Section 8 Appendix 8.2 Underwater Noise Modelling Report

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York Potash Project Harbour Facilities: Underwater Noise Impact Assessment

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1 Introduction

This report has been prepared by Subacoustech Environmental Ltd for Haskoning DHV UK Ltd. York Potash Ltd is proposing to develop harbour facilities at Bran Sands on the Tees Estuary. The harbour facilities would consist of a port terminal, storage facilities and a conveyor system. The facility is proposed to be used to facilitate the export of fertiliser.

This report presents the results of an underwater noise study based on the proposed construction and operational activities in the Tees River and Estuary. This study has been undertaken to predict and assess the environmental impact of underwater noise likely to be produced during the construction and operational phase of the proposed scheme.

There are a number of construction options still under consideration and this study has taken these into account. Underwater noise propagation has been modelled and predicted in regard to impact piling and dredging activities.

This report follows on from a report of a subsea noise baseline survey (Cheesman and Collett, 2014), undertaken by Subacoustech Environmental Ltd, which describes the method for measurements undertaken and presents the data and findings for the baseline underwater noise environment.

1.1 Site details

The proposed harbour facility is to be constructed in the Bran Sands area of the Tees Estuary. Figure 1-1 highlights the proposed location of the port terminal and the key areas that are required to be dredged along with the locations of the other aspects of the facility.

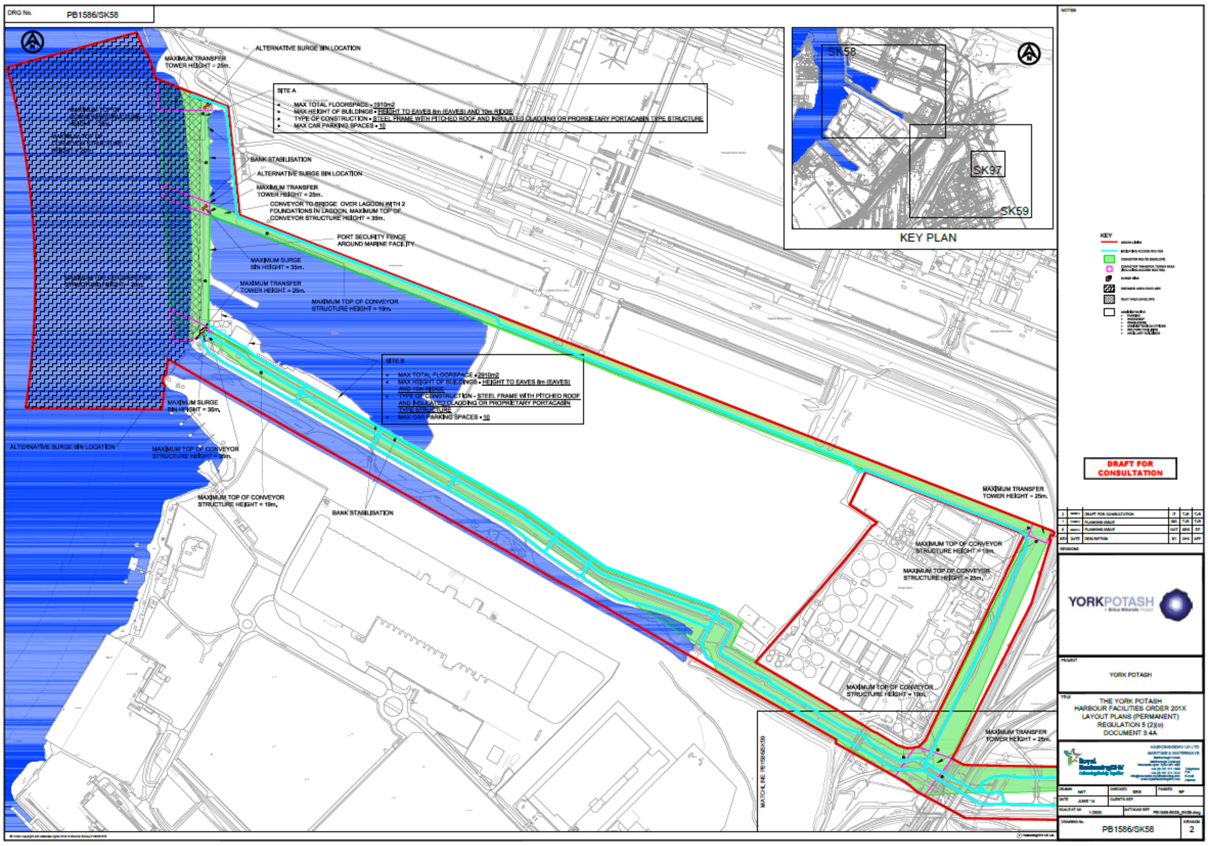

Figure 1-1 Map showing the indicative layout of the proposed harbour facility

1.2 Assessment approach

The approach taken in this assessment is consistent with the latest guidance currently being developed as part of the implementation of the EU Marine Strategy Framework Directive.

Sections 2 to 5 cover the modelling and reporting of noise propagation and transmission loss in terms of the physical processes and are reported in standard measurement units. This describes an estimation of the noise environment as a result of the activities being undertaken.

The results of the modelling are then used to inform an assessment of the potential impact on marine fauna (Section 6). This assessment is based on the currently available scientific literature and other studies. However, it is acknowledged that there are significant gaps in the available scientific knowledge (particularly with regards to the behavioural effects of noise on fish in the wild) and as such the results are presented and discussed with regard to a range of different criteria and metrics.

2 Modelling approach

2.1 Introduction

In order to estimate the noise levels likely to arise during construction of the proposed scheme, predictive underwater noise modelling was undertaken. This involved estimating noise levels from impact piling and dredging operations. This modelling was carried out using Subacoustech's INSPIRE model for impact piling operations and the openly available RAMSGeo software package to provide a comparison to INSPIRE and also to model dredging activities.

2.2 Noise level metrics

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

2.2.1 Sound pressure level (SPL)

The Sound Pressure Level (SPL) is normally used to characterise noise and vibration of a continuous nature such as drilling, boring, continuous wave sonar, 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 Root Mean Square (RMS) level of the time varying sound. 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 1 µPa for underwater sound.

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

Equation 2-1

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

2.2.2 Peak-to-peak level

The peak-to-peak level is a measure of SPL 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, the peak to peak level will be twice the peak (also sometimes known as the zero to peak) level, which equates to a level that is 6dB higher. Peak-to-peak levels of noise are often used to characterise sound transients from impulsive sources such as impact piling and seismic airgun sources.

2.2.3 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 to 1955), and later by Rawlins (1987) to explain the apparent discrepancies in the biological effect of short 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 the sound is present in the acoustic environment.

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 ten 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).

2.3 The INSPIRE model

The INSPIRE model is a semi-empirical underwater noise propagation model based around a combination of numerical modelling and actual measured data. It is designed to calculate the propagation of noise in shallow, mixed coastal water, typical of the coastal conditions around the UK. INSPIRE is designed to model and predict the propagation of underwater impact piling noise.

The model provides estimates of the unweighted peak, peak-to-peak and RMS SPL of noise as well as various other metrics along 180 equally spaced radial transects. For each modelling run, a criterion level can be specified allowing a contour within which a given effect may occur. These results are then plotted over digital bathymetry data so that impact ranges can be clearly visualised and assessed as necessary.

2.3.1 Input parameters

Two modelling positions have been chosen in order to show the greatest spatial range of results. The modelled positions were based on the extremities of the proposed port terminal. From here on, these modelling positions have been referred to as the North and South positions.

The parameters and assumptions used within the INSPIRE model for impact piling are outlined below in Table 2-1. Two different sized pile diameters have been modelled in order to consider the proposed construction options for the berth. One option is based on forming a suspended deck structure with driven steel tubular piles (of the order of 914mm) into the bed. The hammer energy for this option has been assumed to be 125kJ, based on piling operations sampled previously. An alternative proposed construction option comprises of a solid faced structure in the form of a combi-piled wall. This consists of a number of king piles (of the order of 2000mm) which are linked with secondary driven steel sheet piles. The king piles have been modelled using an assumed hammer energy of 305kJ and are expected to produce a greater sound levels, in comparison to sheet piles, due to their size and the energy required to install them.

Table 2-1 INSPIRE input parameters for impact piling

North Position	54.6205° N, 001.1517° W
South Position	54.6163° N, 001.1514° W
Depth above LAT (MHWS)	5.5 m
Assumed Pile Diameter	914 mm/2000 mm
Assumed Hammer Energy	125 kJ/305 kJ

2.4 The RAMSGeo model

The RAMSGeo software package, an acoustic model, is based on the well-known and much used RAM (Range-dependent Acoustic Model) software (Collins 1994 and Collins *et al.* 1996). RAMSGeo is able to model any noise source where it is reasonable to assume it as a point source. As the INSPIRE model is predominantly used and set up to model impact piling noise, RAMSGeo has been used to model underwater noise from dredging. RAMSGeo has also been used as a comparison to INSPIRE to provide confidence in the INSPIRE model outputs.

RAMSGeo is a fully range dependent parabolic equation (PE) model that performs underwater acoustic transmission loss calculations. Unlike INSPIRE, which has an emphasis on real world measurements, 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.

Unlike the INSPIRE model, RAMSGeo software package is currently only setup to run one chosen transect for a given iteration of the model. Therefore, three representative transects have been chosen to model the noise sources of interest as a comparison to INSPIRE.

2.4.1 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. This is based on average temperatures measured by Subacoustech Environmental in UK coastal waters throughout the year. A representative sound speed of 1470 m/s has been used in the calculations.
- The 'nominal' depth of the representative noise sources is taken to be mid-depth.
- The estuary bed substrate is assumed to be made up of predominantly silt (65% to 70%), clay (20%), with sand and gravel providing the remainder (Halcrow, 1991). Consequently the physical parameters shown in Table 2-2, as presented by Jensen *et al*, 1994, have been assumed.

Table 2-2 Physical parameters used in RAMSGeo model

Sound Speed Ratio c_p/c_w	1.1
Density Ratio ρ_b/ρ_w	1.7
Compressional Wave Attenuation α_p	1.0
Shear Wave Attenuation α_s	1.5

The broadband noise source can be broken up into its individual octaves which are modelled under a narrowband approximation and the individual energy contribution from the bands summed. Figure 2-1 and Figure 2-2 show power spectral density (frequency) plots of measured noise sources. These have been used to apply a weighting to the modelled noise and noise propagation. These noise sources are used as a comparison to the proposed work in the River Tees due to their similarity in river situation and activity type and scale.

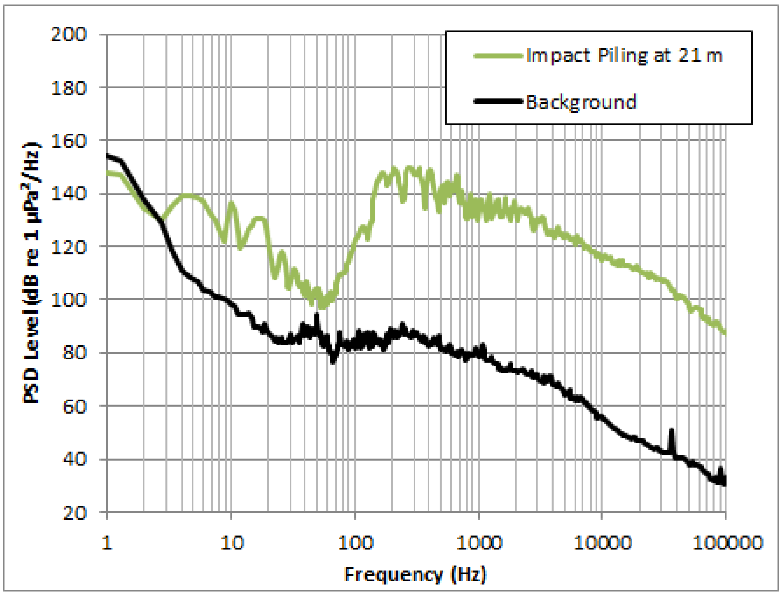

Figure 2-1 Power Spectral Density from measurement taken of impact piling in the River Thames

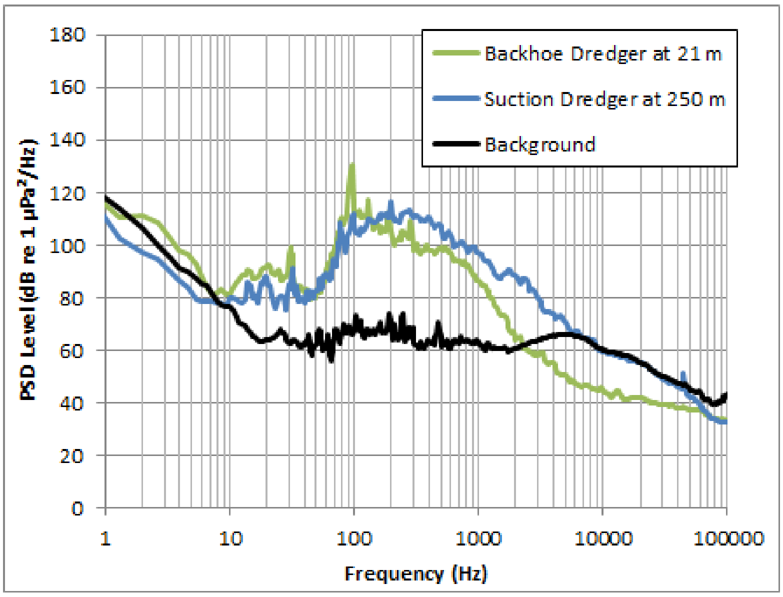

Figure 2-2 Power Spectral Density from measurement taken of backhoe dredging and suction dredging in Broadhaven Bay, Ireland

The South position has been chosen to carry out modelling using RAMSGeo. This is principally because it provides the greatest distance in a straight line before reaching the river bank in the area of interest within the river and hence the furthest distance for the sound to propagate. The bathymetry used for modelling the three chosen transects is shown in Figure 2-3.

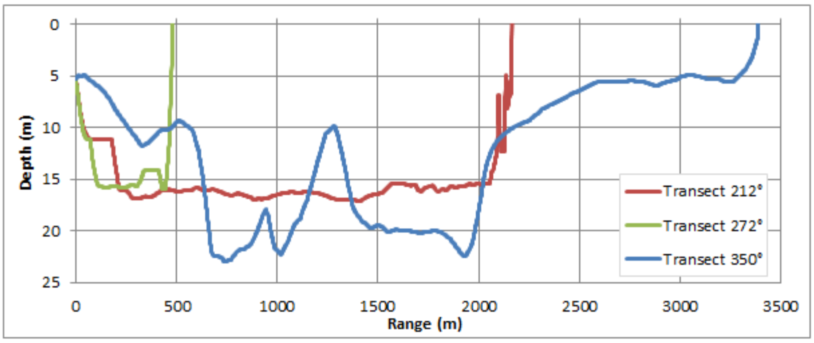

Figure 2-3 Bathymetry used for the three transects modelled in RAMSGeo at the south position

2.5 Review of existing data

2.5.1 Suction dredging

Cutter suction dredging (CSD) involves the use of a rotating cutter head to loosen rock and seabed in conjunction with a suction inlet that sucks up the material onto the vessel. Trailing suction hopper dredging (TSHD) involves a suction pipe with a drag head that is dragged over the seabed whilst dredging.

Underwater noise monitoring carried out by Subacoustech Environmental during CSD and TSHD has shown that suction noise dominates measured levels where the sediment is made up of sand and silt. Figure 2-4 shows a typical time history of dredging noise. The first 40 seconds of the time history are seen to remain at a constant pressure level with a number of transients. After this point the noise levels increase. It is thought that the dredger may have reached a region of gravel or rocky material as noise similar to large aggregate rattling up the suction pipe is audible on the recording. This produces the numerous high level transient peaks in underwater pressure visible between 40 and 70 seconds of the time history shown in Figure 2-4. This shows that there can be considerable variation in the noise levels and frequency components of noise from a suction dredger, which arise from different aspects of the dredger's operation.

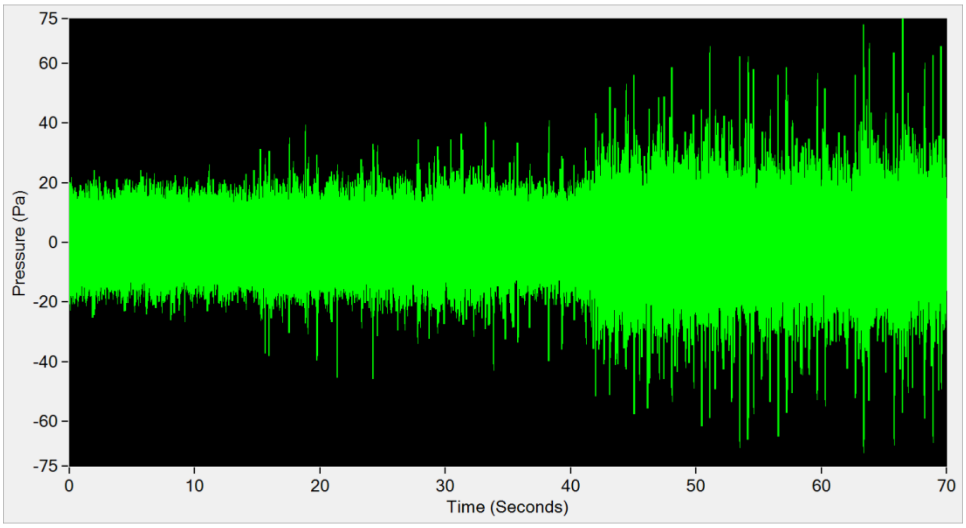

Figure 2-4 Pressure time history from suction dredging activity

Table 2-4 shows a representative number of existing, reported underwater noise data of CSDs and TSHDs. The extrapolated source levels are seen to be greater for TSHDs when compared with CSDs, despite the operation of a cutterhead. As the sediment to be dredged in the River Tees is predominantly sand, silt and clay, it is thought that if a CSD were to be used, similar noise levels would be produced as by TSHDs. For the basis of this study, source levels and spectra from TSHD measurements have been used to represent worst case emitted noise levels from suction dredging.

Table 2-3 Summary of reported CSD and TSHD underwater noise surveys

Dredger	Specification	Date and Location	Sediment	Source Level	Transmission Loss Model	Author
JFJ De Nul (CSD)	Overall Length: 140.7m Cutter Power: 7,600 kW Total Power: 27,240 kW	Coast of Dubai (2004)	Sand/Silt	169 dB re 1 µPa @ 1 m	20 log(r)	Howell and Nedwell, 2004
Florida (CSD)	Overall Length: 160m Cutter Power: 2,237 kW Total Power: 18,938 kW	New York/New Jersey Harbour (2012)	Limestone	175 dB re 1 µPa @ 1 m	15 log(r)	Reine *et al*, 2012
City of Westminster (TSHD)	Overall Length: 99.9 m Total Power: 4,080 kW	Hastings Shingle Bank (2008)	Gravelly sand	186 dB re 1 µPa @ 1 m	16 log(r)	Parvin *et al*, 2008
Taccola (TSHD)	Overall Length: 94.5 m Total Power: 6,050 kW	-	-	188 dB re 1 µPa @ 1 m	20 log(r)	Nedwell *et al,* 2008 (from Langworthy *et al,* 2004)
Mellina (TSHD)	Overall Length: 94.4 m Total Power: 3,300 kW	Broadhaven Bay, Ireland (2009)	Sand/slit	174 dB re 1 µPa @ 1 m	15 log(r)	Nedwell *et al*, 2009

2.5.2 Backhoe dredging

Figure 2-5 presents an example time history of underwater noise measured during operation of a backhoe dredger. The time history indicates considerable variation in underwater pressure levels and illustrates the levels of noise during each part of the dredging process.

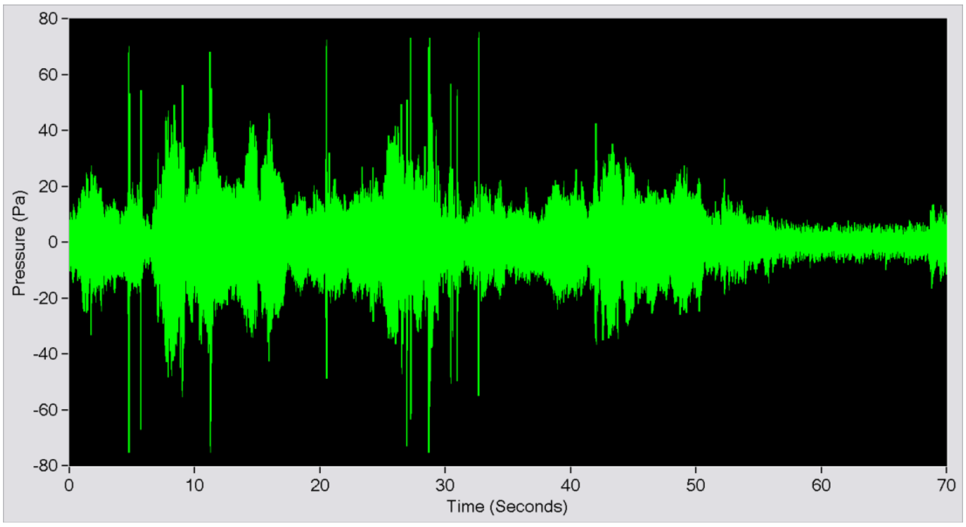

Figure 2-5 Pressure time history from backhoe dredging activity

Table 2-5 shows two reported underwater noise measurements of backhoe dredgers. Nedwell *et al.* (2009) reported that the dominant source of noise in measurements was due to the excavator bucket scraping along the bottom of the seabed. Reine *et al.* (2012) identified six distinct events that occur during a backhoe dredger operation which characterise sounds produced by the *New York* dredger whilst removing fractured limestone. Four of the events were linked to a single cycle of bucket deployment and retrieval which were bottom grab, barge loading, hydraulic ram noise and engine/generator noise. The two other events were associated with the manoeuvring of the dredge plant and with barge anchoring. SPL for the individual source levels of each event were calculated to be between 164 to 179 dB re 1 µPa at 1 m.

Table 2-4 Summary of reported underwater noise surveys of Backhoe Dredgers

Dredger	Specification	Date and Location	Sediment	Source Level	Transmission Loss Model	Author
Zenna	-	Broadhaven Bay, 2008	-	176 dB re 1 µPa @ 1 m	24 log(r)	Nedwell *et al*, 2009
New York	Overall length: 61 m Total power: 2,561 kW Bucket capacity: ~20 m^3	New York/New Jersey Harbour	Limestone	164 - 179 dB re 1 µPa @ 1 m	15 log(r)	Reine *et al*, 2012

2.5.3 Vessel movements

Vessels of all sizes from small speed boats to large super-tankers create underwater noise. Shipping noise is a significant contributor to the overall background levels in the sea and estuarine waters. Table 2-6 shows the range of vessels and their acoustic characteristics in terms of the dominant frequency ranges and source levels. The presented source levels are similar to those presented in the previous section for dredging. One important point to highlight is the transitory nature of underwater noise from passing vessels whereas a dredger will operate in a defined area, so the cumulative noise exposure in a fixed position will be greater than the exposure from a vessel passing by.

Table 2-5 Summary of reported underwater noise source levels and dominant frequency ranges for small, medium and large vessels (OSPAR 2009)

Category	Example Vessel Types	Dominant Frequency Range	Source Level
Small boats	Small leisure vessels, speed boats, work boats (<50 m)	100 – 1000 Hz	160 – 175 dB re 1 µPa @ 1 m
Medium-size ships	Tugboats, supply ships, research vessels (50 – 100 m length)	300 – 1000 Hz	165 - 180 dB re 1 µPa @ 1 m
Large vessels	Container and cargo ships, super-tankers (>100 m length)	50 – 300 Hz	180 - 190 dB re 1 µPa @ 1 m

3 Modelling results

3.1 Introduction

The modelling presented in this section provides the predicted broadband unweighted noise levels for the proposed impact piling operation and dredging activities. The modelling results have been presented as level versus range plots to illustrate the propagation of the noise over distance as well as contour plots showing, visually, the spatial impact of the noise.

The results of the baseline noise survey have been used as a reference for the operational noise impact assessment in Section 3.4, as the construction noise effect is temporary and, in particular with the impact piling, typically much higher than background noise.

3.2 Modelling of impact piling

Modelling unweighted noise levels has been undertaken, using the INSPIRE model, for the installation of contiguous steel piles for construction of the proposed port terminal by means of impact piling, using an impact piling hammer with energy of 125kJ for a 914mm diameter sized pile. An alternative construction option consists of a combi-piled wall with king piles linked with sheet piles. The king piles have been modelled based on a 2000mm diameter sized pile driven using a hammer with energy of 305kJ. Both sized piles have been modelled at two locations, at the extremities of the proposed port terminal, as previously discussed.

Table 3-1 gives a summary of the estimated ranges out to which certain unweighted levels of noise are expected to occur for the installation of a 914mm diameter pile. From this it can be seen that the propagation from the two modelled locations are similar until the sound drops below approximately 170dB re 1 µPa, where the bathymetry causes increased attenuation. Table 3-2 provides a summary of the estimated ranges for unweighted noise levels for the installation of a 2000mm pile.

It is also worth noting that in the case of both modelling locations, the minimum range reaches a limit (24m at the north location and 20m at the south location, indicated by the *). This is because this range is the shortest distance from the modelling location to the river bank, as illustrated in Figure 3-2 and Figure 3-3. Equally, the maximum range reaches a limit (2750m at the north location and 4900m at the south location, indicated by **) because the modelled sound reaches the river bank along the river.

Table 3-1 Summary of the modelled ranges for unweighted peak-to-peak SPL for impact piling operations for a 914mm diameter pile

Impact Piling (914 mm/125 kJ)	North Location			South Location		
	Maximum Range	**Minimum Range**	**Mean Range**	**Maximum Range**	**Minimum Range**	**Mean Range**
220 dB re 1 µPa	6 m	4 m	5 m	6 m	4 m	5 m
200 dB re 1 µPa	42 m	24 m*	37 m	54 m	20 m*	43 m
190 dB re 1 µPa	160 m	24 m*	94 m	210 m	20 m*	120 m
180 dB re 1 µPa	600 m	24 m*	280 m	760 m	20 m*	340 m
170 dB re 1 µPa	1930 m	24 m*	480 m	2400 m	20 m*	550 m
160 dB re 1 µPa	2750 m**	24 m*	510 m	4900 m**	20 m*	630 m

Table 3-2 Summary of the modelled ranges for unweighted peak-to-peak SPL for impact piling operations for a 2000 mm diameter pile

Impact Piling (2000 mm/305 kJ)	North Location			South Location		
	Maximum Range	**Minimum Range**	**Mean Range**	**Maximum Range**	**Minimum Range**	**Mean Range**
220 dB re 1 µPa	14 m	10 m	12 m	16 m	12 m	13 m
200 dB re 1 µPa	150 m	24 m*	88 m	190 m	20 m*	120 m
190 dB re 1 µPa	560 m	24 m*	260 m	700 m	20 m*	330 m
180 dB re 1 µPa	1800 m	24 m*	470 m	2300 m	20 m*	550 m
170 dB re 1 µPa	2750 m**	24 m*	500 m	4900 m**	20 m*	630 m
160 dB re 1 µPa	2750 m**	24 m*	510 m	4900 m**	20 m*	630 m

In order to show the modelled propagation of unweighted peak-to-peak SPLs from the impact piling of a 914mm diameter pile, three representative transects (with the following direction; South West 212°, West 272°, and North 350°) have been chosen to show propagation up and down the river as well as across the river to the opposite bank. Figure 3-1 presents the noise propagation for these three transects as a level versus range plot at the South location. From this figure it can be seen that the modelled transmission loss decays at a greater rate for the North 350° transect when compared to the South West 212° and South 272° transect. This is due to the more variable bathymetry along the route of the North 350° transect (which causes the transmission loss), in comparison with the relatively consistent bathymetry along the South West 212° and South 272° transects (illustrated previously in Figure 2-3 in Section 2.5). Contour plots are presented in Figure 3-2 and Figure 3-3 showing the ranges to which the specified levels have been reached for all 180 transects at the North and South location. Similarly, the same plots are shown for the modelled propagation of unweighted peak-to-peak SPLs from the impact piling of a 2000mm diameter pile in Figure 3-2 to Figure 3-6.

It should be noted that the predicted noise levels due to impact piling operations will exceed the background levels as previously measured by Subacoustech Environmental (Cheesman and Collett, 2014).

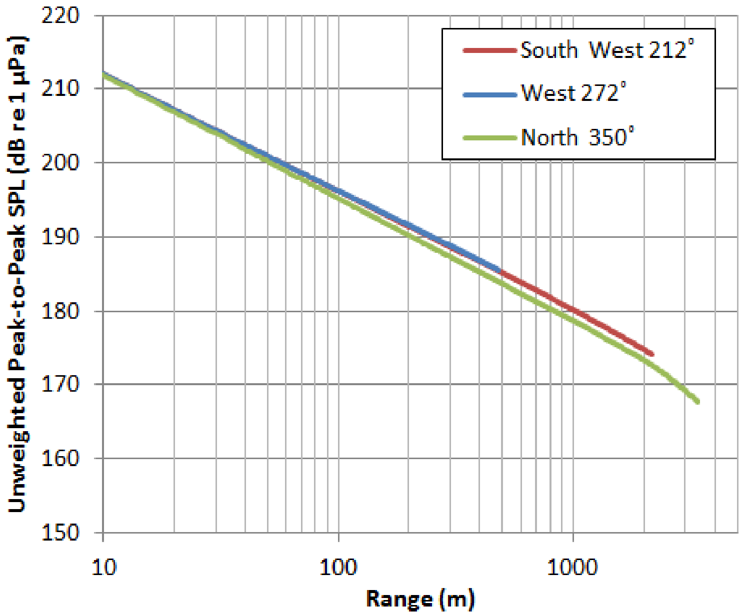

Figure 3-1 Level versus range plot showing the propagation of underwater noise across three transects from impact piling of a 914mm diameter pile using the INSPIRE model at the south location

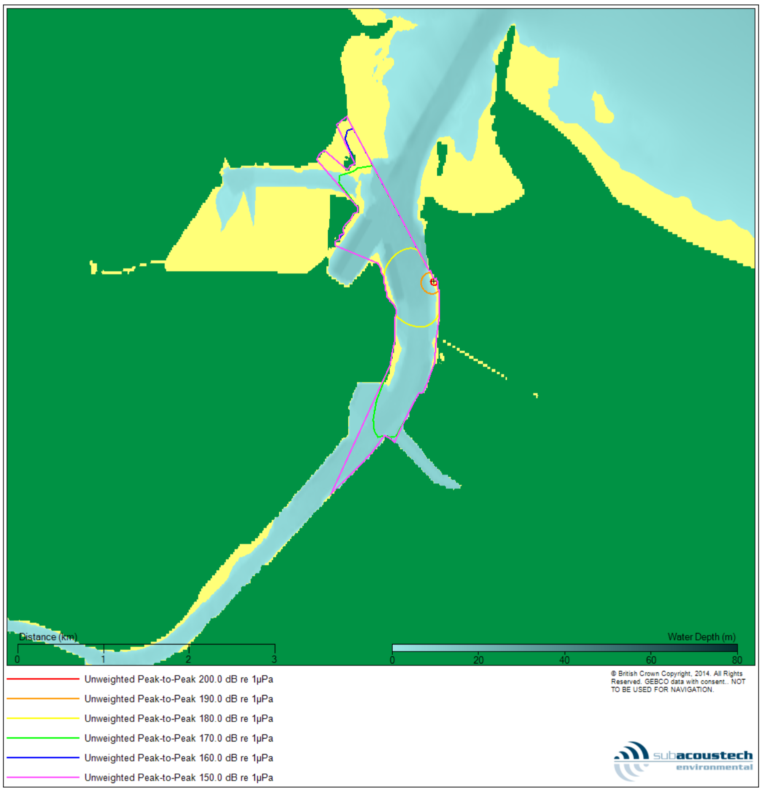

Figure 3-2 Contour plot showing the predicted unweighted peak-to-peak SPL from impact piling of a 914mm diameter pile at the north location

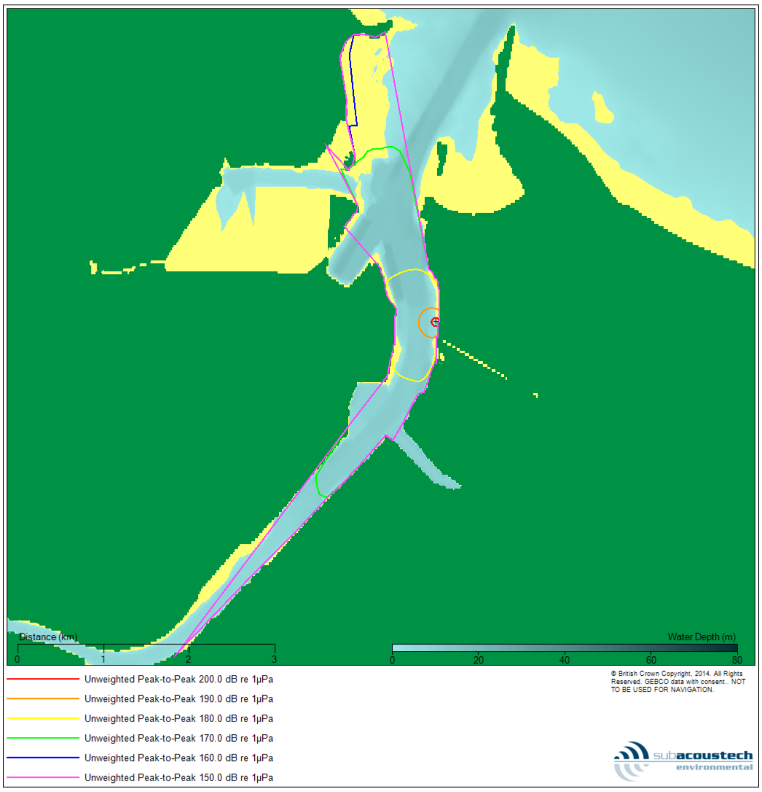

Figure 3-3 Contour plot showing the predicted unweighted peak-to-peak SPL from impact piling of a 914mm diameter pile at the south location

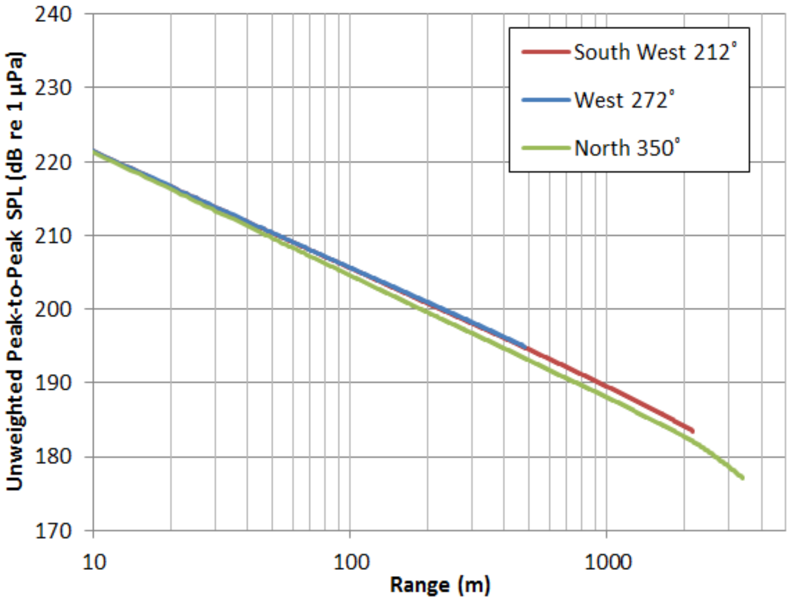

Figure 3-4 Level versus range plot showing the propagation of underwater noise across three transects from impact piling of a 2000mm diameter pile using the INSPIRE model at the south location

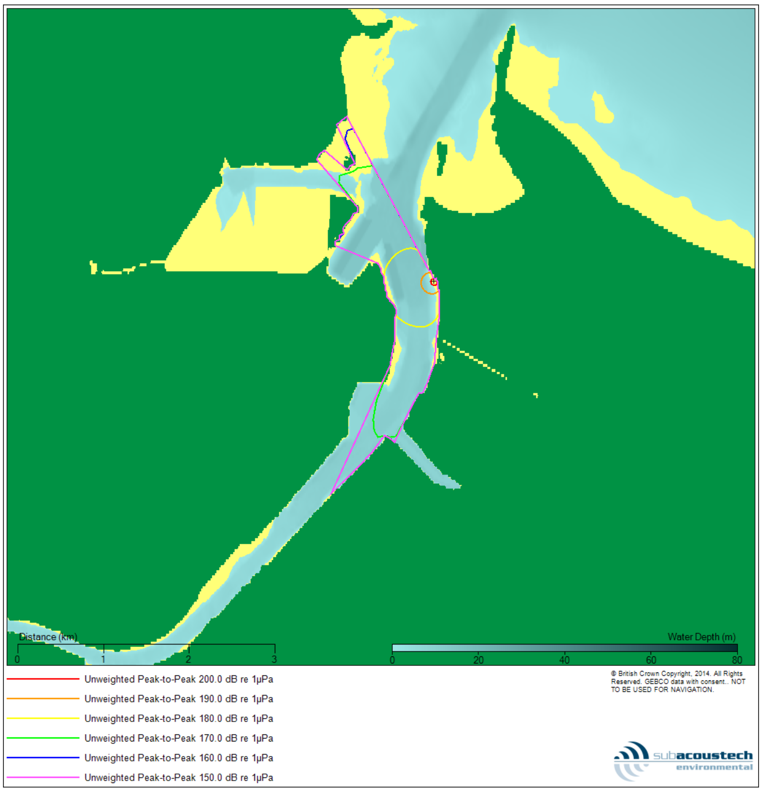

Figure 3-5 Contour plot showing the predicted unweighted peak-to-peak SPL from impact piling of a 2000mm diameter pile at the north location

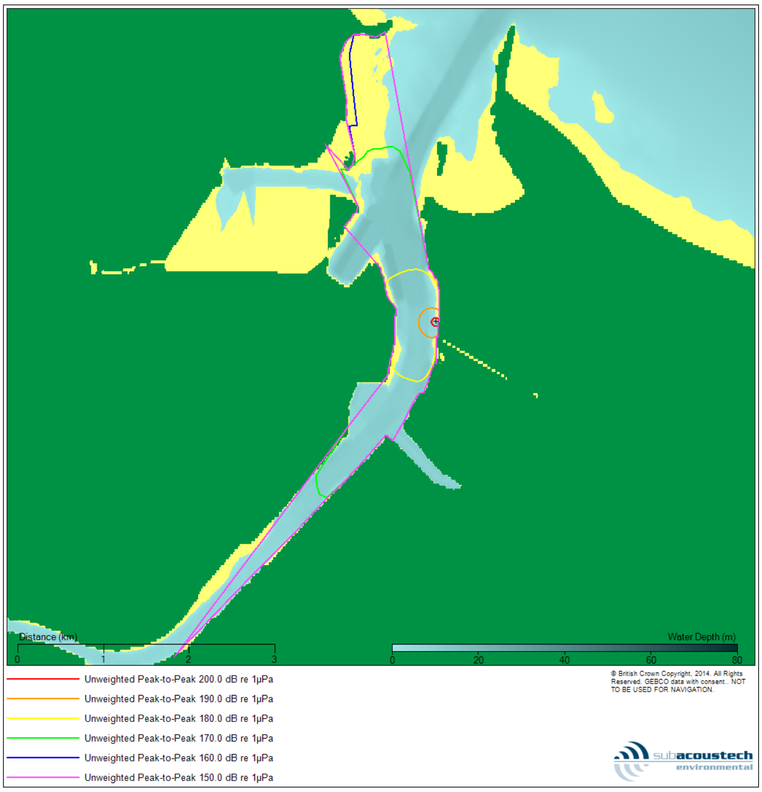

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Figure 3-6 Contour plot showing the predicted unweighted peak-to-peak SPL from impact piling of a 2000mm diameter pile at the south location

3.3 Modelling of dredging noise

Modelling of unweighted noise levels has been carried out, using RAMSGeo, to estimate the RMS SPL from two different dredging operations; backhoe dredging and suction dredging. As previously discussed in Section 2.5, modelling has been undertaken along three transects at the south modelling location.

Table 3-3 summarises the estimated ranges out to which certain unweighted RMS SPLs are expected to occur, given as increments of 10dB. Ranges are presented for levels down to 110dB re 1 µPa, below average background levels as measured by Subacoustech Environmental (Cheesman and Collett, 2014). It can be seen that the unweighted RMS levels for suction dredging extend to a greater range compared to the predicted ranges for a backhoe dredger.

As with the impact piling results, the minimum range reaches a limit. Three representative transects have been modelled, and the limit is the river bank opposite as opposed to the near bank (which in this case is 485m along the West 272° transect, again indicated by the *).

Table 3-3 Summary of the modelled ranges for unweighted RMS sound pressure levels in 10 dB increments for dredging activities (ranges based on three transects)

	Backhoe Dredging			Suction Dredging		
	Maximum Range	**Minimum Range**	**Mean Range**	**Maximum Range**	**Minimum Range**	**Mean Range**
160 dB re 1 µPa	< 5 m	< 5 m	< 5 m	20 m	20 m	20 m
150 dB re 1 µPa	10 m	10 m	10 m	95 m	75 m	88 m
140 dB re 1 µPa	30 m	25 m	28 m	475 m	335 m	423 m
130 dB re 1 µPa	105 m	65 m	92 m	2140 m	485 m*	1310 m
120 dB re 1 µPa	480 m	275 m	400 m	2460 m	485 m*	1700 m
110 dB re 1 µPa	1860 m	485 m*	1090 m	2920 m	485 m*	1860 m

Figure 3-7 and Figure 3-8 present the noise propagation results for the three modelled transects, from a backhoe dredger and a suction dredger, as level versus range plots. These figures show the modelled transmission loss decays at a greater rate for the North 350° transect, similar to the INSPIRE modelled impact piling transects.

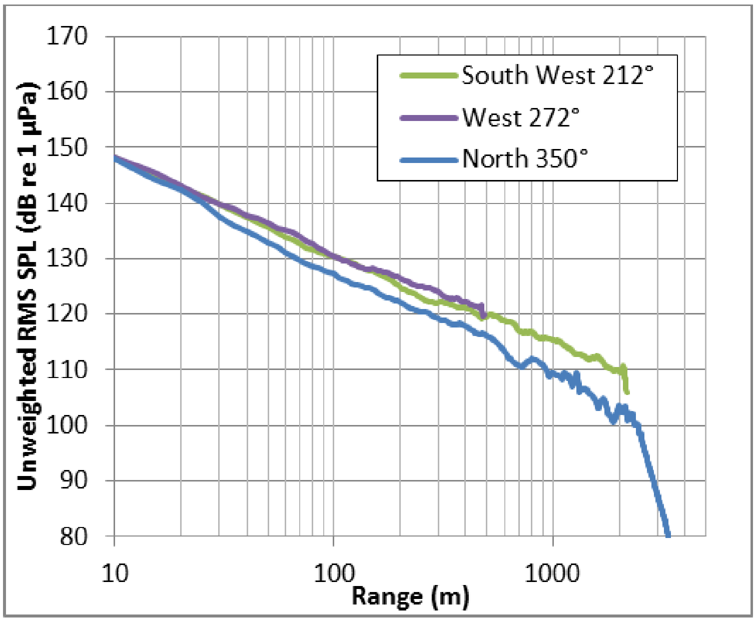

Figure 3-7 Level versus range plot showing the predicted propagation of underwater noise across three transects from a backhoe dredger using the RAMSGeo model

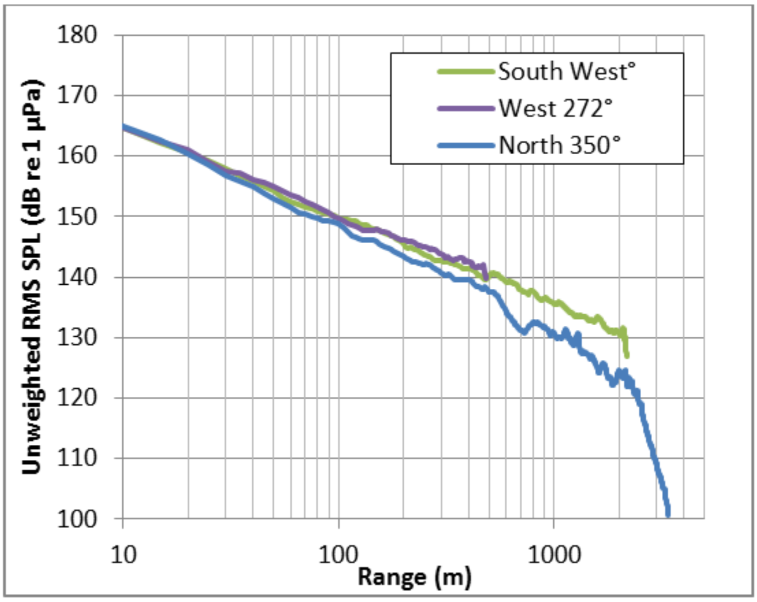

Figure 3-8 Level versus range plot showing the predicted propagation of underwater noise across three transects from a suction dredger using the RAMSGeo model

3.4 Operational phase – Vessel movement noise

The subsea noise baseline survey undertaken by Subacoustech Environmental in April 2014 (Cheesman and Collett, 2014) consisted of measurements of background noise in the River Tees and estuary. Measurements over the first day of the survey ranged from 96.6 to 133.0 dB re 1 µPa with an average of 118.0 dB re 1 µPa. On the second day the noise levels ranged between 105.0 and 142.3 dB re 1 µPa with an average of 118.9 dB re 1 µPa. The higher levels were recorded due to underwater noise from passing and moored vessels.

Table 3-4 provides a summary of the overall number of vessel movements in the River Tees on a monthly basis from January to September 2013. Table 3-5 presents a summary of the expected number of vessel movements during the operational phase of the proposed scheme per year. Based on the greatest number of expected vessel movements of 191 per year (during Phase 2 of the proposed scheme), the overall increase would be less than 1.8 % per year or one vessel movement every two days. Therefore, the increase in average noise levels during the operational phase from increased vessel movements would be minimal.

Table 3-4 Data of vessel movements per month recorded for January to September of 2013 in the River Tees (data provided by Tees Estuary Harbour Master)

Month	Vessel movements
January	824
February	808
March	981
April	922
May	1009
June	871
July	899
August	867
September	869
Monthly Average	**894**

Table 3-5 Summary of the expected number of vessels, dependent on load capacity, that are expected to arrive into the port during operational phase 1 and 2 (data provided by Haskoning DHV UK Ltd)

Vessel size (Dead weight tonnage, DWT)	Vessel numbers anticipated in Phase 1 (per year)	Vessel numbers anticipated in Phase 2 (per year)
55,000	30	59
65,000	25	50
75,000	22	44
85,000	19	38

4 Modelling confidence

4.1 Summary

In order to provide confidence in the accuracy of INSPIRE model, comparisons have been made between the outputs from the model (Section 3), measured data from similar operations elsewhere within the UK and data calculated using RAMSGeo. RAMSGeo is also compared to measured data to demonstrate its proficiency.

Both comparisons show good agreement and indicate a high degree of confidence in the INSPIRE vs RAMSGeo modelling (see Sections 4.2 and 4.3 for details).

4.2 Comparison with measured data

To compare the modelled results against measured data, they have been run retrospectively against a similar impact piling project undertaken in the River Thames, for which measurements have been taken. By plotting the estimated propagation from the models with the measured data points from the survey, the accuracy of the model can be attained.

Figure 4-1 shows the estimated noise level with range for INSPIRE and RAMSGeo models, plotted against unweighted peak-to-peak levels from actual measurements. The piles driven were 762mm in diameter with a blow energy of 126kJ. The source level of the measurements has been extrapolated to be 230dB re 1 µPa @ 1 m. Based on modelled parameters for the River Thames, both models show good agreement with the measured data. It should be noted that the measurements beyond 1km were taken following the bend in the river whereas the models use the bathymetry for a straight line. Hence the sound propagation is modelled to the point at which the river bank is reached, which is a distance of approximately 1km.

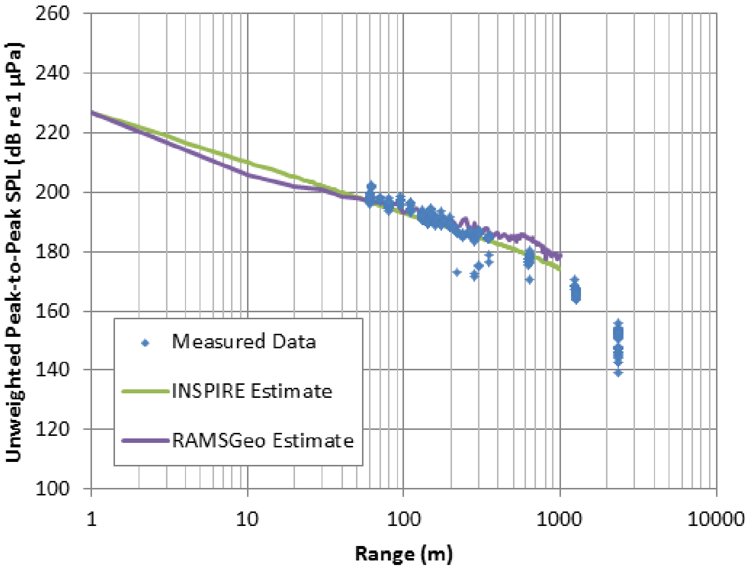

Figure 4-1 Comparison between measured data and an estimate using INSPIRE and RAMSGeo models for impact piling noise propagation in the River Thames

4.3 Comparison of INSPIRE and RAMSGeo models

Two transects using parameters from the River Tees have been chosen to compare the modelled outputs from the INSPIRE and RAMSGeo models with regard to impact piling. The modelled outputs for each transect are presented in Figure 4-2. Again, both plots indicate good agreement between the two models up to a distance of approximately 3 to 4 km from the noise source.

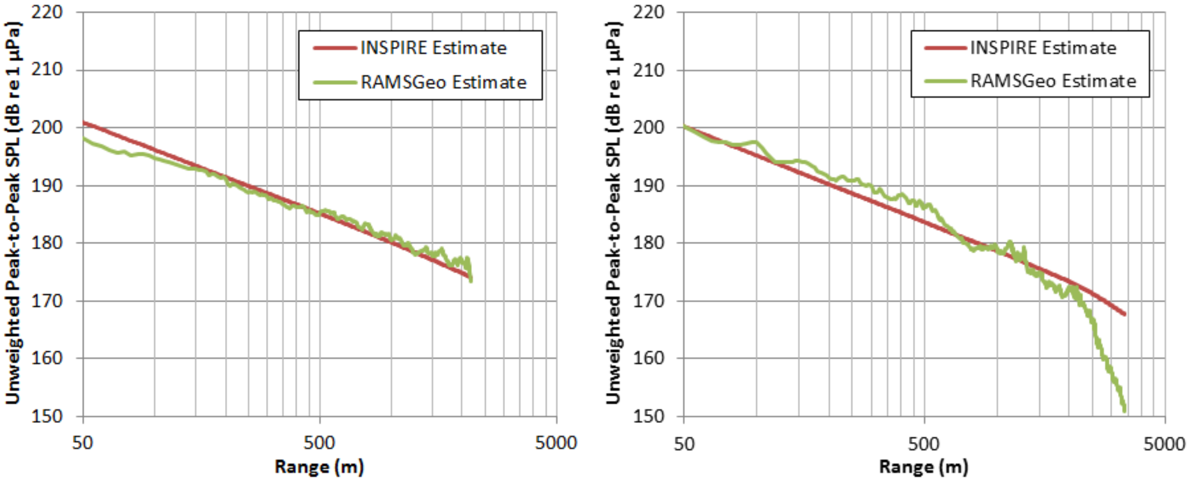

Figure 4-2 Comparison between INSPIRE and RAMSGeo modelling of an impact piling operation along the South West 212° transect (left) and the North 350° transect (right)

5 Analysis of environmental effects

5.1 Background

Over the past 20 years it has become increasingly evident that noise from human activities in and around underwater environments may 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 animal species has increased. These studies are generally based on evidence from high level sources of underwater noise such as blasting 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 such as dredging.

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

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

The criteria used in this study to determine physical injury or fatality have been discussed in section proposed by Parvin *et al* (2007).

Parvin *et al* (2007) suggests that for continuous sound, direct injury to gas-containing structures or auditory mechanisms may occur at lower incident sound levels depending on duration and frequency content of the noise. Several studies have been carried out relating to the onset of auditory damage in terms of Temporary Threshold Shift (TTS) and Permanent Threshold Shift (PTS) (see, for example, Nedwell *et al* (2007) and Southall *et al* (2007) for a review of these studies).

At levels lower than those that cause auditory injury, noise may nevertheless have important behavioural effects on a species, of which the most significant is avoidance of the insonified area (the region within which noise from the source is above ambient underwater noise levels). The significance of the effect requires an understanding of its consequences; for instance, avoidance may be significant if it causes a migratory species to be delayed or diverted. However, in other cases, the movement of species from one area to another may be of no consequence.

5.2 Species of concern

Several species of fish and marine mammal have been identified as being of importance in the areas in and around the Tees River and Estuary.

The species of fish considered in this study are:

- Dab (*Limanda limanda*), a flatfish. Based on current peer reviewed audiogram data (Chapman and Sand, 1974), dab is the most sensitive flatfish to under water sound. Hence, dab has been used as a surrogate for other flatfish (e.g. flounder and plaice) and where quality audiogram data is not available. In this study the dab audiogram has also been used as a surrogate for European eel, due to a similar frequency response (Jerkø *et al*, 1989).
- Herring (*Clupea harengus*), a fish very sensitive to sound pressure. Based on peer reviewed audiogram data (Enger and Andersen, 1967), herring is the most sensitive marine fish to underwater sound. Herring has also been used as a surrogate for sprat as they are also a clupeiform fish.

- Salmon (*Salmo salar*), a fish which possesses a substantial swim bladder but, as it is not in close proximity to the inner ear, salmon are therefore less sensitive to underwater nosie and vibration. In this study audiogram data from Hawkins and Johnstone (1978) have been used.
- Sandeels or sand lances (*Ammodytes tobianus*) lack a swim bladder and generally have poor sensitivity to sound (Suga *et al*, 2005) relative to other species included in this report. They are capable of hearing low frequencies typically less than about 500 Hz.
- Sea trout (*Salmo trutta*) are considered to have a low sensitivity to sound (Nedwell *et al*, 2006).

The species of marine mammal considered in this study are:

- Harbour (common) seal (*Phoca vitulina*), a pinniped that, based on current peer reviewed audiogram data (Møhl, 1968; Kastak and Schusterman, 1998), is the most sensitive seal species to underwater sound and may be representative of other marine mammals that are sensitive to mid-frequency underwater sound (up to 75 kHz). Harbour seal will also be used as a surrogate for grey seal as the audiogram data available from Ridgway and Joyce (1975) do not provide hearing sensitivities for frequencies below 1 kHz. However, the audiogram is similar to Møhl's harbour seal audiogram and hence it has been used as a surrogate.

5.3 Criteria to be used

In order to assess the environmental effects that impact piling and dredging activities are likely to have, the following noise metrics have been used with regards to the impact on the marine species listed in Section 5.2. These noise metrics include unweighted metrics (Parvin *et al*, 2007), the dB_{ht}(*Species*) (Nedwell *et al*, 2007), and M-Weighted SELs (Southall *et al*, 2007).

5.3.1 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 an additional small amount of information on fish kill as a result of impact piling. All the data concentrates on impulse 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 impacts of underwater noise on marine receptors previously studied and propose the following criteria to assess the likelihood of these effects occurring:

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

Additional criteria have also been considered for assessing the impact of noise on fish injury, based on the work of the Fisheries Hydroacoustic Working Group (FHWG) in the USA. FHWG (2008) assigns criteria based on unweighted noise levels. This includes a peak SPL of 206 dB re 1 µPa (SPL_{peak}) and an accumulated SEL over a period of time of 187 dB re 1 $\mu Pa^2 s$. It should be noted that these are generic criteria which make no distinction between individual species.

Other assessments have used data from McCauley *et al* (2000), which investigated the reactions of caged Australian species of fish to seismic airgun blasts to set the criteria, but the applicability of these results to the reality of reactions by wild fish exposed to piling in UK waters is very questionable. However, this paper provides the following values:

- Possible moderate to strong avoidance: 168 – 173 dB SPL_{peak} re 1 µPa.

- Startle response or C-turn reaction: 200 dB SPL_{peak} re 1 µPa.

The 200 dB SPL_{peak} re 1 µPa figure will be referred to in the results, but appropriate cautions should be exercised with drawing any conclusions.

5.3.2 The dB_{ht}(*Species*)

Unweighted noise metrics do not provide an indication of the impact that the sound will have upon a particular fish or marine mammal species. This is of fundamental importance when considering the behavioural impact of aquatic life to underwater sound, as this is associated with the perceived loudness of the sound by the species. Therefore, the same underwater sound will affect marine species in a different manner depending upon the hearing sensitivity of that species.

The dB_{ht}(*Species*) metric (Nedwell *et al,* 2007) incorporates this concept of "loudness" for a species. The metric is built around a species' hearing ability by referencing the sound to the species' hearing threshold, and hence evaluates the level of sound a species can perceive.

Since any given sound will be perceived differently by different species (as they have differing hearing abilities) the species name must be appended when specifying a level. For instance, the same sound might have a level of 70 dB_{ht}(*Gadus morhua*) for cod and 40 dB_{ht}(*Salmo salar*) for salmon.

The perceived noise levels of source measured in dB_{ht}(*Species*) are usually much lower than the unweighted levels because the sound will contain frequency components that the species cannot detect.

The species upon which the dB_{ht}(*Species*) analysis has been conducted in this study have been selected based upon regional significance and also, crucially, upon the availability of a good quality, peer-reviewed audiogram. The audiograms used in this study for the species listed in Section 5.2 are shown in Figure 5-1 and Figure 5-2.

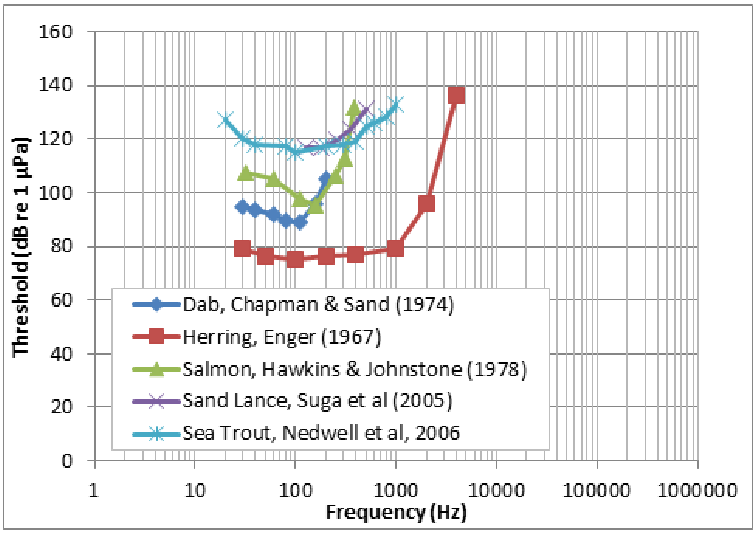

Figure 5-1 Comparison of hearing thresholds for species of fish

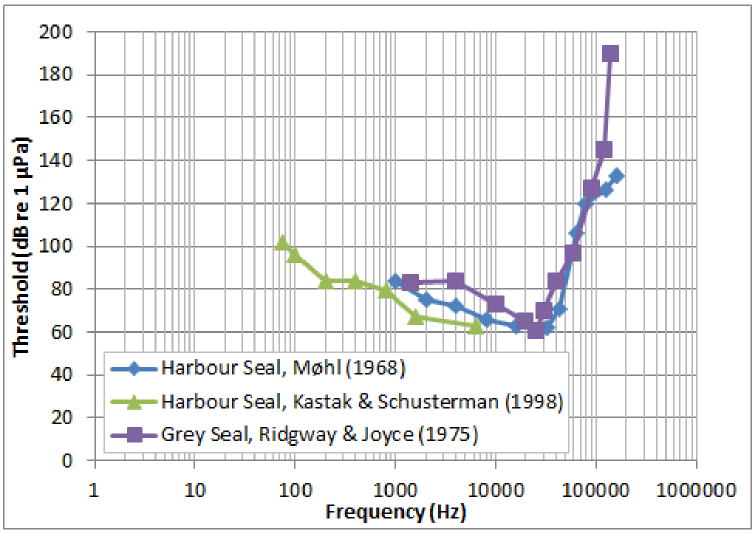

Figure 5-2 Comparison of hearing thresholds for species of marine mammal

Based on a large body of measurements of fish avoidance to noise (Maes *et al*, 2004), and from re-analysis of marine mammal behavioural response to underwater sound using the dB_{ht}(*Species*) metric, the following assessment criteria (Table 5-1) were published by the Department of Business, Enterprise and Regulatory Reform (BERR) (Nedwell *et al*, 2007) to assess the potential impact of underwater noise to marine species. In essence, Nedwell *et al* (2007) suggests the use of criteria which follow a similar approach as used to assess human response to noise (e.g. the dB(A)).

Table 5-1 Assessment criteria used in this study to assess the potential impact of underwater noise on marine species

Level in dB_{ht}(*Species*)	**Effect**
Above 130	Possibilty of traumatic hearing damage from a single event
90 and above	Strong avoidance reaction be virtually all individuals
75 and above	Some avoidance reaction by the majority of individuals, but habituation or context may limit effect.*
*In the presence of another biological imperative (such as migration to breeding or feeding grounds or avoiding a predator) individuals may not exhibit any behavioural reaction to the noise source.	

5.3.3 M-Weighted SELs

Southall *et al* (2007) presents a set of interim criteria for the levels of underwater noise that may lead to auditory injury in marine mammals based on M-Weighted SELs and peak SPLs. These criteria are presented in Table 5-2. Instead of using species specific audiograms to determine hearing sensitivity in marine mammals (as is the case of the dB_{ht}(*Species*)), the criteria proposed by Southall *et* al (2007) groups marine mammals into four main “M-Weighting” groups. These groups are low, mid and high frequency cetaceans and pinnipeds (in water).

Table 5-2 Proposed injury criteria for various marine mammal groups (after Southall, et al, 2007)

Marine mammal group	**Sound type**		
	Single pulse	**Multiple pulses**	**Non-pulses**
Low, Mid, and High Frequency Cetaceans			
Sound Pressure Level	230 dB re. 1 µPa (peak)	230 dB re. 1 µPa (peak)	230 dB re. 1 µPa (peak)
Sound Exposure Level	198 dB re. 1 $\mu Pa^2 s$ (M)	198 dB re. 1 $\mu Pa^2 s$ (M)	215 dB re. 1 $\mu Pa^2 s$ (M)
Pinnipeds (in water)			
Sound Pressure Level	218 dB re. 1 µPa (peak)	218 dB re. 1 µPa (peak)	218 dB re. 1 µPa (peak)
Sound Exposure Level	186 dB re. 1 $\mu Pa^2 s$ (M_{pw})	186 dB re. 1 $\mu Pa^2 s$ (M_{pw})	203 dB re. 1 $\mu Pa^2 s$ (M_{pw})

In order to obtain the weighted sound levels the data are first filtered using the proposed filter responses presented in Southall *et al* (2007), then the sound exposure level is calculated. Table 5-3 presents a summary of the various marine mammal groups, the suggested frequency range of hearing of each, and example species.

In this study only pinnipeds (in water) have been considered, as only harbour and grey seal have been identified as marine mammals of importance at the site.

Table 5-3 Functional marine mammal groups, their assumed auditory bandwidth of hearing, and genera presented in each group (reproduced from Southall et al, 2007)

Functional hearing group	**Estimated auditory bandwidth**	**Genera represented**	**Expample species**
Low frequency cetaceans	7 Hz to 22 kHz	Balaena, Caperea, Eschrichtius, Megaptera, Balaenoptera (13 species/subspecies)	Grey whale, right whale, humpback whale, minke whale
Mid frequency cetaceans	150 Hz to 160 kHz	Steno, Sousa, Sotalia, Tursiops, Stenella, Delphinus, Lagenodelphis, Lagenorhynchus, Lissodelphis, Grampus, Peponocephala, Feresa, Pseudorca, Orcinus, Globicephala, Orcaella, Physeter, Delphinapterus, Monodon, Ziphius, Berardius, Tasmacetus, Hyperoodon, Mesoplodon (57 species/subspecies)	Bottlenose dolphin, striped dolphin, killer whale, sperm whale
High frequency cetaceans	200 Hz to 180 kHz	Phocoena, Neophocaena, Phocoenoides, Platanista, Inia, Kogia, Lipotes, Pontoporia, Cephalorhynchus (20 species/subspecies)	Harbour porpoise, river dolphins, Hector's dolphin
Pinnipeds (in water)	75 Hz to 75 kHz	Arctocephalus, Callorhinus, Zalophus, Eumetopias, Neophoca, Phocarctos, Otaria, Erignathus, Phoca, Pusa, Halichoerus, Histriophoca, Pagophilus, Cystophora, Monachus, Mirounga, Leptonychotes, Ommatophoca, Lobodon, Hydrurga, and Odobenus (41 species/subspecies)	Fur seal, harbour (common) seal, grey seal

Southall *et al* (2007) also discuss the levels of underwater noise that may cause a behavioural avoidance response in marine species. 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 the basis for the Joint Nature Conservation Committee (JNCC) guidance document on the deliberate disturbance of marine mammals (JNCC, 2009). In the document the various severity ratings are summarised as “relatively minor and/or brief, score 0-3; with higher potential to affect feeding, reproduction, or survival, score 4-6; and considered likely to affect these life functions, score 7-9”. It is also noted 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. Generally the guidance indicates that there is a greater risk of a disturbance offence being committed if the observable effect ranks as 5 or above on the Southall *et al* (2007) severity scale.

Whereas 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.

6 Interpretation of results

6.1 Introduction

The following sections discuss the modelling results (Section 3) in terms of noise metrics. This discussion will help guide the assessment of environmental impact to marine species from impact piling and dredging related noise.

6.2 Unweighted metrics

The Source Level for the noise from impact piling operations of a 914mm diameter pile, using a hammer with a maximum blow energy of 125kJ, was estimated to be 223.5 dB re 1 µPa @ 1 m (SPL_{peak}). The Source Level for the impact piling of a 2000 mm diameter pile, using a maximum blow energy of 305kJ, was estimated to be 232.8 dB re 1 µPa @ 1 m (SPL_{peak}). The estimated source levels for both pile diameters exceed the 220 dB re 1 µPa (SPL_{peak}) criteria for physical injury (Parvin *et al*, 2007). The 240 dB re 1 µPa (SPL_{peak}) criteria for lethal effect is not predicted to be reached for the proposed impact piling operations. Table 6-1 and Table 6-2 present a summary of impact ranges to which various unweighted criteria are estimated to extend. The maximum range to which 220 dB re 1 µPa (SPL_{peak}) extends, indicating physical injury, is 4 m for the 914mm pile and 8m for the 2000mm pile. The 206 dB re 1 µPa (SPL_{peak}) criteria for fish injury (FHWG, 2008) is predicted to be a maximum of 10m for 914mm pile and 36m for 2000mm pile. The maximum impact range for the 200 dB re 1 µPa (SPL_{peak}) criteria, where startle reactions in fish have been observed by McCauley *et al,* 2000, is predicted to extend to 22m for 914mm pile and 84m for 2000mm pile.

Table 6-1 Summary of the modelled ranges for unweighted peak sound pressure levels for impact piling operations of a 914mm diameter pile

Criteria and Effect (914 mm/125 kJ)	**Species**	**Max Range**	**Min Range**	**Mean Range**
220 dB re 1 µPa (SPL_{peak}) (Physical injury)	All	4m	2m	3m
206 dB re 1 µPa (SPL_{peak}) (Physical injury)	Fish	10m	8m	9m
200 dB re 1 µPa (SPL_{peak}) (Behavioral effect)	Fish	22m	18m	20m

Table 6-2 Summary of the modelled ranges for unweighted peak sound pressure levels for impact piling operations of a 2000mm diameter pile

Criteria and Effect (2000 mm/305 kJ)	**Species**	**Max Range**	**Min Range**	**Mean Range**
220 dB re 1 µPa (SPL_{peak}) (Physical injury)	All	8 m	6 m	7 m
206 dB re 1 µPa (SPL_{peak}) (Physical injury)	Fish	36 m	20 m*	28 m
200 dB re 1 µPa (SPL_{peak}) (Behavioral effect)	Fish	84 m	20 m*	61 m

The source levels for the noise from dredging operations, using a backhoe dredger was estimated to be 165 dB re 1 µPa @ 1 m (SPL_{RMS}) and for a suction dredger was estimated to be 183 dB re 1 µPa @ 1 m (SPL_{RMS}). These source levels are all below the criteria discussed above in relation to impact piling.

6.3 The dB_{ht}(*Species*)

6.3.1 Auditory injury

The 130 dB_{ht}(*Species*) perceived level is used to indicate traumatic hearing damage over a very short exposure time. Table 6-3 shows the ranges to which traumatic hearing damage may occur. Herring and harbour seal are seen to have the greatest ranges for 130 dB_{ht} which are seen to extend to a maximum of 18m and 34m for the 914mm pile and for the 2000mm pile a maximum range of 56m and 62m, respectively. The dB_{ht} source levels for the other species are not estimated to exceed the 130 dB_{ht} criteria.

The modelled dB_{ht}(*Species*) sound propagation for backhoe and suction dredging are not estimated to reach the level at which traumatic hearing damage is likely to occur for any species.

Table 6-3 Summary of the modelled ranges for 130 dB_{ht}(Species) levels for impact piling operations

130 dB_{ht}(*Species*)		**Impact Piling (914 mm/125 kJ)**		**Impact Piling (2000 mm/305 kJ)**	
		North Position	**South Position**	**North Position**	**South Position**
Dab	**Max**	< 2m	< 2m	6m	6m
	Min	< 2m	< 2m	4m	4m
	Mean	< 2m	< 2m	5m	5m
Herring	**Max**	16m	18m	46m	56m
	Min	14m	14m	24m	20m
	Mean	15m	17m	41m	45m
Salmon	**Max**	< 2m	< 2m	4m	4m
	Min	< 2m	< 2m	2m	2m
	Mean	< 2m	< 2m	3m	3m
Sand Lance	**Max**	< 2m	< 2m	< 2m	< 2m
	Min	< 2m	< 2m	< 2m	< 2m
	Mean	< 2m	< 2m	< 2m	< 2m
Sea Trout	**Max**	< 2m	< 2m	< 2m	< 2m
	Min	< 2m	< 2m	< 2m	< 2m
	Mean	< 2m	< 2m	< 2m	< 2m
Harbour Seal	**Max**	32m	34m	56m	62m
	Min	24m	20m	24m	20m
	Mean	29m	30m	47m	50m

6.3.2 Behavioural response: impact piling

Table 6-4 and Table 6-5 present a comparison of estimated 90 and 75 dB_{ht}(*Species*) impact ranges for behavioural response for the species of interest from impact piling operations. Maximum, minimum and mean ranges are presented for both North and South modelling positions.

As seen with the unweighted levels presented in Section 3-2, the minimum range reaches a limit (24 m at the North position and 20m at the South position, indicated by the *). From Table 6-4 it can be seen that the estimated impact ranges from impact piling a 914mm diameter pile are expected to be less than 400m for dab, salmon, sand lance and sea trout.

Table 6-5 shows that for the impact piling of a 2000mm diameter pile, the estimated impact ranges are seen to reach a maximum of 2.89km for dab and 1.80km for salmon with the maximum ranges for sand lance and sea trout not exceeding 250m. The largest impact ranges are predicted for herring and harbour seal of 4.89km, where 75 dB_{ht} impact ranges extend to the river bank for all 180 modelled transects (where the limit was reached for all transects is indicated by ** next to the maximum range).

Figure 6-1 to Figure 6-12 present the ranges in Table 6-4 and Table 6-5 in the form of contour maps. It can be seen that the impact ranges for the South position are greater for all species. Figure 6-2, Figure 6-6**,** Figure 6-8 and Figure 6-12 again show that the impact ranges for herring and harbour seal are the greatest. Note that the 130 dB_{ht}(*Species*) contours are not visible at the scale on these figures because they cover a very small area.

Table 6-4 Summary of the modelled ranges for 90 and 75 dB_{ht}(Species) levels for impact piling of a 914mm diameter pile (see previous section for explanation of * and **)

Impact Piling (914 mm/125 kJ)		**North Position**		**South Position**	
		90 dB_{ht}(*Species*)	**75 dB_{ht}(*Species*)**	**90 dB_{ht}(*Species*)**	**75 dB_{ht}(*Species*)**
Dab	**Max**	36m	220m	40m	260m
	Min	24m*	24m*	20m*	20m*
	Mean	32m	124m	34m	150m
Herring	**Max**	1.95km	2.75km**	2.37km	4.89km**
	Min	24m*	24m*	20m*	20m*
	Mean	480m	510m	550m	630m
Salmon	**Max**	40m	270m	54m	390m
	Min	24m*	24m*	20m*	20m*
	Mean	35m	140m	42m	210m
Sand Lance	**Max**	12m	60m	14m	80m
	Min	10m	24m*	10m	20m*
	Mean	11m	49m	11m	58m
Sea Trout	**Max**	14m	72m	16m	90m
	Min	12m	24m*	14m	20m*
	Mean	13m	55m	15m	65m
Harbour Seal	**Max**	2.50km	2.75km**	3.01km	4.89km
	Min	24m*	24m*	20m*	20m*
	Mean	500m	510m	580m	630m

Table 6-5 Summary of the modelled ranges for 90 and 75 dB$_{ht}$(Species) levels for impact piling of a 2000 mm diameter pile (see previous section for explanation of * and **)

Impact Piling (2000 mm/305 kJ)		**North Position**		**South Position**	
		90 dB$_{ht}$(*Species*)	**75 dB$_{ht}$(*Species*)**	**90 dB$_{ht}$(*Species*)**	**75 dB$_{ht}$(*Species*)**
Dab	**Max**	460 m	2.30 km	520 m	2.89 km
	Min	24 m*	24 m*	20 m*	20 m*
	Mean	220 m	500 m	280 m	580 m
Herring	**Max**	2.75 km**	2.75 km**	4.89 km**	4.89 km**
	Min	24 m*	24 m*	20 m*	20 m*
	Mean	510 m	510 m	630 m	630 m
Salmon	**Max**	200 m	1.23 km	290 m	1.80 km
	Min	24 m*	24 m*	20 m*	20 m*
	Mean	110 m	410 m	160 m	500 m
Sand Lance	**Max**	26 m	180 m	32 m	240 m
	Min	22 m	24 m*	20 m*	20 m*
	Mean	24 m	100 m	28 m	140 m
Sea Trout	**Max**	46 m	290 m	56 m	360 m
	Min	24 m*	24 m*	20 m*	20 m*
	Mean	40 m	150 m	44 m	200 m
Harbour Seal	**Max**	2.75 km**	2.75 km**	4.47 km	4.89 km**
	Min	24 m*	24 m*	20 m*	20 m*
	Mean	510 m	510 m	620 m	630 m

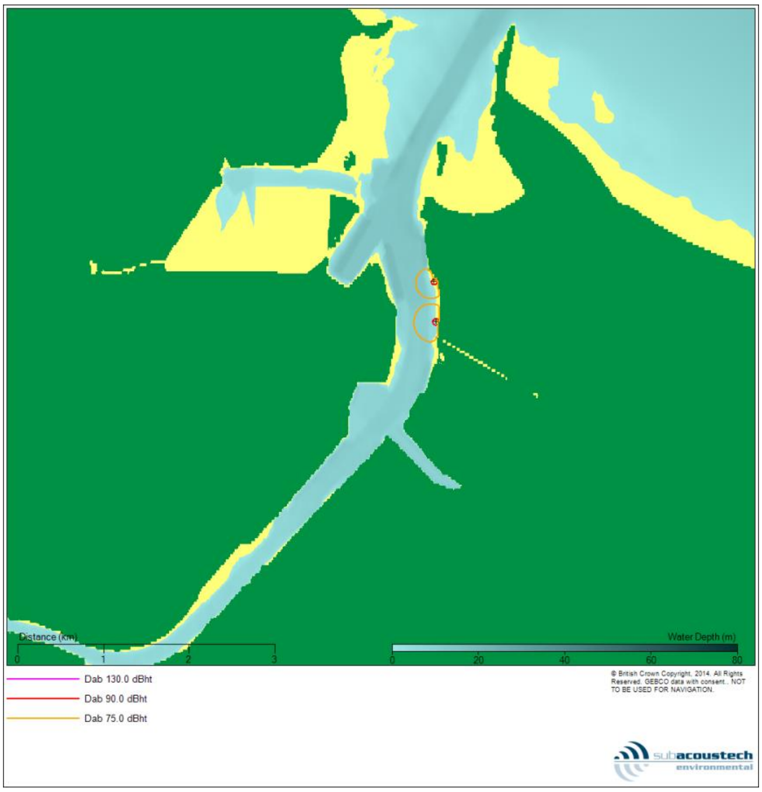

Figure 6-1 Contour plot showing the predicted 90 and 75 dB$_{ht}$ levels for dab for impact piling operations using 914mm diameter pile and blow energy of 125 kJ

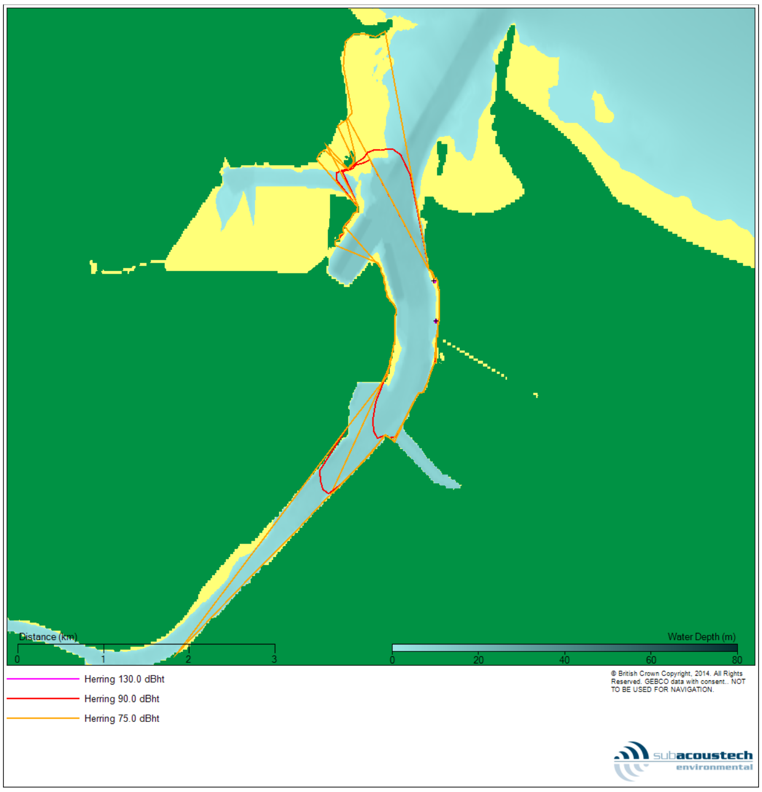

Figure 6-2 Contour plot showing the predicted 130, 90 and 75 dB$_{ht}$ levels for herring for impact piling operations using 914mm diameter pile and blow energy of 125 kJ

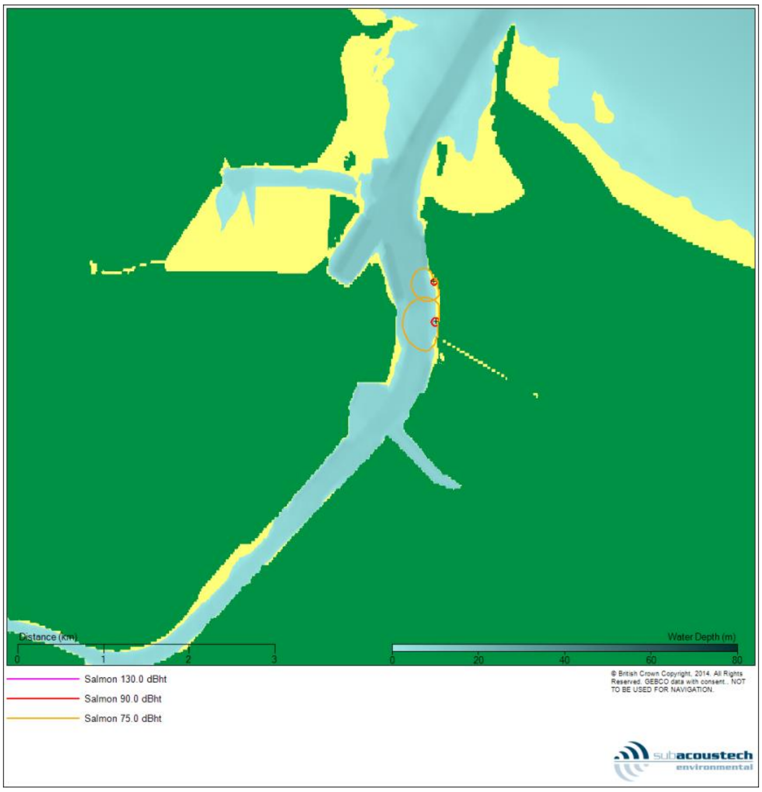

Figure 6-3 Contour plot showing the predicted 90 and 75 dB$_{ht}$ levels for salmon for impact piling operations using 914mm diameter pile and blow energy of 125 kJ

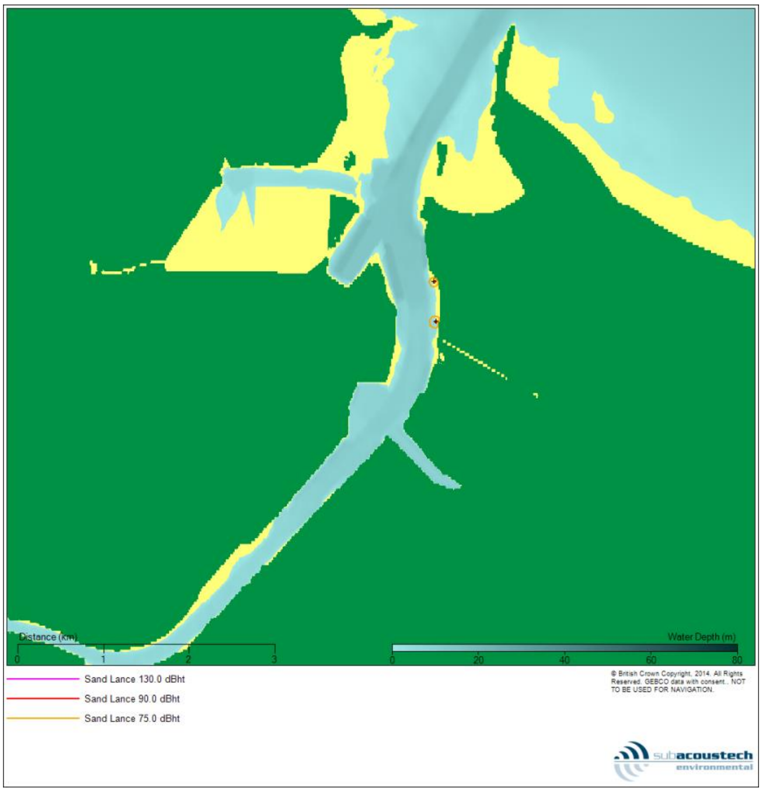

Figure 6-4 Contour plot showing the predicted 90 and 75 dB$_{ht}$ levels for sand lance for impact piling operations using 914mm diameter pile and blow energy of 125 kJ

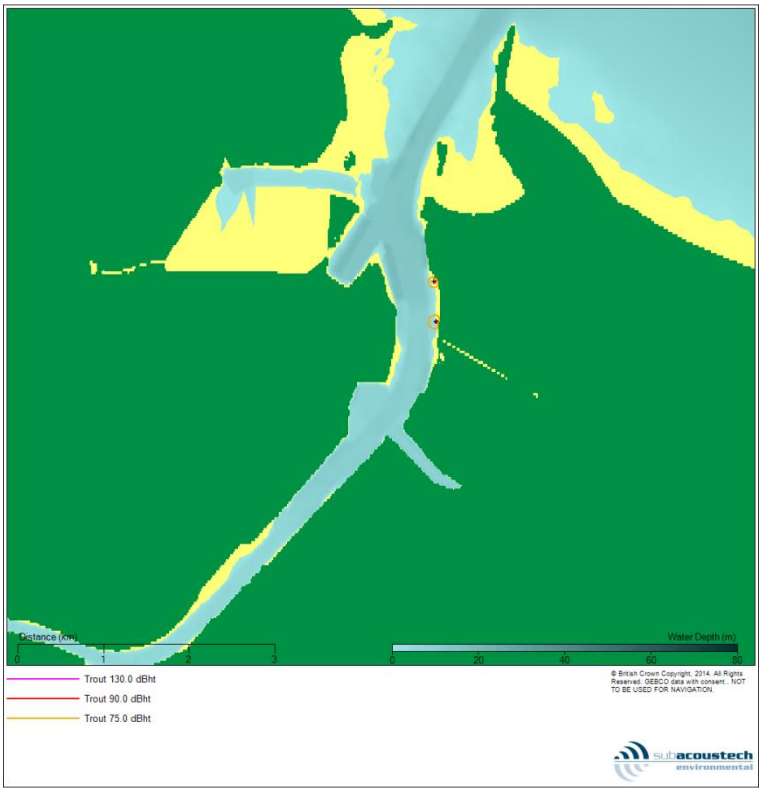

Figure 6-5 Contour plot showing the predicted 90 and 75 dB$_{ht}$ levels for trout for impact piling operations using 914mm diameter pile and blow energy of 125 kJ

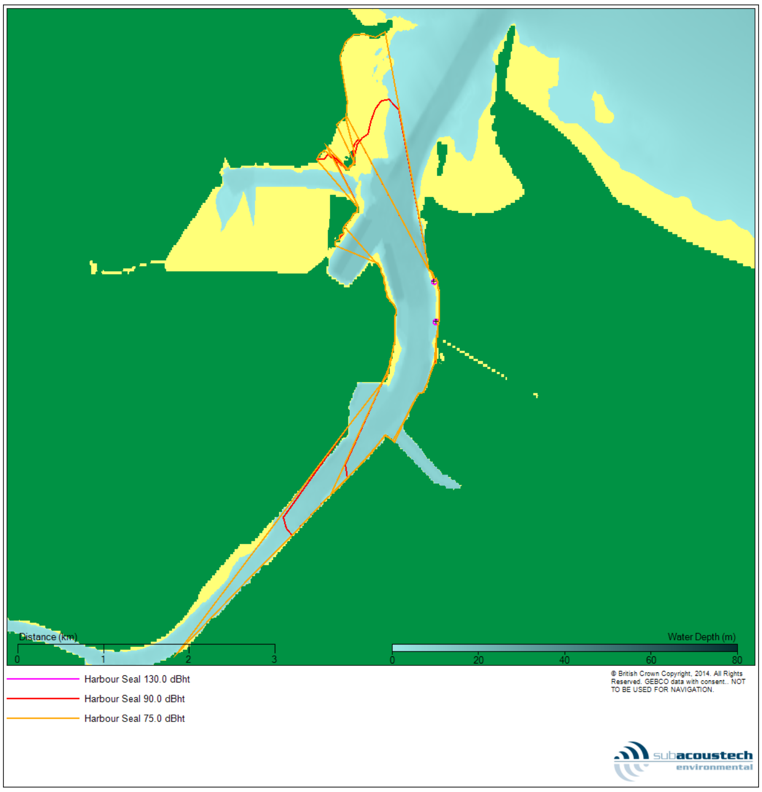

Figure 6-6 Contour plot showing the predicted 130, 90 and 75 dB$_{ht}$ levels for harbour seal for impact piling operations using 914mm diameter pile and blow energy of 125 kJ

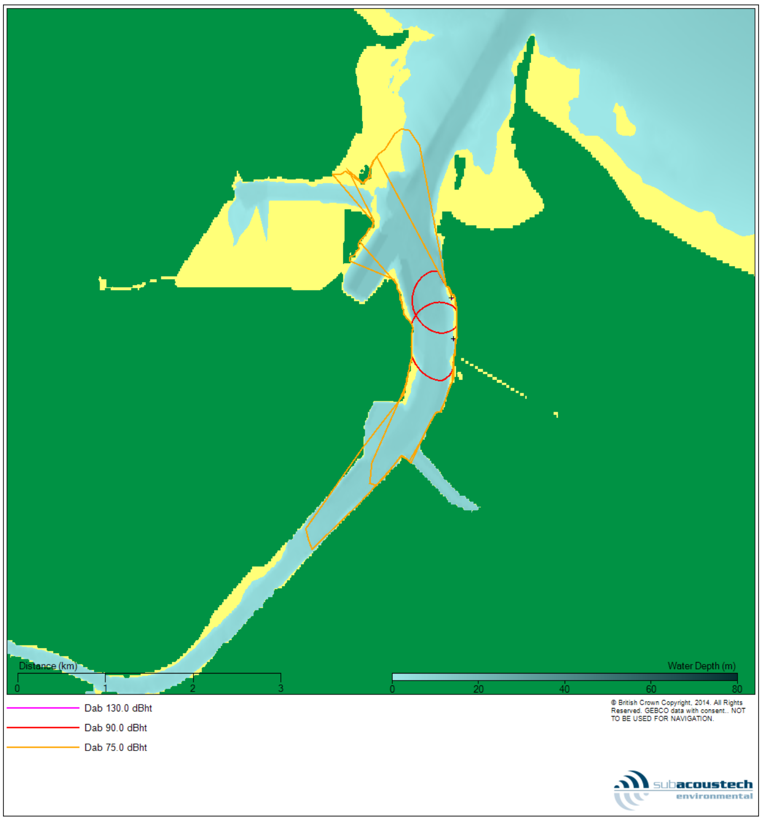

Figure 6-7 Contour plot showing the predicted 90 and 75 dB_{ht} levels for dab for impact piling operations using 2000mm diameter pile and blow energy of 305 kJ

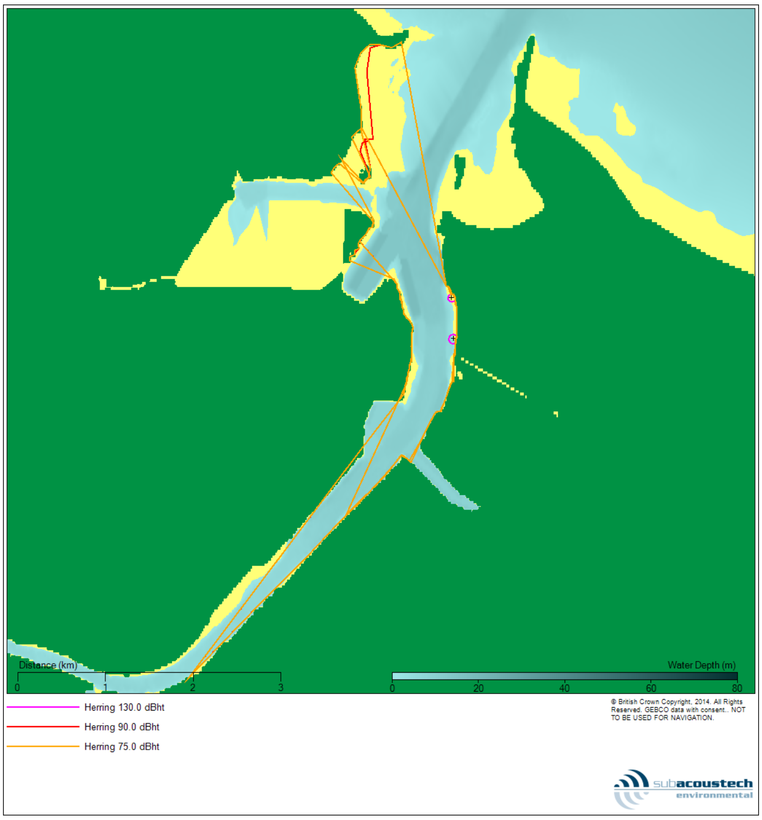

Figure 6-8 Contour plot showing the predicted 130, 90 and 75 dB_{ht} levels for herring for impact piling operations using 2000mm diameter pile and blow energy of 305 kJ

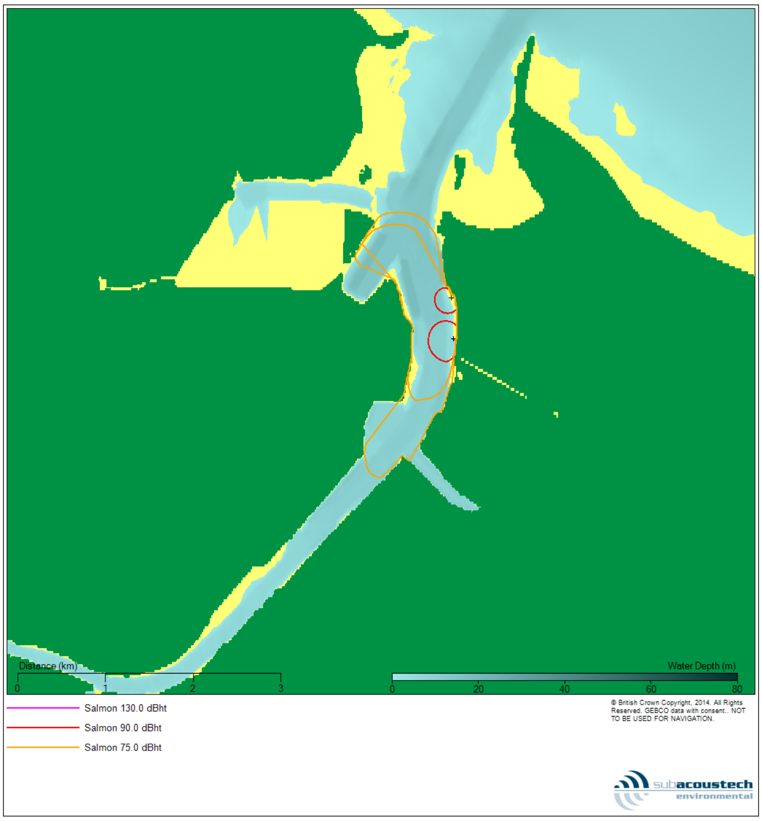

Figure 6-9 Contour plot showing the predicted 90 and 75 dB$_{ht}$ levels for salmon for impact piling operations using 2000mm diameter pile and blow energy of 305 kJ

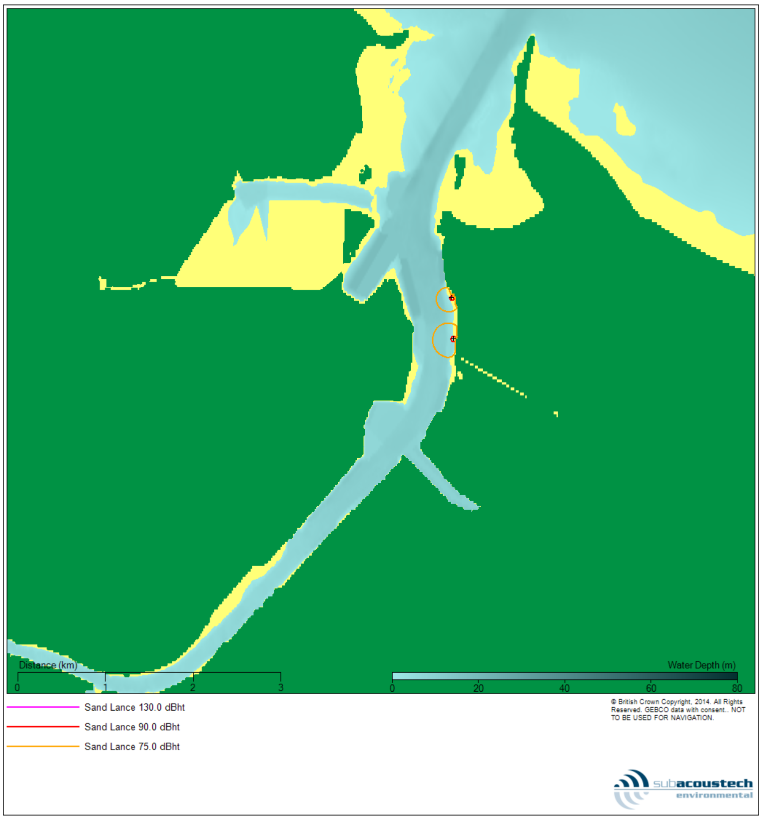

Figure 6-10 Contour plot showing the predicted 90 and 75 dB$_{ht}$ levels for sand lance for impact piling operations using 2000mm diameter pile and blow energy of 305 kJ

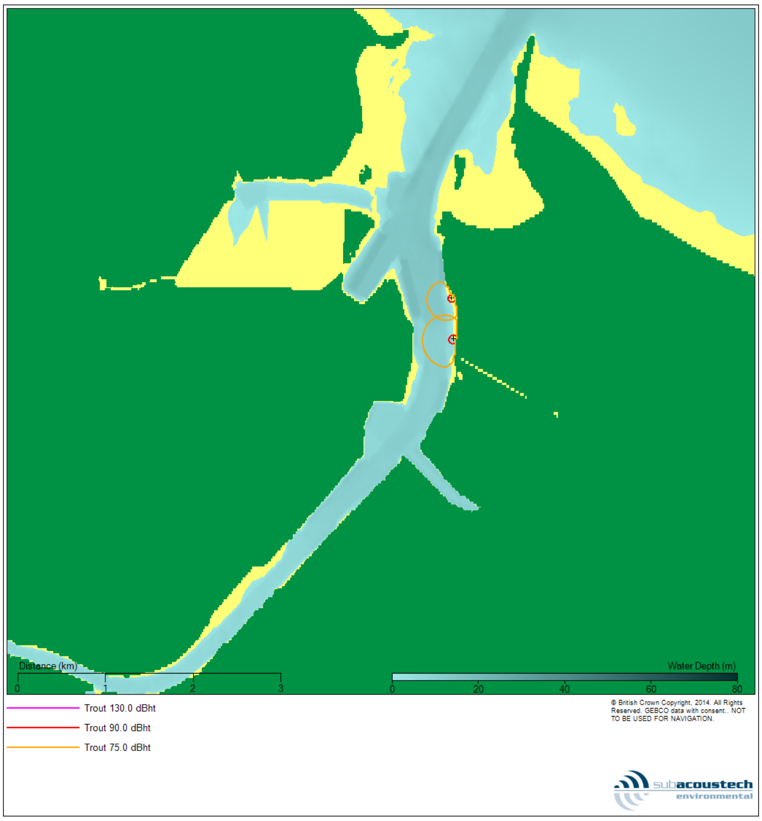

Figure 6-11 Contour plot showing the predicted 90 and 75 dB$_{ht}$ levels for trout for impact piling operations using 2000mm diameter pile and blow energy of 305 kJ

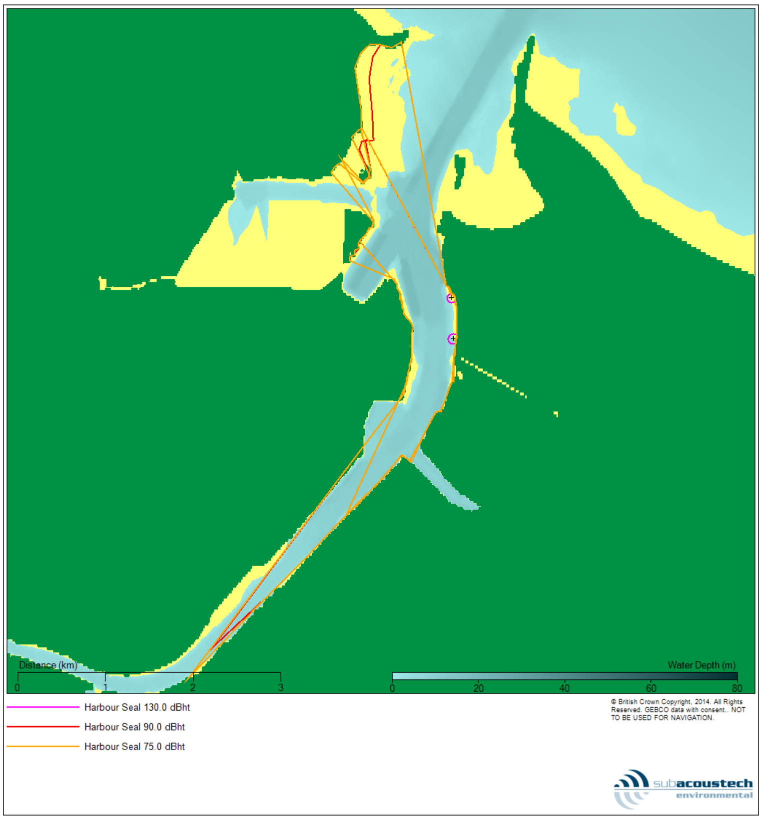

Figure 6-12 Contour plot showing the predicted 130, 90 and 75 dB$_{ht}$ levels for harbour seal for impact piling operations using 2000mm diameter pile and blow energy of 305 kJ

6.3.3 Behavioural response: backhoe and suction dredging noise

Table 6-6 presents a comparison of estimate for 90 dB_{ht} and 75 dB_{ht} impact ranges for behavioural response for the species of interest from dredging activities using a backhoe dredger and a suction dredger. Maximum, minimum and mean ranges are presented for both dredging types. The impact ranges for backhoe dredging are all seen to be 10m or less. The impact ranges for suction dredging are similar for all species except herring. The maximum 75 dB_{ht} impact range for herring where significant avoidance may occur is estimated to be 330m.

Figure 6-13 and Figure 6-14 show the perceived dredging noise level versus ranges for each species along each of the three modelled transects.

Table 6-6 Summary of the modelled ranges for 90 and 75 dB_{ht}(Species) levels for backhoe and suction dredging operations

		Backhoe Dredging		Suction Dredging	
		90 dB_{ht}	**75 dB_{ht}**	**90 dB_{ht}**	**75 dB_{ht}**
Dab	**Max**	< 5 m	< 5 m	< 5 m	15 m
	Min	< 5 m	< 5 m	< 5 m	10 m
	Mean	< 5 m	< 5 m	< 5 m	13 m
Herring	**Max**	< 5 m	10 m	30 m	330 m
	Min	< 5 m	10 m	30 m	165 m
	Mean	< 5 m	10 m	30 m	250 m
Salmon	**Max**	< 5 m	< 5 m	< 5 m	10 m
	Min	< 5 m	< 5 m	< 5 m	10 m
	Mean	< 5 m	< 5 m	< 5 m	10 m
Sand Lance	**Max**	< 5 m	< 5 m	< 5 m	10 m
	Min	< 5 m	< 5 m	< 5 m	5 m
	Mean	< 5 m	< 5 m	< 5 m	8 m
Sea Trout	**Max**	< 5 m	< 5 m	< 5 m	< 5 m
	Min	< 5 m	< 5 m	< 5 m	< 5 m
	Mean	< 5 m	< 5 m	< 5 m	< 5 m
Harbour Seal	**Max**	< 5 m	< 5 m	< 5 m	10 m
	Min	< 5 m	< 5 m	< 5 m	10 m
	Mean	< 5 m	< 5 m	< 5 m	10 m

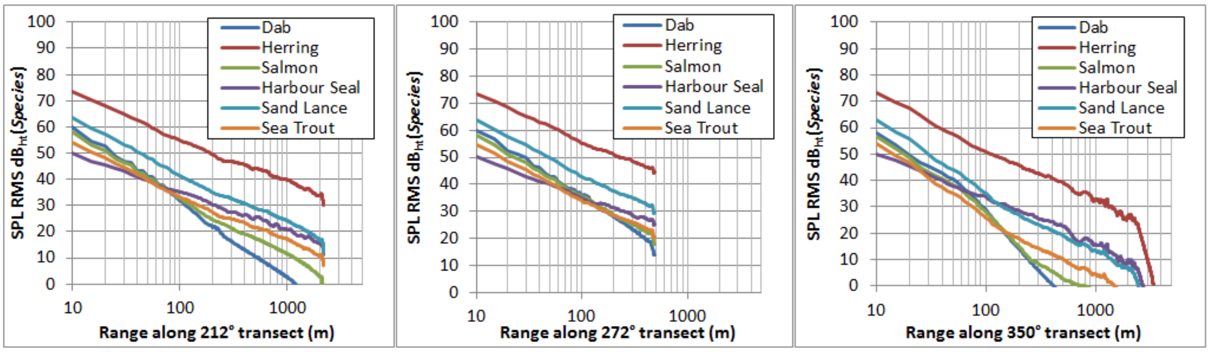

Figure 6-13 Level versus range plots showing the predicted dB_{ht}(Species) levels from backhoe dredging along the three modelled transects

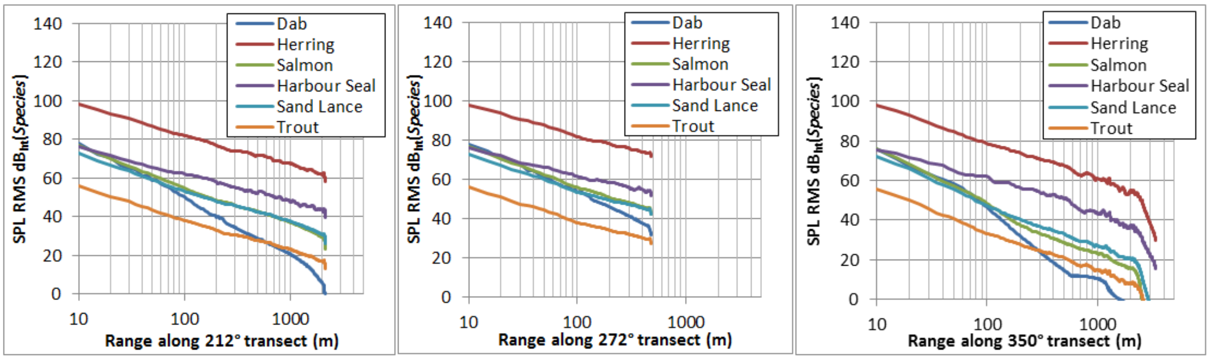

Figure 6-14 Level versus range plots showing the predicted dB$_{ht}$(Species) levels from suction dredging along the three modelled transects

6.4 M-Weighted SELs

The accumulated exposure to sound leading to the potential onset of auditory injury for marine mammals has been assessed using the criteria proposed by Southall *et al* (2007), using M-Weighted SELs. The multiple pulse results have been created by assuming a receptor flees from the noise source at speed of 1.5m/s. It has been assumed herein that one pile will take 90 minutes to install, with six piles being installed in a 12 hour period.

Table 6-7 shows the ranges to which 186 dB re 1 µPa^{2}s for pinnipeds (in water) are likely to extend, for single pulse exposure and for exposure over multiple pulses, based on the assumptions above, for the impact piling of a 914mm diameter pile. The maximum range for single pulse is seen to be 6m at both positions for the 914mm diameter pile. The maximum range for an exposure to multiple pulses, assuming the animal is fleeing, is 310m at the south position. Table 6-8 shows the ranges for the impact piling of a 2000mm diameter pile. The maximum range for single pulse of a 2000mm pile is seen to be 16m at the south position. For an exposure to multiple pulses, assuming a fleeing animal, the maximum range is 880m at the south position.

Table 6-7 Summary of impact ranges from impact piling operations for a 914mm diameter pile using Southall criteria SEL of 186 dB for pinnipeds (in water)

Pinnipeds (in water) 186 dB re 1 µPa^{2}s (M$_{pw}$) (914 mm/125 kJ)	North position		South position	
	Single pulse	Multiple pulse	Single pulse	Multiple pulse
Maximum Range	6m	130m	6m	310m
Minimum Range	4m	100m	4m	100m
Mean Range	5m	110m	5m	130m

Table 6-8 Summary of impact ranges from impact piling operations for a 2000mm diameter pile using Southall criteria SEL of 186 dB for pinnipeds (in water)

Pinnipeds (in water) 186 dB re 1 µPa^{2}s (M$_{pw}$) (2000 mm/305 kJ)	North position		South position	
	Single pulse	Multiple pulse	Single pulse	Multiple pulse
Maximum Range	14m	460m	16m	880m
Minimum Range	12m	100m	12m	100m
Mean Range	13m	190m	15m	260m

7 Summary and conclusions

Subacoustech Environmental Ltd has undertaken a study on behalf of Haskoning DHV UK Ltd to assess the potential impacts of underwater noise during construction activities associated with the proposed York Potash Harbour Facilities project in the Tees Estuary. The construction activities that have been assessed include impact piling, suction dredging and backhoe dredging. The modelling of underwater noise has been carried out using Subacoustech Environmental's INSPIRE model and the RAMSGeo acoustic model. Underwater noise during the operational phase from increased vessel movements has also been considered. However, it has been shown to have minimal impact in raising the average SPL as there will be a maximum increase in vessel movements of less than 1.8% per year, equivalent to one vessel movement every two days.

Modelling of underwater noise form impact piling operations show that, using unweighted SPL_{peak} noise criteria, noise levels are not predicted to be high enough such that marine species will suffer a lethal effect. For the impact piling of a 914mm diameter pile physical traumatic injury could occur out to 4m for all marine species and 10m for species of fish with a maximum range of 22m at which a startle response is likely to be invoked in fish. For the impact piling of a 2000mm diameter pile physical traumatic injury could occur out to 8m for all marine species and 36m for species of fish, and a maximum range of 84m at which a startle response in fish is likely to be caused. Modelling of underwater noise from dredging operations shows that noise levels are not sufficient to reach the unweighted criteria for lethal effect, physical injury or behavioural response.

The largest estimated ranges out to which traumatic hearing damage may occur from impact piling using the 130 dB_{ht}(*Species*) criteria have been calculated to be a maximum of 18m for herring and 34m for harbour seal based on impact piling of a 914mm diameter pile. The maximum range for the impact piling of a 2000mm diameter pile was calculated to be 56m for herring and 62m for harbour seal. The dB_{ht} source levels for the remaining fish species are not estimated to exceed the 130 dB_{ht} criteria. The modelled dB_{ht}(*Species*) sound propagation for backhoe and suction dredging are not estimated to reach the level at which a traumatic hearing damage could occur.

The impact ranges for behavioural response are indicated using the 90 and 75 dB_{ht} perceived level criteria, where 90 dB_{ht} signifies a strong avoidance reaction of a species and 75 dB_{ht} signifies some avoidance, depending on context. Modelling for behavioural response, with respect to the 914mm diameter pile, shows that the largest impact ranges from impact piling are predicted to be for herring and harbour seal with ranges of 2.37km and 3.01km respectively, for 90 dB_{ht}. For 75 dB_{ht} the maximum range reached 4.89km for both herring and harbour seal, as all modelled transects reached the riverbank at this distance before falling below 75 dB_{ht} for these two species. The estimated behavioural impact ranges from impact piling operations are expected to be considerably lower for dab, salmon, sand lance and sea trout, with all dB_{ht} impact range less than 400m. For the impact piling of a 2000mm diameter pile, the estimated impact ranges are seen to reach a maximum of 2.89km for dab and 1.80km for salmon with the maximum ranges for sand lance and sea trout not exceeding 250m. The largest impact ranges are predicted for herring and harbour seal of 4.89km, where 75 dB_{ht} impact ranges extend to the river bank for all modelled transects

The 90 and 75 dB_{ht} impact ranges for backhoe dredging are all seen to be 10m or less. The impact ranges for suction dredging are similar for all species except herring. The maximum 75 dB_{ht} impact range for herring where significant avoidance may occur is estimated to be 330m.

Using the M-Weighted SEL for assessing auditory injury in marine mammals from impact piling of a 914m diameter pile, the ranges have been calculated for the 186 dB criteria for pinnipeds (in water) where the single pulse SEL impact range is calculated to be a maximum of 6 m. The maximum impact range for the multiple pulse SEL over the full piling duration is estimated to be 310 m, for an animal fleeing from the noise, where six piles are driven over the duration of 12 hours. Using the same criteria, the impact ranges for the modelled installation of a 2000mm diameter pile have been calculated to be 16m for the single pulse SEL and 880m for the multiple pulse SEL with the same assumptions made above.

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E473R0200	03	06/06/2014	Amendments
E473R0201	-	06/06/2014	First issue to client
E473R0201	02	17/06/2014	Addition of operational noise from vessel movements
E473R0201	03	23/06/2014	Comments addressed
E473R0202	-	23/06/2014	Second issue to client
E473R0202	01	07/07/2014	Returned with client comments
E473R0202	02	10/07/2014	Comments addressed
E473R0203	-	12/07/2014	Third issue – response to comments
E473R0203	01	28/10/2014	Additional modelling included
E473R0203	02	30/10/2014	Internal review
E473R0203	03	31/10/2014	Minor amendments
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