and harbour seals in Annex II (requiring that Special Areas of Conservation must be designated for these species).

> **Conservation (Natural Habitats, &c) Regulations 1994** (as amended): transposes Habitats Directive into Scottish law for inshore waters (up to 12 nautical miles offshore).

> **Marine Scotland Guidelines** (2014): The Protection of Marine European Protected Species from Injury and Disturbance - Guidance for Scottish Inshore Waters.

> **JNCC Guidelines** (2010, in prep): The Protection of marine European Protected Species from injury and disturbance. Draft guidance for the marine area in England and Wales and the UK offshore marine area. JNCC, Natural England and Countryside Council for Wales.

4 CONSULTATIONS

A scoping report was produced for the project and an opinion on this report was received from Marine Scotland in April 2014. The key points raised by Marine Scotland regarding underwater noise are presented in Table 4.1.

Table 4.1 Key issues raised by stakeholder during consultation (Marine Scotland)

Stakeholder Comment	Response/Action taken
MS-LOT recommends that the potential impacts on marine mammals from noise are carefully assessed in the ES. Mitigation for this impact may well be required and measures to reduce the effects of noise should also be set out in the ES. MS-LOT may require that JNCC accredited Marine Mammal Observers (MMOs) are present during noisy construction activities for, particularly during potentially noisy activities such as piling.	No impact or vibratory pile driving is required for this project. The study assesses noise due to construction, operation and decommissioning of the development. Suitable noise metrics have been used to assess the potential spatial ranges for injury and disturbance to cetaceans and seals. The requirements for and effect of potential mitigation measures (including potential use of MMOs) will be assessed as part of the mammal and fish chapters of the ES.
As always cumulative and in combination effects/impacts need careful assessment. The noise, visual impacts and under keel clearance associated with construction and operation will be important impacts requiring detailed assessment within the ES.	The noise study includes an assessment of the spatial range of potential injury and disturbance to cetaceans and fish. This information will be used to inform the marine mammal and fish ecology impact assessments.
Depending upon the selected methods for installation of the devices, it may be necessary to assess the impact of construction noise on marine mammals. We would consider this necessary for pile driving and potentially for drilling. Marine Scotland Science is in the process of commissioning a study of the noise produced by operational tidal turbines and its potential impacts on marine mammals, which the developer may wish to refer to if it is available in a suitable time frame (anticipated Q2/Q3 2014).	The study includes noise due to construction, operation and decommissioning of the development. Suitable noise metrics have been used to assess the potential spatial ranges for injury and disturbance to cetaceans and seals.

Stakeholder Comment	Response/Action taken
3. Assess the potential impacts of deployed devices on diadromous fish during deployment, operation and decommissioning phases. Potential impacts could include those resulting from:… …c. Noise during construction, operation and decommissioning… Which could cause 4 a. Death, injury or disturbance b. Disorientation that could potentially affect behaviour, susceptibility to predation or bycatch, or ability to locate normal feeding grounds or river of origin c. Avoidance d. Delayed migration For example with respect to impacts of noise and EMF SNH commissioned a review of the potential impacts of EMF and noise on migratory fish which is available at: www.snh.org.uk/pdfs/publications/commissioned_reports/401.pdf which may be useful. We would also draw the attention of the developer to Gill A. B., Bartlett M. and Thomsen F. (2012) Potential interactions between diadromous fishes of U.K. conservation importance and the electromagnetic fields and subsea noise from marine renewable energy. Journal of Fish Biology 81, 664–695 doi:10.1111/j.1095-8649.2012.03374.x, with Corrigendum in Journal of Fish Biology (2012) 81, 1791 doi:10.1111/j.1095-8649.2012.03450.x, available online at www.wileyonlinelibrary.com	Suitable noise metrics have been used to assess the potential spatial ranges for injury and disturbance to fish. Other aspects (disorientation, delayed migration etc.) will be dealt with in the marine mammal and fish impact assessments.
Noise Impact:- The supporting information should address: • Construction noise should be identified along with likely consequences for marine life and human receptors. • Noise from all proposed operations including construction phase, vehicle movements, directional drilling etc. • Noise from all on shore and offshore installations. • Noise from associated works. • Cumulative effects from this and any other renewable energy industry activity in the area will also need to be considered.	This study relates to underwater noise from the development. Onshore or offshore airborne noise and its potential impact on human receptors and wildlife is excluded from its scope. The study includes noise generated underwater due to construction, operation and decommissioning of the development, including vessels. Predicted ranges have been produced for the cumulative impact of multiple turbines operating concurrently. It is assumed that the comment relating to effects of noise on humans is in relation to airborne environmental noise. No high intensity sound sources (e.g. pile driving) are required for this project so the effects of underwater noise on humans has been scoped out of the study.
With regard to identifying what impacts will be assessed for which diadromous fish species, tables 7.14, 7.15, 7.16 and 7.17 are slightly confusing. Table 7.14 (Potential impacts during construction, operation and decommissioning) and much of table 7.16 (Impact assessment strategy) states that the effects of noise and vibration will be assessed for hearing specialists such as herring.. However, Table 7.16	The metrics used to assess the spatial range for injury and disturbance to fish are based on criteria in line with latest scientific consensus. This includes both hearing specialists and hearing generalists as well as those with “intermediate” hearing capabilities. The noise study includes an assessment of potential ranges for multiple sources of noise which occur concurrently in order to assist the cumulative

Stakeholder Comment	Response/Action taken
does also contain, 'Potential effects on migratory species e.g. salmonids, eels', which refers to construction noise and EMF. We recommend that the assessment of potential effects of habitat loss on sea trout, which are predominantly a coastal species, is scoped in. Table 7.17 (Possible mitigation and monitoring measures) refers to the effects of noise and vibration only in the context of hearing specialists and does not identify the species of 'migratory fish' that would be considered in relation to collision risk. The effects of EMF are mentioned in connection with elasmobranches and salmonids, and European eel is not mentioned. Again, the potential effects on sea trout of habitat loss are not recognised. Assessment of underwater noise impacts should include focus on Atlantic salmon, as they are features of several SACs, and the Pentland Firth is thought to be an important route for migratory Atlantic salmon. Sea trout and European eel are species of conservation importance for which there are records from the vicinity of the development area. However, it is recognised that there are limited data available on the hearing sensitivity and related behaviour of these species. The ES should also clarify the times of year / duration of associated activities in consideration of potential impacts.	impact assessments in the fish and marine mammal chapters. Species specific assessments (e.g. Atlantic Salmon) are dealt with in the fish impact assessment.
For underwater baseline conditions, we welcome the undertaking to commission experience underwater noise specialists for this work. We would like to bring to your attention that there is a relevant project due to report in the next few months, regarding guidance as to the underwater noise measurements and methods, commissioned by Marine Scotland. We will keep you updated on this project as this may be useful to inform the methodology and reporting of underwater baseline noise.	We have used ambient noise data measured at other acoustically equivalent sites to characterise the baseline noise environment. No field survey has been undertaken for this project. The justification for doing so and baseline description are further elaborated in Section 7 of this report.
Regarding the proposed desk review of noise generated by tidal stream devices we would highlight a recent Crown Estate Enabling Actions Report "Robinson S.P., & Lepper P.A. (2013) Scoping study: Review of current knowledge of underwater noise emissions from wave and tidal stream energy devices". Within this review we would expect some discussion/modelling as to the likely levels of noise emitted from the chosen device and an estimation as to how these noise levels might propagate through the environment for the proposed array, rather than for an individual device.	Noise modelling has been undertaken for Phase 1 of the project (30 MW and for the cumulative impact of Phases 1 and 2 combined (200 MW). The noise modelling has been undertaken for the project as a whole (not just for a single device). The Robinson and Lepper paper has been included in the review of information informing the study.
We appreciate the developers' view that there is not an expectation that mitigation will be required for vessel underwater noise, operational device noise and risk of injury due to collision with the devices, but we advise that these areas are not scoped out of the ES and given further consideration as the project becomes more defined.	The requirements for mitigation of vessel underwater noise and operational device noise have been reviewed as part of this study.

Stakeholder Comment	Response/Action taken
Issues to consider under Appropriate Assessment: For seals, it is probably conservation objective (iii) that has most relevance – population of the species as a viable component of the SAC. The proposal is far enough away from the above listed SAC for there not to be direct impacts, or disturbance, to the seals whilst they are within the SAC. However, there may be occasions when they forage far enough from the SAC to come into contact with the proposed tidal energy site. We advise that noise impact assessment is likely to be an important part of assessing any disturbance to seals whilst they are out with their SAC, including their potential displacement from feeding grounds and other supporting habitats. We highlight that collision risk will need to be considered, as will potential direct and in-direct impacts on the prey species. While we consider that the installation phase may give rise to the greatest risk of disturbance, potential impacts during the operational phase of the proposal will also need to be considered, as well as any repowering and decommissioning work. Potential for corkscrew injuries from use of vessels with ducted propellers will also need to be considered. For Atlantic salmon we advise that a noise/vibration/EMF impact assessment is likely to be an important part of assessing any disturbance whilst these species are outwith the SAC. Further information on the installation, operation, maintenance and decommissioning of the array is required to assess whether there will be any direct disturbance to Atlantic salmon.	This noise study assesses the spatial range of potential injury and disturbance to both marine mammals (including seals) and fish (i.e. prey species). The impacts will be assessed in the relevant ES chapters and Appropriate Assessment. The study includes noise due to construction, operation and decommissioning of the development. The potential for corkscrew injuries or collision risk is a separate issue that will be assessed in the marine mammals impact assessment chapter.
We note that the OpenHydro Open-Centre Turbine (OCT) is the preferred technology for this development and requires no pile driving during construction. We understand that the final decision on the support structures will be made post-consent due to the advances in technology and the experiences of other tidal sites; however the alternative technologies potentially require pile driving. There is considerable scientific uncertainty surrounding the impacts of pile driving during construction on all species, and in this region. As a result, our preference is that pile driving is not used at all during construction. An effective underwater noise mitigation plan needs to be developed within the Environmental Mitigation Monitoring Plan (EMMP) for all the potential support structures.	No impact or vibratory pile driving is proposed for this project, although inherently quieter methods such as drilled piling are considered within the design envelope. The noise study includes an assessment of the spatial range of potential injury and disturbance to cetaceans. This includes all foreseeable sources of noise during construction, operation and decommissioning as well as associated vessel noise. The results of the noise study will be used to inform the EMMP.

5 ACOUSTIC CONCEPTS AND TERMINOLOGY

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 latter 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 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 1µPa, 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.

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 5.1.

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

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

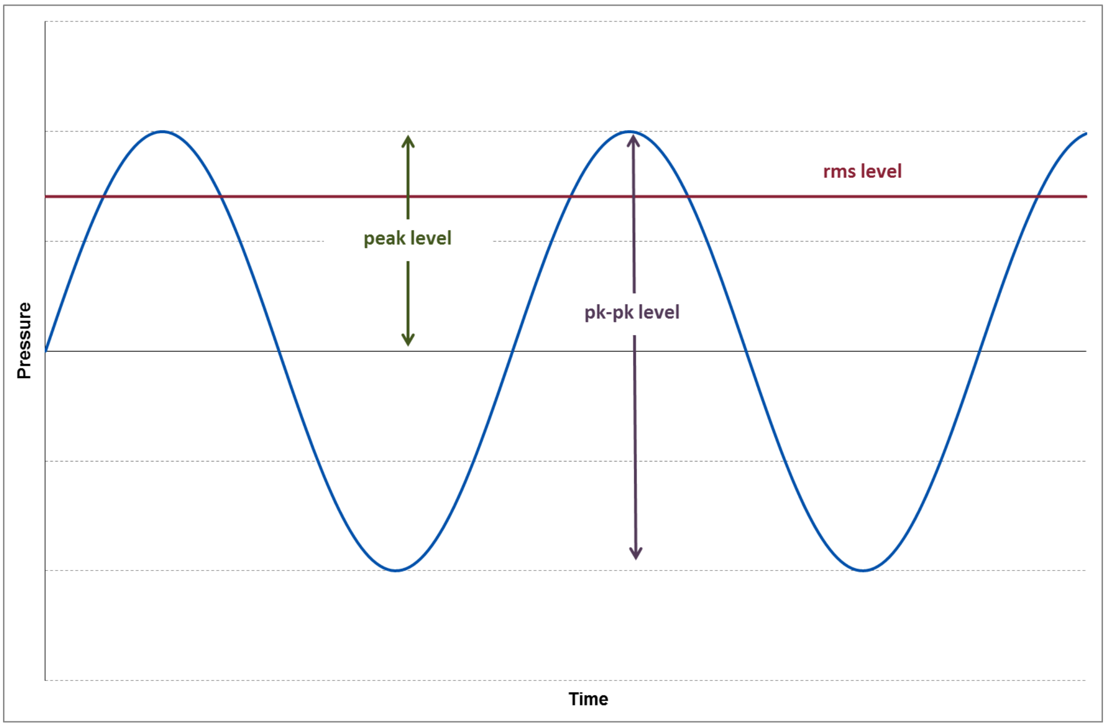

Figure 5.1 Graphical representation of acoustic wave descriptors

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 to be taken into account. The SEL is defined as follows:

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

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 a species' 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 5.2. 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.

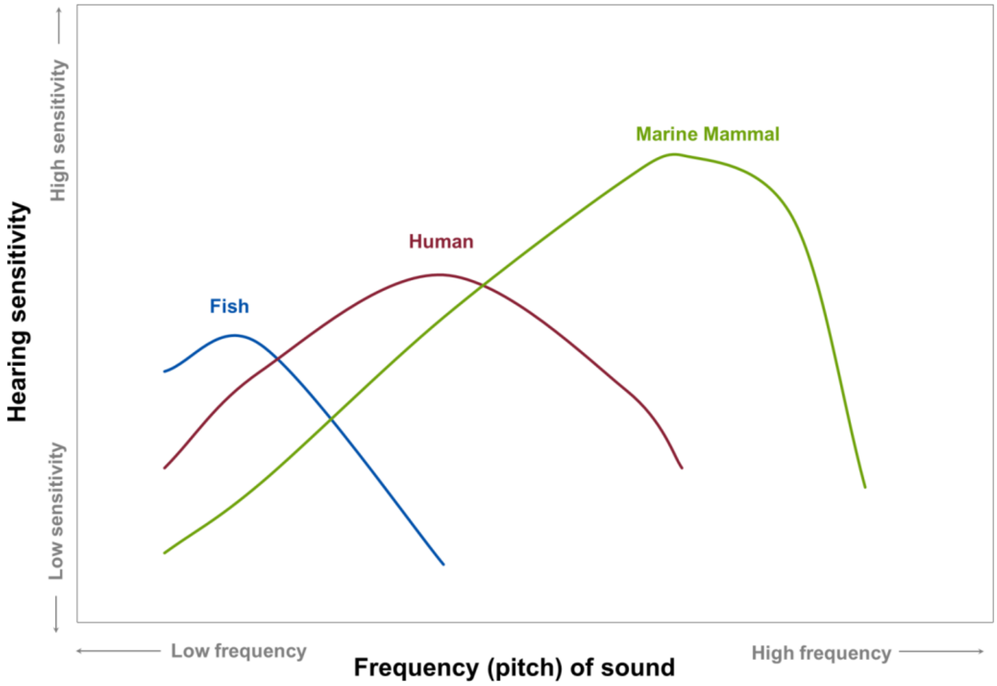

Figure 5.2 Comparison between hearing thresholds of different marine animals and humans

6 THRESHOLDS FOR ASSESSING THE EFFECTS OF SOUND ON MARINE MAMMALS AND FISH

6.1 Introduction

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 behaves 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.

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 and the type and magnitude of sound from the development is not high enough to cause death.) In order to determine the potential spatial range of injury and disturbance, a review has been undertaken of available evidence, including national and 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.

It is important to understand that there will be no impulsive sound (e.g. pile driving) associated with this development. Consequently, the criteria for injury and disturbance only take into account exposure to continuous sound.

6.2 Marine mammals

6.2.1 Injury to marine mammals

To determine the consequence of received sound levels on any marine mammal it is useful to relate the levels to known or estimated impact thresholds. The draft Joint Nature Conservation Committee guidance[1] (JNCC, in prep) and Marine Scotland guidance (Marine Scotland, 2014) both recommend using the injury criteria proposed by Southall *et al.* (2007), which are based on a combination of linear (i.e. un-weighted) peak pressure levels and mammal hearing weighted (M-weighted) SELs. The M-weighting function is designed to represent the bandwidth for each group within which acoustic exposures can have auditory effects. The categories include low-, mid- and

[1] Defra is in the process of preparing guidance on the protection of marine European Protected Species (EPS) from injury and disturbance which will provide the offshore industry with best practice guidance for minimising impacts to marine species. The Defra guidance will be aimed at the English, Welsh and United Kingdom (UK) offshore marine areas and, although not legally binding, will form the basis of the UK's legal obligation to adequately transpose the Habitats Directive. It is understood that the Defra guidance will be a re-release of the draft JNCC guidance (JNCC, 2010a) which, in the meantime, can be considered to be the most relevant guidance on EPS for UK offshore marine areas.

high-frequency cetaceans (whales, dolphins, and porpoises) and pinnipeds in water (seals, walruses and similar animals having finlike flippers). The M-weighting curves are shown graphically in Figure 6.1.

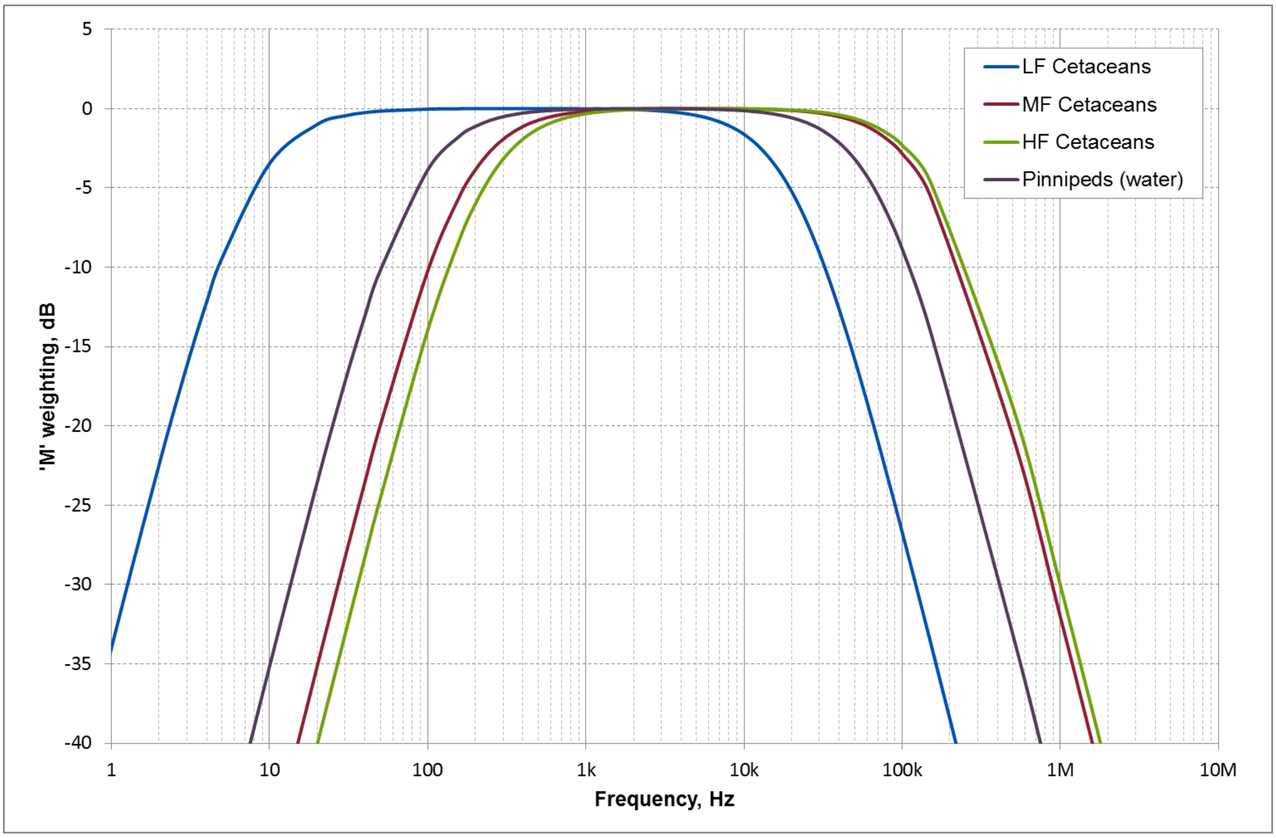

Figure 6.1 **M-weighting functions for pinnipeds and cetaceans in water (LF = low-frequency, MF = mid-frequency, HF = high-frequency (Southall *et al.*, 2007))**

The injury criteria proposed in Southall *et al.* (2007) are for three different types of sound. These sound types include multiple pulsed sound (i.e. sound comprising two or more discrete acoustic events per 24 hour period, such as impact piling and seismic exploration), single pulse sound (i.e. a single acoustic event in any 24 hour period, such as an underwater explosion) and continuous sound (i.e. non-pulsed sound such as continuous running machinery or drilled piling). Of these, only the criteria relating to continuous sound are relevant to this project since no pile driving or other impulsive sound generating activities are proposed.

For non-pulsed sound, the relevant PTS criteria proposed by Southall *et al.* (2007) are an un-weighted peak pressure level of 230 dB re 1 μPa and an M-weighted SEL of 215 dB re 1 $\mu Pa^2 s$ for all cetaceans. The PTS criteria for pinnipeds are an un-weighted peak pressure level of 218 dB re 1 μPa and an M-weighted SEL of 203 dB re 1 $\mu Pa^2 s$.

It is important to note that the above criteria are very precautionary. This is because:

i. The criteria were developed using a precautionary approach at every step;

ii. The criteria do not take into account the potential for recovery in hearing between subsequent days of exposure, and are therefore likely to overestimate hearing damage caused by time varying exposure;

iii. The M-weighting curves are "flatter" in shape than the relevant marine mammal hearing curves; and

iv. The regions of best hearing sensitivity for most species are considerably narrower than the relevant M-weighting curve.

The criteria used to assess the likelihood of injury due to the Project are summarised in Table 6.1.

Table 6.1 Marine mammal criteria for onset of injury (per 24 hour period, continuous sound)

Marine mammal group	PTS criteria		TTS criteria	
	Peak pressure, dB re 1 µPa	SEL, dB re 1 μPa^2s (M-weighted)	Peak pressure, dB re 1 µPa	SEL, dB re 1 μPa^2s (M-weighted)
Low-frequency cetaceans	230	215	224	195
Mid-frequency cetaceans	230	215	224	195
High-frequency cetaceans	230	215	224	195
Pinnipeds in water	218	203	212	183

6.2.2 Disturbance to marine mammals

Beyond the area in which injury may occur, the effect on marine mammal behaviour is the most important measure of impact. The JNCC guidance (JNCC, 2010a) proposes that a disturbance offence may occur when there is a risk of animals incurring sustained or chronic disruption of behaviour or when animals are displaced from an area, with subsequent redistribution being significantly different from that occurring due to natural variation. Marine Scotland guidance (2014) for inshore waters (i.e. for the pipeline route) recommends a precautionary approach in light of the uncertainties surrounding the issue of disturbance and marine mammals. The guidance notes that it is an offence in Scottish inshore waters to *"deliberately or recklessly disturb any dolphin, porpoise or whale (cetacean)"*. An exception be considered only in cases where:

i) There is a licensable purpose to the activity;

ii) There are no satisfactory alternatives; and

iii) The actions will not be detrimental to the maintenance of the population of the species at favourable conservation status in their natural range.

To consider the possibility of a disturbance offence resulting from the Project, it is necessary to consider both the likelihood that the sound could cause non-trivial 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 JNCC guidance (JNCC, 2010a) indicates that a score of 5 or more on the Southall *et al*. (2007) behavioural response severity scale could be significant. 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.

Southall *et al.* (2007) present a summary of observed behavioural responses for various mammal groups exposed to different types of noise (single pulse, multiple pulse and non-pulse).

For non-pulsed sound (e.g. vessels etc.), the lowest sound pressure level at which a score of 5 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. The only study for minke whales showed a response score of 3 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 8 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 this development (e.g. Atlantic white-beaked dolphin). For these species, a response score of 3 was encountered for received levels of 110 – 120 dB re 1 µPa (rms), with no higher severity score encountered. For high frequency cetaceans, a number of individual responses with a response score of 6 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 6 once the received sound pressure level is greater than 140 dB re 1 μPa (rms).

According to Southall *et al*. (2007) there is a general paucity of data relating to the effects of sound on pinnipeds in particular. For non-pulsed sound, one study elicited a significant response on a single harbour seal at a received level of 100 – 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.

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.

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 cetaceans remain protected.

The United States (US) National Marine Fisheries Service guidance (NMFS, 2005) sets the Level B harassment threshold[2] for marine mammals at 120 dB re 1 μPa (rms) for continuous noise. The value for continuous sound sits roughly mid-way between the range of values identified in Southall *et al*. (2007) but is lower than the value at which the majority of mammals responded at a response score of 6 (i.e. once the received rms sound pressure level is greater than 140 dB re 1 μPa). Consequently this criterion has been used (in lieu of more suitable up to date criteria) for assessing onset of potentially strong behavioural reaction in this study, although it should be borne in mind that this value is possibly over-pessimistic Taking into account the paucity and high level of 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 possibly over-precautionary.

The criteria used in assessing the spatial extent of marine mammal disturbance due to different types of sound is summarised in Table 6.2.

Table 6.2 Marine mammal criteria for onset of disturbance (continuous sound)

Type of sound / criteria metric	Effect	Marine mammal hearing group	
		All cetaceans	Pinnipeds
RMS sound pressure level, dB re 1 μPa	Potential behavioural reaction	120	

6.3 Fish

6.3.1 Injury to fish

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 in the immediate vicinity of the sound source, including damage to their hearing, kidneys, hearts and swim bladders. Such effects are unlikely to happen outside of the immediate vicinity of even the highest energy sound sources.

[2] *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.*

For fish, 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 continuous noise (which are applicable for shipping, drilling, thrusters and other continuous sources of sound)[3]. Because 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 metres) 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.

The criteria used in this noise assessment are given in Tables 6.3 – 6.4.

Table 6.3 Criteria for onset of injury to fish due to continuous sound (Popper *et al*., 2014)

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

6.3.2 Disturbance to fish

Behavioural reaction 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

[3] *Guideline exposure criteria for explosions, impact piling, seismic surveys and naval sonar are also presented though are not applicable to this Project.*

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[4].

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.

For assessing the likelihood of behavioural effects in fish, use can be made of the dB_{ht} (*species*) scale (Nedwell *et al.*, 2007a). This is simply a decibel scale reflecting the level above the hearing threshold (i.e. quietest perceptible sound) of that species. In order to determine the dB_{ht} (*species*) level it is necessary to possess audiometric data for that species. However, the range of species for which suitable data are available to allow use of the dB_{ht} metric is highly restricted, limiting the current value of such a metric. Furthermore, there is a paucity of peer reviewed dose-response studies to determine relevant criteria. Consequently, the use of dB_{ht} is not considered to be a useful metric for assessing the effects of noise on fish (or indeed on marine mammals) until suitable peer reviewed data and dose-response studies are published.

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. 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 6.4.

Table 6.4 Criteria for onset of behavioural effects in fish (Popper *et al.*, 2014)

Type of animal	Relative risk of behavioural effects (continuous sound)
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
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*	

[4] *It should be noted that the presence of a swim bladder does not necessarily mean that the fish can detect pressure. Some fish have swim bladders that are not involved in the hearing mechanism and can only detect particle motion.*

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 (e.g. continuous sound from vessels) would result in the same predicted impact, no matter the level of noise produced or the propagation characteristics. Therefore, the criteria presented in the Washington State Department of Transport Biological Assessment Preparation for Transport Projects Advanced Training Manual (WSDOT, 2011) have been used in this study to provide an indication of how the range of effect is likely to vary for each noise source. The WSDOT 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. As stated previously, the predicted range of effect (i.e. exceedance of the 150 dB re 1 μPa (rms) criterion) should be used in conjunction with the Popper *et al*. (2015) qualitative criteria in order to understand the how the range of effect might vary with distance (as opposed to using the WSDOT criterion as a line beyond which an effect definitely will or will not occur).

7 BASELINE DESCRIPTION

7.1 Approach to baseline assessment

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 attributable to various noise sources (Wenz 1962) are shown in Figure 7.1.

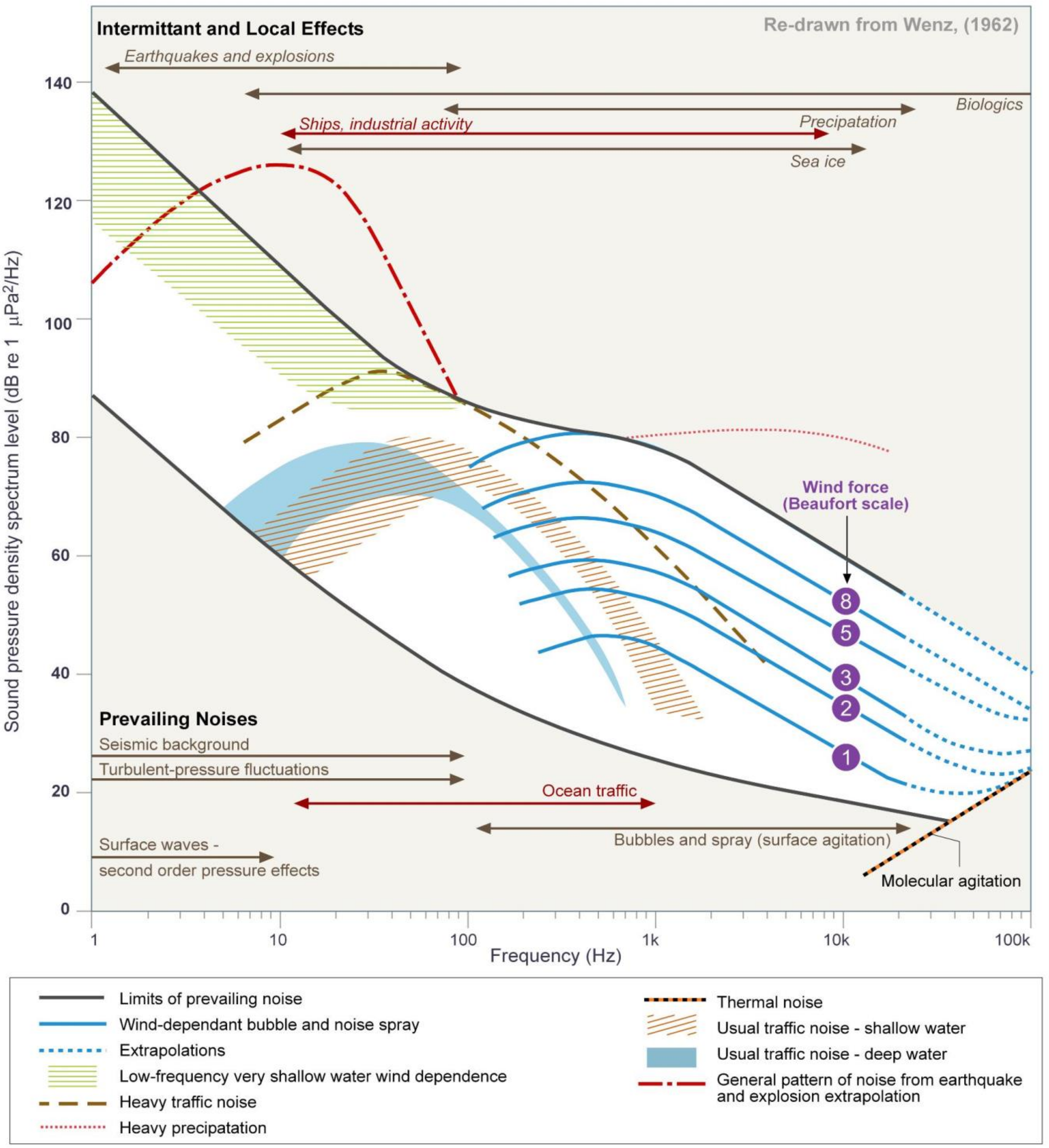

Figure 7.1 Generalised ambient noise spectra attributable to various noise sources

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 (Southall et al. 2007). Given the lack of evidence based studies investigating the effects of noise relative to background on marine species, 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. 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. Therefore, it is necessary to exercise considerable caution if attempting any comparison between noise from the 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.

For the reasons given above, and due to the relatively low risk of 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. This approach has been used for other offshore renewables projects such as TVL in Northern Ireland and Minesto in Wales and was agreed with the stakeholders during project scoping. In order to gain an understanding of the baseline underwater noise environment, noise measurements from nearby and other acoustically similar sites have been reviewed as a proxy for the Brims area.

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 7.1 and Power Spectral Density levels are shown graphically in Figure 7.2 (Sea State 1) and Figure 7.3 (Sea State 3).

Table 7.1 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

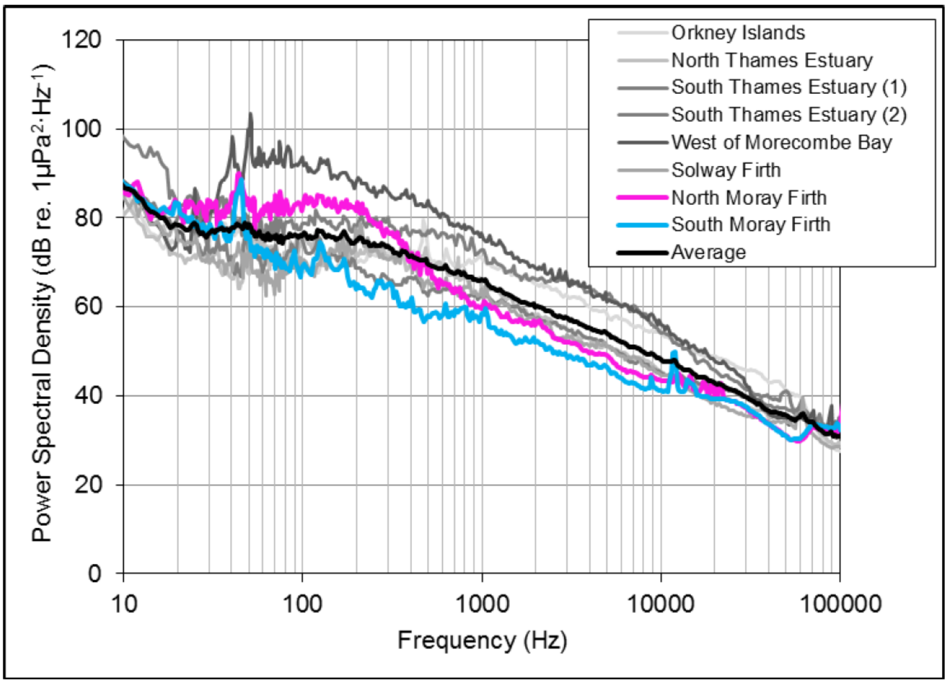

Figure 7.2 **Summary of power spectral density levels of background underwater noise at sea state 1 at sites around the UK coast (Brooker *et al.*, 2012)**

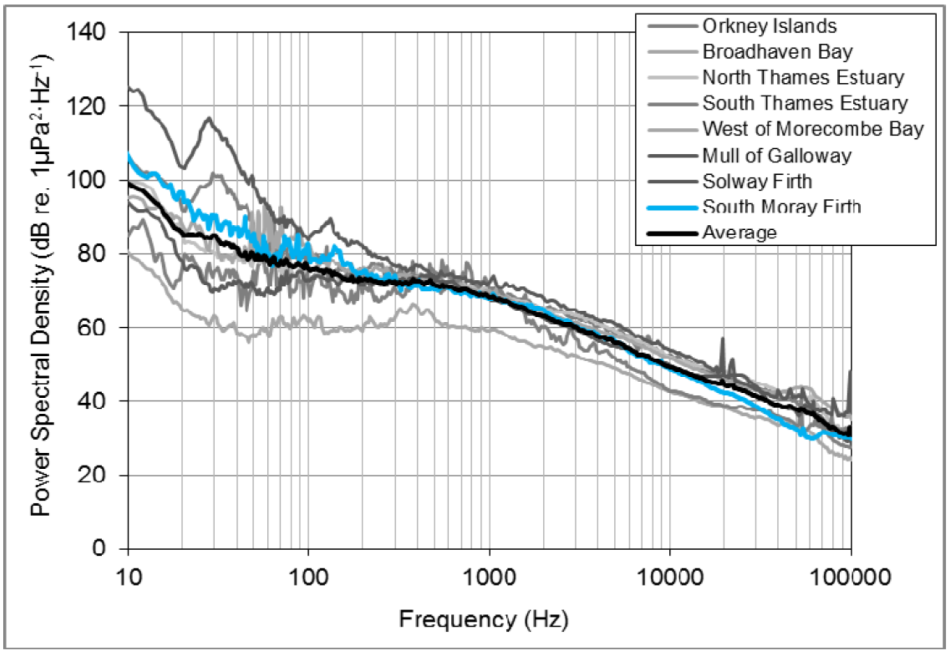

Figure 7.3 **Summary of power spectral density levels of background underwater noise at sea state 3 at sites around the UK coast (Brooker *et al.,* 2012)**

These measurements were undertaken in relatively low tide environments and it is questionable whether they would be a suitable proxy for the Brims area. However, measurements of underwater noise were recorded in the Inner Sound during August 2011 (Kongsberg 2012) as part of the MeyGen Phase 1 impact assessment ("MeyGen Tidal Energy Project Phase 1 Environmental Statement" 2012). The Inner Sound is considered to be acoustically similar to the Brims area in that it is nearby (approximately 12 km south of Brims) and experiences similar high tidal flows (the Inner Sound is a turbulent location with tides reaching speeds of 8-9 knots).

The Kongsberg report notes that, during the survey, an occasional "whooshing" noise was attributed to the movement of sand while the larger stones were heard clicking as they rolled over the seabed. Another source of naturally occurring sound was seal noise. It was noted that there was a seal colony on the south shore of the island of Stroma some 2-3 km distant. On several occasions, seal vocalisations were detected underwater (there is a seal colony on the south shore of the island of Stroma). Sources of man-made noise were predominantly shipping noise from the vessels that transited the Inner Sound including the Orkney Islands ferry MV Pentalina as well as many smaller fishing vessels moving in or out of Scapa Flow. The underwater noise data acquired indicated a generally high noise level environment with overall sound pressure levels in the range 106 - 139 dB re 1 μPa (rms).

The measured power spectral density levels (max values in red, mean values in black and min values in green, in dB re 1 $\mu Pa^2 Hz^{-1}$) and third octave band sound pressure levels (light blue, in dB re 1 μPa) are shown in Figure 7.4.

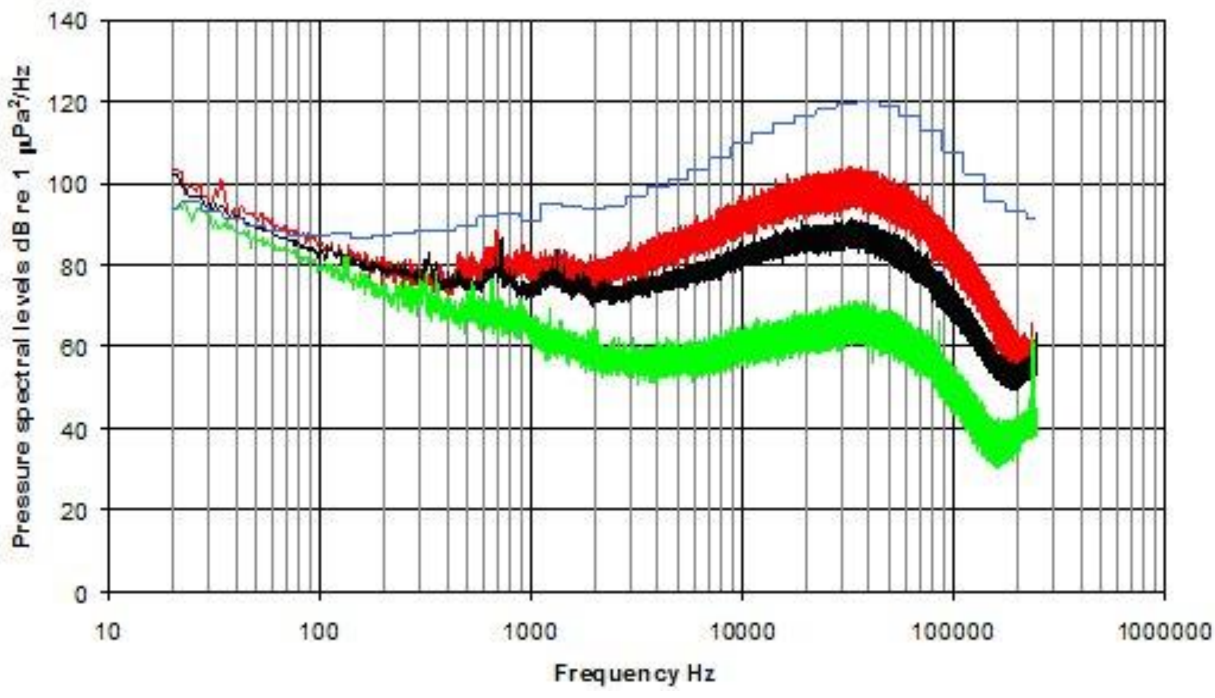

Figure 7.4 Summary of power spectral density levels and third octave band sound pressure levels of background underwater noise measured in the Inner Sound, August 2011 (Kongsberg, 2012)

7.2 Summary

Baseline underwater noise levels in high-tidal, coastal areas are likely to be in the range 106 - 139 dB re 1 μPa (rms). Baseline noise is likely to be at its highest during periods of high tidal flow, which is also when the proposed tidal energy devices are likely to produce the greatest amount of noise. Therefore, taking into account that this assessment is based on worst-case assumptions with respect to operational noise, it is considered most appropriate to compare the baseline against noise levels at the higher end of this scale. Therefore, it is considered likely that baseline noise levels when the turbines are operating will be in the range 120 – 139 dB re 1 μPa (rms), not accounting for any additional noise from the turbines themselves. It is important to understand however that tidal turbine noise could still be audible to marine mammals and fish even when the numerical value of the turbine noise is less than the numerical value of the baseline noise.

8 METHODOLOGY

8.1 Acoustic modelling

The potential sources of underwater noise to be included in the assessment are listed in Table 8.1.

Phase	Activity or source of noise
Construction	Drilled piling of turbine and offshore sub-station foundations
	Use of vessels for drilling piles, turbine placement, cable laying and pull ashore
	Potential use of thrusters for dynamic positioning
	Potential use of trenching vessels for cable burial
	Potential noise from horizontal directional drilling of cable landfall
Operation	Continuous operation of turbine devices
	Maintenance vessels
Decommissioning	Use of vessels

Table 8.1 Potential sources of noise to be included in the assessment

It is not currently envisaged that there will be any impulsive noise sources associated with construction, operation or decommissioning activities. As noted previously, the offshore hubs are cable connection points with no operating machinery and are not considered to be a source of noise. They have therefore been scoped out of the study.

Noise source data has been taken from a combination of specific measured noise data for the plant and equipment proposed for the project (where available), publicly available noise data for other similar developments, empirical calculations and theoretical predictions. It should be noted that even where specific noise measurement data is available, these data are often not in a suitable form for assessing the impacts of noise on wildlife. Consequently, it is often necessary to apply empirical corrections to convert from, for example, rms sound pressure levels to SEL or peak pressure levels.

Construction noise data has primarily been based on published literature and noise measurements on similar vessels and equipment. Although there is a significant amount of publicly available data relating to sources of construction noise and vessels, these data are not always directly applicable to the types of plant and vessels that will be used for this project. Consequently, proxy data for what is considered to be a similar class of vessel or equipment has been used where appropriate. Worst case assumptions have been made about the number of sources, duration and noise level.

A report was recently published by the Crown Estate (Robinson and Lepper 2013) summarising the current knowledge of underwater sound emissions from wave and tidal devices. However, the data contained in this report primarily relate to small test scale devices. Operational noise levels have therefore been based on measurements carried out on a 16 m diameter open centred tidal turbine device in France. Noise source data is described in greater detail in Section 9.

Further information regarding noise source data for each aspect of construction and operation is given in the relevant assessment sections of this report.

8.2 Noise modelling methodology

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.

The way that the noise spreads (geometrical divergence) will depend upon several factors such as bathymetry, pressure, temperature gradients, salinity as well as surface and bottom conditions. Thus, even for a given locality, there are seasonal 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) or somewhere in between, depending on several factors. In shallow waters, the propagation mechanism is also coloured by multiple reflections from the seabed and the water surface.

There are several methods available for estimating 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 (where r is the distance from source to receiver) to full acoustic models[5] (e.g. ray tracing, normal mode, parabolic equation, wavenumber integration and energy flux models). In addition, semi-empirical models are available which lie somewhere in between these two extremes in terms of complexity. 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. Thus, in some situations (e.g. very low risk due to underwater noise, range dependent bathymetry is not an issue) a simple 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, complex source and propagation path characteristics, highly sensitive receivers and low uncertainties in assessment criteria) warrant a more complex modelling methodology.

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

- **Balancing of errors / uncertainties**
  - There are uncertainties in relation to both the source noise data and the assessment thresholds for onset of effect. With respect to source data, the Project is being developed on a technology neutral basis (i.e. the specific tidal turbine type that will be deployed has not yet been selected) and there is sparse data relating to the source noise levels of full scale operational devices. It is therefore possible that there could be a relatively large uncertainty with respect to the source noise levels used for the modelling. This concern is mitigated by the various worst case assumptions made in the assessment (including use of recent measurements undertaken on a 16 m diameter turbines), but it is still the case that the uncertainty introduced due to a lack of measurements on full scale devices is likely to be greater than any errors introduced through modelling.
  - Likewise, there is a paucity of data relating to the effects of sound on marine life, particularly for behavioural effects. Many of the studies for behavioural disturbance fail to properly define dose-response relationships (concentrating on the animal response with little analysis of the noise “dose”) and, taking into account context and location specific factors as well as habituation, it is extremely difficult to estimate the potential error in the effect thresholds. However, referring to the wide ranging spread of onset levels leading to an effect presented in Southall *et al*., 2007, it is speculated that the uncertainty due to onset of effects could well be a magnitude of tens of deciBels.
- **Range dependant bathymetry**

[5] *It is worth noting that additional complexity does not always equate to greater accuracy and may not always be preferable. Many more complex models work over a limited frequency range and the complexity and range of inputs can make them very context specific. Consequently, the model outputs can vary significantly depending on the input assumptions which in themselves can change day-to-day and season-to-season.*

- The Project is to be located in an area where the water depth ranges from 60 – 100 m. Therefore, the propagation model chosen needs to take range dependent bathymetry into account.

> **Frequency dependence**

- Most of the noise sources associated with the development will be primarily low frequency in character. This means that the effect of molecular absorption of acoustic energy will be minimal compared to higher frequency sound sources. However, because the development will be in relatively shallow water and is situated next to the coast, it will be important to ensure that the low-frequency cut-off for sound propagation is taken into account.

On the basis of the above factors, and taking into account the relatively low risk associated with noise from tidal energy developments, it is considered that potential errors due to uncertainty regarding the effects of sound on marine mammals and fish as well as uncertainties in source data are likely to be greater than the uncertainties inherent in acoustic modelling. Xodus has chosen a semi-empirical sound propagation model which provides a reasonable balance between complexity and technical robustness. It should be borne in mind that calculated 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 semi-empirical 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.).

Noise propagation modelling for this assessment was carried out using Xodus's SubsoniX noise model, which implements the sound propagation model developed by (Rogers 1981). The Rogers sound propagation model is a semi-empirical, range dependent propagation which is based on a combination of theoretical considerations and extensive experimental data. Consequently, unlike purely theoretical sound propagation models, the calibration for the Rogers model is built into the model itself and it has subsequently been successfully benchmarked against other sound propagation models (e.g. Etter 2013, Toso *et al.*, 2014, Schulkin and Mercer, 1985) and has been used previously in underwater noise assessments for tidal and wind energy developments (e.g. Xodus 2015, Dawoud *et al.*, 2015). The model takes into account the following parameters:

> 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; and

> sediment attenuation coefficient.

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 was calculated based on Ainslie and McColm (1998). The limiting angle, $\theta_L$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.

$$\theta_g = \sqrt{\frac{2Hg}{c_w}}$$

$$\theta_c = \frac{c_w}{2fH}$$

Where g is the sound speed gradient in water (taken to be 0.2 s^{-1} for the purposes of the modelling) and f is the frequency. The bottom loss β is approximated as:

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

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.

The SubsoniX 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.

As well as calculating the sound pressure levels at various distances from the source, it is also necessary to calculate the SEL for a mammal using the relevant M-weightings described previously taking into account the amount of sound energy to which it is exposed over the course of a day. In order to carry out this 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 1-second period of exposure to be established separately, resulting in a series of discrete SEL values of decreasing magnitude (see Figure 8.1). As the mammal swims away, 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. For fish, the same assumptions about the movement of individual animals relative to the sound source is not as well understood and is therefore not considered in the model. This calculation was used to estimate the approximate minimum start distance for a marine mammal in order for it to be exposed to sufficient sound energy to result in the onset of potential injury. It should be noted that the sound exposure calculations are based on the simplistic assumption that the source is active continuously over a 24 hour period and that the animal will continue to swim away at a fairly constant relative speed. The real world situation is more complex and the noise source will vary in space and time and the animal is likely to move in a more complex manner[6].

[6] *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.*

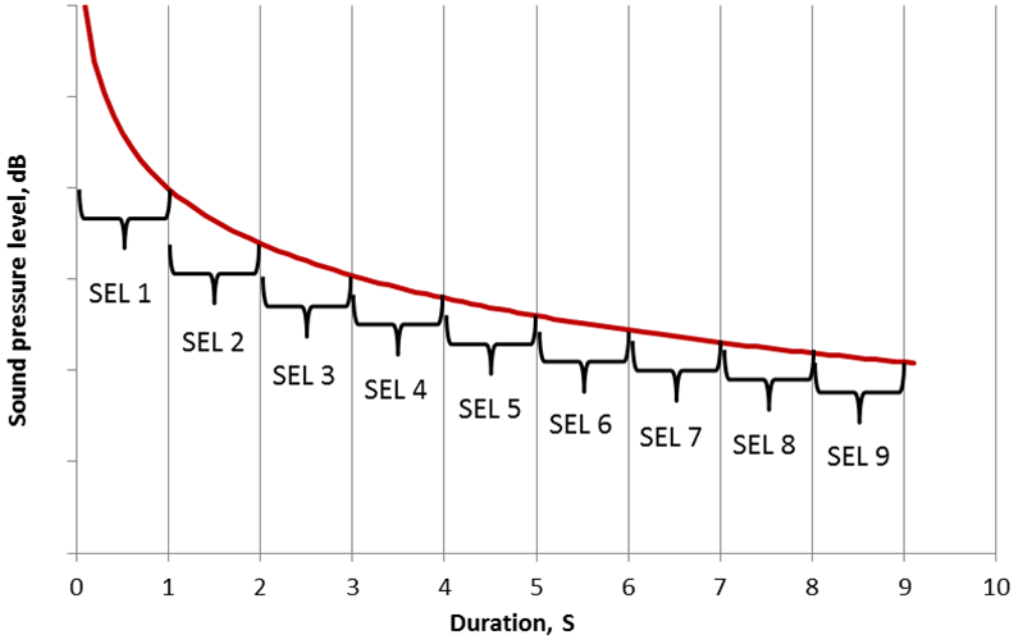

Figure 8.1 Conversion of continuous noise sources into discrete 1-second windows

9 SOURCE NOISE DATA

9.1 Construction and installation

There is potential for installation vessels and other equipment to produce noise during installation of the tidal energy devices and export cables. It is not expected that HDD operations will produce any significant noise since the noise generating equipment will all be located onshore with the exception of the drill bit and string which will be under the sea floor.

The export cable(s) will transmit electricity from the turbines to one of three possible landfall locations; Sheep Skerry, Moodies Eddy or Aith Hope. The export cables will be surface laid as much of the seabed within the AfL area and along proposed export cable routes which comprises hard rock substrate limiting cable burial. Given that the cables cannot be buried cable protection may be required along the full length of the export cables (from the AfL to landfall). Cable protection measures include:

> **Rock placement**: placement of rocks and boulders of various size along the export cables resulting in the creation of a rock berm over the cable;

> **Concrete mattresses**: pre-formed articulate mattresses comprising a mesh of concrete block that are placed across cables; or

> **Grout bags**: bags of hardened gravel, sand / cement grout or concrete placed over the cable.

In areas of softer sediment, e.g. towards the landfalls, options for cable burial (e.g. open cut trenching) may be possible.

The design of the Turbine Support Structures (TSS) varies according to the different turbine types being considered and method of attachment to the seabed. With regard to this Project, the following TSS options are being considered:

> **Gravity Base Structure (GBS) including sub-sea bases (SSBs):** A number of installation techniques are possible for a GBS, including use of a heavy-lift installation vessel or a specialised heavy-lift deployment barge to lower the gravity base as one unit with the turbine already attached.

> **Drilled monopole:** Installation of monopole TSSs requires use of specialist drilling equipment (e.g. drilling unit that sits on the seabed) and multi-stage operations to grout the monopiles into their socket.

> **Pin pile tripods:** Installation of pin pile tripod TSSs is similar to monopile installation and also requires use of specialist drilling equipment (e.g. drilling unit that sits on the seabed) and multi-stage operations to grout the monopiles into their socket.

For the 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 using Seacore's Teredo 40 reverse circulation, large diameter drill rig equipped with a 4.25 m diameter drill bit.

Once the TSSs are in place (for those that do not have turbines pre-attached), the turbines will be transported to the AfL either on a dedicated deployment barge or heavy lift vessel. Turbines with built in buoyancy will be towed to site using standard working class tow vessels. Once the turbines are at site they will be lowered (or pulled down for buoyant turbines) by a winch to the top of the TSSs. ROVs will then be used to guide the turbines into place for attachment to the TSSs. The turbines will then be mechanically secured in place.

Because the development is being progressed on a technology neutral basis, there are no definitive installation methods decided at this stage. Several options are currently being considered in the design envelope and it is possible that some of the TSSs and turbines may be installed using a Dynamic Positioning (DP) construction vessel or an equivalent stable platform (e.g. moored barge). A jack up barge may also be required depending on site conditions, TSS and precise method of installation. Where turbines and TSSs are to be installed as a single unit installation will be carried out using purpose built twin hulled three point heavy lift deployment barge. Other smaller vessels e.g. tugs, vessels carrying ROVs, crew transfer vessels, dive boats and RIBs will also be required to support the installation operations.

The noise emissions from the types of vessels that may be used in the Project are quantified in Table 9.1, based on a review of publicly available data. Data are also presented for underwater pile drilling and cable trenching. For activities such as rock dumping and trenching, it is primarily sound from the vessels (e.g. propeller, thrusters and sonar, if used) that dominates the emission level.

In the table, a correction of +3 dB has been applied to the rms sound pressure level to estimate the likely peak sound pressure level. SELs have been estimated for each source based on 24 hours continuous operation, although 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, the acoustic modelling has been undertaken based on an animal swimming away from the source (or the source moving away from an animal) at an average speed of 1.5 ms^{-1}. 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 worst-case assumptions (i.e. using noise data toward the higher end of the scale for the relevant class of ship as a proxy). In the case of the cable laying vessel, no publicly available information was available for a similar vessel and therefore measurements on a suction dredger using DP thrusters was used as a proxy.

Table 9.1 Source noise data for construction and installation

Item	Description/assumptions	Data source	Source sound pressure level at 1 m		
			RMS, dB re 1 µPa	*Peak, dB re 1 µPa*	*SEL(24h), dB re 1 µPa²s*
Anchor handling vessel	Tug used as proxy	Richardson (1995)	172	175	221
Installation / construction vessel (using DP)	'Gerardus Mercator' trailer hopper suction dredger using DP as proxy	Wyatt (2008)	188	191	237
Support vessel	Based on measurements on offshore support vessel	(McCauley 1998)	179	182	228
Rock placement vessel	'Gerardus Mercator' trailer hopper suction dredger using DP as proxy	Wyatt (2008)	188	191	237
Cable lay vessel	'Gerardus Mercator' trailer hopper suction dredger using DP as proxy	Wyatt (2008)	188	191	237
Misc. small vessels (e.g. tugs, vessels carrying ROVs, crew transfer vessels, dive boats and RIBs)	Tug used as proxy	Richardson (1995)	172	175	221
Pile drilling	Pile drilling for Oyster 800 project	Kongsberg (2011)	163	166	212
Cable trenching / cutting	Based on measurements made at North Hoyle during trenching	J. Nedwell, Langworthy and Howell 2003	178	181	227
Jack up barge	Drilling rig used as proxy	Hannay et al. 2004 - 1/3 octaves measured for drilling rig (Wyatt 2008)	162	165	211

9.2 Operational noise

9.2.1 Tidal energy device source noise data

Tidal energy devices consists of a turbine coupled to a generator housed inside a nacelle. Noise generated by the unit is primarily from the action of the turbine itself, meaning that it is a function of the speed of the unit and is characteristically tonal at multiples of the blade pass frequency. The key noise generating mechanisms for an underwater turbine are as follows;

- Vortex shedding by the blade tip;
- Vortex shedding by the structural elements of the turbine;
- Cavitation on the turbine blade surface; and
- Noise from displacement of fluid by turbine blades.

Vortex shedding is a phenomenon which occurs when a fluid (either a liquid or a gas) moves past a bluff (as opposed to stream-lined) object at certain speeds, and is characterised by tones (narrow-band frequency sounds) at specific frequencies related to the size of the object. The rate at which this occurs, the vortex-shedding frequency f_v, is dependent upon a number of factors; the size of the object, the speed of the fluid as it moves past the body (or, conversely, the speed of the body as it moves through the fluid), and the viscosity of the fluid. These factors are usually expressed in terms of 'Strouhal number' (the ratio of object size to fluid flow speed) and 'Reynold's number' (the ratio of the inertial forces to the viscous forces in the fluid medium).

The vortex shedding frequency is then expected to increase as the size of the object decreases (i.e. smaller objects produce higher frequency tones than large objects) and as fluid flow speed increases (i.e. the faster an object moves through a fluid, the higher the tones it produces). For a turbine blade, vortex shedding is most likely at the leading edge of each blade. Vortex shedding frequency in this instance is then a function of the operational speed of the turbine.

Cavitation is a phenomenon relating to the formation of bubbles, either on a surface which is moving through a fluid medium or on a surface over which a fluid medium passes (Massey 2005). As a high velocity fluid passes over a surface, the pressure on that surface can be seen to fluctuate rapidly. When the pressure decreases, bubbles (or cavities, hence 'cavitation') form on the surface, and then collapse as the pressure increases, resulting in the "firing" of a jet of fluid from the bubble surface on to the cavitating surface. For a turbine, cavitation is likely to occur on the face of the turbine blades, normal to the direction of fluid flow, which is termed 'sheet cavitation'. When cavitation occurs, it can result in damage to the cavitating surface, unwanted vibration and noise and, in general, the larger the cavitation area, the larger the generated noise and vibration. Consequently, tidal turbines will usually be designed to minimise the effect of cavitation which will also result in lower levels of noise.

Because the noise generation mechanism is rather complex, it is not possible to simply scale up noise emissions from a smaller turbine to a larger one using a 10 x log W relationship (where W represents the turbine power rating). In some cases, the lower rotational speed and improved design of the turbine blades on larger turbines can result in reductions in noise from full scale devices compared to small scale devices. This will be accompanied by a shift in the frequency content of the noise from higher frequencies towards lower frequencies. This is important because marine mammals have less sensitive hearing at these lower frequencies meaning that they could potentially be *less* affected by sound from the full scale devices compared to smaller scale test devices.

The proposed Project is technology neutral on the basis that BTAL has not yet identified a preferred technology / device type. All device types will be seabed-mounted and will have minimum clearance from the blade tip to sea surface at LAT of 20 m. To generate electricity the turbines will convert kinetic energy from the flow of water into electrical energy via the turbine blades turning the generator. The turbines being considered are either mono or bi-directional:

- **Mono-directional:** Uses a yaw system to re-orientate rotor blades during slack tide in order to optimise tidal flow from both ebb and flood tides; and
- **Bi-directional:** has fixed pitch blades which generate energy from flows in both directions (ebb and flood tides).

Rotor diameters for the turbines range from 13 m to 23 m. The number of blades per rotor on the unshrouded turbines will be three. The shrouded turbine has one rotor comprising up to 10 blades. The turbines are expected to have a rated power output of between 1 to 2 MW per turbine. The rated power output of the turbines depends on a number of factors including technological developments, site conditions and array layout. For the purpose of this assessment, it is assumed that all turbines will have a rated power output of at least 1 MW. Given that the maximum capacity of the AfL area is 200 MW, the total number of turbines required for the Project will decrease as the rated power of the tidal turbines increases. For example, if the turbines have a rated power output of 2 MW only 100 turbines will be required. However, for the purposes of the noise modelling it has been assumed that Phase 1 will comprise up to 30 off 1 MW devices and Phase 2 will comprise up to 170 off 1 MW devices, making a total of 200 devices for Phases 1 and 2 combined.

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, only seven of which report operational noise from tidal energy devices, as summarised in Table 9.2.

Table 9.2 Summary of publicly available measured data for tidal 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 $\mu Pa^2/Hz$
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 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

The authors of the Pentland Firth and Enabling Actions Report noted that all values and units quoted in Table 9.2 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[7]. Another useful study was based on noise measurements of an OpenHydro tidal turbine at the EMEC facility in Orkney (Parvin and Brooker, 2008). This report provides power spectrum density levels for operational noise from the OpenHydro turbine and reports a source noise level of 162 dB re 1 μPa referred to 1 m. However, this was for a small scale test turbine and is not comparable to the size and scale of turbines likely to be deployed as part of this project.

Based on the aforementioned data quality and scaling issues, the noise modelling for this study has been undertaken based on noise measurements on a 16 m diameter OpenHydro tidal turbine off the Brittany coast. This is considered to be the most suitable study because the 16 m diameter turbines are much more similar to the size of turbine likely to be deployed as part of this project than the measurements on small scale test devices. As

[7] *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.*

previously noted, the speed and size of the turbine will have a significant effect on noise emissions both in terms of overall sound emission level and frequency content. Basing the assessment on this larger scale device therefore reduces the potential for uncertainty in the source noise level data.

Measurements were carried out during four months between December 2013 and April 2014 in 40 m water depths (Lossent, 2015 in prep) and with tidal speeds ranging between 0.7 to 1.7 ms^{-1}. The (preliminary) source sound pressure levels (in third-octave bands) are presented in Figure 9.1. The overall source sound pressure level is estimated at 152 dB re 1 µPa rms at 1 m. It should be noted that whilst the bandwidth of some of the bands is one third of an octave wide, it would appear that some bands are one octave wide. Nevertheless, it can clearly be seen that the overall un-weighted sound pressure level is dominated by the 128 Hz third-octave band.

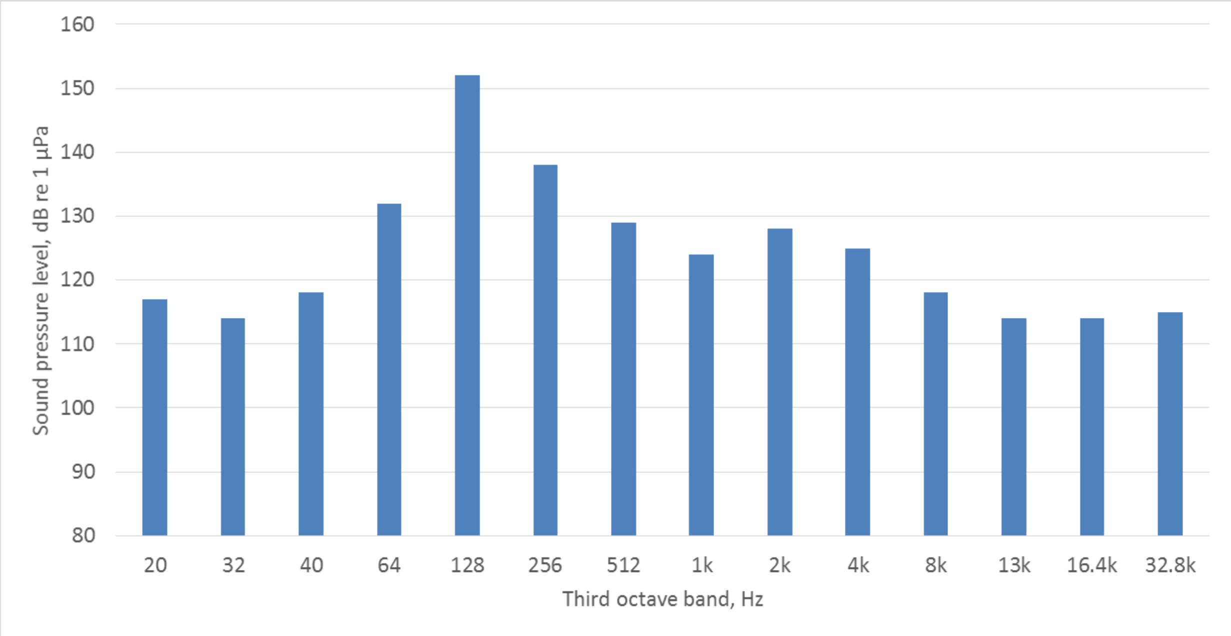

Figure 9.1 Source noise data – Openhydro 16 m diameter turbine

Whilst it would be preferable to carry out modelling for a wider range of potential turbines, the ability to do so is limited by the lack of sufficient data reported in the available literature.

Although peak pressure levels are not reported in the literature, for the purposes of this study Xodus has assumed that zero-peak sound pressure levels will be 3 dB higher than the rms sound pressure level for continuous operational noise. Therefore, the source peak sound pressure level at 1 m will be approximately 155 dB re 1 µPa. This is well below the peak pressure injury criteria for all marine mammals and fish.

9.2.2 Operational and Maintenance Vessel Source Noise Data

The types of vessel used for maintenance of the tidal energy devices are likely to be similar to those used for construction, as detailed in the previous sections of this report.

9.3 Decommissioning Noise

The types of vessel used for decommissioning of the tidal energy devices are likely to be similar to those used for construction, as detailed in the previous sections of this report.

10 RESULTS AND ASSESSMENT

10.1 General

The various potential sources of underwater noise (as detailed in Section 9 of this report) are considered for each of the phases of the project in turn in the following sections. This includes noise modelling results and an assessment of potential zones of effect on marine mammals and fish.

10.2 Construction and installation

10.2.1 Effects of construction and installation on marine mammals

Construction noise impacts will be the same for Phases 1 and 2. Estimated ranges for injury to marine mammals are presented in Table 10.1, assuming a swim speed of 1.5 ms^{-1}. The table also includes the time taken to reach the injury onset threshold assuming that a mammal remains stationary within a 10 m range from the noise source. The source peak sound pressure levels are all below the criteria for injury so all injury ranges have been calculated using M-weighted SEL. Because noise from vessels is dominated by low frequencies, the potential for impact on low-frequency hearing group cetaceans is greater than for mid and high-frequency cetaceans once the M-weighting is applied.

It should be noted that impact range is not a hard and fast 'line' which has impact on one side and no impact on the other; impact is more probabilistic than that. Dose dependency in TTS/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 line around a noise source. These ranges are therefore simplistic representations of 'potential impact range' designed to provide an understandable way in which a wider audience can appreciate the complexities and thus inform decision making. It should be borne in mind that there is a considerable degree of uncertainty and variability in the onset of disturbance and therefore any disturbance ranges should be treated as potentially over precautionary. Another important consideration is that vessels and construction noise will be temporary and transitory, as opposed to permanent and fixed. In this respect, construction noise is unlikely to differ significantly from vessel traffic already in the area.

Table 10.1 Estimated injury ranges and times for marine mammals during construction

Activity / source	PTS injury zone radius (assuming 1.5 ms^{-1} swim speed)		TTS injury zone radius (assuming 1.5 ms^{-1} swim speed)		Time taken to reach PTS injury threshold at 10 m from source for stationary mammal	
	Cetacean	***Pinniped***	***Cetacean***	***Pinniped***	***Cetacean***	***Pinniped***
Anchor handling vessel	0 m	0 m	0 m	0 m	Not exceeded	Not exceeded
Installation / construction vessel (using DP)	0 m	0 m	0 m	0 m	19 hours for LF cetaceans HF/MF cetaceans - not exceeded	2.4 hours
Support vessel	0 m	0 m	0 m	0 m	Not exceeded	9 hours
Rock placement vessel	0 m	0 m	0 m	0 m	19 hours for LF cetaceans HF/MF cetaceans - not exceeded	2.4 hours
Cable lay vessel	0 m	0 m	0 m	0 m	19 hours for LF cetaceans HF/MF cetaceans - not exceeded	2.4 hours
Misc. small vessels	0 m	0 m	0 m	0 m	Not exceeded	Not exceeded
Pile drilling	0 m	0 m	0 m	0 m	Not exceeded	Not exceeded
Cable trenching / cutting	0 m	0 m	0 m	0 m	Not exceeded	11 hours
Jack up barge	0 m	0 m	0 m	0 m	Not exceeded	Not exceeded

Based on an animal swimming at an average speed of 1.5 ms^{-1} from the sources of construction noise, the noise modelling shows that TTS or PTS injury to marine mammals is unlikely to occur for any of the vessels or construction activities. The injury thresholds in Southall et al. (2007) are not exceeded even if a very low swim speed of 0.5 ms^{-1} is assumed. Even if a mammal was to stay stationary in the vicinity of construction operations, a cetacean would need to stay within a radius of 10 m from construction vessels using DP for a period of 19 hours in order to exceed the Southall et al. (2007) SEL injury criteria and pinnipeds would need to stay in the vicinity for 2.4 hours.

The estimated ranges for onset of disturbance effects are shown in Table 10.2. It should be noted that these values are based on an average water depth of 80 m and that in reality the range will vary depending on both source and receiver location. The values in the table are based on exceeding the 120 dB re 1 μPa (rms) threshold applicable for all marine mammals. However, as noted previously, disturbance zones are not a hard and fast line but rather a probabilistic and variable zone which will depend upon numerous factors, not least hearing capabilities, availability of food, habituation and masking by other sounds.

An example contour (using the actual bathymetry of the area) for a vessel using DP thrusters is provided in Figure 10.1. This is the worst-case noise contour for the noisiest vessels likely to be used – e.g. installation, construction, rock placement and cable lay vessels.

Table 10.2 Estimated disturbance ranges for marine mammals during construction

Source / vessel	Estimated range for onset of disturbance (all marine mammal species[8])	
	Radius from source	***Area[9]***
Anchor handling vessel	1.4 km	6 km^2
Installation / construction vessel (using DP)	14 km	616 km^2
Support vessel	4 km	50 km^2
Rock placement vessel	14 km	616 km^2
Cable lay vessel	14 km	616 km^2
Misc. small vessels (e.g. tugs, vessels carrying ROVs, crew transfer vessels, dive boats and RIBs)	1.4 km	6 km^2
Pile drilling	375 m	0.4 km^2
Cable trenching / cutting	3.5 km	38 km^2
Jack up barge	430 m	0.6 km^2

It is important to place the results in Table 10.2 in the context of the baseline noise environment. The 120 dB re 1 μPa rms sound pressure level criterion is within the range of typical baseline noise levels in the area. There is already some degree of anthropogenic noise from vessels (e.g. ferries) and it is therefore possible that marine mammals could be more habituated to vessel noise than in less heavily trafficked areas. Furthermore, the relatively high tidal currents mean that the ambient noise levels will generally be higher than encountered in open sea or many other coastal areas of the UK. Consequently, these predicted ranges for onset of disturbance should be viewed as very precautionary. It is therefore important to understand that exceeding the criteria for potential onset of disturbance effects does not in itself mean that disturbance will occur. Southall *et al.* (2007) notes that "…*the available data on behavioural responses do not converge on specific exposure conditions resulting in particular reactions, nor do they point to a common behavioural mechanism. Even data obtained with substantial*

[8] Based on the literature review described in Section 6.2.2 it is considered that there is not sufficient peer reviewed scientific evidence at this time to establish species specific criteria for disturbance. The predicted indicative range of effect will therefore be combined with species sensitivities and vulnerabilities in the marine mammal chapter to provide an indicative and qualitative assessment of potential for disturbance.

[9] The approximate area can be multiplied by the marine mammal density for each species to estimate the potential number of animals likely to be exposed to sound levels that could lead to the onset of behavioural effects and to compare this to the local population estimates, as recommended in JNCC guidelines. However, as noted previously the criterion for onset of disturbance is very precautionary and exceedance does not necessarily mean that disturbance will occur, or that such disturbance if it does occur will be significant.

controls, precision, and standardized metrics indicate high variance both in behavioural responses and in exposure conditions required to elicit a given response. It is clear that behavioural responses are strongly affected by the context of exposure and by the animal's experience, motivation, and conditioning. This reality, which is generally consistent with patterns of behaviour in other mammals (including humans), hampered our efforts to formulate broadly applicable behavioural response criteria for marine mammals based on exposure level alone."

It is also worth noting that these noise sources are temporary and transitory.

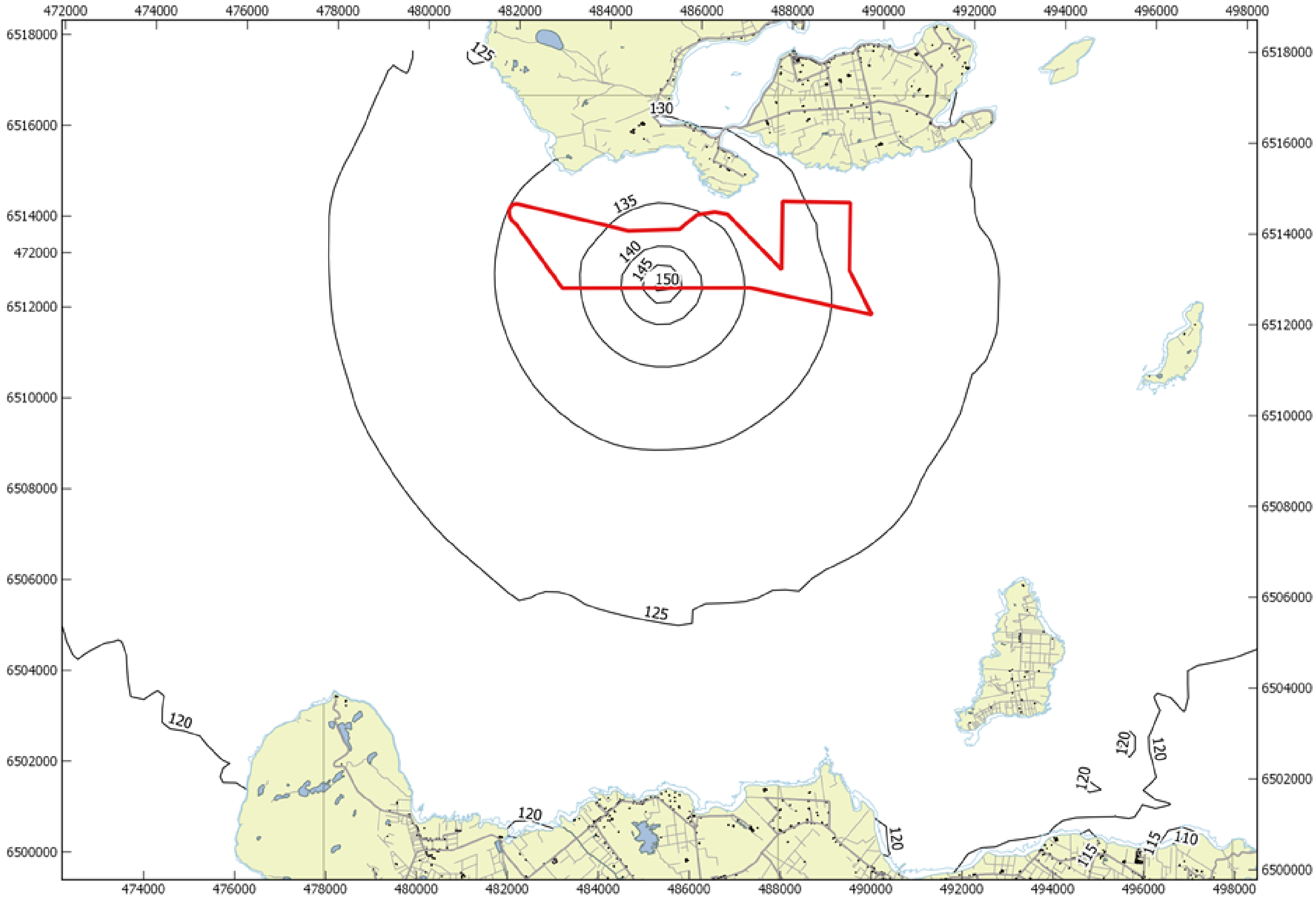

Figure 10.1 Construction underwater noise contours, dB re 1 µPa rms (un-weighted) - installation / construction vessel and other large vessels using DP

Figure 10.2 shows the un-weighted rms sound pressure level contours for an anchor handling vessel and other miscellaneous small vessels.

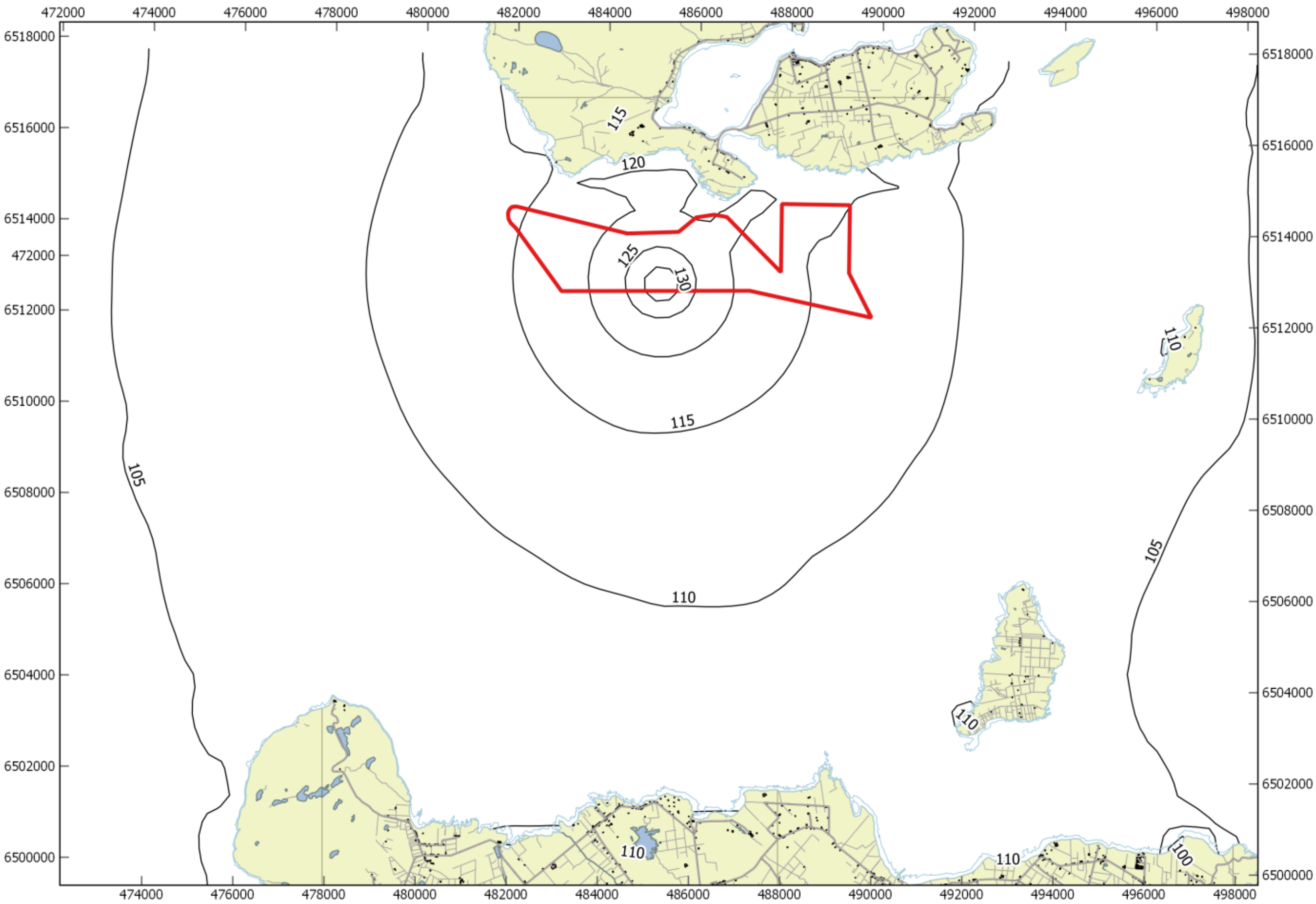

Figure 10.2 Construction underwater noise contours, dB re 1 μPa rms (un-weighted) – anchor handling vessel and miscellaneous small vessels

Figure 10.3 shows the un-weighted rms sound pressure level contours for pile drilling.

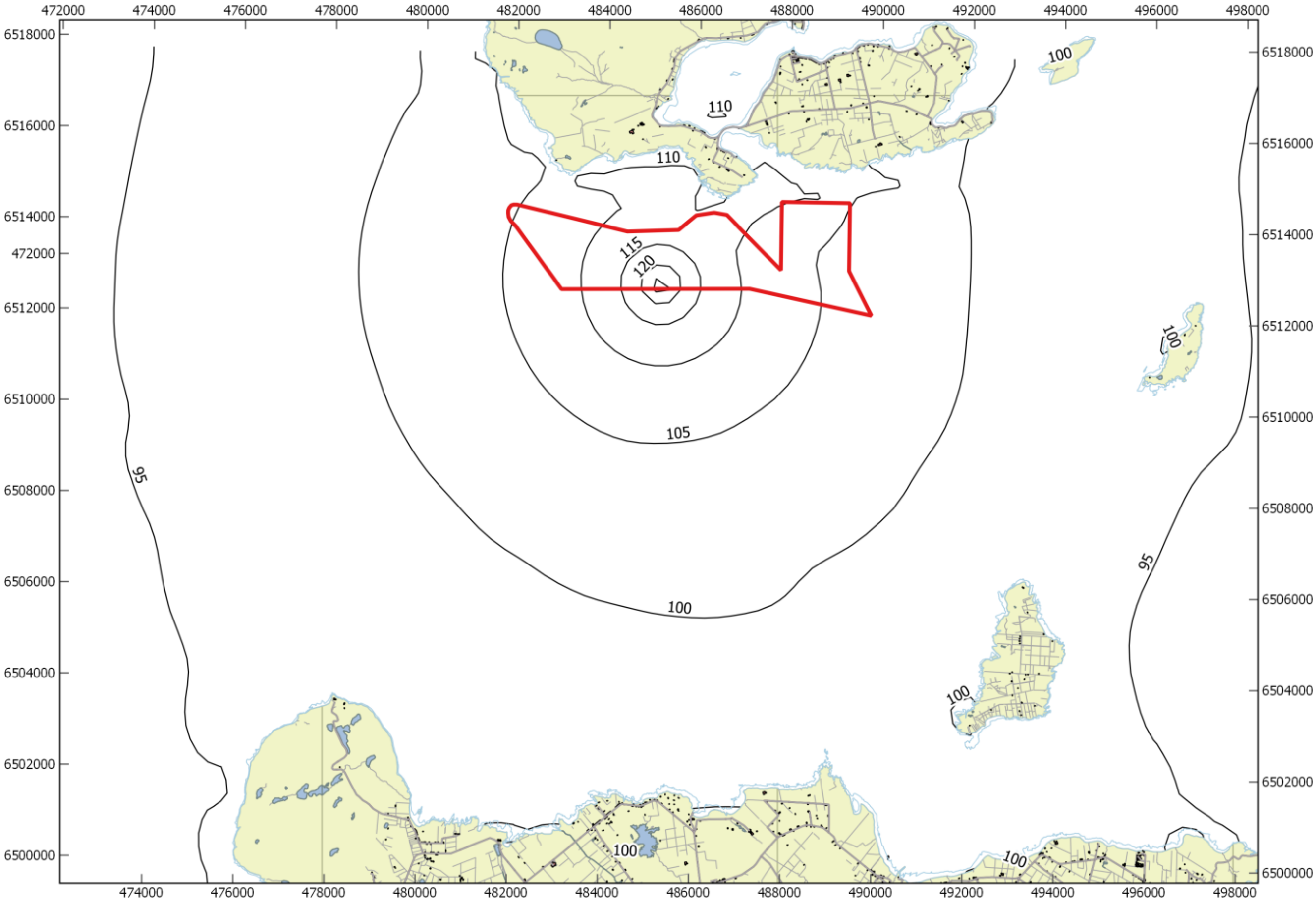

Figure 10.3 Construction underwater noise contours, dB re 1 µPa rms (un-weighted) – pile drilling

10.2.2 Effects of construction and installation on fish

The potential for injury and disturbance to fish is shown in the following tables. Table 10.3 shows the qualitative risk of injury and disturbance to different fish types depending on range, in accordance with ASA guidance.

Table 10.3 Effects of continuous vessel / construction noise based on ASA qualitative criteria

	Qualitative risk due to exposure to continuous noise		
Range:	***Near*** *(10s of meters)*	***Intermediate*** *(100s of meters)*	***Far*** *(1,000s of meters)*
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 11.5		
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

Table 10.4 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 10.4 Calculated effects of continuous vessel / construction noise

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	<5 m	16 m
Installation / construction vessel (using DP)	10 m	185 m
Support vessel	<5 m	50 m
Rock placement vessel	10 m	185 m
Cable lay vessel	10 m	185 m
Misc. small vessels (e.g. tugs, vessels carrying ROVs, crew transfer vessels, dive boats and RIBs)	<5 m	16 m
Pile drilling	0 m	5 m
Cable trenching / cutting	<5 m	40 m
Jack up barge	0 m	4 m

For continuous sounds such as vessels, only fish with swim bladders are likely to have a high risk of behavioural effects and then only within tens of meters of the source, according to the ASA guidelines. The relative risks for other fish should be downgraded accordingly.

10.3 Operational noise

10.3.1 Effects of Operational Noise on Marine Mammals

Predicted noise contours for the operational turbine devices are shown in Figures 10.4 to 10.7. The contours include overall sound pressure levels for Phase 1 (30 tidal energy devices) and the worst-case scenario cumulative contours for Phases 1 and 2 combined (200 tidal energy devices). Contours are presented both as un-weighted rms sound pressure levels and M-weighted rms sound pressure levels.

The SEL injury criteria will not be exceeded for all cetaceans and pinnipeds even if they were to spend 24 hours immediately adjacent to a turbine. Likewise, the peak injury criteria are not exceeded at any location, even immediately adjacent to the turbines, as shown in Table 10.5.

Table 10.5 Estimated injury ranges and times for marine mammals for operational turbines

Activity / source	PTS injury zone radius (assuming 1.5 ms^{-1} swim speed)	TTS injury zone radius (assuming 1.5 ms^{-1} swim speed)	Time taken to reach PTS injury threshold at 10 m from source for stationary mammal

	Cetacean	*Pinniped*	*Cetacean*	*Pinniped*	*Cetacean*	*Pinniped*
Operational turbines (Phases 1 and 2 combined)	0 m	0 m	0 m	0 m	Not exceeded	Not exceeded

The extent of the potential disturbance zone for marine mammals is a radius of approximately 1 km from the centre of the array for Phase 1, equating to an area of approximately 2.8 km^2, based on the very precautionary disturbance criterion of 120 dB re 1 µPa (rms). For Phase 2, the extent of the potential disturbance zone will be 2 to 4 km and covers an area of approximately 30 km^2. However, this needs to be put in the context of likely baseline noise levels. The turbines are not expected to generate significant noise when idle (during slacker periods when the baseline noise level will be low) and during periods of higher velocity flow, when the rotor will be spinning and noise generated, the background noise will also be at its highest. There is therefore potential that noise from the turbines could be masked. If, for example, the baseline noise was in the order of 130 dB re 1 µPa (rms) then it is unlikely that a significant effect would occur outside the 130 dB re 1 µPa (rms) contour, which is contained within the AfL boundary.

Table 10.6 Estimated disturbance ranges for marine mammals for operational turbines

Source / vessel	Estimated range for onset of disturbance (all marine mammal species[10])	
	Radius from source	*Area[11]*
Operational turbines (Phase 1)	1 km	2.8 km^2
Operational turbines (Phases 1 and 2 combined)	2 km (north or south) - 4 km (east or west)	30 km^2

Although the criterion for onset of disturbance for all marine mammals is based on exceedance of an un-weighted rms sound pressure level, it is likely that different species will react differently to the sound, in part due to differences in their hearing in combination with other non-acoustic factors. Although there is insufficient scientific evidence at this time to calculate a definitive zone of disturbance for a hearing group or species, understanding how the noise will vary according to marine mammal hearing group may be helpful to aid a comparison of the likely relative effect of noise on each group. The associated area of the 120 dB rms sound pressure level contour (M-weighted) is listed in Table 10.7, although it is important to note that it is not possible based on the available scientific evidence to directly correlate onset of disturbance with M-weighted sound pressure levels. This is because it only takes into account the M-weighting curve (as an approximation for hearing threshold and bandwidth) as opposed to a species' behavioural sensitivity to the stimulus.

[10] *Based on the literature review described in Section 6.2.2 it is considered that there is not sufficient peer reviewed scientific evidence at this time to establish species specific criteria for disturbance. The predicted indicative range of effect will therefore be combined with species sensitivities and vulnerabilities in the marine mammal chapter to provide an indicative and qualitative assessment of potential for disturbance.*

[11] *The approximate area can be multiplied by the marine mammal density for each species to estimate the potential number of animals likely to be exposed to sound levels that could lead to the onset of behavioural effects and to compare this to the local population estimates, as recommended in JNCC guidelines. However, as noted previously the criterion for onset of disturbance is very precautionary and exceedance does not necessarily mean that disturbance will occur, or that such disturbance if it does occur will be significant.*

Table 10.7 Estimated disturbance ranges for marine mammals for operational turbines

Source / vessel	Estimated 120 dB rms (M-weighted) contour area	
	Phase 1	*Phases 1 and 2 combined*
Low frequency cetaceans	2.8 km^2	30 km^2
Mid frequency cetaceans	0.3 km^2	5 km^2
High frequency cetaceans	0.1 km^2	1.4 km^2
Pinnipeds	1.5 km^2	18 km^2

The operational noise contours for Phase 1 are shown in Figure 10.4 (un-weighted) and Figure 10.5 (M-weighted). Operational noise contours for Phases 1 and 2 combined are shown in Figure 10.6 (un-weighted) and Figure 10.7 (M-weighted).

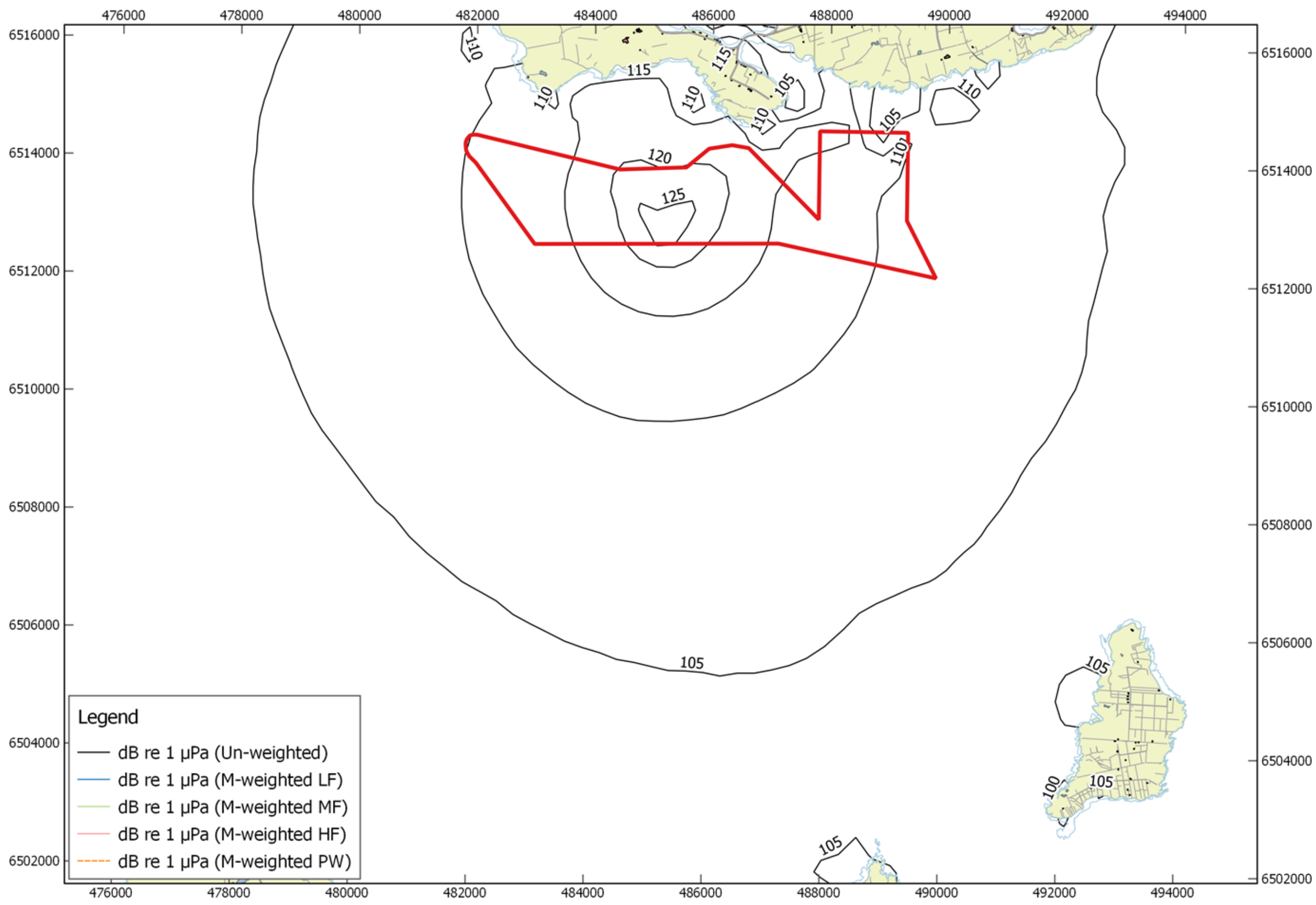

Figure 10.4 Phase 1 underwater noise contours, dB re 1 µPa rms (un-weighted)

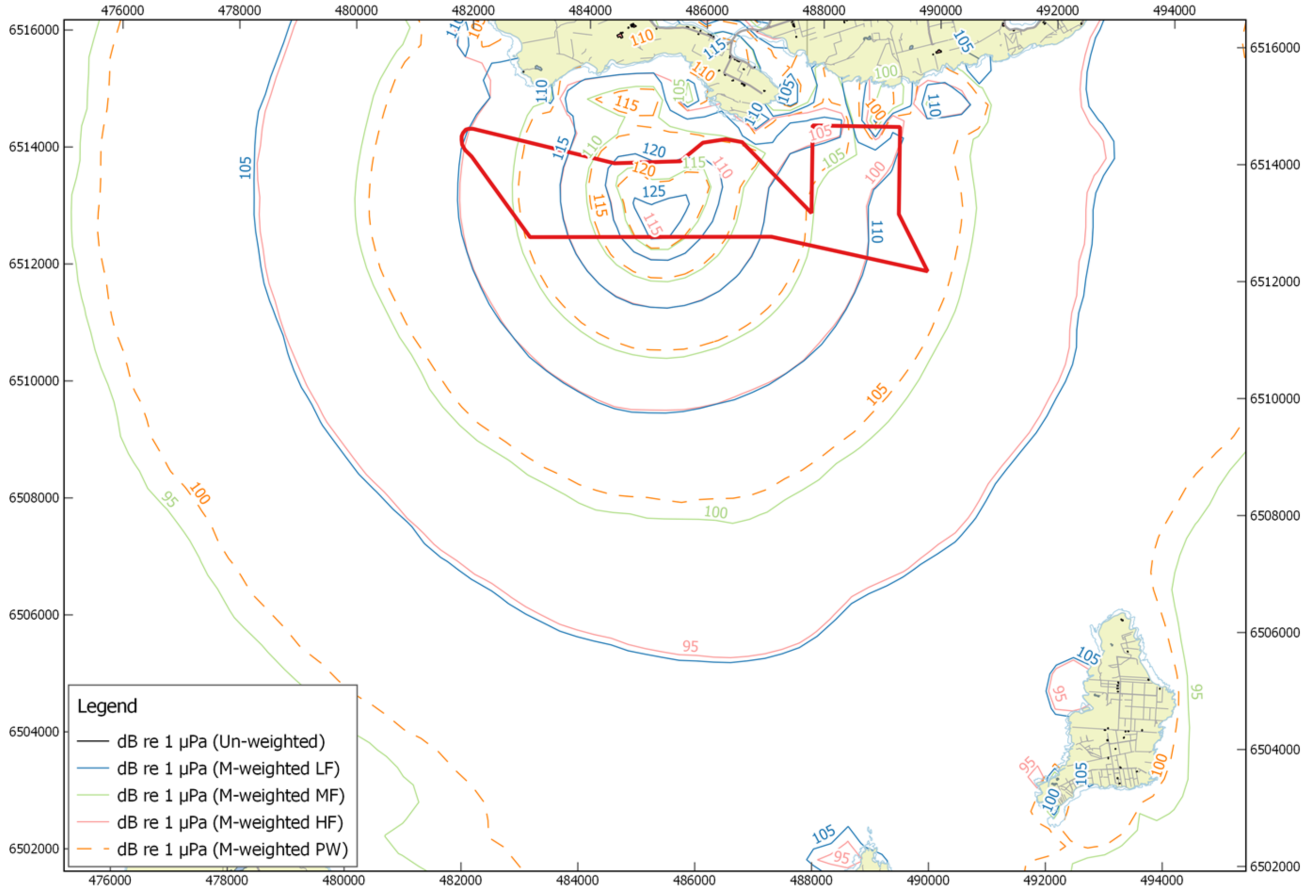

Figure 10.5 Phase 1 underwater noise contours, dB re 1 μPa rms (M-weighted)

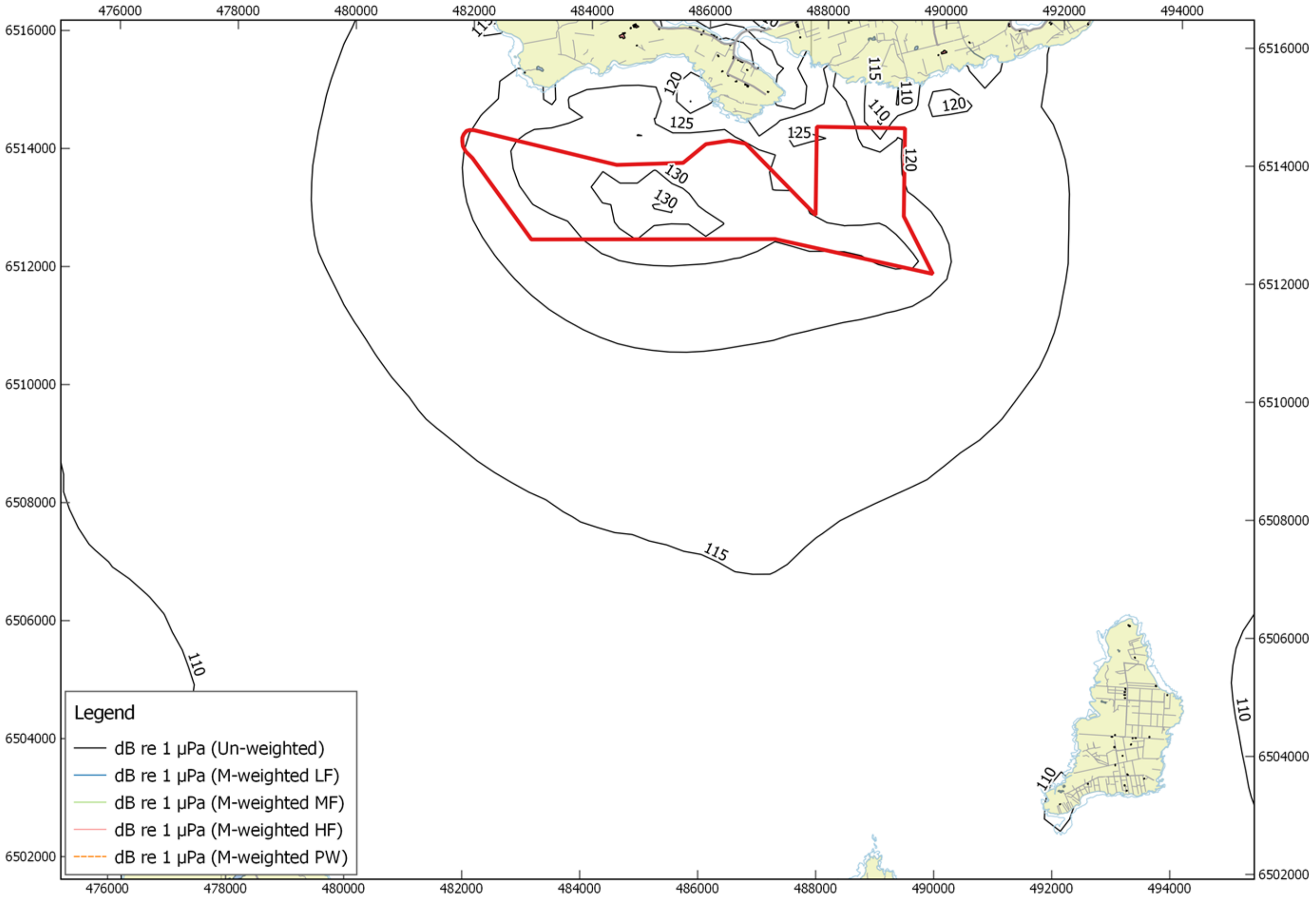

Figure 10.6 Phase 1 and 2 cumulative underwater noise contours, dB re 1 µPa rms (un-weighted)

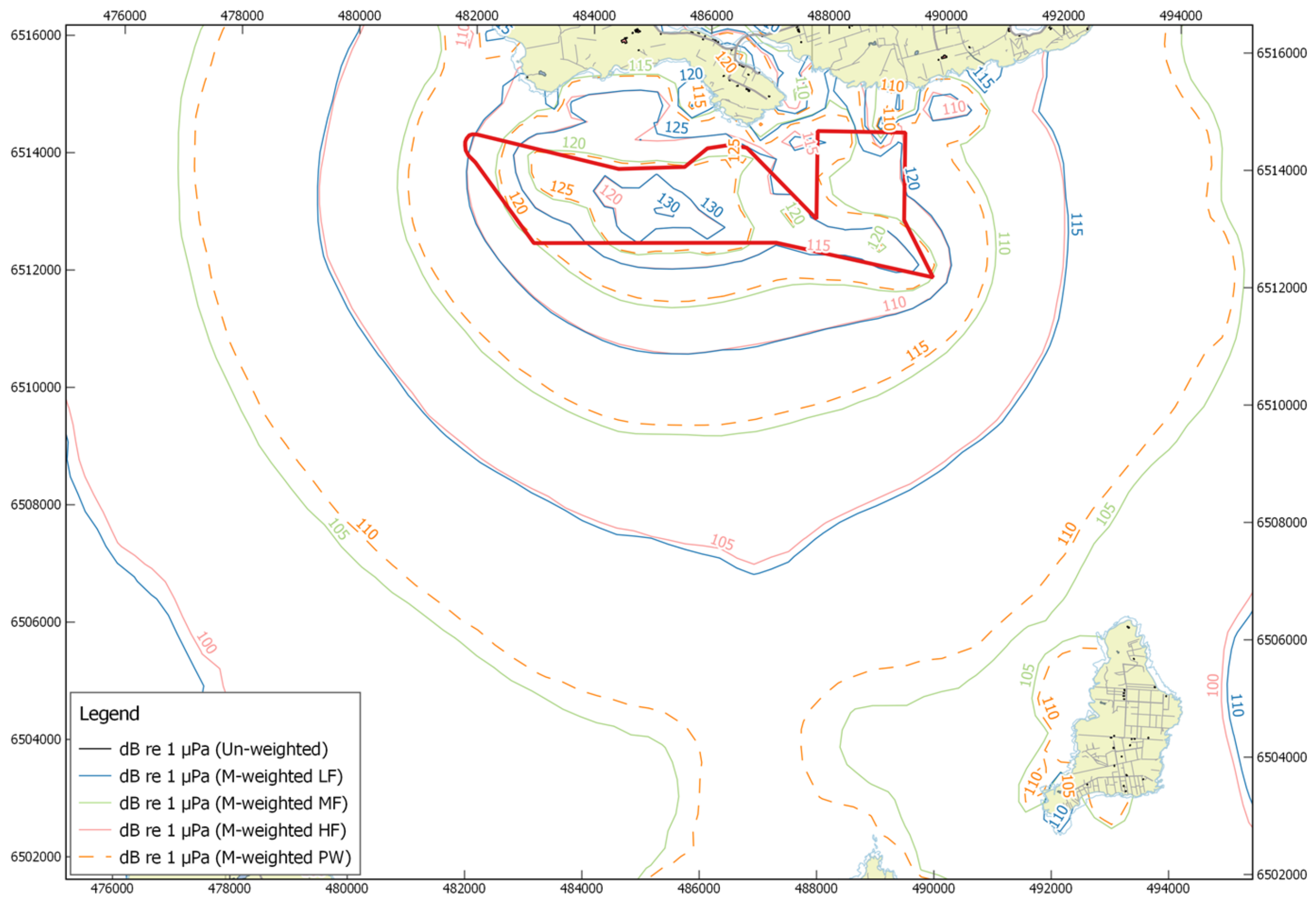

Figure 10.7 Phase 1 and 2 cumulative underwater noise contours, dB re 1 µPa rms (M-weighted)

Figure 10.8 shows a comparison between the hearing threshold levels of various marine mammals and the expected sound pressure level from a single turbine at various distances. The figure shows that, theoretically, a turbine could be audible to most marine mammals even at a distance of 1 km from the turbine. However, it is likely that detection will be limited to a much smaller range than this due to masking by background noise including both natural sources (e.g. waves, stones moving with the tide) and anthropogenic noise such as local vessel traffic. (Given that baseline noise levels range between 106 - 139 dB re 1 μPa (rms) and that the sound pressure level due to the turbine at 1 km would be 104 dB re 1 μPa (rms) then it can be expected that some degree of masking will occur for the majority of the time[12].) It should be noted that audibility does not necessarily directly correlate with behavioural effects, though if a turbine is inaudible then it is unlikely that it will affect behaviour. It should also be noted that this graph is for a single turbine as opposed to the effects of Phase 1 or Phases 1 and 2 combined. However, given the variation in likely baseline noise levels as well as uncertainties in animal response and detection capabilities, the figure is meant more as an indicative comparison between the acoustic characteristics of the tidal turbines and animal hearing bandwidths as opposed to a quantitative assessment.

[12] It is important to understand that masking does not necessarily occur when the numerical value of the turbine sound pressure level is equal to or less than the numerical value of the baseline noise. It is possible that marine mammals can detect sound, especial tonal sound such as from a turbine, even when the overall level is lower than the broadband masking noise level. Further research with respect to detection and masking of tones by sound in marine mammals would be required in order to carry out a quantitative analysis of this effect. At this time, it is therefore considered unfeasible to carry out such an assessment.

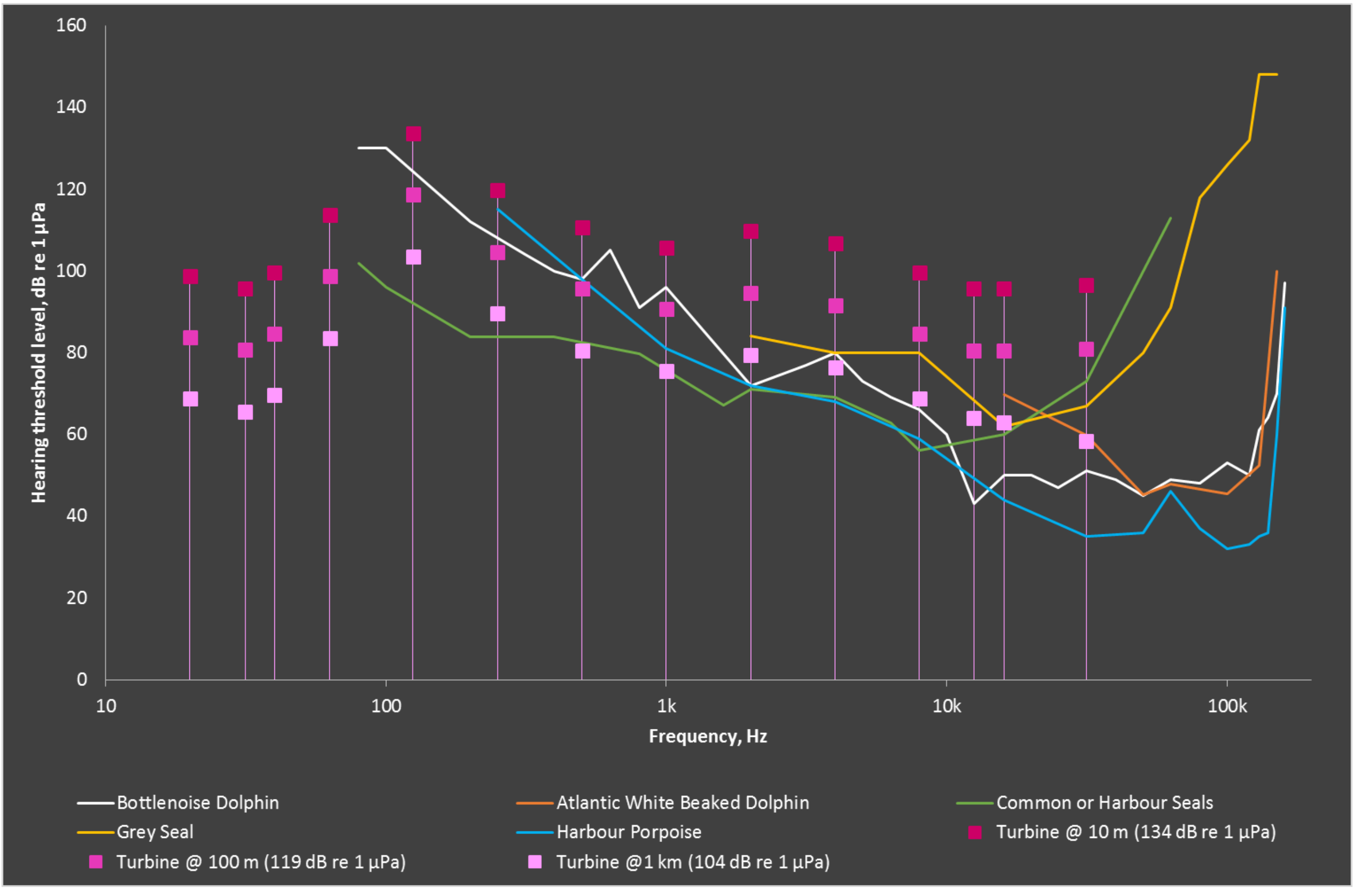

Figure 10.8 Comparison of marine mammal hearing threshold levels against turbine sound pressure levels at various distances from turbine

The potential effects from maintenance vessels will be the same as determined for the construction phase, assuming similar classes of vessel are used.

10.3.2 Effects of operation and maintenance on fish

Based on the ASA guideline criterion of 170 dB re 1 µPa (rms) over 48 hours continuous exposure for potential injury to fish with swim bladders involved in hearing, it is not expected that any fish will experience injury as a result of exposure to noise from the turbines.

Based on the WSDOT criterion of 150 dB re 1 µPa (rms) for potential disturbance to fish, it is not anticipated that fish will experience disturbance due to the turbines[13].

Figure 10.9 shows a comparison between the hearing threshold levels of example fish species and the expected sound pressure level from a single turbine at various distances. The figure shows that, theoretically, a turbine

[13] Although the source noise level for the turbines of 152 dB re 1 µPa at 1 m just exceeds the 150 dB re 1 µPa criterion, it should be noted that this is a theoretical source level based on the assumption that the source is infinitely small. In reality, the source dimensions for the turbines will be such that this theoretical source level does not occur in real space.

could be audible to some fish even at a distance of 1 km from the turbine. However, it is likely that detection will be limited to a much smaller range than this due to masking by background noise including both natural sources (e.g. waves, stones moving with the tide) and anthropogenic noise such as local vessel traffic. It should be noted that there is a paucity of data in relation to hearing threshold levels for basking shark. Therefore, the hearing threshold level of the Atlantic sharpnose shark has been used as a proxy. Current understanding of sharks' hearing suggests a relatively narrow hearing range with relatively poor hearing sensitivity (Casper, Halvorsen, and Popper 2012). Consequently, it is considered likely that noise from the project will affect basking shark to a lesser degree than other fish species.

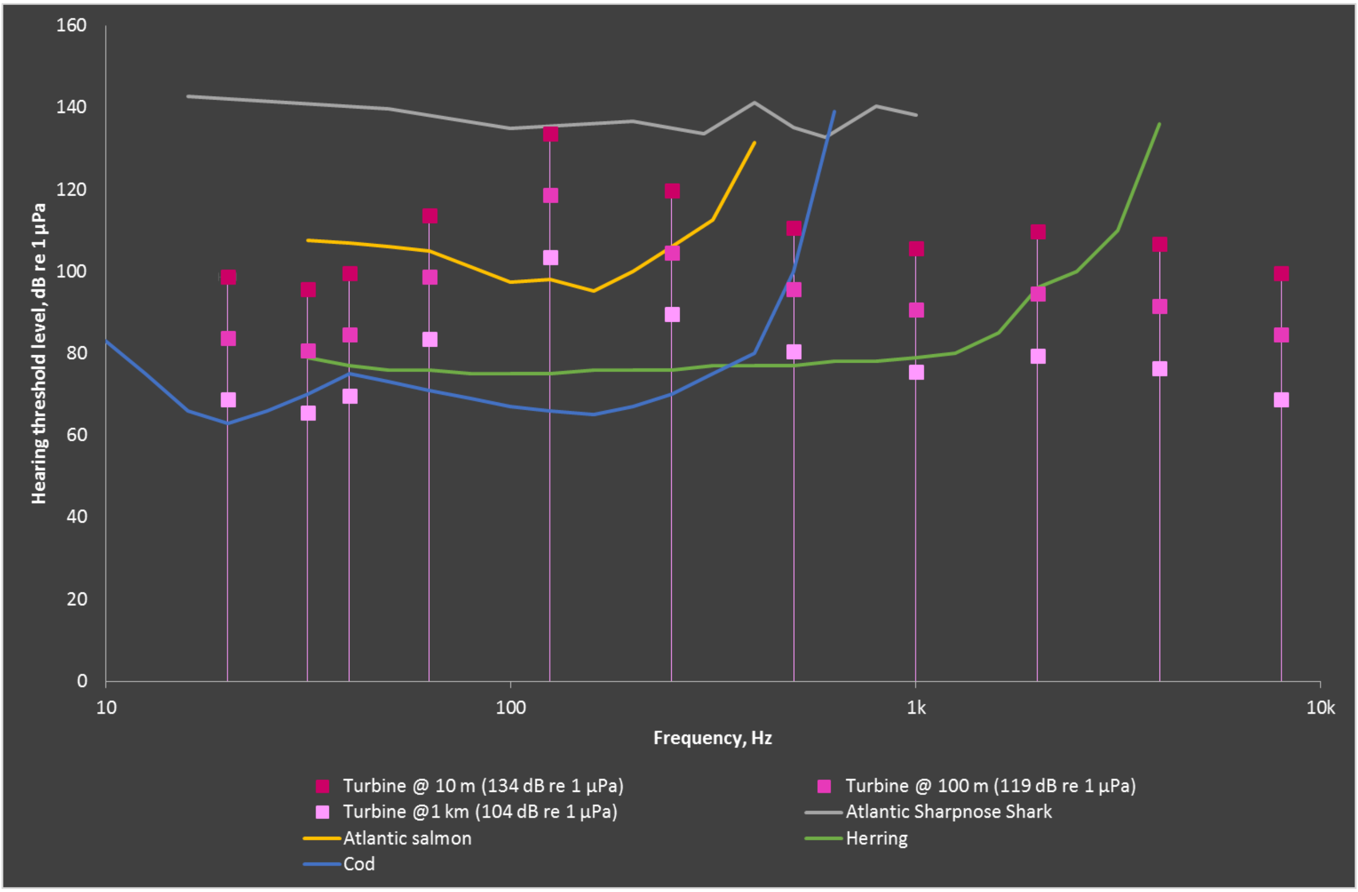

Figure 10.9 Comparison of fish hearing threshold levels against turbine sound pressure levels at various distances from turbine

10.4 Decommissioning

10.4.1 Effects of decommissioning on marine mammals

Estimated ranges for injury to marine mammals are presented in Table 10.1, assuming a swim speed of 1.5 ms^{-1}. The table also includes the time taken to reach the injury onset threshold assuming that a mammal remains stationary within a 10 m range from the noise source. However, it is unlikely that marine mammals would stay in such close proximity to a vessel and it is considered unlikely that injury will occur. A more likely scenario is that an animal would swim away from the source. Based on an animal swimming at an average speed of 1.5 ms^{-1} from the sources of decommissioning noise, the noise modelling shows that injury to marine mammals is unlikely to occur for any of the vessels.

Table 10.8 Estimated injury ranges and times for marine mammals during decommissioning

Activity / source	PTS injury zone radius (assuming 1.5 ms^{-1} swim speed)		TTS injury zone radius (assuming 1.5 ms^{-1} swim speed)		Time taken to reach PTS injury threshold at 10 m from source for stationary mammal	
	Cetacean	***Pinniped***	***Cetacean***	***Pinniped***	***Cetacean***	***Pinniped***
Decommissioning vessel (using DP)	0 m	0 m	0 m	0 m	19 hours for LF cetaceans HF/MF cetaceans - not exceeded	2.4 hours
Support vessel	0 m	0 m	0 m	0 m	Not exceeded	9 hours
Misc. small vessels	0 m	0 m	0 m	0 m	Not exceeded	Not exceeded

The estimated ranges for onset of disturbance effects are shown in Table 10.9. It should be noted that these values are based on an average water depth of 80 m and that in reality the range will vary depending on both source and receiver location. Example contours are the same as presented for construction noise.

Table 10.9 Estimated disturbance ranges for marine mammals during construction

Source / vessel	Estimated range for onset of disturbance (all marine mammal species[14])	
	Radius from source	***Area***
Decommissioning vessel (using DP)	14 km	616 km^2
Support vessel	4 km	50 km^2
Misc. small vessels	1.4 km	6 km^2

[14] Based on the literature review described in Section 6.2.2 it is considered that there is not sufficient peer reviewed scientific evidence at this time to establish species specific criteria for disturbance. The predicted indicative range of effect will therefore be combined with species sensitivities and vulnerabilities in the marine mammal chapter to provide an indicative and qualitative assessment of potential for disturbance.

10.4.2 Effects of decommissioning on fish

The potential for injury and disturbance to fish is shown in the following tables. Table 10.10 shows the qualitative risk of injury and disturbance to different fish types depending on range, in accordance with ASA guidance.

Table 10.10 Effects of decommissioning noise based on ASA qualitative criteria

	Qualitative risk due to exposure to continuous noise		
Range:	*Near* *(10s of meters)*	*Intermediate* *(100s of meters)*	*Far* *(1,000s of meters)*
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 11.5		
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

Table 10.11 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 10.11 Calculated effects of decommissioning noise

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*
Decommissioning vessel (using DP)	10 m	185 m
Support vessel	<5 m	50 m
Misc. small vessels	<5 m	16 m

11 SUMMARY OF DATA GAPS AND UNCERTAINTIES

In summary, turbine noise has been based on measurements carried out on a 16 m diameter Openhydro turbine. This is towards the upper end of the likely turbine sizes to be utilised for this project but it is worth noting that the project is being progressed on an open technology basis. As discussed previously, the noise level and characteristics of a turbine does not necessarily increase with diameter or power rating. Turbine speed and blade design will be the primary parameters impacting on noise emissions. The assessment is based on noise measurements on the largest turbine carried out to date. However, there is the possibility that noise emissions during operations could vary from those predicted in this report depending on the type and layout of the final turbine array. Nevertheless, because the assessment is based on up 200 large (16 m diameter) turbines, it is considered that this is a worst case assessment. If even larger turbines are used, it is likely that there will be nearer 100 turbines instead of the 200 used in this assessment. Thus, even if there was an increase in noise due to an increased turbine diameter, this would be counteracted by the corresponding reduction in the number of turbines.

Another area of uncertainty is in relation to the availability of suitable noise data for the various vessels likely to be used during the project construction, operation and decommissioning. Where no suitable data was available, proxy noise data has been used based on similar sized vessels. However, given that the noise signature of vessels can vary significantly even for vessels in the same class, it is considered likely that this is an area of uncertainty. In order to carry out a precautionary assessment, noise levels at the upper end of the range for each vessel class were used. Therefore, it is likely that this study presents a very worst case scenario which mitigates for the uncertainty in using proxy data.

There is a relatively high uncertainty in relation to the criteria for onset of both physiological and behavioural effects used in this study. In particular, there is a high degree of possible variability in behavioural effects due to individual circumstances for the various marine mammals and fish, including effects such as habituation, availability of food and site specific conditions (such as baseline noise). It is considered likely that the uncertainty in criteria for onset of effects is potentially the highest source of error in the assessment. Any impact zones presented in this report should not be treated as exact lines beyond which an impact does or does not occur. Rather, they should be treated as an indication of the likely zone for onset of effect. Effects will become progressively more likely closer to the noise source and progressively less likely towards the outer edges of the impact zones. In this sense, the impact zones and ranges presented in this report can be taken as a worst case, precautionary assessment.

12 MITIGATION

The assessment has shown that there is very little risk in terms of physiological effects to marine mammals or fish for construction, operations and maintenance. The impact of these activities will be assessed fully in the marine mammal and fish chapters of the ES.

12.1 Vessels

As vessel sound sources are sufficiently low that no lethality or injury is expected especially if the mammal swims away. As the distances within which injury might occur are so small (no injury zone for swimming animals and generally tens of metres even if the mammals were to spend an hour in the vicinity of a vessel), prevention of disturbance will be the key driver for any mitigation measure. However, there are no industry standard mitigation measures currently available that would reduce the possible disturbance effects of the vessels since the main source of that noise is the use of DP thrusters which cannot be shut down in the presence of cetaceans as they are required to maintain control of the vessel. However, consideration could be given to the timing of activities to avoid activity within, or restrict activity during, times of the year during with sensitivity might be considered higher.

Importantly, mammals would need to be exposed over several hours at less than a maximum of 10 m to experience hearing damage, which is not a realistic scenario. On that basis, it is considered that there is likely to be no requirement for additional mitigation measures.

Note: Any mitigation measure aimed at marine mammals that results in reduced noise emissions into the marine environment will also act, by extension, as a mitigation measure to limit the potential impact on fish species.

12.2 Operational Turbines

With respect to the operational turbines, the primary factors affecting noise emission are likely to be the blade design and tip speed. The project is being progressed on a technology neutral basis but it is recommended, where possible, that underwater noise generation mechanisms are investigated during the design and trial of devices and the blade design refined to minimise noise generation. For example, it is desirable to design turbine blades to minimise cavitation in order to minimise stress on the blades and to increase operational efficiency. Nevertheless, it is considered that there is no requirement for mitigation over and above this because it is considered highly unlikely that noise from operating turbines would cause injury to marine mammals or fish.

13 CUMULATIVE IMPACTS

There is potential for cumulative impacts with other projects in the area as well as from existing vessel traffic. It is extremely difficult to predict how the cumulative effect of vessel traffic will affect marine mammals and fish. Whilst it is possible that increased vessel traffic in the area could adversely affect aquatic life, there is also the possibility that animals could acclimatise to (or already be acclimatised to) local vessels. For example, the Pentland Ferry makes 50 journeys each week and the Northlands Ferry 40 journeys per week. It is likely that construction and maintenance vessels for the MeyGen development at Inner Sound will produce a similar impact to that from this project, although the location of the activities will be several kilometres away. Because it is extremely unlikely that any of the vessels will cause injury, even within a few meters of the vessel, the addition of construction vessels at MeyGen will not act in a cumulative way. However, it is possible that potential disturbance zones could overlap if large DP vessels are used at the same time at both locations, although it is likely that animals are already habituated to vessel noise in the area due to the local ferries and other boats. The potential for cumulative impact in terms of disturbance will be addressed in the marine mammals chapter. No cumulative impacts are expected for fish due to the extremely small ranges of disturbance.

In terms of operational noise, the potential zone of disturbance is unlikely to extend beyond 2 to 4 km from the centre of the AfL area. Therefore, it is highly unlikely that any zones of disturbance would overlap with operational noise from MeyGen, which is 12 km south of the Brims area.

The cumulative effect of Phases 1 and 2 together has already been assessed as part of this study. Because noise from construction and installation vessels will be significantly higher than the operational turbines, it is expected that the operational noise from Phase 1 and construction of Phase 2 will not differ significantly from the Phase 1 construction impacts.

14 CONCLUSIONS

Based on the results of the underwater noise assessment, it is concluded that:

> Based on an animal swimming at an average speed of 1.5 ms^{-1} from the sources of construction, maintenance and decommissioning noise, the noise modelling shows that injury to marine mammals is unlikely to occur for any of the vessels.

> The estimated ranges for onset of disturbance effects due construction and decommissioning vessels are likely to range from 1.4 to 14 km, although this is a worst case assessment. Actual disturbance ranges are likely to be smaller due to both masking by background noise and because animals in the area are already used to regular vessel traffic. It is worth noting that these noise sources are temporary and transitory. Effects due to construction are likely to be similar for Phases 1 and 2.

> Injury zones for fish will be less than 10 m and the disturbance zone will be up to 185 m for larger construction and decommissioning vessels.

> Drilled piling is unlikely to result in injury to marine mammals or fish and the disturbance zone will be up to 375 m for marine mammals and 5 m for fish.

> For operational turbine noise, the SEL injury criteria will not be exceeded for cetaceans and pinnipeds even if they were to spend 24 hours immediately adjacent to a turbine. Likewise, the peak injury criteria are not exceeded at any location, even immediately adjacent to the turbines.

> For Phase 1 the extent of the potential disturbance zone for marine mammals for the operational tidal array is a radius of approximately 1 km from the centre of the array, equating to an area of approximately 2.8 km^2.

> For Phase 2, the extent of the potential disturbance zone will be 2 to 4 km and covers an area of approximately 30 km^2.

> It is unlikely that fish will experience any injury or disturbance due to the operating turbines.

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