HORIZON NUCLEAR POWER

WYLFA NEWYDD

ENERGY WORKING FOR BRITAIN

Wylfa Newydd Project

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App D13.09 - Underwater noise baseline and modelling

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1 Introduction

Horizon Nuclear Power (Horizon) intends to submit a separate Development Consent Order (DCO) and Marine Licence application for a new Nuclear Power Station on land adjacent to the Existing Power Station. The proposed development site is located on the Wylfa peninsula, extending into the Irish Sea between the bays of Cemlyn and Cemaes, on the northern tip of the Isle of Anglesey off the north Wales coast. An Environmental Statement is being prepared to accompany the application.

Subacoustech Environmental (Subacoustech) has undertaken underwater noise modelling in order to assess the possible noise impacts to marine fauna resulting from the various activities planned during construction at the Wylfa Newydd Power Station. Marine construction activities include rock breaking and dredging to enable vessels to reach the site as well as piling and drilling in order to construct cofferdams and construction of breakwaters. The results of the modelling have been presented in terms of biologically significant metrics and criteria.

2 Underwater noise

Sound may be expressed in many different ways depending on the particular type of noise, and the parameters of the noise that will allow it to be evaluated in terms of a biological effect. These are described in more detail below.

The attenuation of sound in the water as it propagates from the noise source must be considered in an impact assessment. As the measurement or receiver point moves away from the source, the sound pressure measured will decrease due to spreading. To standardise all source levels, regardless of where they are measured, they are referred back to a conceptual point 1m away from the point of origin of the noise. Consequently, source levels should and will be presented with units of ‘dB re 1µPa @ 1m’.

2.1 Sound pressure level Root Mean Square (RMS)

The sound pressure level (SPL) is normally used to characterise noise and vibration of a continuous nature such as drilling, boring, or background sea and river noise levels. To calculate the SPL, the variation in sound pressure is measured over a specific time period to determine the RMS level of the time varying acoustic pressure. The SPL_{RMS} can therefore be considered to be a measure of the average unweighted level of the sound over the measurement period.

The SPL is calculated using the following formula where p is the sound pressure in Pascals (Pa), and p_{ref} is the reference sound pressure, which is typically 1µPa for underwater sound.

$$SPL = 20\log_{10}\left(\frac{p}{p_{ref}}\right)$$

As an example, small sea-going vessels typically produce broadband noise at source SPLs of between 170 and 180dB re 1µPa @ 1m (Richardson *et al.*, 1995), whereas a supertanker generates SPLs in the region of 198dB re 1µPa @ 1m (Hildebrand, 2004).

2.2 Peak sound pressure level

The peak sound pressure level is the maximum level of the acoustic pressure, usually a positive pressure. This form of measurement is often used to characterise underwater blasts where there is a clear positive peak following the detonation of explosives. Examples of this type of measurement used to define underwater blast waves can be found in Bebb and Wright (1953, 1955), Richmond *et al.* (1973), Yelverton *et al.* (1973), and Yelverton and Richmond (1981). The data from these studies have been widely interpreted in a number of reviews on the impact of high level underwater noise causing fatality and injury in human divers, marine mammals and fish (see, for example, Rawlins, 1974; Hill, 1978; Goertner, 1982; Richardson *et al.*, 1995; Cudahy and Parvin, 2001; Hastings and Popper, 2005).

For offshore operations such as well head severance, typical weights of 40kg may be used, giving a source peak sound pressure of 195dB re 1μPa @ 1m (Parvin *et al.*, 2007).

2.3 Peak-to-peak sound pressure level

The peak-to-peak level is usually calculated using the maximum variation of the pressure from positive to negative within the wave. This represents the maximum change in pressure (differential pressure from positive to negative) as the transient pressure wave propagates. Where the wave is symmetrically distributed in positive and negative pressure (i.e. the negative part of the wave has the same amplitude as the positive part), the peak-to-peak level will be twice the peak level, and hence 6dB higher.

Peak-to-peak levels of noise are often used to characterise sound transients from impulsive sources such as percussive impact piling and seismic airgun sources. As an example, measurements during offshore impact piling operations to secure tubular steel piles into the seabed have indicated peak-to-peak source level noise from 244 to 252dB re 1μPa @ 1m for piles from 4.0 to 4.7m in diameter (Parvin *et al.*, 2006; Nedwell *et al.*, 2007).

2.4 Sound exposure level (SEL)

When assessing the noise from transient sources such as blast waves, impact piling or seismic airgun noise, the issue of the time period of the pressure wave is often addressed by measuring the total energy of the wave. This form of analysis was used by Bebb and Wright (1953, 1954a, 1954b, 1955), and later by Rawlins (1987) to explain the apparent discrepancies in the biological effect of short-range and long-range blast waves on human divers. More recently, this form of analysis has been used to develop an interim exposure criterion for assessing the injury range for fish from impact piling operations (Hastings and Popper, 2005; Popper *et al.*, 2006; Carlson *et al.*, 2007).

The sound exposure level (SEL) sums the acoustic energy over a measurement period, and effectively takes account of both the SPL of the sound source and the duration for which the sound is present in the acoustic environment. Sound exposure (SE) is defined by the equation:

$$SE = \int_0^T p^2(t)dt$$

where p is the acoustic pressure in Pa, T is the total duration of the sound in seconds and t is time in seconds. The sound exposure is a measure of the acoustic energy and, therefore, has units of Pascal squared seconds (Pa^2s).

To express the sound exposure on a logarithmic scale by means of a dB, it is compared with a reference acoustic energy level of 1μPa (${p^2}_{ref}$) and a reference time (T_{ref}). The sound exposure level (SEL) is then defined by:

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

By selecting a common reference pressure p_{ref} of 1μPa for assessments of underwater noise the SEL and SPL can be compared using the expression:

$$SEL = SPL + 10\log_{10} T$$

where the SPL is a measure of the average level of the broadband noise and the SEL sums the cumulative broadband noise energy.

Therefore, for continuous sounds of duration less than one second, the SEL will be lower than the SPL. For periods of greater than one second, the SEL will be numerically greater than the SPL (i.e. for a continuous sound of 10 seconds' duration, the SEL will be 10dB higher than the SPL, for a sound of 100 seconds' duration, the SEL will be 20dB higher than the SPL, and so on).

3 Noise sources

Noise from the following construction activities has been considered in this assessment:

- drilling (percussive and rotary);
- piling;
- dredging (suction and backhoe);
- rock breaking (or peckering); and
- associated vessel noise.

A brief overview of each of these noise sources and how they have been assessed in this study is outlined in the sections below.

3.1 Drilling

Drilling would be employed in order to drill boreholes for the installation of piles for cofferdams, etc. Two specific types of drilling have been identified: rotary drilling and percussive drilling. It has also been proposed that two concurrent drilling rigs may be operational during the works.

3.1.1 Rotary drilling

Rotary drilling consists of a rotating head forced into the seabed. Measurements of a Wirth B5 rotary drilling rig taken from a marine development in Northern Ireland are presented below to demonstrate the typical noise outputs from rotary drilling.

Figure 3-1 presents a typical time history of underwater noise measured in close proximity to the rotary drilling operation, in this case just over 50m. The noise is characterised by a fairly continuous low-pitched rumble with intermittent higher levels of noise for short periods of time, as a result of the drill bit hitting inconsistencies in the rock. At this range from the drilling operation the 1-second RMS sound pressure varied from 2.3 to 4.2Pa (127 to 133dB re 1µPa RMS). The analysis of this data file indicated that the mean RMS level of the sound during this period was at a level of 3Pa, equivalent to a one-second SEL of 130dB re 1µPa^{2}s.

Figure 3-2 presents a typical time history of underwater noise at a range of 830m from the drilling operation. On listening to the recording, the low-pitched rumble of the drill is still audible but the figure indicates that much of the signal is below background noise in the region. Note that the scale is ±3Pa, whereas the scale on figure 3-1 is ±25Pa.

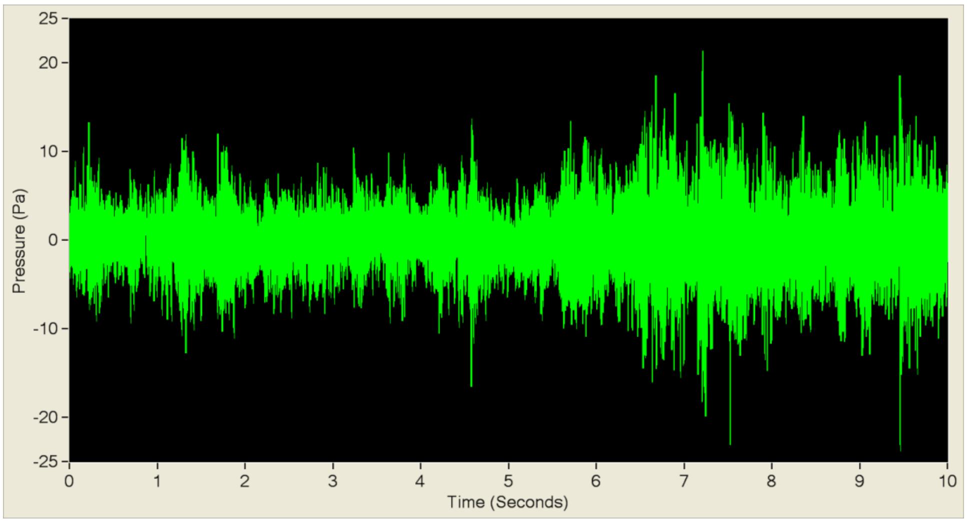

Figure 3-1 Underwater noise time history at a range of 54m from rotary drilling operations

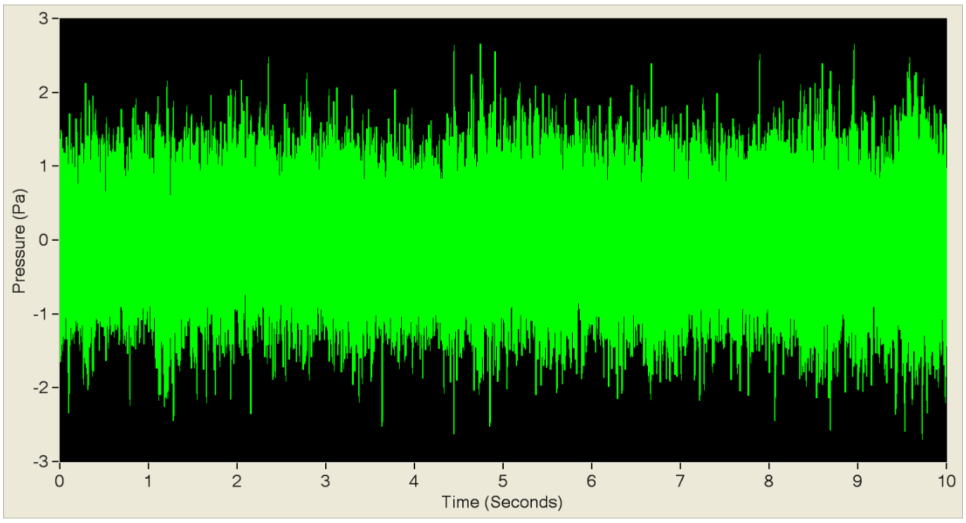

Figure 3-2 Underwater noise time history at a range of 830m from rotary drilling operations (note difference in scale from Figure 3-1)

3.1.2 Percussive drilling

Percussive drilling is different from rotary drilling as it adds a rapid hammer action to the rotating head. Measurements taken from a percussive drilling operation in Orkney have been used to demonstrate a typical noise signature.

Figure 3-3 presents a typical time history of underwater noise measured at a range of 34m from drilling operations. The noise is characterised by very rapid transient peaks associated with the hammer action of the drilling rig being used. Figure 3-4 presents a 0.5s duration windowed section of the same recording, which shows more clearly the individual strikes of the drill. It can be seen that the strikes occur approximately 15 times per second. The data indicate that during this recording the RMS underwater pressure levels varied between approximately 26 and 38Pa or 1-second RMS SPL of about 148 to 151dB re 1µPa. Comparing the levels from these operations with the rotary drilling in the previous section shows that percussive drilling is a louder process overall.

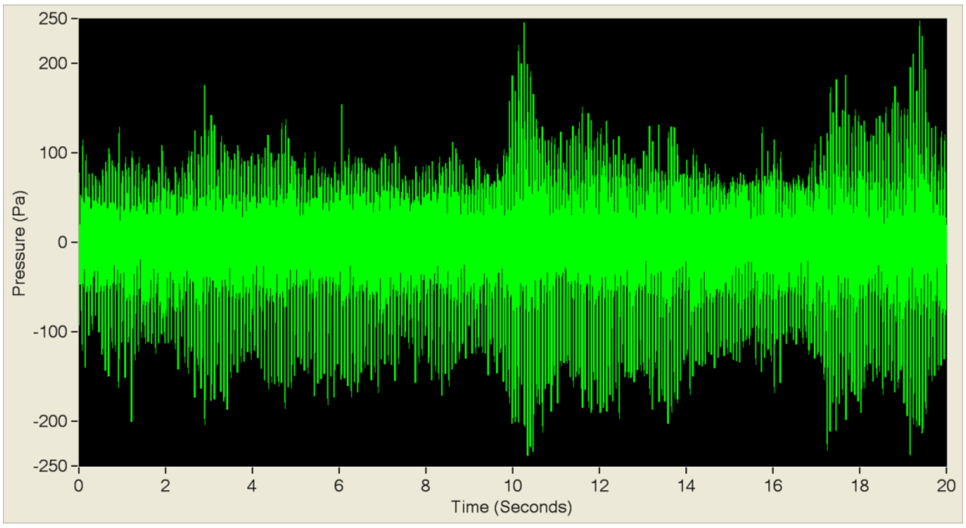

Figure 3-3 Underwater noise time history at a range of 34m from percussive drilling operations

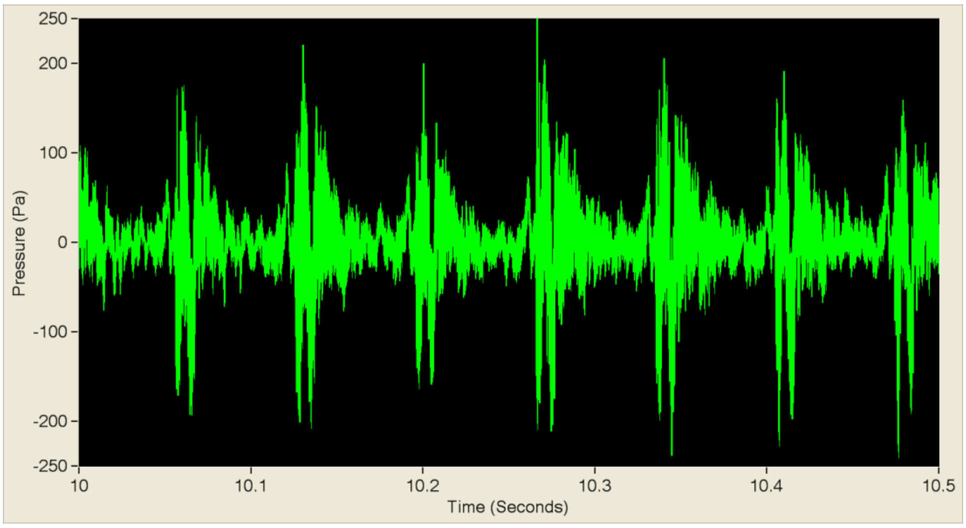

Figure 3-4 Time pressure history of a section of underwater noise recording of 0.5 s duration measured at a range of 34m from percussive drilling operations

Percussive drilling is likely to be used rather than rotary drilling where harder substrate exists as the hammer action of the drill head would enable penetration into this material.

3.2 Piling

Piling involves exerting a downward pressure onto either sheet or tubular piles in order to secure them into the sediment. The main methods are impact piling, where a hammer is dropped with great force onto the top of the pile, and vibro piling, where the hammer vibrates while applying pressure to force the pile into the ground.

Impact piling is characterised by high level transient peaks in pressure levels corresponding to each hammer blow to the top of the pile; impact piling is an impulsive noise and as such, noise from impact piling is usually presented as peak or peak-to-peak. Vibro piling produces a much steadier, constant noise as the hammer oscillates rapidly on top of the pile; noise levels vary when different ground conditions are met. Due to the continuous nature of vibro piling the noise generated is usually presented as RMS rather than peak levels. The noise generated from vibro piling is much lower than that generated by impact piling.

For the Wylfa Newydd Project, sheet piles would be installed as part of the temporary causeway and cofferdam construction; these would likely be driven with vibro piling. The piling would take place out of the water (i.e. dry). Piling on land acts as a substantial barrier to sound in the water as little sound from the activity reaches the water either via the air or via the ground due to large sound reductions at the ground/water and air/water interfaces. Therefore, the effects of piling noise will not be considered as part of this study and focus will be on potentially significant noise sources in the water itself. Natural Resource Wales has been consulted on the underwater noise modelling methodology and results.

Tubular piles and mono piles are expected to be installed in the water and would be installed using a rotary drilling rig. The results of this have been presented with the drilling outputs.

3.3 Dredging

The primary way to remove loose rocks and rubble from the seabed would be dredging. The main types of dredger considered for the works are cutter-suction dredging and backhoe dredging. A rock breaker would also be used for rock clearance as required.

3.3.1 Cutter-suction dredging

Cutter-suction dredging involves the use of a rotating cutter head to loosen rock and seabed in conjunction with a suction inlet that sucks up material onto the vessel. Due to the cutting mechanism, cutter-suction dredgers are often used in areas with harder rock and substrate.

A vessel similar to the Athena/Artemis cutter-suction dredger operated by Van Oord is proposed to be used for the Wylfa Newydd Project. Subacoustech has measurements of the slightly larger-sized ‘Phoenix’ cutter-suction dredger, which would act as a worst case for the noise at the Wylfa Newydd Development Area.

Figure 3-5 presents a time history of sound pressure measurements taken of the noise from the dredging vessel Phoenix at a range of 85m from the dredger. The noise is characterised by short pulses that correspond with the cutter tool on the dredger, which dominate the recording; noise from the vessel’s engines can also be heard.

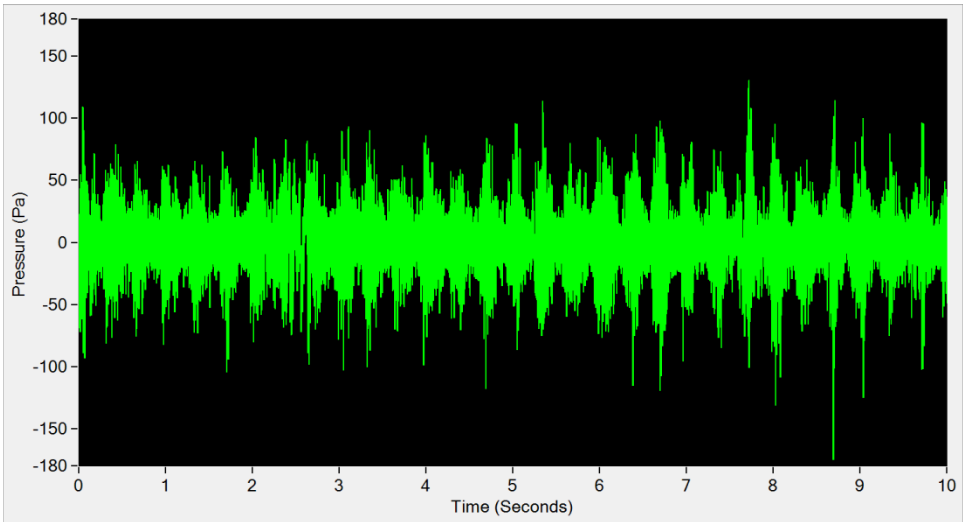

Figure 3-5 Time history of sound pressure measurements recorded at a range of 85m from the cutter-suction dredger Phoenix

3.3.2 Backhoe dredging

A backhoe dredger is a more rudimentary way of removing rock and sediment from the seabed, and involves a large vessel with an excavator fitted, scooping the sediment from the seabed into a hopper or similar. By its nature, backhoe dredging has a much more variable noise level as several processes are taking place: the plant noise of moving the excavator bucket, the scooping of rock and sediment and dropping the material into a hopper. There are transient peaks in the time history where the bucket hits the seabed or when material is placed into a hopper (figure 3-6).

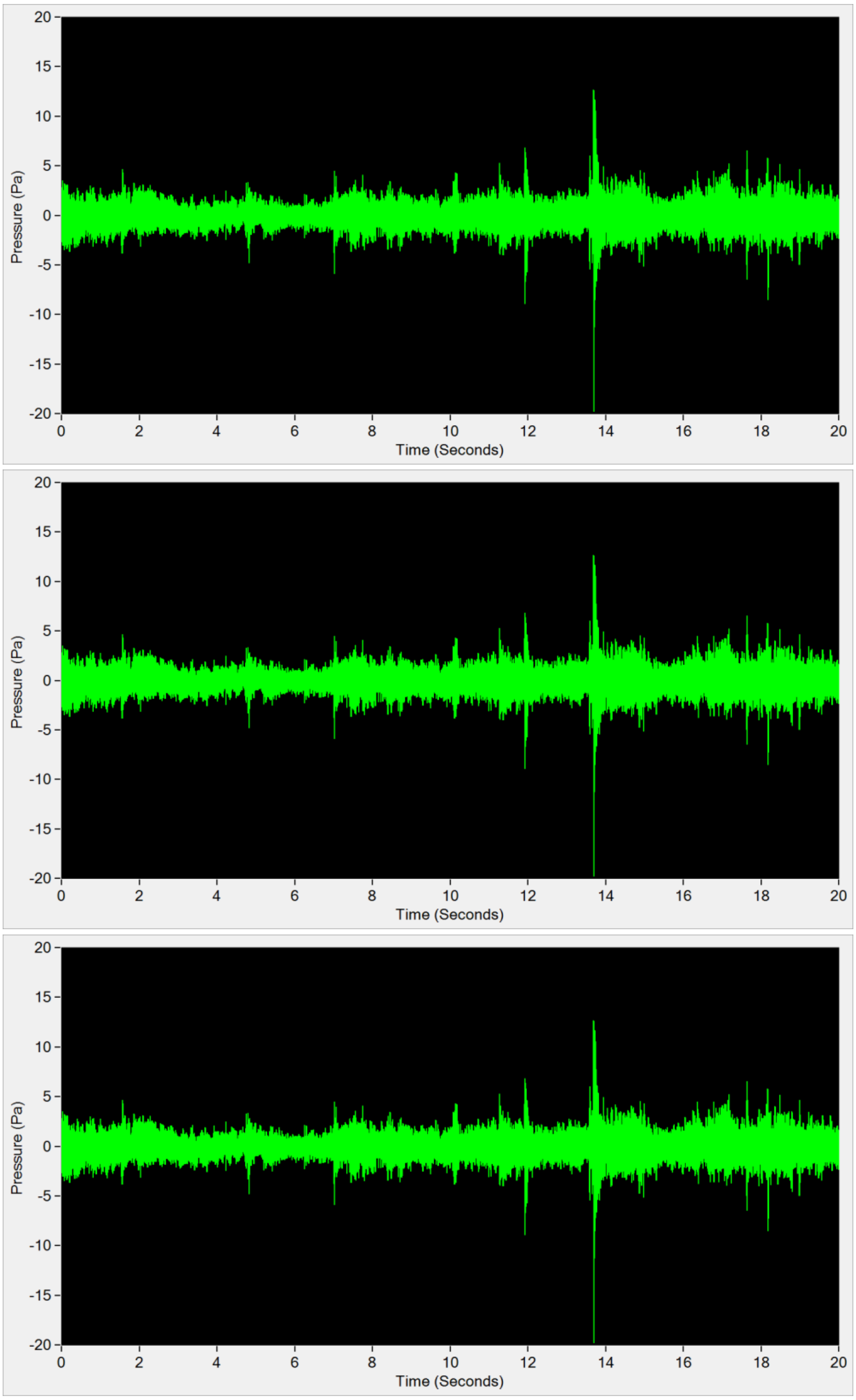

Figure 3-6 Time history of sound pressure measurements recorded at a range of 113m from the backhoe dredger Zenna

Comparing the levels given at similar ranges from the cutter-suction dredger (figure 3-5) and the backhoe dredger (figure 3-6), it is clear that cutter-suction dredging produces much more noise than backhoe, which is down to the additional machinery involved when using the cutter-suction method. The cutter-suction dredger will be considered further in this study as a worst case. Comparative source levels are provided in sections 5.2.2 and 5.2.4.

3.3.3 Rock breaker/cutter

The final ways of removing rock and sediment from the seabed being considered are rock breaking (peckering) and rock cutting.

Rock breaking involves a drill-bit-like hammer rapidly striking the seabed to break up rock and sediment. It is still uncertain which equipment would be used to undertake rock breaking operations for the Wylfa Newydd Project, but one option is an IHC S70; this hammer operates with a maximum blow energy of 70kJ and has a typical strike rate of approximately 43 strikes per minute.

For this study, it has been assumed that the noise from the rock-breaking machinery would be similar to a small-scale tubular piling operation, due to the similar motion of metal hitting bedrock. The modelling has taken account of the size of the rock breaker head, the blow energy exerted into the ground and the frequency of the blows when source levels have been generated. It is expected that this is represents an overestimation of the noise from this activity and consultation has been carried out with Natural Resource Wales on the methodology for modelling and to inform the assessment. The source levels are provided in section 5.2.4.

A rock cutter is similar in design to the cutting head of a cutter-suction dredger, with teeth designed to grind the rock in order to remove it. For the Wylfa Newydd Project, the rock-cutting equipment to be used is expected to be a Rockwheel G55 hydraulic cutting wheel, which operates with an output power of approximately 261kW based on the maximum torque and rotations per minute.

3.4 Vessel movements

In addition to these noise sources, there would be increased vessel movement in and around the site relating to the construction of the Wylfa Newydd Project. This would include vessels bringing equipment to the site and transporting the dredged material, as well as support vessels while activities are taking place. Shipping noise is a significant contributor to the overall background levels in the sea. For the purposes of this study, the dredging vessels and jack-up barges from which the other activities are carried out are contained as part of the noise source for those activities and are not included under the vessel movement assessment.

The noise levels measured from large vessels are of a similar magnitude to those from cutter-suction dredgers, or slightly quieter (section 5.2.4), as the dredging process increases the noise output. It is important to highlight the transitory nature of underwater noise from passing vessels. A dredger would operate over an extended period in a defined area, so the cumulative noise exposure in a fixed position would be greater than the exposure from a vessel passing by.

4 Existing baseline data

A selection of ambient, underwater sound pressure level datasets was acquired between 2013 and 2014 to establish a baseline level of noise in the vicinity of Cemlyn Bay, Cemaes Bay and the Wylfa Newydd Project. Fixed location hydrophone and vessel-based transect datasets were sampled over three seasonal periods: one in late summer (August 2013), one in late autumn (November 2013) and one in late winter/early spring (March 2014). Two consecutive days were sampled over each seasonal period.

Figure 4-1 shows a map of the area, detailing the locations of the measurements previously undertaken. Five transects were monitored, in additional to a fixed-position monitor, which was suspended from a surface buoy. The four transects to the west (1 to 4) represent locations of existing or proposed noise sources, whereas the easternmost transect (5), was a sheltered ‘control’ position. The fixed-location monitor sampled continuously while transect measurements were taken from a vessel in the bays. Measurements along transects were only taken during the daytime. Very little vessel traffic was noted throughout the measurement period.

Table 4-1 gives a summary of the mean underwater noise levels recorded along each of the five transects and from the fixed monitor.

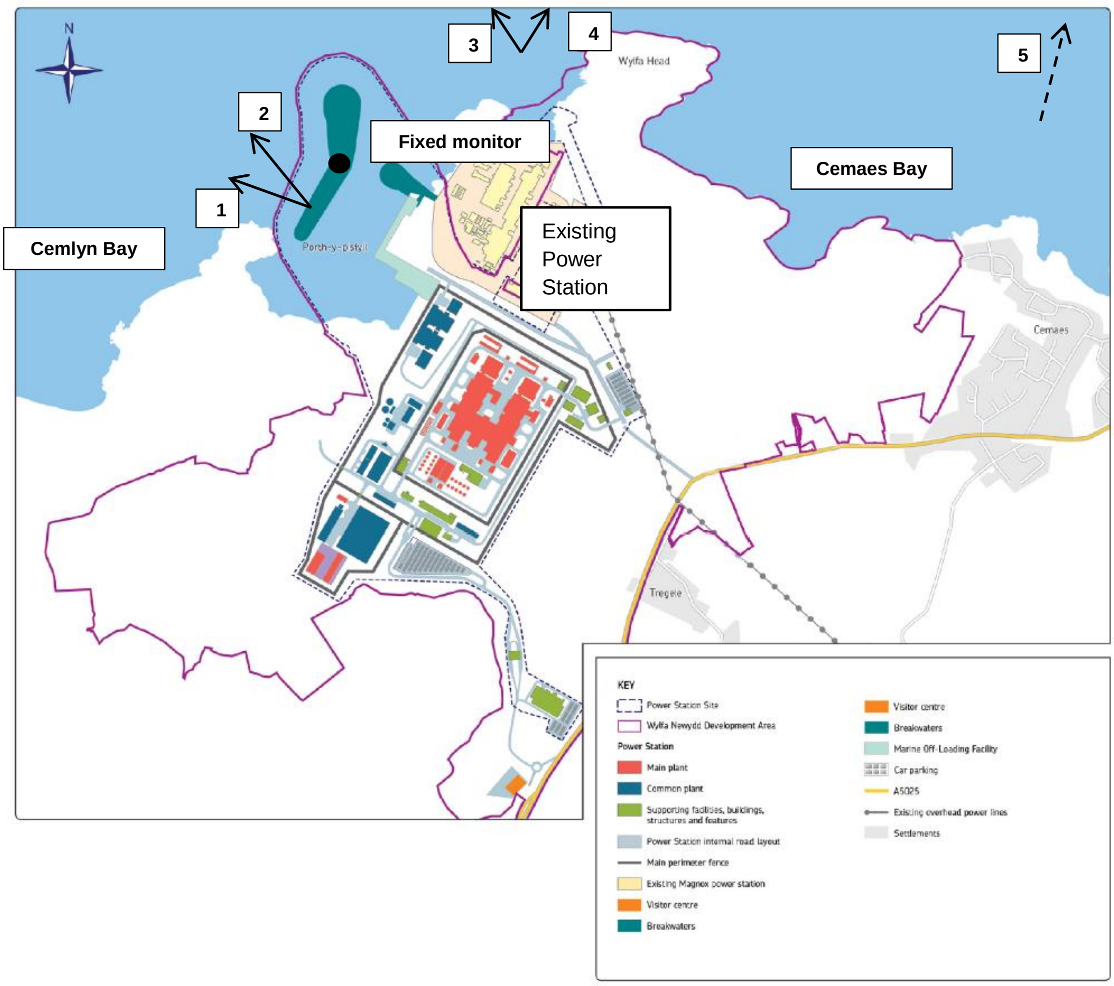

Figure 4-1 Approximate transect measurement trajectories and location of the fixed-position monitor for baseline noise monitoring

Date	Mean underwater noise levels sampled over transect (dB re 1μPa (RMS))					
	Transect 1	Transect 2	Transect 3	Transect 4	Transect 5	Fixed monitor
06/08/2013	115.7	115.4	116.7	117.9	115.9	*
07/08/2013	111.4	114.2	116.3	117.8	121.0	*
25/11/2013	113.1	113.0	112.9	114.5	*	107.5
26/11/2013	116.8	119.1	120.9	120.6	119.5	108.6
12/03/2014	115.6	119.5	116.9	116.9	114.9	106.7
13/03/2014	111.9	115.1	117.3	117.3	*	106.7

Table 4-1 Summary of the mean unweighted underwater noise levels recorded (Note: cells containing an asterisk (*) signify where the measurements could not be taken)

Since the original baseline noise levels were sampled, new recommendations (Robinson *et al*., 2014) have been issued by various groups, including the Planning Inspectorate and Natural Resources Wales, in respect of proposed developments that are likely to have an effect on the underwater noise environment. This new guidance largely follows the publication of the National Physical Laboratory's Good Practice Guide for Underwater Noise Measurements (Robinson *et al.*, 2014), but also monitoring requirements for other large developments.

The Marine Management Organisation Review of post-consent offshore wind farm monitoring (Marine Management Organisation, 2014) identifies licence conditions for the Walney, Lincs, and Teeside offshore wind farms, which state *"environmental monitoring… shall include pre-construction monitoring for a minimum of one year prior to the commencement of construction, to provide a baseline for subsequent monitoring… following the completion of the works"*. We interpret this as not necessarily requiring continuous sampling over a year, but rather that a series of discrete periods over a year, such as those previously undertaken, should be sufficient. The data sampled at the site over the three seasons do not demonstrate a significant variation in noise level at different times of the year.

In the National Physical Laboratory's Good Practice Guide, an appropriate period is not defined explicitly, but instead as *"perhaps a few weeks".* The Guide also recommends that diurnal and local tidal variations should be encompassed by the measurements, with enough time to cover variation in local shipping traffic. Whilst extended monitoring periods could capture longer-term variations in the background noise, the seasonal measurements undertaken over a range of water temperatures and under calm conditions are likely to be representative of typical ambient noise levels as there is an absence of any notable anthropogenic sources in the area. As such they are likely to represent worst case conditions for underwater noise impacts. The seabed thickness used in the RAMSGeo modelling assumes a single substrate type throughout; the modelling is not able to trace the seabed bathymetry as is the case in newer modelling software. To compensate for this, the substrate properties used in the modelling present an average of the sandy gravel layer with the rock and hard substrate also considered. The exact parameters used are detailed in table 5-1. The monitor at the fixed location sampled underwater noise levels over a range of tidal states. Natural Resource Wales has been consulted on the underwater noise modelling methodology and results.

Conditions that have not been sampled are those that could be categorised as under inclement weather conditions: rain or higher winds that cause surface agitation. These would lead to higher noise levels and therefore the existing measurements would be considered conservative in respect of any future introduced noise source, and also the most repeatable.

It is therefore suggested that the measurements taken to date represent a reasonable baseline underwater noise level in the waters around Porth-y-pistyll, Wylfa Head and Cemaes Bay that could be affected by the proposed development.

5 Assessment approach

The following sections present a summary of the modelling approach taken in order to assess the expected underwater noise levels from the proposed activities for the Wylfa Newydd Project. The primary modelling will be undertaken using the RAMSGeo acoustic model.

The modelling approach undertaken in this study conforms to the National Physical Laboratory's Good Practice Guide 133 for Underwater Noise (Robinson *et al.*, 2014).

The RAMSGeo software package, an acoustic model, is based on the well-known and much used RAM (Range-dependent Acoustic Model) software (Collins, 1994; Collins *et al.*, 1996). RAMSGeo is designed to model any noise source where it is reasonable to assume it as a point source.

RAMSGeo is a fully range-dependent parabolic equation model that performs underwater acoustic transmission loss calculations. RAMSGeo is a purely theoretical model based solely around the physical acoustic processes that occur underwater.

The software is widely used for the modelling of propagation since it:

- models low frequency propagation well;
- allows for the incorporation of variable bathymetry; and
- allows for the incorporation of complex bottom types.

Three representative transects have been chosen to model the noise sources of interest.

5.1 Assumptions

The following assumptions have been made about the nature of the environment with respect to acoustic propagation modelling.

- The variation of temperature throughout the water column can affect sound propagation. As the depth of water is shallow and exhibits a great deal of mixing, a uniform temperature profile has been assumed. The speed of sound in water is connected to temperature, and a representative sound speed of 1489m/s has been used in the calculations.
- The seabed along the transects is assumed to be made up of predominately rock and hard substrate covered by a layer of sandy gravel (Titan 2012 and see section 4). Consequently, the physical parameters shown in table 5-1, as presented by Jensen *et al.* (1994), have been assumed.

Sound speed ratio c_ρ/c_w	1.1
Density ratio ρ_b/ρ_w	1.9
Compressional wave attenuation α_ρ	0.8
Shear wave attenuation α_s	2.5

Table 5-1 Physical parameters used in the RAMSGeo model

The broadband noise source inputted into RAMSGeo is broken up into its individual octave-band centre frequencies which are modelled under a narrowband approximation and the individual energy contribution from the bands summed. Figure 5-1 shows power spectral density (frequency) plots of measured propagation. These noise sources are used as a comparison to the proposed activities for the Wylfa Newydd Project site due to their similarity in situation and activity type and scale.

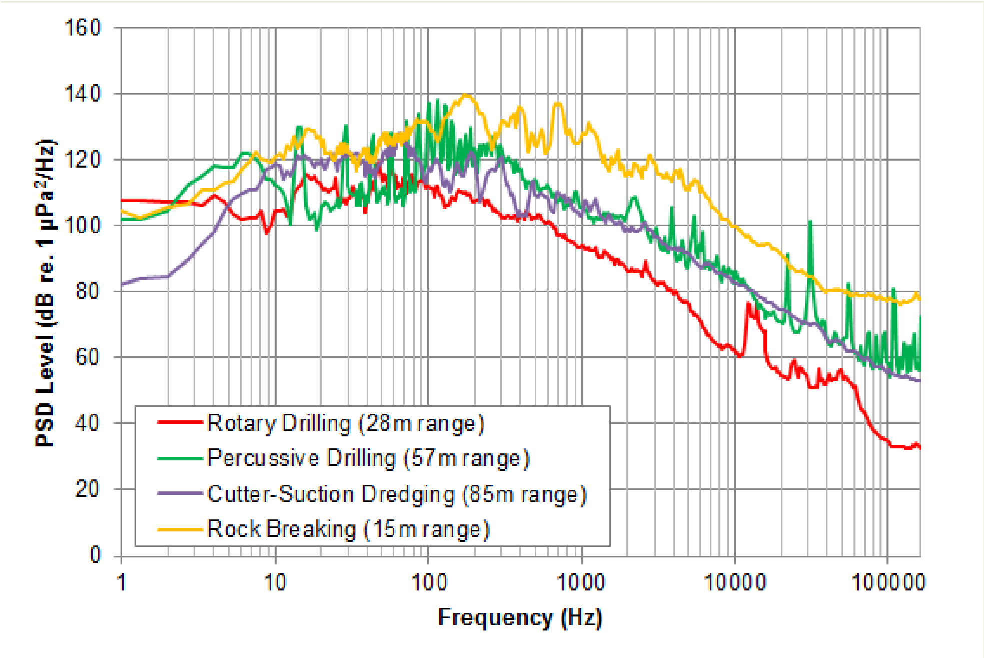

Figure 5-1 power spectral density from measurements used as inputs for RAMSGeo modelling

A location in -10m Above Ordnance Datum water depth has been selected as the noise source location for the modelling, as this acts as a good representative worst case for the noise sources being considered in the vicinity of the work locations. Three transects have been chosen to illustrate the propagation of noise from the Wylfa Newydd Project: the northeast (038°) and northwest (332°) transects extend out into the Irish Sea and deeper water, and the southeast (156°) transect shows the propagation back to the coast. The three transects are illustrated in figure 5-2, and the bathymetry of each transect is shown in figure 5-3.

All modelling has been carried out assuming a worst case Mean High Water Springs tide of 6.6m above Lowest Astronomical Tide (being -3.6m Above Ordnance Datum) from the nearby Cemaes Bay.

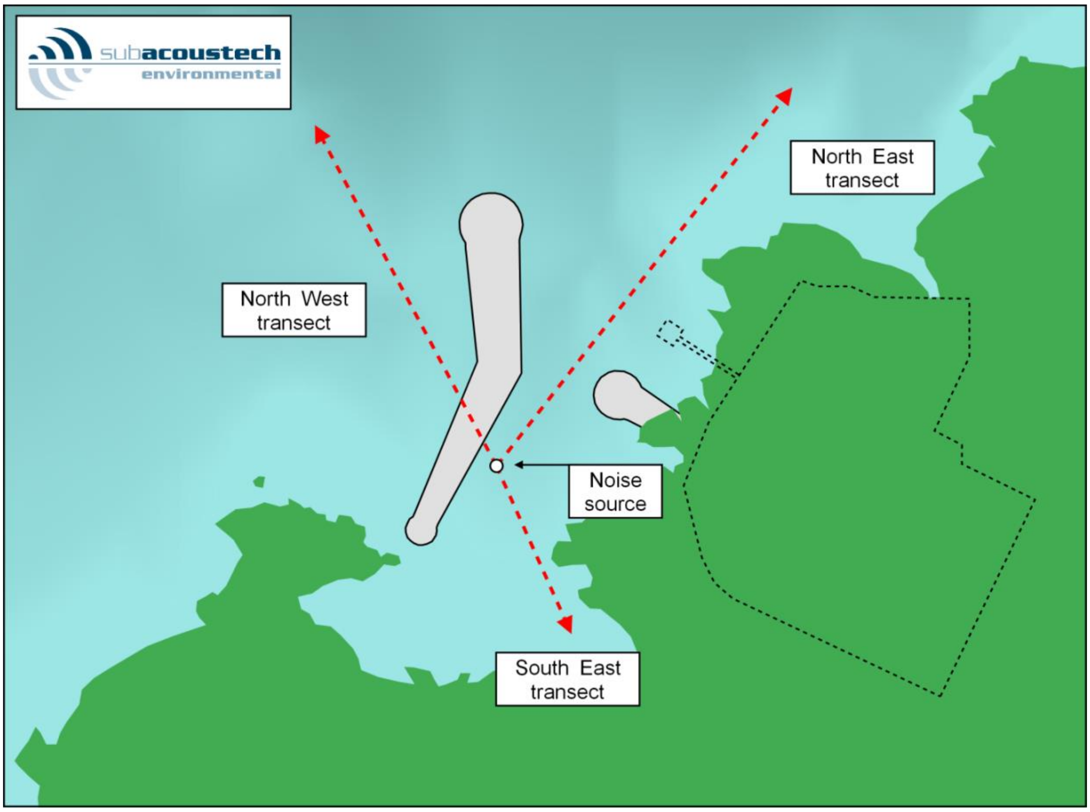

Figure 5-2 Schematic showing the three transects modelled using RAMSGeo and the breakwater

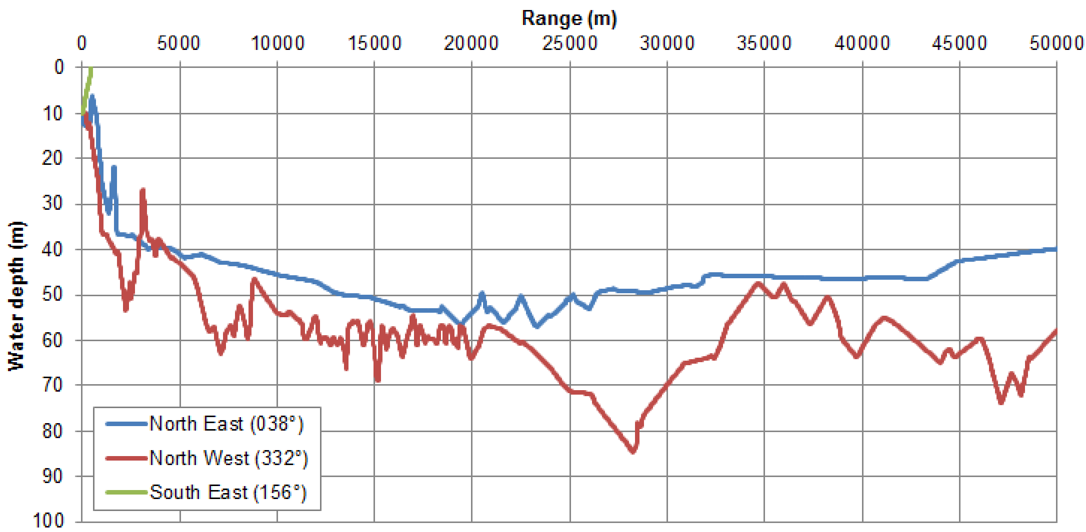

Figure 5-3 Bathymetry used for the three transects modelled in RAMSGeo

5.2 Source levels for modelling

In order to obtain likely levels of noise using the transmission losses calculated using RAMSGeo, a source level must also be estimated. This has been done using a combination of measurement data taken by Subacoustech and extrapolations based on the differences in methodology, equipment and location. It should be noted that the source levels given are not necessarily the actual level of noise that may be present at the noise source; rather, the source level represents the input level for the model at which the correct levels are modelled at the distances of interest from the source. The actual noise level very close to the source is highly complex.

5.2.1 Drilling

This assessment considers both rotary and percussive drilling, the source levels for which have been extrapolated from real world data. Measurements of rotary drilling have been taken from measurements at close range to operations in Strangford Lough, Northern Ireland and the percussive drilling measurements that have been used were taken at the European Marine Energy Centre site off the coast of Eday, Orkney.

The drills proposed for the Wylfa Newydd Project vary in size when compared to those used at Strangford Lough, and as such a scaling factor has been applied to the noise measurements in order to give a good estimate of the likely source levels of the machinery. In each case, the power of the drill has been taken and with the simple scaling factor given below (where W_1 is the power of the proposed drill and W_2 is the power of the existing drill) they have been adjusted accordingly.

$$Scaling\ factor\ (dB) = 10 \times \log_{10}\left(\frac{W_1}{W_2}\right)$$

The assumption that has been made for this scaling is that the power of the drill is essentially that the energy conversion efficiency, in terms of the acoustic energy radiated versus the power of the drill. This is the same for the drill modelled and the measurements of the drill that the calculations are based on. This approach has been used due to the lack of available detailed underwater noise data from drilling operations.

The rotary drilling at Strangford Lough used a drill power of 209kW, whereas the proposed rotary drill for the Wylfa Newydd Project (a C50) has a power output of 242kW. As such a 0.6dB increase has been added to the source level. Further rotary drilling is expected to install pile sockets at the site using a Bauer BG42 drilling rig for piles measuring up to 1.85m in diameter. The overall drill power output given from manufacturer's specifications is 570kW, which, using the scaling factor above, results in an increase of approximately 4.4dB in source level from the Strangford Lough drill.

The percussive drilling in Orkney used a drill power of 52kW; there is no specific power output data available for the proposed Numa Champion 330 down hole hammer drill. However, other data were available such as the drill diameter (up to 42in), torque (55kNm) and rotational speed of the drill bit (approximately 30rpm). Using these upper limits, a power output of 173kW is estimated. Using this as a scaling factor results in an increase in source level of 5.3dB for the equipment to be used for the Wylfa Newydd Project, compared to the measured drill in Orkney.

Using these measurements and the scaling factor, the source levels used in the modelling are:

- 161.2dB re 1µPa (RMS) @ 1m and 164.9dB re 1µPa (RMS) @ 1m for rotary drilling (242kW and 570kW respectively); and
- 185.3dB re 1µPa (RMS) @ 1m for percussive drilling.

In the case that two drilling rigs are being used simultaneously, a worst case doubling of pressure has been used to assess the noise level.

5.2.2 Dredging

Measurements of the cutter-suction dredger Phoenix, as described in section 3.3.1, have been used to identify a source level for modelling. As the vessel Phoenix is a larger vessel than the Athena/Artemis vessels proposed for the Wylfa Newydd Project, the noise levels predicted can be considered a worst case. As such, the source level used for cutter-suction dredging in this assessment is 176.1dB re 1µPa (RMS) @ 1m.

5.2.3 Rock breaking/cutting

As discussed in section 3.3.3, the noise from rock breaking, or peckering, has been assumed to be similar in nature to small-scale impact piling, albeit directly into the seabed as opposed to transmitted through a pile. The IHC S70 Hydrohammer has a 50cm diameter head and operates with a maximum blow energy of 70kJ. These inputs result in a source level of 208.6dB re 1µPa (Peak) @ 1m for rock breaking activities for the Wylfa Newydd Project.

Rock cutting is to be undertaken using a Rockwheel G55 hydraulic cutting unit. Due to the similarity in design, the levels from the cutter-suction dredger (section 5.2.2) have been scaled based on the power of the device. The Rockwheel G55 has an output power of approximately 261kW, and the cutter fitted to the Phoenix cutter-suction dredger has an output of approximately 678kW. Using the power scaling factor used previously (section 5.2.1) this results in a reduction in source level of around 4.1dB resulting in a rock cutting source level of 172.0dB re 1µPa (RMS) @ 1m.

5.2.4 Summary

Noise source	Predicted source level
Rotary drilling (242kW)	161.2dB re 1µPa (RMS) @ 1m
Rotary drilling (570kW)	164.9dB re 1µPa (RMS) @ 1m
Percussive drilling	185.3dB re 1µPa (RMS) @ 1m
Cutter-suction dredging	176.1dB re 1µPa (RMS) @ 1m
Rock breaking (peckering)	208.6dB re 1µPa (Peak) @ 1m
Rock cutting	172. dB re 1µPa (RMS) @ 1m

Table 5-2 Summary of predicted source levels used for RAMSGeo modelling

6 Underwater noise modelling

Using the information given in the preceding sections, underwater noise modelling has been carried out to predict the levels of noise created from various activities associated with the Marine Works for the Wylfa Newydd DCO Project, including borehole drilling, dredging and rock breaking. RAMSGeo modelling has been carried out along the transects given in figure 5-2 and figure 5-3 and the assumptions listed in section 5.1.

6.1 Drilling

RAMSGeo modelling has been carried out to ascertain the likely levels of underwater noise for three types of drilling: rotary (242kW), rotary (570kW) for piling, and percussive, which are discussed in section 3.1. figure 6-1 to figure 6-3 show the unweighted RMS level versus range plots for the drilling operations. It can be seen from these that the percussive drilling scenario produces a greater level of noise than the rotary drilling. The modelled ranges at which unweighted RMS levels, in 10dB increments, are modelled are summarised in table 6-1 to table 6-3.

Some ranges given in the results tables are ‘N/A’ as the coast is reached before the noise drops below this level.

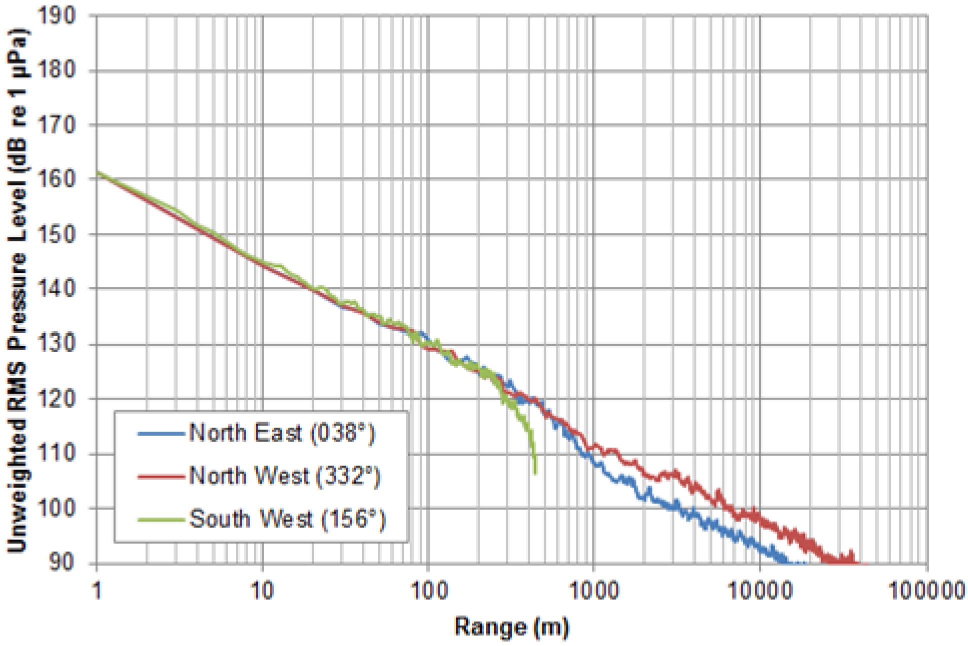

Figure 6-1 Level versus range plot showing the predicted unweighted RMS noise levels from rotary drilling operations (242kW) along three transects

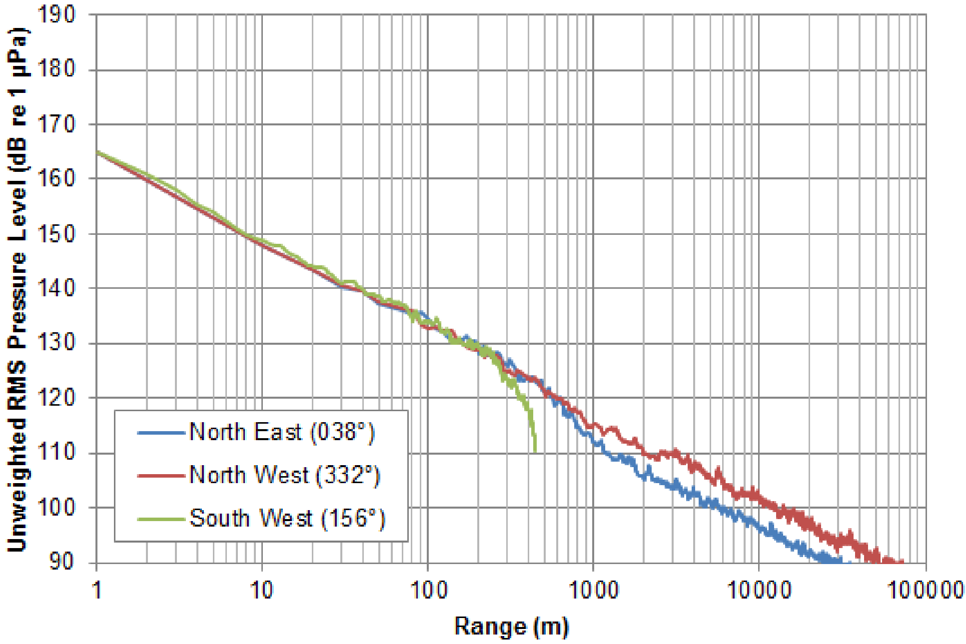

Figure 6-2 Level versus range plot showing the predicted unweighted RMS noise levels from rotary drilling operations (570kW) along three transects

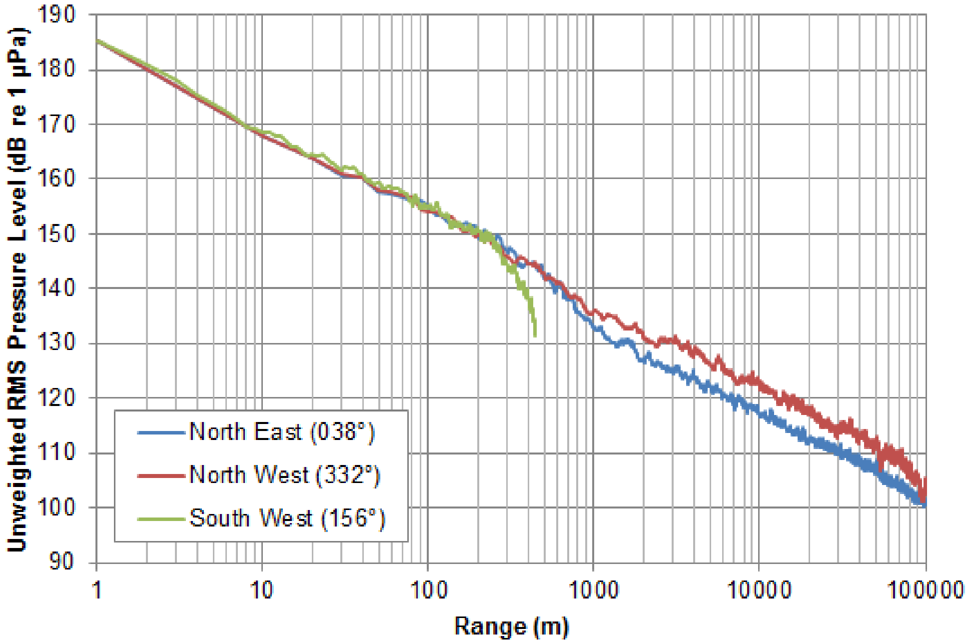

Figure 6-3 Level versus range plot showing the predicted unweighted RMS noise levels from percussive drilling operations along three transects

Rotary drilling (242kW) (RMS)	**Northeast (038°)**	**Northwest (332°)**	**Southwest (156°)**
Range to 150dB re 1µPa	5m	5m	5m
Range to 140dB re 1µPa	20m	20m	23m
Range to 130dB re 1µPa	100m	89m	120m
Range to 120dB re 1µPa	340m	390m	300m
Range to 110dB re 1µPa	850m	1.1km	430m
Range to 100dB re 1µPa	3.2km	6.3km	N/A

Table 6-1 Summary of the modelled ranges to unweighted RMS levels for rotary drilling (242kW)

Rotary drilling (570kW) (RMS)	**Northeast (038°)**	**Northwest (332°)**	**Southwest (156°)**
Range to 150dB re 1µPa	8m	8m	8m
Range to 140dB re 1µPa	40m	40m	41m
Range to 130dB re 1µPa	200m	170m	160m
Range to 120dB re 1µPa	640m	620m	380m
Range to 110dB re 1µPa	1.2km	2.0km	N/A
Range to 100dB re 1µPa	6.1km	12.5km	N/A

Table 6-2 Summary of the modelled ranges to unweighted RMS levels for rotary drilling (570kW)

Percussive drilling (RMS)	**Northeast (038°)**	**Northwest (332°)**	**Southwest (156°)**
Range to 170dB re 1µPa	8m	8m	8m
Range to 160dB re 1µPa	42m	42m	41m
Range to 150dB re 1µPa	220m	200m	210m
Range to 140dB re 1µPa	630m	650m	380m
Range to 130dB re 1µPa	1.7m	3.2km	N/A
Range to 120dB re 1µPa	6.4km	14km	N/A
Range to 110dB re 1µPa	32km	60km	N/A

Table 6-3 Summary of the modelled ranges to unweighted RMS levels for percussive drilling

6.1.1 <u>Concurrent drilling</u>

There is the potential for two drilling rigs to be operating simultaneously for the Wylfa Newydd Project. In order to model this, a worst case doubling of pressure has been assumed. The drilling rigs would be moving throughout their operations. As such, the most conservative assumption to make is that both rigs would be operational side-by-side, which would result in a doubling of pressure, equivalent to an increase in source level of approximately 3dB re 1µPa (RMS).

Table 6-4 to table 6-6 show the modelled ranges for two identical rigs operating simultaneously, in 10dB increments. These results can be compared with the ranges in table 6-1 to table 6-3 to show the expected increase when using two drilling rigs rather than one.

Rotary drilling (242kW) (RMS) (two rigs)	**Northeast (038°)**	**Northwest (332°)**	**Southwest (156°)**
Range to 150dB re 1µPa	7m	7m	7m
Range to 140dB re 1µPa	29m	30m	37m
Range to 130dB re 1µPa	170m	140m	140m
Range to 120dB re 1µPa	540m	500m	350m
Range to 110dB re 1µPa	1.1km	2.0km	440m
Range to 100dB re 1µPa	4.4km	11km	N/A

Table 6-4 Summary of the modelled ranges to unweighted RMS levels for rotary drilling (242kW) assuming two concurrent drilling operations

Rotary drilling (570kW) (RMS) (two rigs)	Northeast (038°)	Northwest (332°)	Southwest (156°)
Range to 150dB re 1µPa	14m	14m	14m
Range to 140dB re 1µPa	60m	60m	73m
Range to 130dB re 1µPa	320m	280m	260m
Range to 120dB re 1µPa	750m	850m	N/A
Range to 110dB re 1µPa	2.2km	4.5km	N/A
Range to 100dB re 1µPa	9.8km	18km	N/A

Table 6-5 Summary of the modelled ranges to unweighted RMS levels for rotary drilling (570kW) assuming two concurrent drilling operations

Percussive drilling (RMS) (two rigs)	Northeast (038°)	Northwest (332°)	Southwest (156°)
Range to 170dB re 1µPa	14m	14m	14m
Range to 160dB re 1µPa	66m	74m	74m
Range to 150dB re 1µPa	320m	270m	270m
Range to 140dB re 1µPa	760m	860m	420m
Range to 130dB re 1µPa	1.9km	4.7km	N/A
Range to 120dB re 1µPa	10km	21km	N/A
Range to 110dB re 1µPa	50km	82km	N/A

Table 6-6 Summary of the modelled ranges to unweighted RMS levels for percussive drilling assuming two concurrent drilling operations

6.2 Cutter-suction dredging

The predicted unweighted levels of underwater noise from cutter-suction dredging using RAMSGeo are shown as a level versus range plot in figure 6-4 and a table of ranges to unweighted RMS levels in table 6-7.

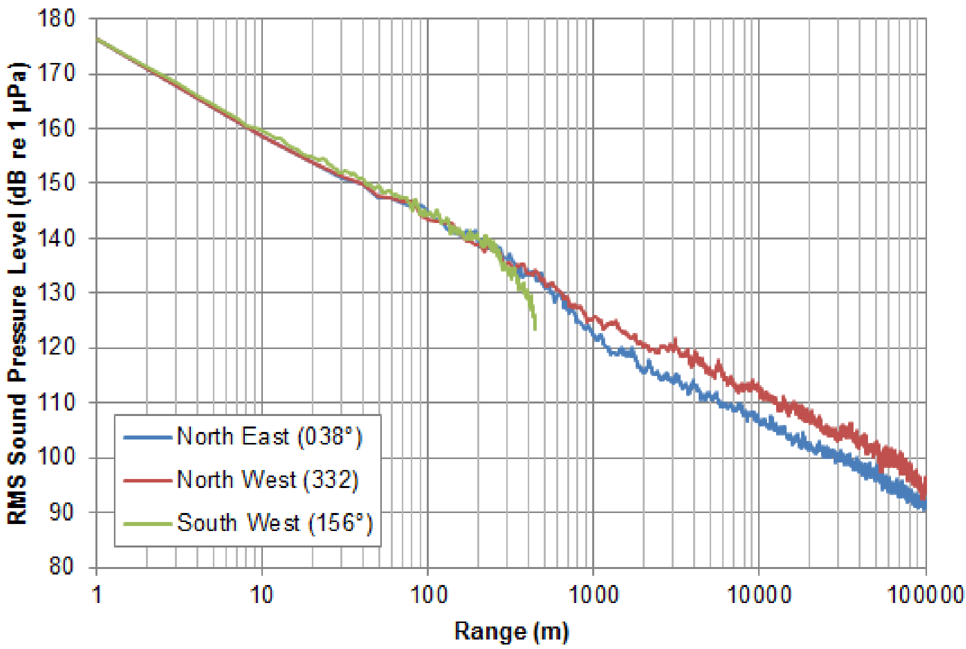

Figure 6-4 Level versus range plot showing the predicted unweighted RMS noise levels from cutter-suction dredging operations along three transects

As previously, some ranges given in the results tables are 'N/A' as the coast is reached before the noise can drop to this level.

Cutter-suction dredging (RMS)	Northeast (038°)	Northwest (332°)	Southwest (156°)
Range to 160dB re 1µPa	8m	8m	9m
Range to 150dB re 1µPa	41m	40m	41m
Range to 140dB re 1µPa	220m	160m	200m
Range to 130dB re 1µPa	560m	640m	400m
Range to 120dB re 1µPa	1.2km	3.1km	N/A
Range to 110dB re 1µPa	5.6km	14km	N/A

Table 6-7 Summary of the modelled ranges to unweighted RMS levels for cutter-suction dredging operations

6.3 Rock breaking/cutting

The levels of noise modelled for rock breaking and cutting are shown as level versus range plots in figure 6-5 and figure 6-6 and are summarised as ranges in table 6-8 and table 6-9. The rock breaking assumes use of an IHC S70 Hydrohammer and noise levels similar in nature to a small-scale piling operation have been used in the assessment. The results have been given as unweighted peak SPLs, rather than RMS as for drilling in the previous sections, as the strike rate of the rock breaker would result in clear, transient peaks. The rock cutting assumes a Rockwheel G55, the noise from which is classified as continuous, and as such the results are presented as unweighted RMS levels.

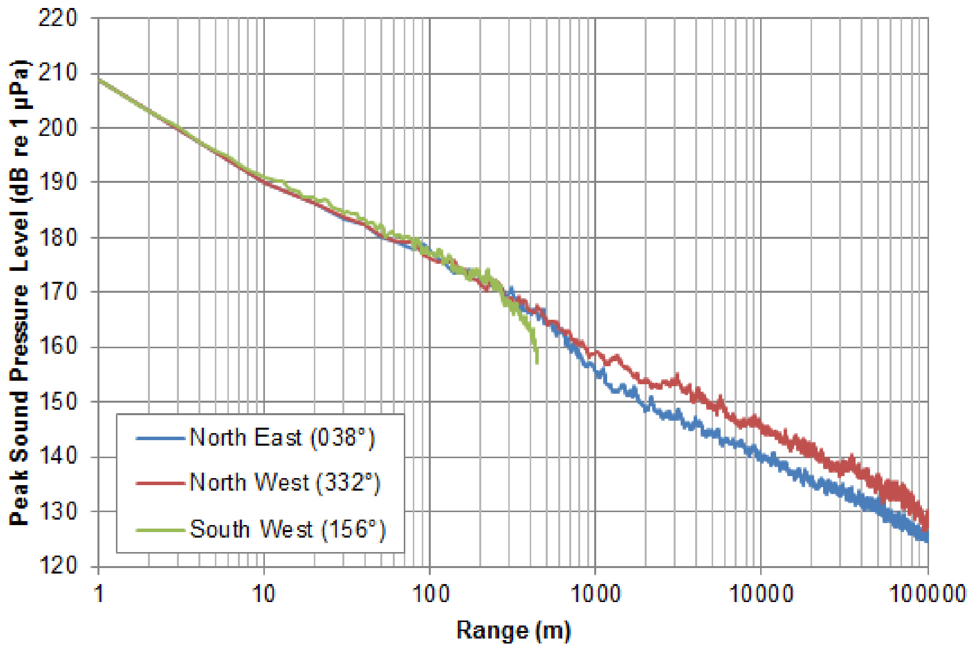

Figure 6-5 Level versus range plot showing the predicted unweighted peak noise levels from rock breaking operations along three transects

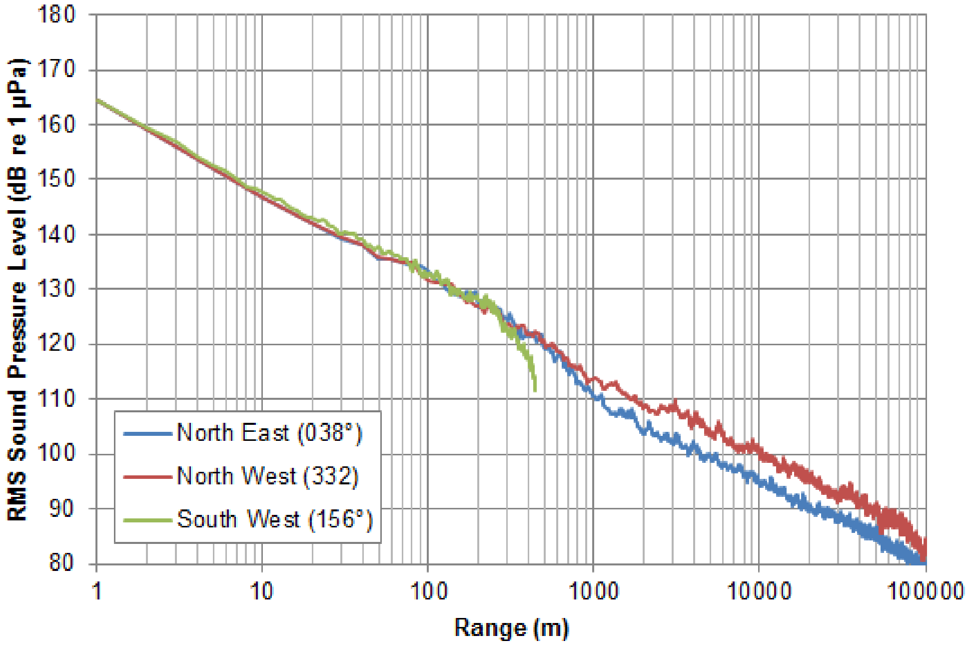

Figure 6-6 Level versus range plot showing the predicted unweighted RMS noise levels from rock cutting operations along three transects

Rock breaking (peak)	**Northeast (038°)**	**Northwest (332°)**	**Southwest (156°)**
Range to 190dB re 1µPa	10m	10m	13m
Range to 180dB re 1µPa	51m	53m	74m
Range to 170dB re 1µPa	270m	270m	270m
Range to 160dB re 1µPa	680m	850m	430m
Range to 150dB re 1µPa	1.8km	4.6km	N/A
Range to 140dB re 1µPa	9.8km	21km	N/A

Table 6-8 Summary of the modelled ranges to unweighted peak levels for rock breaking operations

Rock cutting (RMS)	**Northeast (038°)**	**Northwest (332°)**	**Southwest (156°)**
Range to 150dB re 1µPa	7m	7m	7m
Range to 140dB re 1µPa	30m	30m	37m
Range to 130dB re 1µPa	140m	150m	150m
Range to 120dB re 1µPa	500m	570m	350m
Range to 110dB re 1µPa	1.1km	1.8km	N/A
Range to 100dB re 1µPa	4.4km	10km	N/A

Table 6-9 Summary of the modelled ranges to unweighted RMS levels for rock cutting operations

6.4 Vessel movements

Figure 6-7 and table 6-10 summarise the estimated noise levels for generic vessel noise based on a variety of vessel noise measurements taken by Subacoustech, ranging from large container vessels and floating production storage and offloading vessels to small ferries and survey vessels. The noise has been split into two categories, medium vessels and large-sized vessels, which encompass the majority of the vessels that could be in the vicinity of the Wylfa Newydd Development Area during construction. Large vessels include most of the vessels directly involved in the construction such as dredgers and drilling rigs (during transit rather than during operation) and vessels transporting equipment to and from the site. Medium vessels include all the smaller support boats, such as multi-cats, tugs and workboats. For this modelling, it is assumed that the vessels are travelling at approximately 10 knots.

These results use a simple modelling process and do not take environmental parameters, such as bathymetry into account. It can be assumed that noise levels in shallow waters (less than 10m) are likely to be lower than those reported below because of higher attenuation in shallow water. Also, variability in actual levels on site would be dependent on vessel speed (the faster the vessel is moving the more sound it is likely to make) and the direction that the vessel is travelling in.

The estimated source levels for the vessels are approximately 168dB re 1µPa (RMS) @ 1m for large vessels and 161dB re 1µPa (RMS) @ 1m for medium vessels. The results shown in figure 6-7 and table 6-10 show that the predicted noise levels from various vessels are in general below the noise levels predicted for the other noise sources modelled, with the exception of rotary drilling.

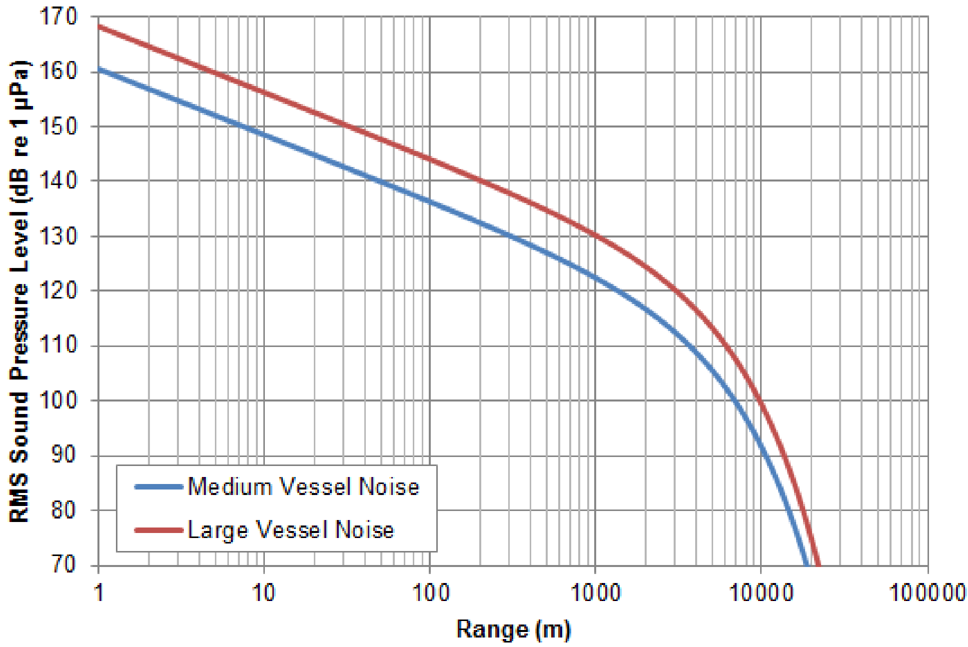

Figure 6-7 Approximate level versus range plot showing the unweighted RMS levels for generic vessel noise

Vessel noise	Large vessels	Medium vessels
Range to 160dB re 1µPa	4m	1m
Range to 150dB re 1µPa	32m	7m
Range to 140dB re 1µPa	200m	50m
Range to 130dB re 1µPa	1.0km	300m
Range to 120dB re 1µPa	3.0km	1.3km
Range to 110dB re 1µPa	6.1km	3.6km

Table 6-10 Summary of ranges to unweighted RMS levels for generic vessel noise

7 Assessment of underwater noise

Over the past 20 years it has become increasingly evident that noise from human activities in and around underwater environments can have an impact on the marine species in the area. The extent to which intense underwater sound might cause an adverse environmental impact in a particular species is dependent upon the incident sound level, frequency, duration, and/or repetition rate of the sound wave (see, for example, Hastings and Popper, 2005). As a result, scientific interest in the hearing abilities of aquatic species has increased. These studies are often based on evidence from high-level sources of underwater noise, such as seismic airguns or impact piling, as these sources are likely to have the greatest environmental impact and therefore the clearest observable effects. In the absence of direct evidence from other sources, these reviews have been used to inform assessments of lower-level underwater noise sources.

The impacts of underwater sound can be broadly summarised into three categories:

- physical traumatic injury or fatality;
- auditory damage (either permanent or temporary); and
- behavioural avoidance.

In order to assess the environmental impacts that the various noise sources are likely to have, the noise metrics which have been used with regards to the impact of noise on the marine species are described in the following sections.

7.1 Unweighted metrics

The data currently available relating to the levels of underwater noise likely to cause physical injury or fatality are primarily based on studies of blast injury at close range to explosives with some additional data on fish kill as a result of impact piling. All the data concentrate on impulsive underwater noise sources as other sources of noise are rarely of a sufficient level to cause these effects.

Parvin *et al.* (2007) present a comprehensive review of information on lethal and physical impact of underwater noise on marine receptors, and propose the following criteria to assess the likelihood of these effects occurring in all receptors:

- lethal effect may occur where peak noise levels exceed 240dB re 1µPa; and
- physical injury may occur where peak noise levels exceed 220dB re 1µPa.

Additional criteria have also been considered with regards to injury to marine receptors.

Southall *et al.* (2007) present a set of interim criteria for the levels of underwater noise that may lead to a permanent threshold shift (PTS) or a temporary threshold shift (TTS) in marine mammals based on peak SPLs. Instead of using species-specific criteria to determine hearing sensitivity in marine mammals, the criteria place marine mammals into four main groups for underwater hearing: low (e.g. baleen whales), mid (e.g. bottlenose dolphin), and high (e.g. harbour porpoise) frequency cetaceans, and pinnipeds (in water), based on the broad hearing capabilities of that group. The criteria also split noise sources into multiple pulses (piling and rock breaking), and non-pulses (drilling, dredging and vessel noise). However, in the case of the unweighted SPL_{peak} criteria, the criteria are the same across the four groups. The noise criteria are:

- PTS may occur in low, mid, and high frequency cetaceans where peak noise levels exceed 230dB re 1µPa;
- PTS may occur in pinnipeds (in water) where peak noise levels exceed 218dB re 1µPa;
- TTS may occur in low, mid, and high frequency cetaceans where peak noise levels exceed 224dB re 1µPa; and

- TTS may occur in pinnipeds (in water) where peak noise levels exceed 212dB re 1µPa.

Southall *et al.* (2007) also discuss the levels of underwater noise that may cause a behavioural avoidance response in marine mammals. The study concludes that the currently available evidence does not support the development of specific numeric criteria for the levels of underwater noise likely to cause a behavioural avoidance response. Instead, a severity scale is developed to rank the effects of a source of underwater noise in terms of the observable behavioural response. The findings of this study are used as a basis for the Joint Nature Conservation Committee guidance document on the deliberate disturbance of marine mammals (Joint Nature Conservation Committee, 2009). It is noted in this document that the timescales over which a noisy activity may occur may be of significance. If an avoidance reaction lasts for less than 24 hours and does not occur again in subsequent days, it may not be considered to have caused a significant avoidance response, whereas an activity causing an avoidance response over a longer period would be.

Although this is useful in the context of observing behavioural response in marine species during an activity, it is difficult to quantify the potential for a behavioural avoidance response to occur in a predictive exercise such as this study.

Nehls *et al.* (2014) used criteria based on data from Lucke *et al.* (2009), Kastelein *et al.* (2012) and Tougaard (2013) for assessing PTS and TTS in harbour porpoise. These are:

- PTS in harbour porpoise at levels exceeding 180dB re 1µPa^{2}s unweighted SEL (single strike) (using the method described in Southall *et al.* (2007), where PTS onset is estimated to occur at 15dB above the level of TTS onset); and
- TTS in harbour porpoise at levels exceeding 165dB re 1µPa^{2}s unweighted SEL (single strike), which was used by Tougaard (2013) based on data from Lucke *et al.* (2009) and Kastelein *et al.* (2012).

Furthermore, Lucke *et al.* (2009) also identified levels where a minor behavioural effect may occur in harbour porpoise at levels exceeding 145dB re 1µPa^{2}s unweighted SEL (single strike).

A recent publication by Popper *et al.* (2014) has identified noise levels, split by noise source, that could cause impacts to various species of fish. Popper *et al.* (2014) give unweighted peak criteria for pile driving, and these criteria have been used as a surrogate for the rock breaking operations in this study. These criteria state that for species of fish with no swim bladder, peak levels exceeding 213dB re 1µPa could cause either mortality and potential mortal injury, or recoverable injury. For species of fish with a swim bladder, levels exceeding 207dB re 1µPa would have the same effect. Unweighted cumulative SEL values are also given, with recoverable injury occurring at levels where the cumulative SEL exceeds 203dB re 1µPa^{2}s for fish with swim bladders, and TTS at levels where the cumulative SEL exceeds 186dB re 1µPa^{2}s in all species of fish.

The same study also provided noise levels from continuous noise sources (such as shipping, dredging and drilling) that could cause recoverable injury or TTS in species of fish with swim bladders involved in hearing. These criteria are:

- recoverable injury in fish at levels of 170dB re 1µPa unweighted SPL_{RMS} over a period of 48 hours; and
- TTS in fish at levels of 158dB re 1µPa unweighted SPL_{RMS} over a period of 12 hours.

7.2 Weighted Metrics

Additional criteria based on an individual receptor's hearing acuity have also been considered. The first of these are M-Weighted SELs from Southall *et al.* (2007). Instead of using species-specific audiograms to determine hearing sensitivity in marine mammals, the criteria from Southall *et al.* (2007) group marine mammals into four M-Weighting groups for underwater noise, as mentioned in section 7.1. These groups are low, mid, and high frequency cetaceans, and pinnipeds (in water).

In order to obtain the weighted sound levels, the data are first filtered using the proposed M-Weighting filter, and then the SEL is calculated. Southall *et al.* (2007) give M-Weighted criteria for PTS and TTS depending on the noise source: single pulse, multiple pulse or non-pulsed.

- PTS criteria are given as:
  - 198dB re 1µPa^{2}s (M) for PTS in species of cetaceans for single pulse and multiple pulse sounds over a 24-hour period;
  - 186dB re 1µPa^{2}s (M) for PTS in pinnipeds for single pulse and multiple pulse sounds over a 24-hour period;
  - 215dB re 1µPa^{2}s (M) for PTS in species of cetaceans for non-pulsed (continuous) sounds over a 24-hour period; and
  - 203dB re 1µPa^{2}s (M) for PTS in pinnipeds for non-pulsed (continuous) sounds over a 24-hour period.
- TTS criteria are given as:
  - 183dB re 1µPa^{2}s (M) for PTS in species of cetaceans for single pulse sounds; and
  - 171dB re 1µPa^{2}s (M) for PTS in species of pinnipeds for single pulse sounds.

TTS criteria are not given for multiple pulse or non-pulsed sounds.

In order to assess avoidance behaviour to noise in species of marine mammals, criteria from Finneran and Jenkins (2012) have been used; these use several different weightings listed as 'Type I', which is the same as M-Weighting from Southall *et al.* (2007), and 'Type II', which is a modified version of the filter based on an alternative weighting function. The behavioural avoidance criteria suggested, covering the species of interest in this study are:

- 167dB re 1µPa^{2}s for behavioural avoidance in mid frequency cetaceans using the Type II weighting function, covering bottlenose dolphin;
- 141dB re 1µPa^{2}s for behavioural avoidance in high frequency cetaceans using the Type II weighting function, covering harbour porpoise;
- 172dB re 1µPa^{2}s for behavioural avoidance in phocids (in water) using the Type I weighting function, covering species of seal.

Finneran and Jenkins (2012) state that, for single pulses, behavioural disturbance is likely to be limited to a short-lived startle reaction; therefore, Finneran and Jenkins (2012) do not suggest any unique behavioural disturbance thresholds for marine mammals exposed to single pulse events. The criteria have only been used in this study in lieu of further information on behavioural avoidance in marine mammals.

The Type I and Type II weighting functions share a concept with new criteria very recently published by the National Marine Fisheries Service (2016) for marine mammal auditory injury (PTS and TTS) thresholds. However, to maintain consistency with previous assessments for this project, the more established Southall *et al.* (2007) criteria will be used for auditory injury in this assessment.

7.3 Levels relative to background noise

For lower-level noise sources, such as vessel noise, an additional criterion for assessing the effect of noise has been used, comparing the predicted levels with the background noise levels from section 4. This comparison will give an estimate of the range over which the noise can be perceived by receptors over background levels.

7.4 Summary of the criteria considered in this study

Table 7-1 collates all the criteria used in this assessment. It should be noted that the criteria include both SPL_{peak} and SEL metrics, which are not directly comparable with some of the noise sources due to some being continuous and others being impulsive.

Effect	Criteria	Weighting	Species covered	Reference
lethal effect	240dB re 1µPa	unweighted SPL_{peak}	all	Parvin *et al.* (2007)
physical injury	220dB re 1µPa	unweighted SPL_{peak}	all	
PTS	230dB re 1µPa	unweighted SPL_{peak}	low, mid, high freq. Cetaceans	Southall *et al.* (2007)
TTS	224dB re 1µPa	unweighted SPL_{peak}		
PTS (single and multiple pulses)	198dB re 1µPa^{2}s	M-Weighted SEL		
TTS (single pulse)	183dB re 1µPa^{2}s	M-Weighted SEL		
PTS (Non-pulses)	215dB re 1µPa^{2}s	M-Weighted SEL		
PTS	218dB re 1µPa	unweighted SPL_{peak}	pinnipeds (in water)	
TTS	212dB re 1µPa	unweighted SPL_{peak}		
PTS (single and multiple pulses)	186dB re 1µPa^{2}s	M-Weighted SEL		
PTS (Non-pulses)	203dB re 1µPa^{2}s	M-Weighted SEL		
behavioural avoidance	167dB re 1µPa^{2}s	type II weighted SEL	mid freq. cetaceans	Finneran and Jenkins (2012)
behavioural avoidance	141dB re 1µPa^{2}s	type II weighted SEL	high freq. cetaceans	
behavioural avoidance	172dB re 1µPa^{2}s	type I weighted SEL	phocids (seals) (in water)	
PTS	180dB re 1µPa^{2}s	single strike unweighted SEL	harbour porpoise	Nehls *et al.* (2014)
TTS	165dB re 1µPa^{2}s	single strike unweighted SEL		
minor behavioural effect	145dB re 1µPa^{2}s	single strike unweighted SEL		Lucke *et al.* (2009)
mortality and potential mortal injury (explosions)	234 to 229dB re 1µPa	unweighted SPL_{peak}	fish and sea turtles	Popper *et al.* (2014)
mortality and potential mortal injury/mecoverable injury (pile driving)	> 213dB re 1µPa	unweighted SPL_{peak}	fish (no swim bladder)	
	> 207dB re 1µPa	unweighted SPL_{peak}	fish (with swim bladder), sea turtles, and eggs and larvae	
recoverable injury (pile driving)	203dB re 1µPa^{2}s	cumulative unweighted SEL	fish (with swim bladder)	
TTS (pile driving)	186dB re 1µPa^{2}s	cumulative unweighted SEL	fish	
recoverable injury (shipping and continuous sounds)	170dB re 1µPa for 48 hours	unweighted SPL_{RMS}	fish (with swim bladder involved in hearing)	
TTS (shipping and continuous sounds)	158dB re 1µPa for 12 hours	unweighted SPL_{RMS}		

Table 7-1 Summary of the noise criteria used in this assessment

8 Interpretation of results

The following section discusses the modelling results (section 6) in terms of biologically significant noise metrics and impact criteria (section 7). This discussion will help guide the assessment of environmental impact to marine species from the various operations proposed for the Wylfa Newydd Project. The results in the following pages have been grouped by noise source:

- drilling;
- dredging;
- rock breaking; and
- vessel movements.

At this point it should be noted that mathematical modelling (by its nature) will produce results which indicate a precise range at which a criterion will be met but this does not reflect the inherent uncertainty in the process. The results give a specific numerical value to a problem with a vast number of variables and parameters, including many that change constantly when considering real-world conditions. As such, while the results given in this section give the specific ranges at which each criterion in section 7 is met based on the modelling results, the ranges should be taken as a guideline, albeit worst case, in determining where environmental effects may occur in receptors during construction works.

8.1 Drilling

The source level inputs that have been used for the assessments based on the drilling modelling are presented in table 8-1. The values give 1-second RMS values for all the SEL metrics. It should be noted that ‘equivalent unweighted SPL_{peak}’ values have also been given; as drilling noise is not impulsive, peak sound levels do not strictly apply; however, they have been included here to allow the use of certain assessment criteria.

Drilling source levels	**Rotary drilling (242kW)**	**Rotary drilling (570kW)**	**Percussive drilling**
equivalent Unwtd SPL_{peak}	173.4dB re 1µPa (Peak)	177.1dB re 1µPa (Peak)	198.5dB re 1µPa (Peak)
unweighted SEL_{ss}	161.2dB re 1µPa^{2}s	164.9dB re 1µPa^{2}s	185.3dB re 1µPa^{2}s
LF cetacean M-Wtd SEL	160.9dB re 1µPa^{2}s (M_{lf})	164.6dB re 1µPa^{2}s (M_{lf})	185.1dB re 1µPa^{2}s (M_{lf})
MF cetacean M-Wtd SEL	149.6dB re 1µPa^{2}s (M_{mf})	153.3dB re 1µPa^{2}s (M_{mf})	173.8dB re 1µPa^{2}s (M_{mf})
HF Cetacean M-Wtd SEL	147.6dB re 1µPa^{2}s (M_{hf})	151.3dB re 1µPa^{2}s (M_{hf})	171.7dB re 1µPa^{2}s (M_{hf})
pinniped M-Wtd SEL	154.3dB re 1µPa^{2}s (M_{pw})	158.0dB re 1µPa^{2}s (M_{pw})	178.5dB re 1µPa^{2}s (M_{pw})
MF cetaceans Type II Wtd SEL	133.0dB re 1µPa^{2}s (MF)	136.7dB re 1µPa^{2}s (MF)	160.0dB re 1µPa^{2}s (MF)
HF cetaceans type II wtd SEL	127.5dB re 1µPa^{2}s (HF)	131.2dB re 1µPa^{2}s (HF)	154.8dB re 1µPa^{2}s (HF)

Table 8-1 Summary of the drilling source level inputs at 1m, used for modelling the effect of noise on receptors; all SELs are given as 1s RMS levels

Table 8-2 to Table 8-13 show the drilling noise impact ranges for rotary drilling and percussive drilling respectively. For the cumulative noise criteria (Southall *et al.* 2007; Finneran and Jenkins, 2012) a worst case stationary animal model over 24 hours of operation has been assumed. This is a highly unlikely scenario and if an animal moves away from the noise the effect will be greatly reduced, in most cases to a negligible range.

The Popper *et al.* (2014) criteria shown in table 8-11 to table 8-13 are different from those used previously, as drilling noise is classed as a continuous sound and well below the levels that could cause mortality. Also, the Parvin *et al.* (2007) and the Southall *et al.* (2007) SPL_{peak} criteria have not been included here as the drilling source levels fall well below those criteria. It should also be noted that there are no M-Weighted criteria for TTS given by Southall *et al.* (2007) for non-pulsed (continuous) sounds.

Southall *et al.* (2007) (rotary drilling [242kW])	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Range to PTS in low freq. cetaceans 215dB re 1µPa²s(M_{lf})	< 1	< 1	< 1
Range to PTS in mid freq. cetaceans 215dB re 1µPa²s(M_{mf})	< 1	< 1	< 1
Range to PTS in high freq. cetaceans 215dB re 1µPa²s(M_{hf})	< 1	< 1	< 1
Range to PTS in pinnipeds (in water) 203dB re 1µPa²s(M_{pw})	1	1	1

Table 8-2 Summary of the predicted M-Weighted SEL impact ranges from Southall et al. (2007) for non-pulsed sounds, based on a rotary drilling (242kW) noise

Southall *et al.* (2007) (rotary drilling [570kW])	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Range to PTS in Low freq. cetaceans 215dB re 1µPa²s(M_{lf})	< 1	< 1	< 1
Range to PTS in Mid freq. cetaceans 215dB re 1µPa²s(M_{mf})	< 1	< 1	< 1
Range to PTS in High freq. cetaceans 215dB re 1µPa²s(M_{hf})	< 1	< 1	< 1
Range to PTS in Pinnipeds (in water) 203dB re 1µPa²s(M_{pw})	1	1	1

Table 8-3 Summary of the predicted M-Weighted SEL impact ranges from Southall et al. (2007) for non-pulsed sounds, based on a rotary drilling (570kW) noise and continuous 24-hour exposure

Southall *et al.* (2007) (percussive drilling)	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Range to PTS in low freq. cetaceans 215dB re 1µPa²s(M_{lf})	14	14	15
Range to PTS in mid freq. cetaceans 215dB re 1µPa²s(M_{mf})	3	3	3
Range to PTS in high freq. cetaceans 215dB re 1µPa²s(M_{hf})	2	2	2
Range to PTS in pinnipeds (in water) 203dB re 1µPa²s(M_{pw})	37	37	41

Table 8-4 Summary of the predicted M-Weighted SEL impact ranges from Southall et al. (2007) for non-pulsed sounds, based on a percussive drilling noise and continuous 24-hour exposure

Finneran and Jenkins (2012) (rotary drilling [242kW])	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Behavioural avoidance in mid freq. cetaceans 167dB re 1µPa²s (Type II)	7	7	7
Behavioural avoidance in high freq. cetaceans 141dB re 1µPa²s (Type II)	220	170	230
Behavioural avoidance in phocids (in water) 172dB re 1µPa²s (Type I)	110	110	130

Table 8-5 Summary of the predicted weighted SEL impact ranges for behavioural avoidance using the criteria from Finneran and Jenkins (2012) for rotary drilling (242kW) noise

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Finneran and Jenkins (2012) (rotary drilling [570kW])	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Behavioural avoidance in mid freq. cetaceans 167dB re 1µPa²s (Type II)	16	16	16
Behavioural avoidance in high freq. cetaceans 141dB re 1µPa²s (Type II)	360	380	300
Behavioural avoidance in phocids (in water) 172dB re 1µPa²s (Type I)	230	190	210

Table 8-6 Summary of the predicted weighted SEL impact ranges for behavioural avoidance using the criteria from Finneran and Jenkins (2012) for rotary drilling (570kW) noise

Finneran and Jenkins (2012) (percussive drilling)	**Northeast (038°)**	**Northwest (332°)**	**Southwest (156°)**
Behavioural avoidance in mid freq. cetaceans 167dB re 1µPa²s (Type II)	480m	460m	340m
Behavioural avoidance in high freq. cetaceans 141dB re 1µPa²s (Type II)	4.1km	9.9km	N/A
Behavioural avoidance in phocids (in water) 172dB re 1µPa²s (Type I)	1.8km	4.1km	N/A

Table 8-7 Summary of the predicted weighted SEL impact ranges for behavioural avoidance using the criteria from Finneran and Jenkins (2012) for percussive drilling noise

Nehls *et al.* (2014), Tougaard (2013), Lucke *et al.* (2009) (rotary drilling [242kW])	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Range to PTS in h. porpoise 180dB re 1µPa²s (SEL_{ss})	< 1	< 1	< 1
Range to TTS in h. porpoise 165dB re 1µPa²s (SEL_{ss})	< 1	< 1	< 1
Range to minor behavioural effect in h. porpoise 145dB re 1µPa²s (SEL_{ss})	9	9	9

Table 8-8 Summary of the predicted unweighted, single strike, SEL impact ranges for PTS, TTS, and behavioural effect in harbour porpoise using the criteria from Nehls et al. (2014), Tougaard (2013) and Lucke et al. (2009) for rotary drilling [242kW] noise

Nehls *et al.* (2014), Tougaard (2013), Lucke *et al.* (2009) (rotary drilling [570kW])	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Range to PTS in h. porpoise 180dB re 1µPa²s (SEL_{ss})	< 1	< 1	< 1
Range to TTS in h. porpoise 165dB re 1µPa²s (SEL_{ss})	< 1	< 1	< 1
Range to minor behavioural effect in h. porpoise 145dB re 1µPa²s (SEL_{ss})	18	18	18

Table 8-9 Summary of the predicted unweighted, single strike, SEL impact ranges for PTS, TTS, and behavioural effect in harbour porpoise using the criteria from Nehls et al. (2014), Tougaard (2013) and Lucke et al. (2009) for rotary drilling (570kW) noise

Nehls *et al.* (2014), Tougaard (2013), Lucke *et al.* (2009) (percussive drilling)	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Range to PTS in h. porpoise 180dB re 1µPa²s (SEL_{ss})	2	2	2
Range to TTS in h. porpoise 165dB re 1µPa²s (SEL_{ss})	16	16	17
Range to minor behavioural effect in h. porpoise 145dB re 1µPa²s (SEL_{ss})	340	390	290

Table 8-10 Summary of the predicted unweighted, single strike, SEL impact ranges for PTS, TTS, and behavioural effect in harbour porpoise using the criteria from Nehls et al. (2014), Tougaard (2013) and Lucke et al. (2009) for percussive drilling noise

Popper *et al.* (2014) (rotary drilling [242kW])	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Recoverable injury (fish with swim bladders involved in hearing) (48 h) 170dB re 1µPa (SPL_{RMS})	< 1	< 1	< 1
TTS (fish with swim bladders involved in hearing) (12 h) 158dB re 1µPa (SPL_{RMS})	2	2	2

Table 8-11 Summary of the predicted SPL_{RMS} impact ranges from Popper et al. (2014) for continuous sounds, based on a rotary drilling (242kW) noise

Popper *et al.* (2014) (rotary drilling [570kW])	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Recoverable injury (fish with swim bladders involved in hearing) (48 h) 170dB re 1µPa (SPL_{RMS})	< 1	< 1	< 1
TTS (fish with swim bladders involved in hearing) (12 h) 158dB re 1µPa (SPL_{RMS})	3	3	3

Table 8-12 Summary of the predicted SPL_{RMS} impact ranges from Popper et al. (2014) for continuous sounds, based on a rotary drilling (570kW) noise

Popper *et al.* (2014) (percussive drilling)	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Recoverable injury (fish with swim bladders involved in hearing) (48 h) 170dB re 1µPa (SPL_{RMS})	8	8	7
TTS (fish with swim bladders involved in hearing) (12 h) 158dB re 1µPa (SPL_{RMS})	48	50	67

Table 8-13 Summary of the predicted SPL_{RMS} impact ranges from Popper et al. (2014) for continuous sounds, based on a percussive drilling noise

8.1.1 Concurrent drilling

Table 8-14 to table 8-25 show the same drilling noise criteria as the previous section, but for two drilling operations occurring at the same time, assuming the same stationary animal model over 24 hours. As discussed in section 5.2.1, a doubling of pressure has been assumed for the noise from two rigs, which is a worst case as the two operations are unlikely to be happening side by side.

Southall *et al.* (2007) (two rotary drilling rigs [242kW])	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Range to PTS in low freq. cetaceans 215dB re 1µPa²s(M_{lf})	< 1	< 1	< 1
Range to PTS in mid freq. cetaceans 215dB re 1µPa²s(M_{mf})	< 1	< 1	< 1
Range to PTS in high freq. cetaceans 215dB re 1µPa²s(M_{hf})	< 1	< 1	< 1
Range to PTS in pinnipeds (in water) 203dB re 1µPa²s(M_{pw})	2	2	2

Table 8-14 Summary of the predicted M-Weighted SEL impact ranges from Southall et al. (2007) for non-pulsed sounds, based on noise from two percussive drilling rigs (242kW) operating simultaneously

Southall *et al.* (2007) (two rotary drilling rigs [570kW])	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Range to PTS in low freq. cetaceans 215dB re 1µPa²s(M_{lf})	1	1	1
Range to PTS in mid freq. cetaceans 215dB re 1µPa²s(M_{mf})	< 1	< 1	< 1
Range to PTS in high freq. cetaceans 215dB re 1µPa²s(M_{hf})	< 1	< 1	< 1
Range to PTS in pinnipeds (in water) 203dB re 1µPa²s(M_{pw})	3	3	3

Table 8-15 Summary of the predicted M-Weighted SEL impact ranges from Southall et al. (2007) for non-pulsed sounds, based on noise from two percussive drilling rigs (570kW) operating simultaneously

Southall *et al.* (2007) (Two percussive drilling rigs)	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Range to PTS in low freq. cetaceans 215dB re 1µPa²s(M_{lf})	23	23	26
Range to PTS in mid freq. cetaceans 215dB re 1µPa²s(M_{mf})	4	4	4
Range to PTS in high freq. cetaceans 215dB re 1µPa²s(M_{hf})	3	3	3
Range to PTS in pinnipeds (in water) 203dB re 1µPa²s(M_{pw})	55	59	71

Table 8-16 Summary of the predicted M-Weighted SEL impact ranges from Southall et al. (2007) for non-pulsed sounds, based on noise from two percussive drilling rigs operating simultaneously

Finneran and Jenkins (2012) (two rotary drilling rigs [242kW])	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Behavioural avoidance in mid freq. cetaceans 167dB re 1µPa²s (Type II)	11	11	13
Behavioural avoidance in high freq. cetaceans 141dB re 1µPa²s (Type II)	320	280	270
Behavioural avoidance in phocids (in water) 172dB re 1µPa²s (Type I)	220	170	220

Table 8-17 Summary of the predicted weighted SEL impact ranges for behavioural avoidance using the criteria from Finneran and Jenkins (2012) for noise from two rotary drilling rigs (242kW) operating simultaneously

Finneran and Jenkins (2012) (Two rotary drilling rigs [570kW])	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Behavioural avoidance in mid freq. cetaceans 167dB re 1μPa²s (Type II)	26	26	26
Behavioural avoidance in high freq. cetaceans 141dB re 1μPa²s (Type II)	500	510	380
Behavioural avoidance in phocids (in water) 172dB re 1μPa²s (Type I)	300	290	270

Table 8-18 Summary of the predicted weighted SEL impact ranges for behavioural avoidance using the criteria from Finneran and Jenkins (2012) for noise from two rotary drilling rigs (570kW) operating simultaneously

Finneran and Jenkins (2012) (two percussive drilling rigs)	**Northeast (038°)**	**Northwest (332°)**	**Southwest (156°)**
Behavioural avoidance in Mid freq. cetaceans 167dB re 1μPa²s (Type II)	540m	620m	400m
Behavioural avoidance in High freq. cetaceans 141dB re 1μPa²s (Type II)	7.5km	16km	N/A
Behavioural avoidance in Phocids (in water) 172dB re 1μPa²s (Type I)	2.5km	5.9km	N/A

Table 8-19 Summary of the predicted weighted SEL impact ranges for behavioural avoidance using the criteria from Finneran and Jenkins (2012) for noise from two percussive drilling rigs

Nehls *et al.* (2014), Tougaard (2013), Lucke *et al.* (2009) (two rotary drilling rigs [242kW])	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Range to PTS in h. porpoise 180dB re 1μPa²s (SEL_{ss})	< 1	< 1	< 1
Range to TTS in h. porpoise 165dB re 1μPa²s (SEL_{ss})	< 1	< 1	< 1
Range to minor behavioural effect in h. porpoise 145dB re 1μPa²s (SEL_{ss})	14	14	16

Table 8-20 Summary of the predicted unweighted, single strike, SEL impact ranges for PTS, TTS, and behavioural effect in harbour porpoise using the criteria from Nehls et al. (2014), Tougaard (2013) and Lucke et al. (2009) for two rotary drilling rigs operating simultaneously

Nehls *et al.* (2014), Tougaard (2013), Lucke *et al.* (2009) (two rotary drilling rigs [570kW])	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Range to PTS in h. porpoise 180dB re 1µPa²s (SEL_{ss})	< 1	< 1	< 1
Range to TTS in h. porpoise 165dB re 1µPa²s (SEL_{ss})	1	1	1
Range to minor behavioural effect in h. porpoise 145dB re 1µPa²s (SEL_{ss})	28	28	28

Table 8-21 Summary of the predicted unweighted, single strike, SEL impact ranges for PTS, TTS, and behavioural effect in harbour porpoise using the criteria from Nehls et al. (2014), Tougaard (2013) and Lucke et al. (2009) for two rotary drilling rigs operating (570kW) simultaneously

Nehls *et al.* (2014), Tougaard (2013), Lucke *et al.* (2009) (Two percussive drilling rigs)	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Range to PTS in h. porpoise 180dB re 1µPa²s (SEL_{ss})	3	3	3
Range to TTS in h. porpoise 165dB re 1µPa²s (SEL_{ss})	25	25	36
Range to minor behavioural effect in h. porpoise 145dB re 1µPa²s (SEL_{ss})	530	500	340

Table 8-22 Summary of the predicted unweighted, single strike, SEL impact ranges for PTS, TTS, and behavioural effect in harbour porpoise using the criteria from Nehls et al. (2014), Tougaard (2013) and Lucke et al. (2009) for two percussive drilling rigs operating simultaneously

Popper *et al.* (2014) (two rotary drilling rigs [242kW])	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Recoverable injury (fish with swim bladders involved in hearing) (48 h) 170dB re 1µPa (SPL_{RMS})	< 1	< 1	< 1
TTS (fish with swim bladders involved in hearing) (12 h) 158dB re 1µPa (SPL_{RMS})	2	2	2

Table 8-23 Summary of the predicted SPL_{RMS} impact ranges from Popper et al. (2014) for continuous sounds, based on noise from two rotary drilling rigs (242kW) operating simultaneously

Popper *et al.* (2014) (two rotary drilling rigs [570kW])	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Recoverable injury (fish with swim bladders involved in hearing) (48 h) 170dB re 1µPa (SPL_{RMS})	< 1	< 1	< 1
TTS (fish with swim bladders involved in hearing) (12 h) 158dB re 1µPa (SPL_{RMS})	5	5	5

Table 8-24 Summary of the predicted SPL_{RMS} impact ranges from Popper et al. (2014) for continuous sounds, based on noise from two rotary drilling rigs (570kW) operating simultaneously

Popper *et al.* (2014) (two percussive drilling rigs)	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Recoverable injury (fish with swim bladders involved in hearing) (48 h) 170dB re 1µPa (SPL_{RMS})	12	12	13
TTS (fish with swim bladders involved in hearing) (12 h) 158dB re 1µPa (SPL_{RMS})	100	87	100

Table 8-25 Summary of the predicted SPL_{RMS} impact ranges from Popper et al. (2014) for continuous sounds, based on noise from two percussive drilling rigs operating simultaneously

8.2 Cutter-suction dredging

The source level inputs that have been used for the assessing dredging noise are presented in table 8-26. As before, the values give 1-second RMS values for all the SEL metrics and an 'equivalent unweighted SPL_{peak}' level has been used for certain criteria.

Dredging source levels	**Cutter-suction dredging**
Equivalent unweighted SPL_{peak}	186.4dB re 1µPa (Peak)
Unweighted SEL_{ss}	176.1dB re 1µPa^{2}s
Low Freq. Cetacean M-Weighted SEL	175.8dB re 1µPa^{2}s (M_{lf})
Mid Freq. Cetacean M-Weighted SEL	164.5dB re 1µPa^{2}s (M_{mf})
High Freq. Cetacean M-Weighted SEL	162.5dB re 1µPa^{2}s (M_{hf})
Pinniped (in water) M-Weighted SEL	169.2dB re 1µPa^{2}s (M_{pw})
Mid freq. cetaceans Type II Weighted SEL	154.6dB re 1µPa^{2}s (MF)
High freq. cetaceans Type II Weighted SEL	152.4dB re 1µPa^{2}s (HF)

Table 8-26 Summary of the dredging source level inputs at 1m, used for modelling the effect of noise on receptors, all SELs are given as 1s RMS levels

Table 8-27 to table 8-30 show the modelled impact ranges for cutter-suction dredging. As with drilling noise, dredging noise is considered a continuous sound and the source level falls well below the criteria from Parvin *et al.* (2007) and the SPL_{peak} criteria from Southall *et al.* (2007). A stationary animal model over 24 hours has been used as a worst case. The use of a fleeing animal model would greatly reduce any impact ranges and in most cases, eliminate them completely.

Using the impact criteria, the modelled ranges predict that there are unlikely to be injurious effects for receptors at ranges greater than 100m. At greater ranges, behavioural avoidance is predicted using the Finneran and Jenkins (2012) cumulative SEL criteria.

Southall *et al.* (2007)	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Range to PTS in low freq. cetaceans 215dB re 1µPa^{2}s(M_{lf})	3	3	3
Range to PTS in mid freq. cetaceans 215dB re 1µPa^{2}s(M_{mf})	< 1	< 1	< 1
Range to PTS in high freq. cetaceans 215dB re 1µPa^{2}s(M_{hf})	< 1	< 1	< 1
Range to PTS in pinnipeds (in water) 203dB re 1µPa^{2}s(M_{pw})	5	5	5

Table 8-27 Summary of the predicted M-Weighted SEL impact ranges from Southall et al. (2007) for non-pulsed sounds, based on noise from cutter-suction dredging operations

Finneran and Jenkins (2012)	**Northeast (038°)**	**Northwest (332°)**	**Southwest (156°)**
Behavioural avoidance in mid freq. cetaceans 167dB re 1μPa²s (Type II)	96m	90m	130m
Behavioural avoidance in high freq. cetaceans 141dB re 1μPa²s (Type II)	1.0km	1.8km	N/A
Behavioural avoidance in phocids (in water) 172dB re 1μPa²s (Type I)	490m	500m	380m

Table 8-28 Summary of the predicted weighted SEL impact ranges for behavioural avoidance using the criteria from Finneran and Jenkins (2012) for noise from cutter-suction dredging operations

Nehls *et al.* (2014), Tougaard (2013), Lucke *et al.* (2009)	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Range to PTS in h. porpoise 180dB re 1μPa²s (SEL_{ss})	< 1	< 1	< 1
Range to TTS in h. porpoise 165dB re 1μPa²s (SEL_{ss})	4	4	4
Range to minor behavioural effect in h. porpoise 145dB re 1μPa²s (SEL_{ss})	99	87	88

Table 8-29 Summary of the predicted unweighted, single strike, SEL impact ranges for PTS, TTS, and behavioural effect in harbour porpoise using the criteria from Nehls et al. (2014), Tougaard (2013) and Lucke et al. (2009) for cutter-suction dredger noise

Popper *et al.* (2014)	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Recoverable injury (fish with swim bladders involved in hearing) (48 h) 170dB re 1μPa (SPL_{RMS})	2	2	2
TTS (fish with swim bladders involved in hearing) (12 h) 158dB re 1μPa (SPL_{RMS})	11	11	13

Table 8-30 Summary of the predicted SPL_{RMS} impact ranges from Popper et al. (2014) for continuous sounds, based on noise from cutter-suction dredging operations

8.3 Rock breaker/cutter

The source level inputs that have been used for the assessment of rock breaking noise are presented in table 8-31.

Rock breaker source levels	**Rock breaker**	**Rock cutter**
Unweighted SPL_{peak} (equivalent level for rock cutting)	208.6dB re 1μPa (Peak)	182.3dB re 1μPa (Peak)
Unweighted SEL_{ss}	186.2dB re 1μPa²s	172.0dB re 1μPa²s
Low freq. cetacean M-Weighted SEL	185.9dB re 1μPa²s (M_{lf})	171.7dB re 1μPa²s (M_{lf})
Mid freq. cetacean M-Weighted SEL	174.6dB re 1μPa²s (M_{mf})	160.4dB re 1μPa²s (M_{mf})
High freq. cetacean M-Weighted SEL	172.6dB re 1μPa²s (M_{hf})	158.4dB re 1μPa²s (M_{hf})
Pinniped (in water) M-Weighted SEL	179.3dB re 1μPa²s (M_{pw})	165.1dB re 1μPa²s (M_{pw})
Mid freq. cetaceans Type II Weighted SEL	165.3dB re 1μPa²s (MF)	150.5dB re 1μPa²s (MF)
High freq. cetaceans Type II Weighted SEL	161.2dB re 1μPa²s (HF)	148.3dB re 1μPa²s (HF)

Table 8-31 Summary of the rock breaker source level inputs at 1m, used for modelling the effect of noise on receptors, all SELs are given as single strike

Table 8-32 to table 8-39 show the modelled impact ranges for the proposed rock breaking and cutting operations for the Wylfa Newydd Project, outlined in sections 3.3.3 and 5.2.3. For the multiple pulse criteria, a worst case stationary animal model has been used, assuming rock breaking activity over a

24-hour period operating with strike rate of 43 strikes per minute, or a continuous rock cutting operation over the same period. A fleeing receptor or shorter rock breaking periods will greatly reduce these impact ranges.

The SPL_{peak} pile driving criteria from Popper *et al.* (2014) have been used to assess mortality and recoverable injury during rock breaking; however, this could only happen at very close range to the activity. Larger impact ranges have been predicted for the cumulative noise criteria. The predicted source level for rock breaking noise is lower than the threshold given by Parvin *et al.* (2007) and the SPL_{peak} criteria from Southall *et al.* (2007) for injury. As such, they have not been presented.

Southall *et al.* (2007) (Rock breaking)	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Range to PTS in low freq. cetaceans 198dB re 1µPa^{2}s(M_{lf})	220	170	230
Range to PTS in mid freq. cetaceans 198dB re 1µPa^{2}s(M_{mf})	28	29	36
Range to PTS in high freq. cetaceans 198dB re 1µPa^{2}s(M_{hf})	20	20	25
Range to PTS in pinnipeds (in water) 186dB re 1µPa^{2}s(M_{pw})	370	450	340

Table 8-32 Summary of the predicted M-Weighted SEL impact ranges from Southall et al. (2007) for multiple pulse sounds for rock breaking, based on noise from pile driving operations

Southall *et al.* (2007) (Rock cutting)	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Range to PTS in low freq. cetaceans 215dB re 1µPa^{2}s(M_{lf})	2	2	2
Range to PTS in mid freq. cetaceans 215dB re 1µPa^{2}s(M_{mf})	< 1	< 1	< 1
Range to PTS in high freq. cetaceans 215dB re 1µPa^{2}s(M_{hf})	< 1	< 1	< 1
Range to PTS in pinnipeds (in water) 203dB re 1µPa^{2}s(M_{pw})	4	4	4

Table 8-33 Summary of the predicted M-Weighted SEL impact ranges from Southall et al. (2007) for non-pulsed sounds for rock cutting operations

Finneran and Jenkins (2012) (Rock breaking)	**Northeast (038°)**	**Northwest (332°)**	**Southwest (156°)**
Behavioural avoidance in mid freq. cetaceans 167dB re 1µPa^{2}s (Type II)	560m	600m	410m
Behavioural avoidance in high freq. cetaceans 141dB re 1µPa^{2}s (Type II)	7.7km	21km	N/A
Behavioural avoidance in phocids (in water) 172dB re 1µPa^{2}s (Type I)	1.4km	3.3km	N/A

Table 8-34 Summary of the predicted weighted SEL impact ranges for behavioural avoidance using the criteria from Finneran and Jenkins (2012) for rock breaking, based on noise from pile driving operations

Finneran and Jenkins (2012) (rock cutting)	**Northeast (038°)**	**Northwest (332°)**	**Southwest (156°)**
Behavioural avoidance in mid freq. cetaceans 167dB re 1µPa^{2}s (Type II)	60m	60m	88m
Behavioural avoidance in high freq. cetaceans 141dB re 1µPa^{2}s (Type II)	940m	1.5km	N/A
Behavioural avoidance in phocids (in water) 172dB re 1µPa^{2}s (Type I)	320m	280m	280m

Table 8-35 Summary of the predicted weighted SEL impact ranges for behavioural avoidance using the criteria from Finneran and Jenkins (2012) for rock cutting operations

Nehls *et al.* (2014), Tougaard (2013), Lucke *et al.* (2009) (rock breaking)	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Range to PTS in h. porpoise 180dB re 1µPa^{2}s (SEL_{ss})	3	3	3
Range to TTS in h. porpoise 165dB re 1µPa^{2}s (SEL_{ss})	22	22	25
Range to minor behavioural effect in h. porpoise 145dB re 1µPa^{2}s (SEL_{ss})	480	490	350

Table 8-36 Summary of the predicted unweighted, single strike, SEL impact ranges for PTS, TTS, and behavioural effect in harbour porpoise using the criteria from Nehls et al. (2014), Tougaard (2013) and Lucke et al. (2009) for rock breaking noise

Nehls *et al.* (2014), Tougaard (2013), Lucke *et al.* (2009) (rock cutting)	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Range to PTS in h. porpoise 180dB re 1µPa^{2}s (SEL_{ss})	< 1	< 1	< 1
Range to TTS in h. porpoise 165dB re 1µPa^{2}s (SEL_{ss})	< 1	< 1	< 1
Range to minor behavioural effect in h. porpoise 145dB re 1µPa^{2}s (SEL_{ss})	15	15	15

Table 8-37 Summary of the predicted unweighted, single strike, SEL impact ranges for PTS, TTS, and behavioural effect in harbour porpoise using the criteria from Nehls et al. (2014), Tougaard (2013) and Lucke et al. (2009) for rock cutting noise

Popper *et al.* (2014) (rock breaking)	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Mortality and potential mortal injury/recoverable injury (fish with swim bladders, sea turtles, and eggs and larvae) > 207dB re 1µPa (SPL_{peak})	1	1	1
Recoverable injury (fish with swim bladders) 203dB re 1µPa^{2}s (SEL_{cum})	9	9	10
TTS (fish) 186dB re 1µPa^{2}s (SEL_{cum})	130	160	180

Table 8-38 Summary of the predicted SPL_{peak} and SEL_{cum} impact ranges from Popper et al. (2014) for rock breaking, based on criteria for pile driving operations

Popper *et al.* (2014) (rock cutting)	**Northeast (038°) (m)**	**Northwest (332°) (m)**	**Southwest (156°) (m)**
Recoverable injury (fish with swim bladders involved in hearing) (48 h) 170dB re 1µPa (SPL_{RMS})	< 1	< 1	< 1
TTS (fish with swim bladders involved in hearing) (12 h) 158dB re 1µPa (SPL_{RMS})	3	3	3

Table 8-39 Summary of the predicted SPL_{peak} and SEL_{cum} impact ranges from Popper et al. (2014) for rock breaking, based on criteria for continuous noise sources

8.4 Vessel movements

The effect of noise from the additional vessel movements that would occur around the Wylfa Newydd Development Area has been assessed by using generic noise levels from a selection of vessels as discussed in section 3.4 and presented in section 6.4. The level of noise from vessels is expected to be low compared to the other sources considered, especially when considering SPL criteria. With regards to cumulative noise exposure, the noise from large vessels is comparable to that from those vessels presented for dredging in section 8.2; as before, these results assume an animal staying at the same distance from the noise source over a 24-hour period, which makes these results highly conservative. A summary of the predicted impact ranges using this approach is given in table 8-40 to table 8-43 below. It should be noted that most of the criteria are in excess of the predicted source levels given in section 6.4 and hence ranges of < 1m have been applied.

Southall *et al.* (2007)	**Large vessels (m)**	**Medium vessels (m)**
Range to PTS in low freq. cetaceans 215dB re 1µPa²s(M_{lf})	< 1	< 1
Range to PTS in mid freq. cetaceans 215dB re 1µPa²s(M_{mf})	< 1	< 1
Range to PTS in high freq. cetaceans 215dB re 1µPa²s(M_{hf})	< 1	< 1
Range to PTS in pinnipeds (in water) 203dB re 1µPa²s(M_{pw})	< 1	< 1

Table 8-40 Summary of the predicted M-Weighted SEL impact ranges from Southall et al. (2007) for non-pulsed sounds, based on noise from vessel movements

Finneran and Jenkins (2012)	**Large vessels**	**Medium vessels**
Behavioural avoidance in mid freq. cetaceans 167dB re 1µPa²s (Type II)	< 1m	< 1m
Behavioural avoidance in high freq. cetaceans 141dB re 1µPa²s (Type II)	1.7km	500m
Behavioural avoidance in phocids (in water) 172dB re 1µPa²s (Type I)	< 1m	< 1m

Table 8-41 Summary of the predicted weighted SEL impact ranges for behavioural avoidance using the criteria from Finneran and Jenkins (2012) for noise from vessel movements

Nehls *et al.* (2014), Tougaard (2013), Lucke *et al.* (2009)	**Large vessels (m)**	**Medium vessels (m)**
Range to PTS in h. porpoise 180dB re 1µPa^{2}s (SEL_{ss})	< 1	< 1
Range to TTS in h. porpoise 165dB re 1µPa^{2}s (SEL_{ss})	< 1	< 1
Range to minor behavioural effect in h. porpoise 145dB re 1µPa^{2}s (SEL_{ss})	60	10

Table 8-42 Summary of the predicted unweighted, single strike, SEL impact ranges for PTS, TTS, and behavioural effect in harbour porpoise using the criteria from Nehls et al. (2014), Tougaard (2013) and Lucke et al. (2009) for vessel noise

Popper *et al.* (2014)	**Large vessels (m)**	**Medium vessels (m)**
Recoverable injury (fish with swim bladders involved in hearing) (48h) 170dB re 1µPa (SPL_{RMS})	< 1	< 1
TTS (fish with swim bladders involved in hearing) (12h) 158dB re 1µPa (SPL_{RMS})	4	< 1

Table 8-43 Summary of the predicted SPL_{RMS} impact ranges from Popper et al. (2014) for continuous sounds, based on noise from cutter-suction dredging operations

In addition, these predicted levels have been compared with the baseline noise levels presented in section 4. When using the calculated average baseline level measured across all days and all transects (115.2dB re 1µPa (RMS)) the predicted vessel noise drops to this level at 2.4km for medium vessels and 4.4km for large vessels, as shown in table 8-44.

	Large vessels	**Medium vessels**
Range to average background noise 115.2dB re 1µPa (RMS)	4.4km	2.4km

Table 8-44 Summary of the predicted ranges out to which vessel noise drops below the average background noise

It should be noted that background noise levels will be variable.

9 Summary and Conclusions

An underwater noise assessment has been carried out in order to assess the possible noise impacts to marine fauna resulting from the various activities planned during construction of the Marine Works for the Wylfa Newydd DCO Project. The noise from drilling (both percussive and rotary), piling, dredging (both cutter-suction and backhoe), rock breaking (or peckering) and the associated vessel noise have been considered. Overall, it is considered that the methodology is based on a precautionary approach to assessment, which is demonstrated in the following conclusions.

A selection of ambient, underwater sound pressure level datasets was acquired between 2013 and 2014 to establish a baseline level of noise in the vicinity of the site, the results of which can be compared with modelling results. Measurements of noise were not taken during inclement conditions and as such these measurements are considered conservative (i.e. relatively low).

The RAMSGeo acoustic model has been used in order to predict noise levels from the various sources for the Wylfa Newydd Project. The unweighted noise levels from the modelling have been presented along with biologically significant criteria in order to assess any possible effects on receptors in the area.

Three types of drilling have been considered, two sizes of rotary drill and a percussive drill, with noise levels highest for percussive drilling. For example, the range out to which a behavioural avoidance is predicted in high frequency cetaceans (Finneran and Jenkins, 2012) for rotary drilling is up to 380m and for percussive drilling is 9.9km, considering a stationary animal over 24 hours. For concurrent drilling, behavioural avoidance could extend to 16km in high frequency cetaceans and 5.9km for pinnipeds. These ranges are considered to be highly conservative owing to the fact that the criteria are based on a stationary animal exposed to the sound source for 24 hours.

Sheet piles would be used as part of the temporary causeway and cofferdam construction, most likely installed using vibro piling. However, as the operations would be undertaken out of the water, the noise levels and effects of piling noise in the water have not been modelled. Some tubular piles would be installed using the larger rotary drilling rig mentioned above.

The dredging for the Wylfa Newydd Project is planned to include both backhoe and cutter-suction dredging. As cutter-suction dredging is louder, only modelling of this noise type was carried out. The results showed that while injury may occur at close range there are unlikely to be any adverse effects for receptors at ranges up to 2km, where a behavioural avoidance is expected in high frequency cetaceans assuming a 24-hour exposure (Finneran and Jenkins 2012). Behavioural effects on pinniped in water are limited to within 500m of the source again assuming a 24-hour exposure (Finneran and Jenkins 2012). These ranges are considered to be highly conservative owing to the fact that the criteria are based on a stationary animal exposed to the sound source for 24 hours.

Rock breaking, or peckering, has been assessed using small-scale piling noise as a proxy. Injurious effects in fish and marine mammals are only predicted to occur at close ranges; a behavioural effect extends further with behavioural avoidance in high frequency cetaceans predicted at ranges of up to 21km. This assumes a worst case, stationary receptor. Rock cutting has also been assessed, resulting in predicted impact ranges out to 1.5km in high frequency cetaceans.

The level of noise from increased vessel movements has also been considered and compared with the measured baseline levels. This showed that the predicted vessel noise drops to average background noise levels at ranges of 2.4km for medium vessels and 4.4km for larger vessels.

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