Annex D

# Sound Propagation Modelling and Environmental Impact Mitigation Strategy for Rhyl Flats Wind Farm

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## Abstract

QinetiQ has been tasked by Hayes-McKenzie Partnership to report on predicted underwater sound pressure levels during two stages in the development of an offshore wind farm in North Wales. The stages are the piledriving operation and the subsequent post-commission operation of the wind turbines. In addition, a high level mitigation strategy has been produced in order to assist in the minimisation of any potential impacts on the environment during the development of the wind farm.

Keywords: Propagation Modelling, SAFARI, Rhyl Flats, Wind Turbine, Environment, Mitigation, Strategy

## Executive summary

The proposed development at Rhyl Flats is an offshore wind farm containing up to 30 wind turbines. The turbines will be sited on a sandy bank a few kilometres off the North Wales coast and, in order to provide firm foundations for the subsequent building work, it is proposed that a number of concrete pilings be hammered into the subsea sediment. It is anticipated that sound pressure levels underwater during the development stage may be sufficient as to disturb the marine environment. Following completion of the wind farm construction, each turbine will generate electricity and this will be fed into the national grid. However, as the turbine blades rotate, it is anticipated that vibrations could arise and these would be transmitted down the wind tower and in to the underwater environment. Once again, subsequent noise levels could be sufficient to disturb marine life.

The extensive nature of this kind of activity requires that an assessment of the potential impact on the environment be determined. An essential part of the Environmental Impact Assessment process is to propose appropriate mitigation strategies that can reduce environmental risk to an acceptable level whilst still fulfilling the objectives of the engineering project. In the event that the proposed development does, indeed, impact on the environment, suitable mitigation procedures are required to be implemented in order to minimise subsequent disturbance.

The first stage in determining the scale of any potential impact on the environment is to determine sound pressure levels underwater during the construction and post-commission phases. This document reports on the findings from a number of computer model simulations using frequencies appropriate to both piledriving and wind turbine operations and for this, the underwater acoustic propagation computer program SAFARI has been used.

The modelling results show that:

- sound pressure levels during the piledriving phase are likely to remain above background noise levels over a range of 20 km;
- sound pressure levels during the post-commission stage for most of the frequencies considered in the range 30-1600 Hz are likely to fall below background noise levels at ranges of a few metres. The one exception to this is the 400 Hz component where the SPL is likely to remain above the background noise level up to a range of 5 km.

Environmental risk mitigation is possible, which, in relation to the construction and operation of the wind farm at Rhyl Flats, will reduce but not negate the environmental risks. However, although the risks remain numerous and varied, they are generally considered manageable.

This work has been carried out for the Hayes-McKenzie Partnership under contract SSDW4/577.

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## 1 Introduction

1.1 Rhyl Flats, off the north Wales coast is the chosen site for an offshore windfarm. A total of 30 wind towers are to be sited some 6-10 kilometres offshore in varying water depths.

1.2 Although wind power is generally considered to be an environmentally friendly method of generating electricity, two stages during the construction and subsequent operation phase may have the potential to create an impact on the environment due to the transmission of sound underwater. The objective of this program of work is to predict likely underwater sound pressure levels for frequencies relating to the piledriving stage and to the post-commission, operating stage.

## 2 Description of operations

2.1 The piledriving stage consists of a number of tubular steel piles 3.5 - 4.5 m in diameter and up to 30 m long, being driven through the relatively soft seabed sediment until contact is made with the underlying bedrock. The purpose of this operation is to provide a firm and secure foundation for subsequent building work.

2.2 Currently there is very little data available relating to source levels for piledriving. Richardson *et al*. (1995) states that impulsive hammering sounds may be as high as 131-135 dB re 1 μPa at a range of 1 km from the source and that the transient signals had strongest components at frequencies of 30-40 Hz and ~100 Hz. Using a spherical spreading argument for the propagation of sound, this suggests that source levels could be of the order of 195 dB re 1 μPa at 1 m. Strictly, spherical spreading is only applicable in deep water; Richardson *et al*. (1995) makes no comment on water depth and fails to provide any information that would allow for the determination of an appropriate propagation law. The Pile Installation Demonstration Project (PIDP 2001) gave sound pressure levels of 185-196 dB rms. and 197-207 linear-peak re 1 μPa at a distance of 109 m from the source and in a water depth of 1-6 m. Source levels were estimated at 225-236 dB rms. and 237-247 dB linear-peak re 1 μPa. It is assumed that the source levels quoted here are measured across a frequency band of 1-1000 Hz. In addition, measurements indicate that the peak of the acoustic energy was found to be around 130-150 Hz and for these frequencies, spectrum levels are estimated to be around 202 dB re 1 μPa/Hz.

2.3 For the case considered in this report, piledriving involves the hammering of a long, cylindrical steel structure into relatively soft undersea sediments. The force is applied to the top of the pile and it may be assumed that the ensuing noise is radiated into the water via two transmission paths. For the first path, the sound travels directly from the pile and into the water column while for the second path, the sound travels from the pile and into the seabed before being re-radiated back into the water column. Therefore, the piledriving operation may be represented by a vertical sound source with both cylindrical and end-fire radiation patterns and this is shown schematically in Figure 1. The radiation patterns may be compared with those from an underwater line array the source elements of which may be steered electronically so that a beam of sound is projected out of the end of the array (Urick 1983). In this example, the line array is often referred to as an end-fire array. The difficulty in modelling the pile as an end-fire array is related to the distribution of sound over the length of the sound source. For a sonar array, the source elements have a half wavelength spacing over the length of the array whereas the pile is continuous. It is likely that this would lead to differences in the subsequent radiated pattern of energy between pile and end-fire array, but with the modelling techniques currently available, any differences arising are unquantifiable.

2.4 During the construction phase subsequently modelled, the sound source is initially waterborne but becomes increasingly located in the sediment as the pile sinks lower through the seabed.

2.5 When finally in operation, the blades on each turbine will rotate at speeds of 9-15 rpm. Vibrations arising from the movement of the blades along with general turbine noise are transmitted down the tower and into the water where they may be detected as noise levels. Figure 2 shows that wind turbine noise in air is broadband in nature. However, as a large proportion of the acoustic energy is transmitted down the wind turbine tower from the drive train of the turbine, peaks of energy are found across a number of somewhat narrower bands, these being 30-90 Hz, 400 –800 Hz and 800-1600 Hz. The exact frequencies will be dependent upon the final turbine selected but are indicative of the range of frequencies that are radiated directly from a wind turbine tower.

## 3 Computer model

3.1 Over the last 30 years, many underwater acoustic propagation models have been developed (see e.g. Buckingham 1992, Etter 1996) but only one, SAFARI (Seismo-Acoustic Fast field Algorithm for Range-Independent environments), can deal with the main model requirement for this program of work, that being a sound source located in a solid layer.

3.2 SAFARI was developed at NATO-SACLANTCEN in 1985 (Schmidt, 1988). It consists of an algorithm for solving the depth-separated wave equation in general fluid/solid horizontally stratified media. The algorithm is solved numerically using the Fast Field Program developed by di Napoli *et al.* (1980). The program handles multiple sources and receivers simultaneously, deals with compressional, shear and interface waves at all ranges and provides an exact solution of the wave equation except within a range of a wavelength or so of the source. Running SAFARI requires a considerable level of care and expertise in order to obtain a convergent solution.

## 4 Geoacoustic model

4.1 British Geological Survey (1984) charts of the Rhyl Flats show that the seabed typically consists of a sand layer of thickness 1m overlying a gravelly sand layer 5 m thick lying on top of a semi-infinite basement. The ocean is isospeed having a sound velocity of 1487 m/s over a constant depth of 10 m. Hence, the model environment may be represented by a fluid medium representing the ocean being separated from a number of solid layers representing subsea sediments. The subsea layers have geoacoustic parameters representative of sand and gravelly sand and the basement rock has values typical of granite. Compressional and shear wave velocities and attenuations are given in Table 1.

| Layer | Thickness (m) | Relative Density | Velocity (m/s) | | Attenuation (dB/λ) | |
|---|---|---|---|---|---|---|
| | | | $c_p$ | $c_s$ | $\gamma_p$ | $\gamma_s$ |
| Water | 10 | 1.0 | 1487 | - | - | - |
| Sand | 1 | 2.0 | 1575 | 96 | 0.74 | 3.0 |
| Gravelly Sand | 5 | 1.9 | 16985 | 380 | 0.68 | 3.9 |
| Basement | ∝ | 2.4 | 3386 | 1768 | 1.4 | 2.1 |

*Table 1: Geoacoustic parameters for the Rhyl Flats site*

## 5 Background noise levels

5.1 The Rhyl Flats Wind Farm will be located in the southern part of the Irish Sea and this area has relatively high levels of background noise. Archived measurements of the 50 Hz shipping noise component show a level of 86 dB re 1 μPa/Hz. Figure 3 shows noise levels across all the frequencies of interest to the Rhyl Flats development and it will be seen that the background noise levels tend to be due to shipping noise at low frequencies (20-200 Hz) and to wind noise at frequencies up to around 10 kHz.

## 6 Results

6.1 The computer program SAFARI was run over a number of frequencies, these being 130-150 Hz for the piledriving and 30-90 Hz, 160 Hz, 250 Hz, 400-800 Hz and 800-1600 Hz for the wind-turbine operations. For each frequency, the sound pressure level (SPL) in the water was computed as a function of range and depth for a number of receptor depths. The SPL was subsequently compared with background noise levels. The results are presented in Figures 4 to 28.

## 7 Discussion of modelling results

### 7.1 Discussion of piledriving modelling results

7.1.1 The results for the piledriving operation are given in the form of plots of underwater SPL in dB, as a function of range. SPLs over a range of 20 km from the source are computed for the 130 Hz, 140 Hz and 150 Hz components of the noise arising from the piling operation for receptor depths of 3 m, 6 m and 9 m. Figure 4 shows the predicted SPL for a 30 Hz signal for a pile depth of 0 m below the seabed for each receptor depth over a range of 20 km while, for clarification purposes, the first 5 km of the transect is shown in Figure 4a. In each case, it will be seen that over a distance of approximately 5 km, the SPL can vary by up to 20 dB and this pattern is typical of multi-mode interference found at short ranges. At long range, the monotonic nature of the propagation function shows that the transmission of energy is dominated by the propagation of the first mode of energy only with higher modes being rapidly attenuated. Consequently, SPL at longer ranges does not fluctuate. Two further points may be made about the nature of the SPL. It will be seen that there is a small decrease in SPL as receptor depth increases and, as the piling depth increases, the SPL in the water at a given range, tends to increase. This may be explained in terms of the more effective coupling of acoustic energy into the basement rock with the result that less energy is therefore available for transmission through the water column. Also included is the background noise level $NL_{BG}$ at 130 Hz. At 130 Hz (and indeed, for all frequencies considered for the piling operation), background noise levels are predominantly due to shipping noise. It will be seen that the SPL remains above the $NL_{BG}$ over the entire range considered of 20 km.

7.1.2 Figure 5 shows the SPL for a piling depth of 2 m below the seabed. By comparison with the previous examples, it will be seen that the SPL at a given range and depth increases very slightly. Figures 6 and 7 show SPL for piling depths of 4 m and 6 m below the seabed respectively. Over the ranges considered, there is generally very little difference in SPLs at a given receptor location. In addition, the SPLs remain above the $NL_{BG}$ for all receptor depths and piling depths considered.

7.1.3 Figures 8 to 11 shows the predicted SPL for the 140 Hz signal and Figures 12 to 15 shows SPL for the 150 Hz component. The same general trends are in evidence for these examples as for the 30 Hz case. Over the first 2 km, the propagation losses vary by 20 dB and generally around 10 dB for the 140 Hz and 150 Hz signals respectively. In each case beyond around 5 km, multipath interference dies down, single mode propagation is approached with its attendant small fluctuations over range. The SPLs for both frequencies remain above the $NL_{BG}$ for all receptor depths considered.

### 7.2 Discussion of wind turbine modelling results

7.2.1 Noise levels generated by the wind turbine during post-commission operation were also computed. The results for the wind-turbine operation are given in the form of contour plots of underwater SPL in dB re 1 μPa as a function of range in km and depth in m. The SPL was plotted over a maximum range of 20 km and a maximum depth of 10 m. The range of the contour colours vary for each plot. The highest SPL considered corresponds to the source spectrum level at each frequency while the lowest corresponds to the ambient noise level in a 1 Hz band less 20 dB. The source spectrum levels (Hayes 2002) and ambient noise levels (Urick 1983) for each frequency modelled are given in Table 2. Also included is a description of the dominant component of the background noise: at the low frequencies, this is shipping noise while at the higher frequencies, this is wind noise for a wind speed around 10 knots. Clearly, as wind speed increases, the background noise level increases and the range at which a signal drops below the background level, falls. Conversely, the range at which a signal falls into the background noise, is at a maximum for zero wind speed, however, the wind turbines would not operate under these conditions. Archived measurements show that over the course of a year, the minimum average wind speed over the Rhyl Flats site is 10 knots, recorded during the summer months and around 18-20 knots during the winter months. Accordingly, it is the summer climatological conditions that have been modelled as this is deemed the most precautionary of all scenarios. The additional effect of rain noise over the frequencies considered, is negligible for all but the very heaviest of rainfall conditions.

| Frequency (Hz) | Spectral levels (dB re 1 μPa at 1 m/Hz) | Ambient noise (dB re 1 μPa/Hz) | Predominant noise component |
|---|---|---|---|
| 30 | 82.5 | 85 | Shipping |
| 50 | 74.7 | 86 | Shipping |
| 70 | 81.3 | 84 | Shipping |
| 90 | 83.2 | 81 | Shipping |
| 160 | 84.3 | 78 | Shipping |
| 250 | 82.4 | 74 | Wind noise |
| 400 | 78.8 | 68 | Wind noise |
| 600 | 67.8 | 61 | Wind noise |
| 800 | 64.1 | 56 | Wind noise |
| 1000 | 55.3 | 52 | Wind noise |
| 1200 | 49.8 | 48 | Wind noise |
| 1400 | 48.5 | 47 | Wind noise |
| 1600 | 47.3 | 46 | Wind noise |

*Table 2: Spectrum levels and ambient noise levels for representative wind turbine frequencies*

7.2.2 Figures 16, 17 and 18 show the modelled contours of SPL for the 30 Hz, 50 Hz and 70 Hz components of the wind turbine noise. In each case, the 1/3 octave band level is below the $NL_{BG}$ at the source position, hence, at frequencies lying in the range 30-70 Hz, the source is inaudible. The 90 Hz component, shown in Figure 19, falls below the background noise level at a range around a few metres. Hawkins (1973) shows that a number of fish species tend to have hearing that is most sensitive at frequencies around 160 - 250 Hz: the results show that the 160 Hz component (Figure 20) and the 250 Hz component (Figure 21) both fall below the $NL_{BG}$ at ranges around a few metres. SPLs for the 400 Hz component (Figure 22) fall below the $NL_{BG}$ at a range around 5 km while for all remaining frequency components considered (Figures 23-28), the SPLs fall below the $NL_{BG}$ at ranges less than 0.5 km.

## 8 Advice on mitigation measures that could be applied during construction and operation

### 8.1 Introduction

8.1.1 The construction and operation of the wind farm at Rhyl Flats has the potential for impacting adversely on the environment, through the introduction of sound energy into the water column. The environmental receptors that are likely to be sensitive to sound energy and may be adversely impacted by the construction and operation of the wind farm will include marine mammals, fish and birds. Humans may also be affected if they are diving, swimming or participating in water contact sports. It is possible that the sound levels that are generated could also affect invertebrates, crustacea, molluscs and marine flora and fauna in general. However, less is known about the sensitivity of these receptors to underwater sound.

8.1.2 The purpose of this section is to provide an overview of appropriate environmental mitigation and monitoring techniques. This is necessarily a generic strategy as the impact assessment, and baseline study of the environmental receptors and protected habitats is being performed under a separate contract.

## 8.2 Mitigation methods

### 8.2.1 Introduction

8.2.1.1 Environmental risk mitigation measures are designed to ensure that the risk of adverse effects on environmental receptors from an activity is minimised. Depending on the type, duration and location of the activity, a variety of methods can be used, singly or combined to reduce risk:

a. waterspace management,
b. time management,
c. acoustic deterrents,
d. acoustic shielding,
e. visual monitoring,
f. passive acoustic monitoring,
g. active acoustic monitoring.

These methods are described briefly below.

### 8.2.2 Waterspace management

8.2.2.1 A primary mitigation strategy is to ensure that sources of sound are deployed at a safe distance from humans and marine life. The wind farm site is fixed and so this can only be achieved by deterring human beings, fish, marine mammals or birds from approaching the area. Humans may be deterred from entering the area by ensuring that the public is aware of the potential dangers of the wind farm during construction and operation. Before construction takes place, advice should be passed to relevant authorities such as the Coast Guard; however, it is likely that such measures will be implemented as part of the normal Health and Safety procedures, that are applicable to this type of activity. Fish scarers, Acoustic Deterrent or Harassment Devices (ADDs or AHDs respectively) could, potentially, be used to deter biological receptors from entering or remaining within the volume of water affected. (See below).

### 8.2.3 Time management

8.2.3.1 Marine life usually exhibits seasonal trends and so animals may be particularly abundant or sensitive to anthropogenic activity at specific times during the year. In addition, the propagation of sound energy in the marine environment is controlled by the properties of the water column and so can show significant seasonal variation. An effective method of mitigation against the adverse environmental effects of wind farm construction is to time-manage the activities. This might involve moving the activities to another month or season when their impact will be lowered, or introducing time-breaks into the programme to allow animals to leave (or be moved from) the area, or to avoid harm when monitoring techniques are likely to be least effective. Re-scheduling could be short-term (hours), medium-term (days) or longer term (months).

8.2.3.2 Thus construction of the wind farm could, potentially, be rescheduled in order to have least impact on biological receptors. QinetiQ are unable however to comment on the validity of the approach as the assessment of environmental receptors is being undertaken under a separate contract.

### 8.2.4 Use of deterrent devices

8.2.4.1 Acoustic devices are used to deter cetaceans and pinnipeds from fishing and fish farming activities or from areas that need to be kept clear, such as water intakes for power stations. For the fishing and mariculture industries, two main types of device are available, depending on whether the aim is to reduce bycatch or to decrease depredation of valuable fish stocks. ‘Pingers’ are low intensity sound sources and are designed to alert marine mammals to the presence of fishing nets, in order to prevent entanglement. (Animals may be completely unaware of the presence of a net but may be attracted to fish caught in it, without realising the danger). New techniques, operating at about 10 kHz, developed in the UK, have also shown success for deterring harbour porpoises (Newborough *et al*, 1997). High intensity Acoustic Harassment Devices (AHDs) are designed as a non-lethal method of protecting fish stocks from marine mammals such as pinnipeds (e.g. QinetiQ have developed a ‘seal scaring’ device operating at 7kHz/197dB that was recently deployed effectively during an oil rig decommissioning programme in the North Sea).

8.2.4.2 Fish scarers have been used to deter fish from entering hydroelectric power stations (Nuttal, Times 2000). Similar devices have been used to keep seals away from fish farms. In both case there have been mixed success rates, depending on the fish species and the nature of the sounds used as the deterrent (Nuttal, Times 2000).

8.2.4.3 Although reductions in bycatch and depredation have been reported, it is also clear from the literature that insufficient information is known about the effectiveness of different acoustic sources and the applicability to different species, age and sex of marine animals. In addition there is the risk that animals may identify the sound with prey and be attracted rather than repelled (Reeves *et al*, 1996). However, despite some shortcomings, pingers and AHDs could be implemented as a mitigation strategy to deter marine mammals from entering the area around the construction site. Such devices could be deployed from a variety of monitoring platforms (either fixed or mobile) or be moored to buoys. An alternative deterrent to acoustic sources is a barrier, such as nets or bubble curtains. Bubble curtains have been successfully used to deter fish from areas such as turbines - an example is the Bioacoustic-Acoustic Fish Fence, developed by Fish Guidance Systems Ltd. This system combines a bubble screen with a chirp sound source to act as a deterrent (Nuttall, 2000).

### 8.2.5 Acoustic shielding techniques

8.2.5.1 During construction of the fuel receiving facility for Hong Kong airport at Sha Chau, sound from pile driving operations was shielded using acoustic barriers constructed from air bubbles (Wursig *et al*. 2000). These barriers were designed to reduce propagation of sound and hence potential negative environmental impacts upon receptors. Wursig *et al* reported 8 - 10 dB reduction in broadband sound levels between 400 Hz and 800 Hz and 15 – 20 dB reduction in the 1.6 kHz to 6.4 kHz frequency band. The bubble screens were deployed in shallow water (8-10 m) which is similar to the depths being considered at Rhyl Flats.

### 8.2.6 Monitoring

8.2.6.1 In general, monitoring may be achieved by remote or *in situ* means both in real time and over longer periods. 'Real time' monitoring techniques include the use of visual observers and acoustic sensing methods for detecting and/or localising environmental receptors. Long-term techniques include methods such as analysis of data from fixed sonar receivers deployed in the area of concern. Real-time techniques enable immediate decisions to be made about mitigation. The long-term methods however are useful for providing baseline information against which any changes in behaviour due to construction and operation of the wind farm may be determined.

8.2.6.2 Monitoring for the presence of cetaceans, and pinnipeds should be undertaken so that appropriate mitigation measures can be implemented to minimise risk. Human activity, such as diving and any recreational activity (i.e. yachting, angling) also needs to be monitored to ensure that animal deaths are not being wrongly attributed to the wind farm. Monitoring for fish could only be achieved directly using fish finding sonar. This is believed to be impractical, as it would involve frequent sweeps close to the construction site from a boat. A number of techniques are available for monitoring for the presence of marine mammals, visual monitoring, passive acoustic monitoring, and active acoustic monitoring.

8.2.6.3 Visual monitoring for marine mammals is a simple and reasonably effective method for detection of animals at the sea surface, in daylight hours. In addition to monitoring for the animal itself, other clues, such as the appearance of feeding seabirds, can sometimes be evidence of their presence (Pollock *et al.*, 2000). The effectiveness of visual monitoring is significantly reduced in rough weather and some small animals such as seals and porpoises are very difficult to see over long distances, even in calm conditions. Marine mammals can spend a considerable amount of time submerged. Visual monitoring on its own will not detect submerged animals and so it is best undertaken in conjunction with passive acoustic monitoring, which alerts monitors to the presence of vocalising animals below the sea surface.

8.2.6.4 A number of personnel are required for effective visual monitoring. It is important that they are adequately trained[1] and provided with the correct equipment - binoculars, logbook, handbook and possibly a range finder. Visual observers should if possible have

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[1] 'Training' is most likely to have been gained through direct experience with this or similar types of monitoring activity. QinetiQ have a number of trained monitors.

some flexibility in their movements during period of monitoring, so access to an independent boat is preferable. More than one boat will enable better coverage to be achieved as will the presence of more than one observer on each vessel. Visual monitoring could also be undertaken from the shore or from appropriate construction platforms. For those people engaged in monitoring activities, it is advised that they have sufficient breaks and rest periods to maintain a sufficiently high monitoring effort. This, in turn, will require enough observers to be available to work in shifts. Monitoring should start well before the first pile driving operation (at least 30 minutes) and should be used to determine the effectiveness of any ADDs or AHDs, if used. Monitoring should be undertaken throughout the activity and should continue for a reasonable period afterwards, to determine if negative environmental effects have occurred.

8.2.6.5 A valuable method for marine mammal monitoring is the use of passive acoustic systems to detect vocalisations. In practice however, the ability to undertake this technique is driven by the availability of dedicated equipment and trained personnel. Detection systems can be simple hydrophones or more sophisticated line arrays deployed from ships, free-floating sonobuoys or systems located on the seabed, such as ‘pop-ups’[2]. Receiver systems will need to be located on a support vessel with the necessary interpretation software such as PAVAN[3]. QinetiQ recently deployed successfully two passive line arrays for acoustic monitoring purposes during decommissioning of an oilrig in the North Sea. The decommissioning operation involved the detonation of explosive charges and it was vital to be aware of the presence of marine mammals at this time. Passive acoustic techniques are complimentary to visual monitoring and are particularly useful for activity undertaken after dark.

8.2.6.6 The presence of marine mammals can be detected using active acoustic systems. This is particularly useful if they are not vocalising when they cannot be detected using passive techniques. However, there is an associated negative environmental impact with the introduction of more sound into the environment and this is not a preferred option.

8.2.6.7 Records should be kept of all monitoring effort, whether anything is seen or not. Records should include any sightings of marine mammals, their location and their behaviour and also the presence of any injured or dead animals. Any sightings of vessels (i.e. human activity) or of marine mammals should be recorded using appropriate Joint Nature Conservation Committee (JNCC) forms, giving as much detail as possible.

### 8.3 Mitigation measures that could be applied during construction of the wind farm

8.3.1 A number of environmental risk mitigation measures can be undertaken to protect local environmental receptors from any potential negative impact, resulting from the construction of an offshore wind farm on Rhyl Flats. A comprehensive mitigation strategy is required, which combines the most relevant and practical techniques described above. It is also required to ensure that risk to the environment is reduced to a

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[2] Pop-ups are receivers designed to record marine mammal vocalisations over a period of time. They are lowered onto the seafloor, held in place by a weight and are retrieved by the receiver part being released and ‘popping-up’ to the sea surface.

[3] Interpretation software enables the monitoring personnel to view marine mammal vocalisations on a frequency-time plot. This technique is most effective when the monitoring staff can view and listen to the vocalisations simultaneously. The calls of different species can be recognised by their characteristic patterns such as ‘clicks’ and ‘whistles’.

satisfactory level, at acceptable cost and minimal disruption to the construction programme. The information provided below is divided into four phases and a number of mitigation measures are provided for each. It may not be necessary, affordable or practicable to undertake some of these measures but they are listed to provide the maximum number of options available to protect the environment.

**Before construction starts**

1. Identify which environmental receptors (e.g. fish, marine mammals, seabirds) are likely to be present and establish the location of any protected or sensitive habitats, particularly those covered by statutes or conventions.
2. Undertake pre-activity baseline monitoring and desk studies to establish baseline levels for ambient noise and number and species of animals likely to be present in the area.
3. Notify the relevant authorities of the construction programme, including the Coast Guard, dive clubs, and provide input to Notice to Mariners.
4. Recruit an experienced marine mammal monitoring team and equip them with binoculars, video cameras, logbooks and marine mammal identification handbooks. Sufficient personnel are required to work continuously for the whole construction period.
5. Determine where the monitoring personnel will be located - onshore, on an independent boat or on a construction boat or platform as appropriate.
6. Obtain hydrophones and recording equipment that can be deployed by the monitoring personnel from boats, from any platforms related to the construction process, or mounted on the seabed.
7. Charter/obtain an independent boat for undertaking marine mammal monitoring, if required from 5 above.
8. Undertake a pre-activity environmental briefing, so that all participants involved in the wind farm construction are fully aware of the aims and objectives of the mitigation strategy.

**Start of construction**

1. Deploy Acoustic Deterrent Devices (ADDs) and fish scarers around the construction site to clear the area of marine mammals & fish before construction begins. If possible, gradually ramp up the power of such devices.
2. Where possible, plan to increase the level of noise due to construction activities gradually over a period of days to allow animals to become aware of the sound (i.e. start with less noisy activities first, e.g. seabed surveys, and work up to noisy activities, e.g. pile driving).
3. Undertake monitoring for marine mammals and other sensitive or critical species as identified in the recommended baseline survey (see above), using visual and passive acoustic techniques to determine if animals are moving away from the area around the construction site.
4. If appropriate, deploy active sonar systems (e.g. fish finding sonars) to detect animals in the vicinity of the construction site.

5. Cease activities if significant numbers of marine mammals (or other sensitive species) are detected close enough to the construction site to cause them physical injury.
6. Erect bubble screens around the site to act as acoustic barriers. Once the area is believed to be clear following the use of the ADD, switch on the bubble screens.

**During construction**

1. Undertake monitoring for marine mammals and other sensitive species identified in baseline studies for at least 30 minutes before the start of construction activity.
2. If there are significant periods where there is no construction activity, continue to use ADDs to deter animals from re-entering the area between these phases of activity.
3. Undertake monitoring continuously during operations.
4. If marine mammals are observed within the calculated danger-zone around the construction activity (as defined elsewhere in the EIA), further pile driving, trenching or other potentially disturbing activities should be delayed, until the animals move away.
5. Use an agreed start-up procedure after any substantial break in activity.
6. Record all monitoring activity using forms provided in this document. The records provide documented evidence that mitigation strategies were undertaken during the construction phase.

**After construction**

1. Survey the area for dead or injured marine mammals and fish, or other animals as appropriate. Record the results of the survey.
2. Collate all monitoring records as a permanent record.
3. Undertake a post-activity environmental de-brief so that all participants involved in the activity can contribute to lessons learnt.
4. Undertake post activity analysis of the environmental risk mitigation strategy to ascertain, if possible, whether enough was done to protect the environment and whether adverse environmental effects were either observed or believed to have occurred.
5. Produce a statement of lessons learnt to benefit any future activities.

## 8.4 Mitigation measures that could be applied during operation of the wind farm

8.4.1 The acoustic modelling, impact modelling and consequent impact assessment will determine the type and magnitude of risk to the environment resulting from the operation of the wind farm, e.g. structural borne noise from machinery coupled into the water column and seabed. This is being undertaken elsewhere and so it is not possible to be sure what the findings are.

8.4.2 The most practicable mitigation would be to monitor noise levels, periodically to ensure that they stay within 'safe' and predetermined (i.e. in the EIA) limits and on which some assessment of risk has been based.

8.4.3 If monitoring was to show higher levels than predicted, then the mitigation would be to modify the way the turbines are used (i.e. reduce the total number) to bring noise levels back to the levels determined to be acceptable in the EIA.

# 9 Advice on the likely requirements for noise monitoring before, during and after construction and during operation

## 9.1 Need for noise monitoring

9.1.1 Noise monitoring undertaken before construction begins enables baseline levels of sound in the environment to be established, against which the impact of additional noise due to construction and operation of the wind farm can be assessed.

9.1.2 Noise monitoring during construction enables the received levels of sound at distances from the site to be established and compared with the predicted values used in the risk assessment. This ensures that the range at which noise might reach dangerous or unpleasant levels for environmental receptors can be determined. As a result the most appropriate mitigation measures, such as monitoring or deterrents, can be selected and implemented appropriately.

9.1.3 Periodic noise monitoring during the operational lifetime of the wind farm is recommended in Section 1.4 above. This will determine whether the wind farm is continuing to operate within the safe limits as defined by the EIA. If during monitoring, operational levels are found to be unacceptably high, then further mitigation will be required.

## 9.2 Strategy for noise monitoring

9.2.1 In the previous section, methods for monitoring for environmental receptors were described. In this Section, advice on monitoring the noise levels of the construction and operation of the wind farm are provided.

9.2.2 Noise monitoring can be undertaken using relatively simple equipment. There are a number of alternatives as to how the receive/record devices are deployed but they all need to be of sufficiently wide bandwidth to detect a wide range of sounds commonly detected in the marine environment.

9.2.3 Noise monitoring should be undertaken before construction begins to determine the baseline sound levels. This would be best achieved from a fixed hydrophone or array to monitor sound over a period of time. It would also be advantageous to monitor sound levels at more than one location, perhaps at the planned construction site and then at various points and distances from the site. If any sensitive or protected sites are identified, as part of the risk assessment, it is particularly important that received noise levels are known before and during construction and operation. If the necessary equipment is not available or there is insufficient time before construction for a long-term monitoring programme, it would be possible to undertake noise monitoring from a boat. This has the advantage that the hydrophone can be easily moved around the site so a number of locations can be assessed.

9.2.4 During the construction period, fixed and/or mobile monitoring and recordings systems could be deployed. It is advisable that this is undertaken either continuously or regularly throughout construction. It is assumed that part of the impact assessment is based on predicted noise levels and it is important that these are checked to ensure that the risk assessment is accurate. If noise levels are significantly higher than predicted, the mitigation strategy will need to be modified to ensure that risks to identified environmental receptors are minimised.

9.2.5 During the operational lifetime of the wind farm, it has been recommended above that noise levels be monitored regularly. This could be achieved using a fixed sonar array, with data records retrieved regularly. Alternatively, noise levels could be obtained periodically, perhaps as part of a regular maintenance programme. Action will be required if noise levels are significantly higher than predicted in the risk assessment, and thereby pose unacceptable risks to environmental receptors.

## 10 Limitations

10.1 Source levels for the piledriving operations were taken from PIDP (2001). These may not agree with those used for the on-site piledrivers.

10.2 The piledriver sound source was modelled as a vertical line array with a predominantly downwards radiation pattern. It is not known how rigorous this assumption is.

## 11 Summary and recommendations

11.1 A series of computer simulations using the program SAFARI were carried out in order to obtain predictions of noise levels for the operations of piledriving and subsequent post-commission operation of the wind turbines.

11.2 It was found that piling noise levels are likely to remain above background noise levels out to the maximum ranges considered of 20 km.

11.3 Wind turbine noise is broadband. For most of the frequencies modelled in the range 30-1600 Hz, it is likely that the sound pressure levels will fall below background noise levels at ranges of a few metres. The one exception to this is the 400 Hz component where the SPL is likely to remain above the background noise level up to a range around 5 km.

11.4 Environmental risk mitigation is possible, which, in relation to the construction and operation of the wind farm at Rhyl Flats, will reduce but not negate the environmental risks. However, although the risks remain numerous and varied, they are generally considered manageable.

11.5 QinetiQ have a trained and experienced monitoring team and would be able to assist with any aspect of mitigation in support of the construction and operation of the wind farm. This team has been employed on a range of MoD and commercial projects for monitoring and risk mitigation. The team was recently deployed in the North Sea where explosives were used to break up the steelwork on a decommissioned oilrig. During this operation acoustic monitoring and deterrent equipment were used to good effect.

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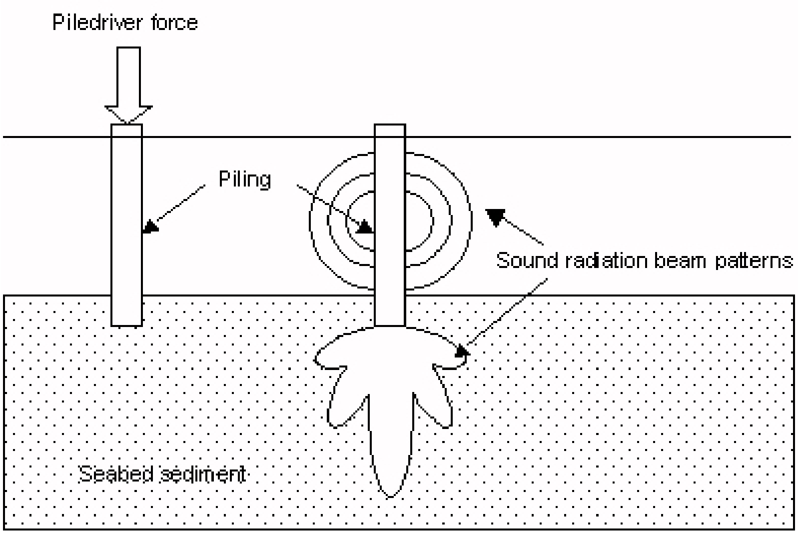


*Figure 1: Schematic showing piling being driven into seabed and subsequent radiation of sound from the piling*

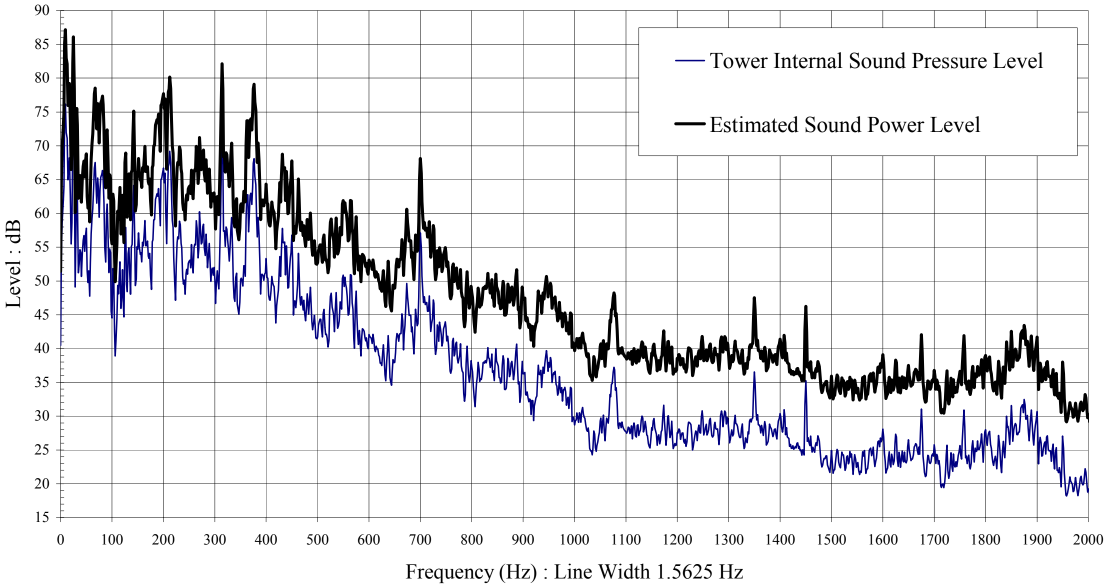


*Figure 2: Approximate source levels from tower from turbine operation measurement location: 30 m from nacelle*

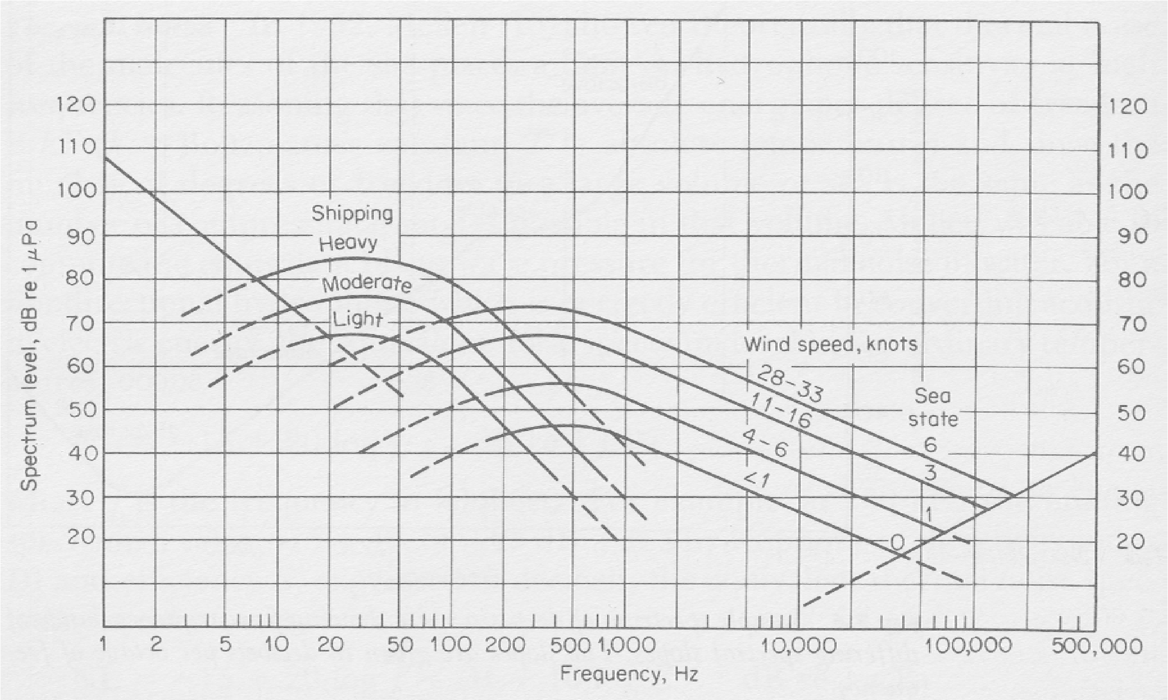


*Figure 3: Average deep water ambient noise spectra*

## Piling operation - 130 Hz component

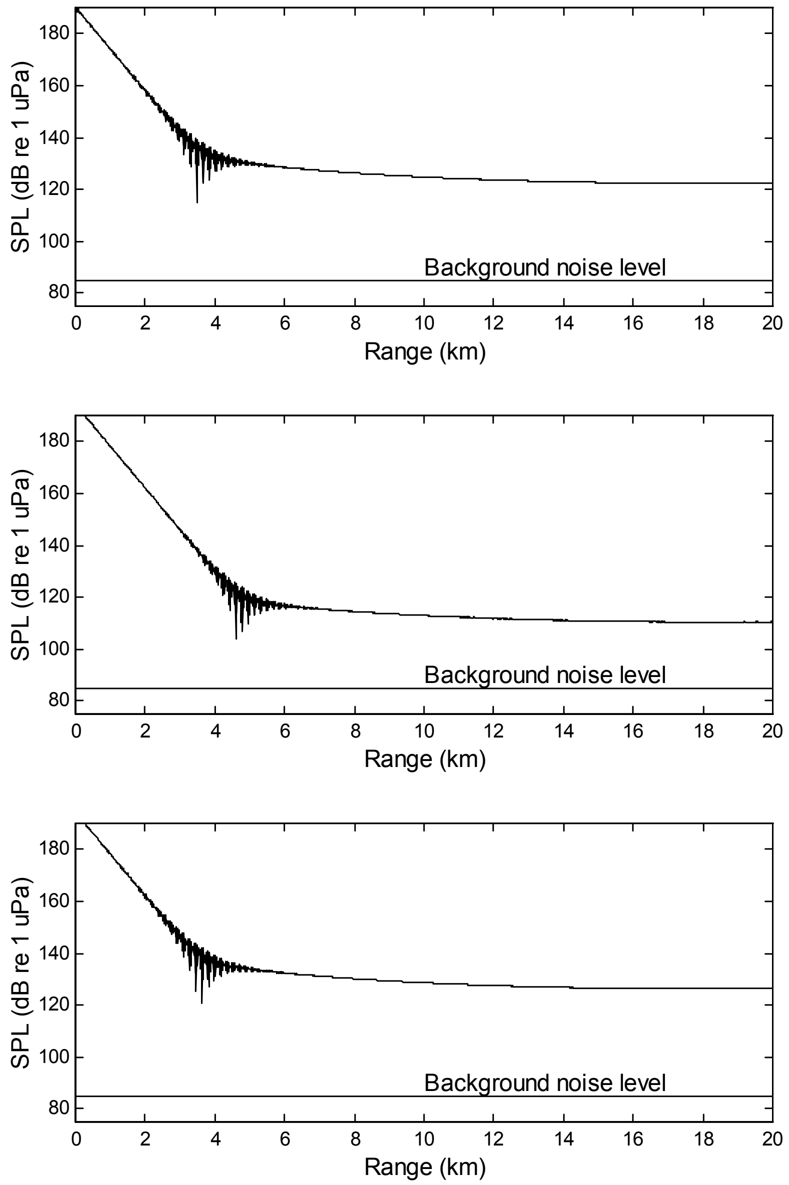


*Figure 4: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 0 m below the seabed*

## Piling operation - 130 Hz component

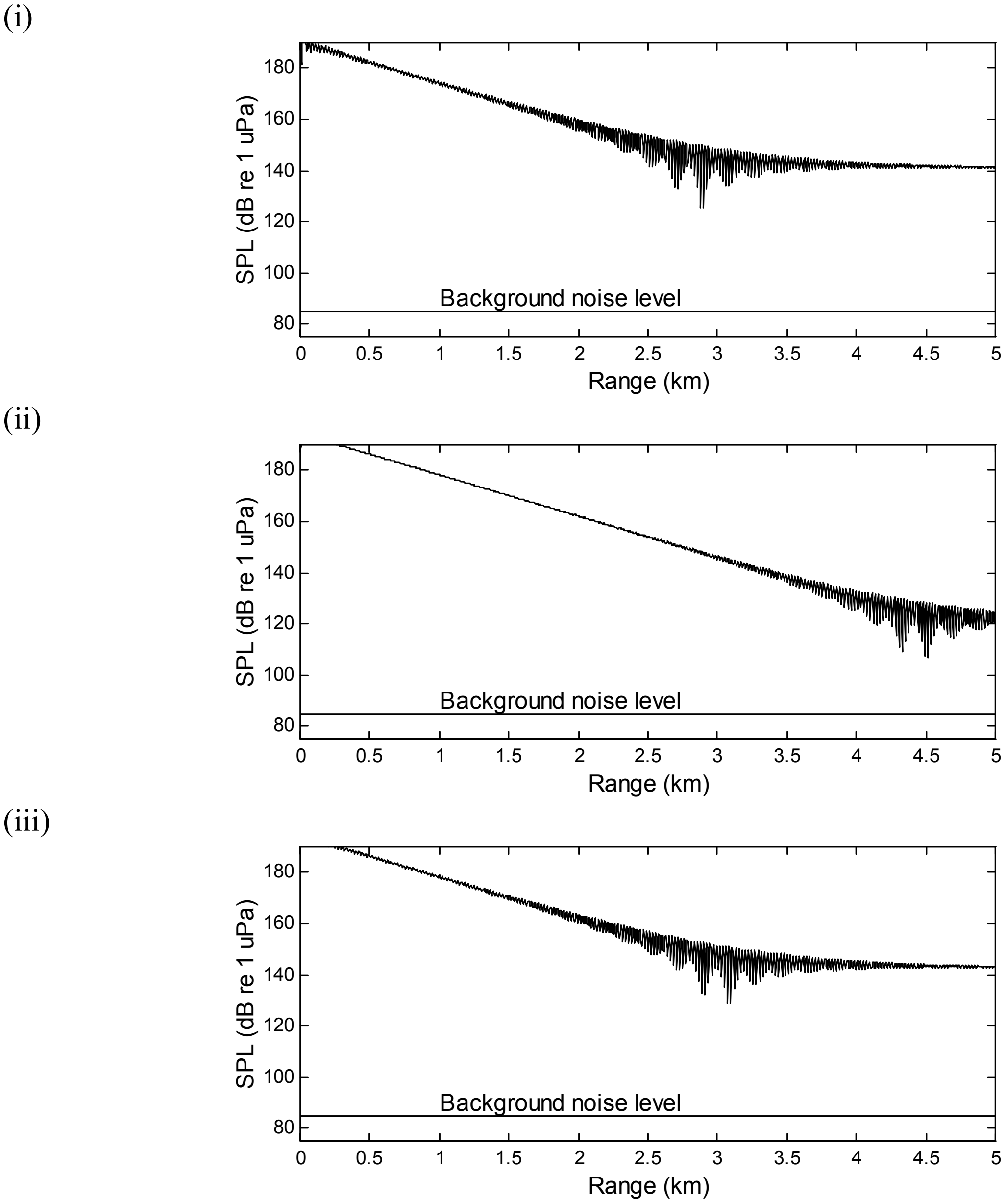


*Figure 4a: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 0 m below the seabed*

## Piling operation - 130 Hz component

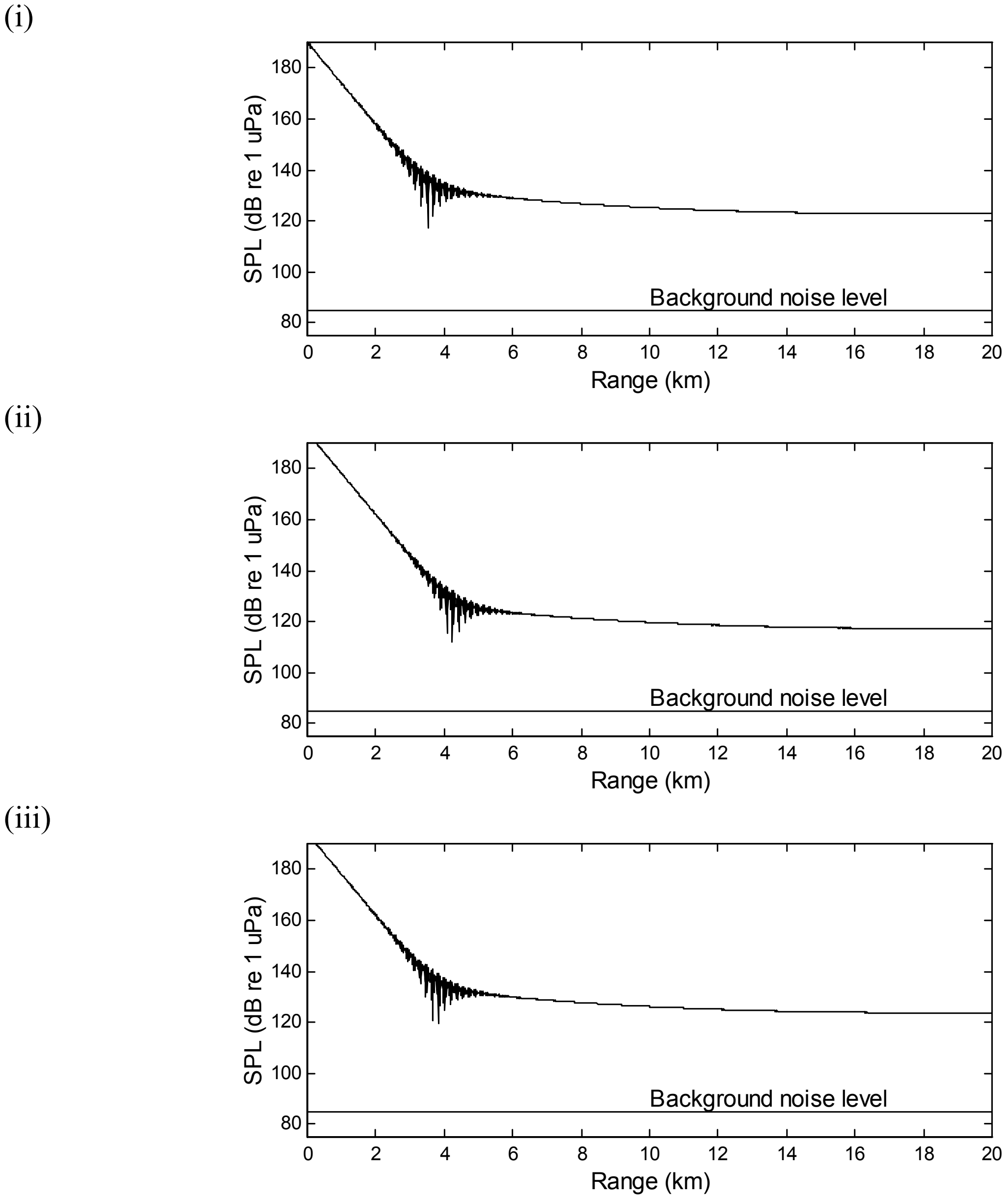


*Figure 5: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 2 m below the seabed*

## Piling operation - 130 Hz component

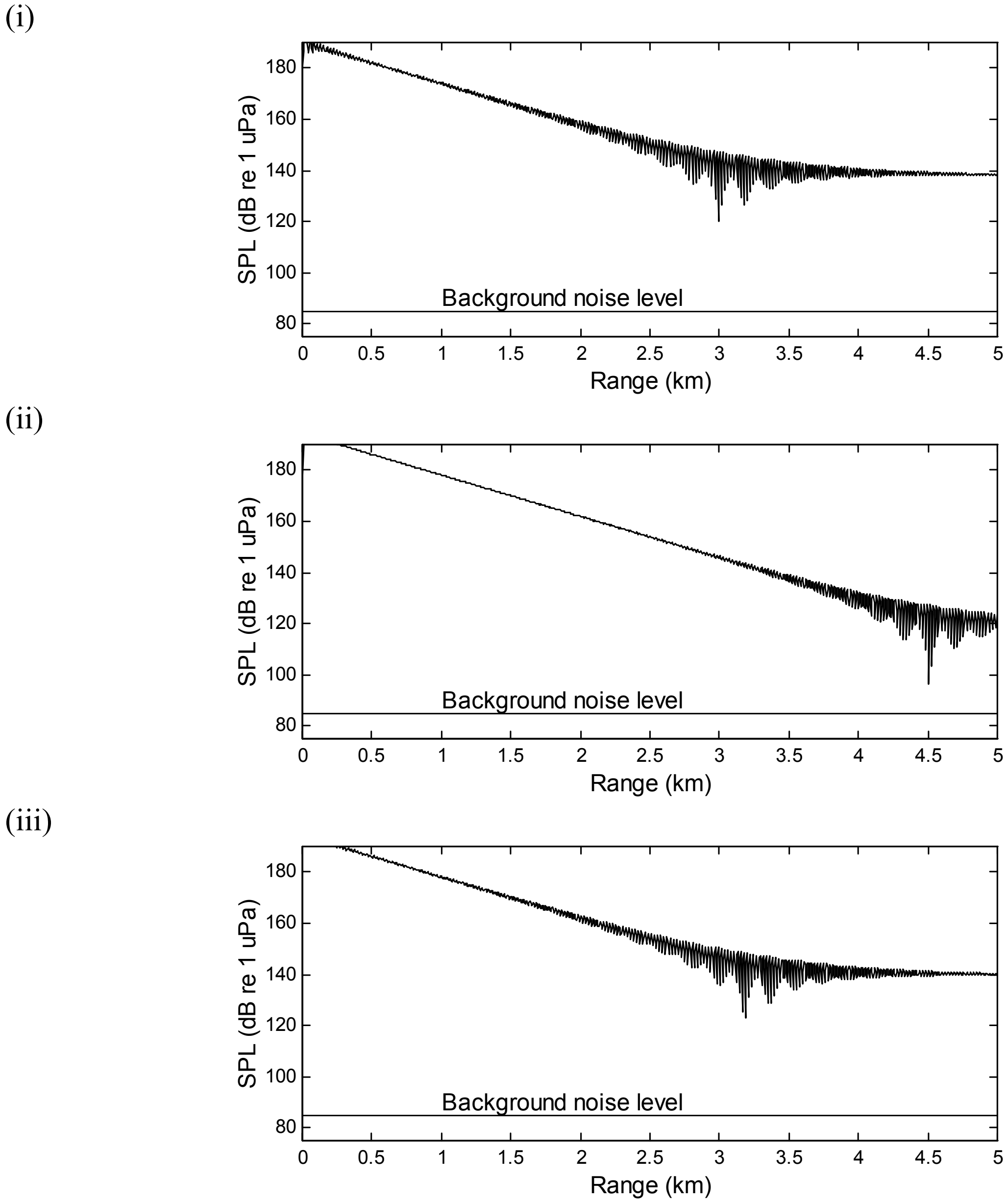


*Figure 5a: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 2 m below the seabed*

## Piling operation - 130 Hz component

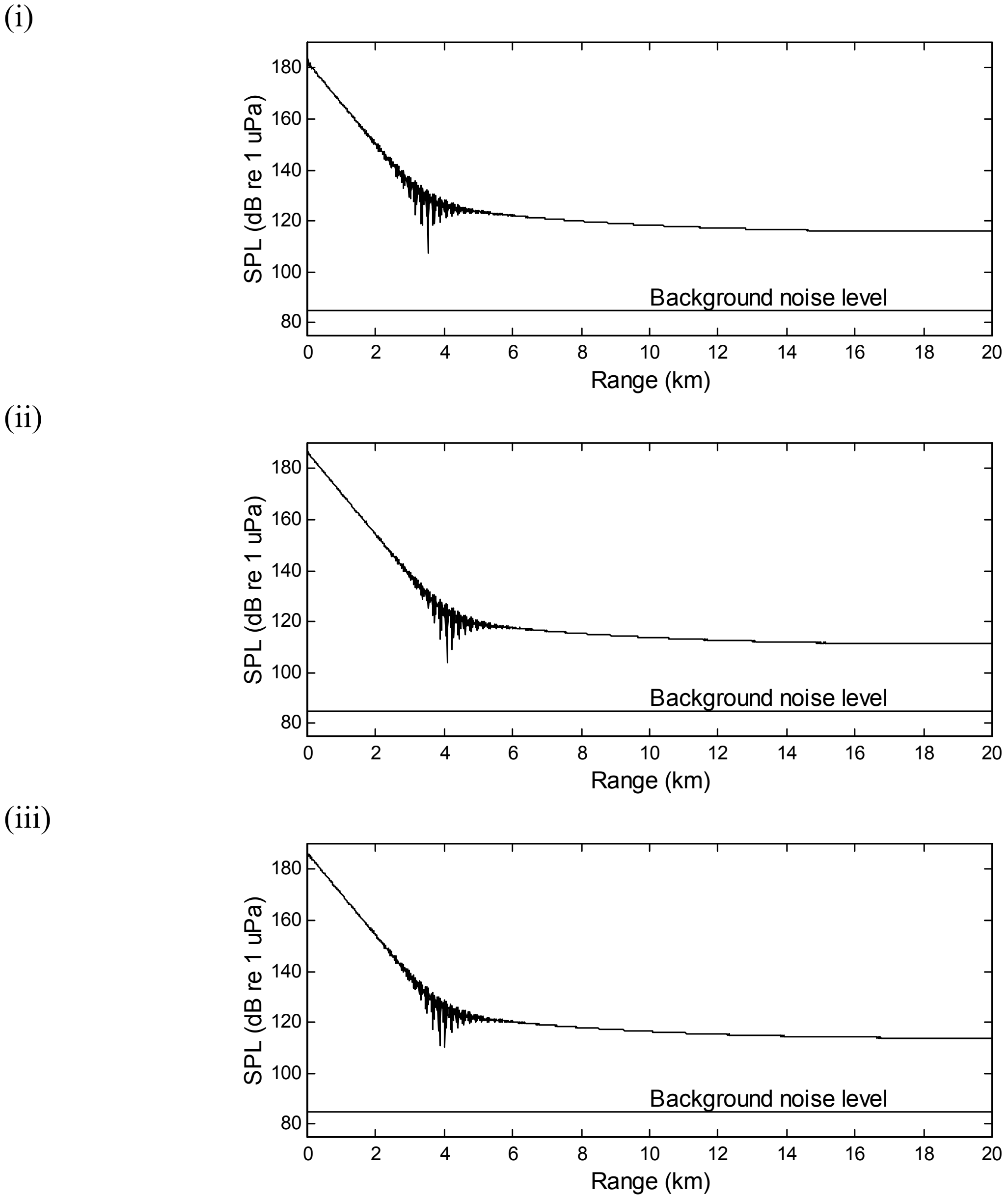


*Figure 6: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 4 m below the seabed*

### Piling operation - 130 Hz component

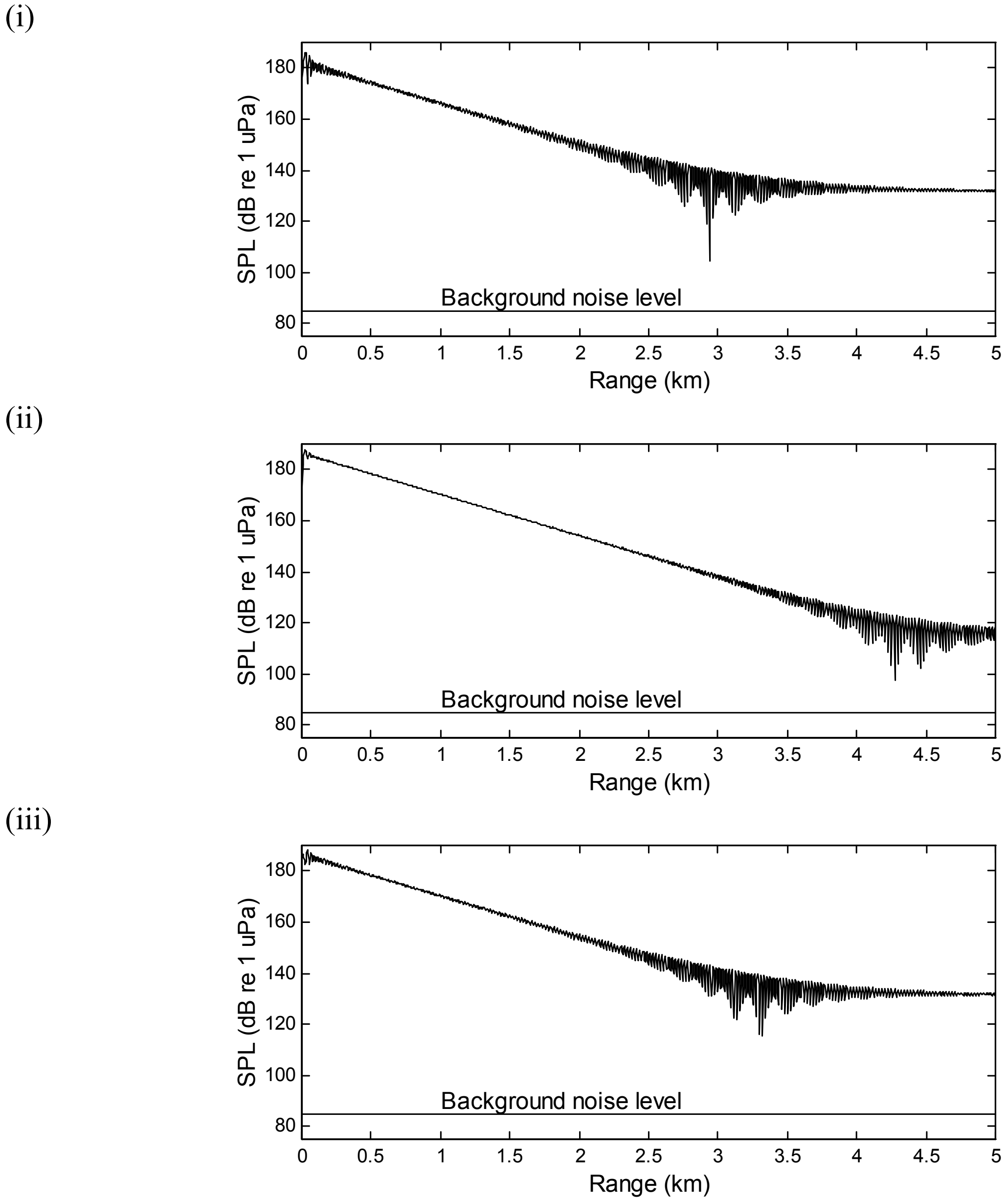
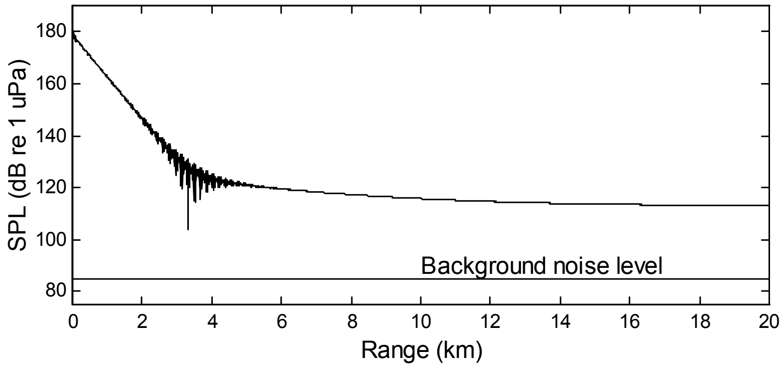


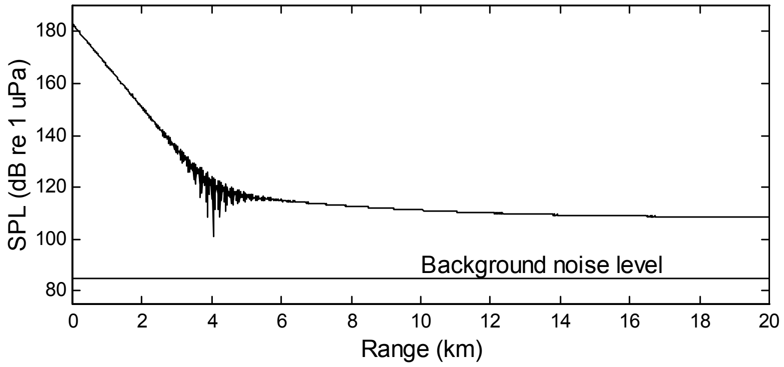
*Figure 6a: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 4 m below the seabed*

## Piling operation - 130 Hz component

(i)



(ii)



(iii)

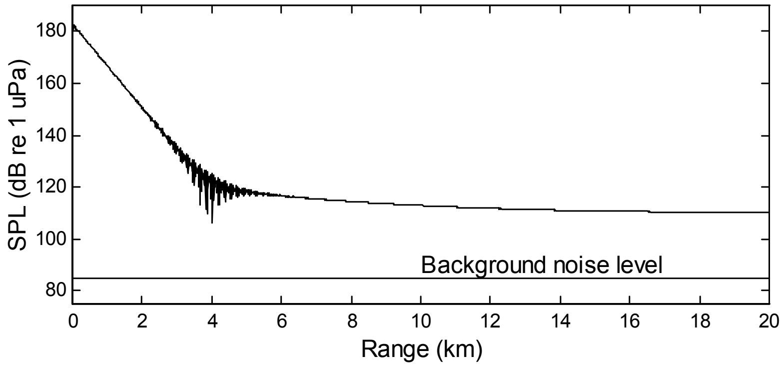


*Figure 7: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 6 m below the seabed*

## Piling operation - 130 Hz component

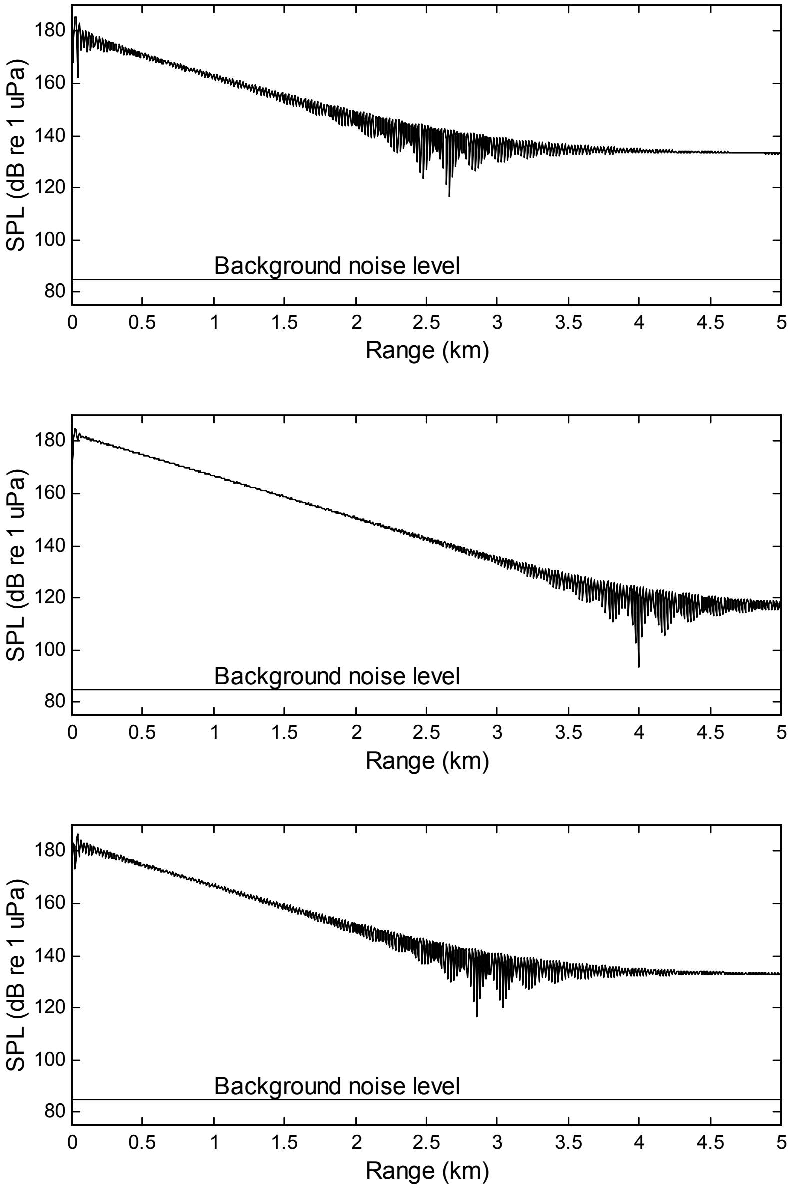
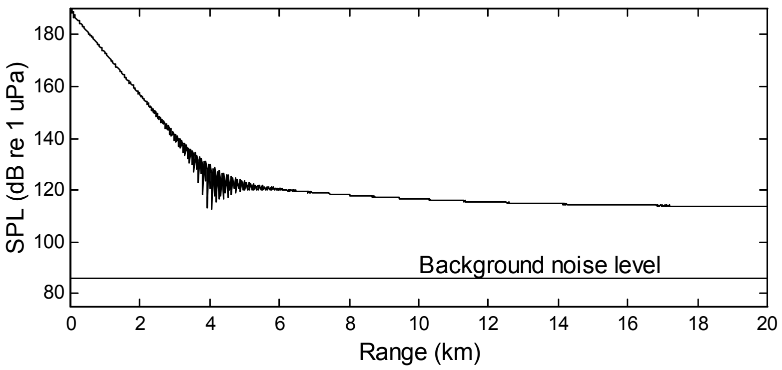

(i)
(ii)
(iii)

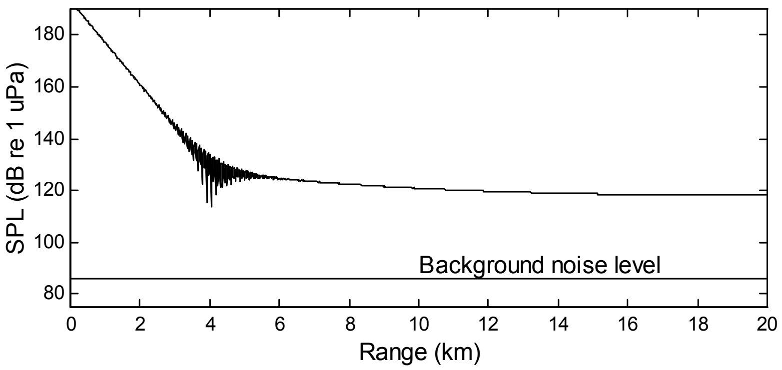
*Figure 7a: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 6 m below the seabed*

## Piling operation - 140 Hz component

(i)



(ii)



(iii)

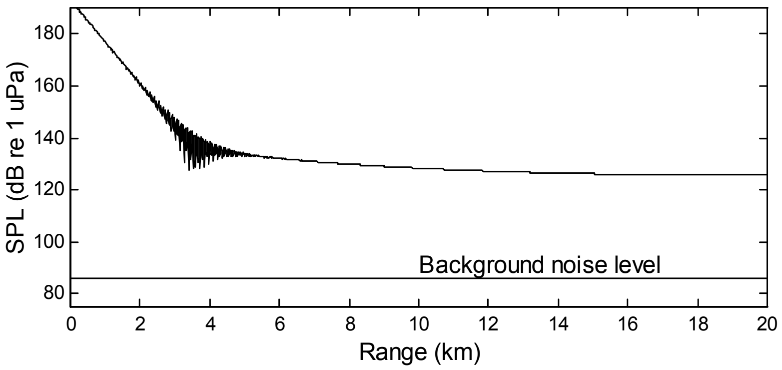


*Figure 8: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 0 m below the seabed*

### Piling operation - 140 Hz component

(i)

(ii)

(iii)

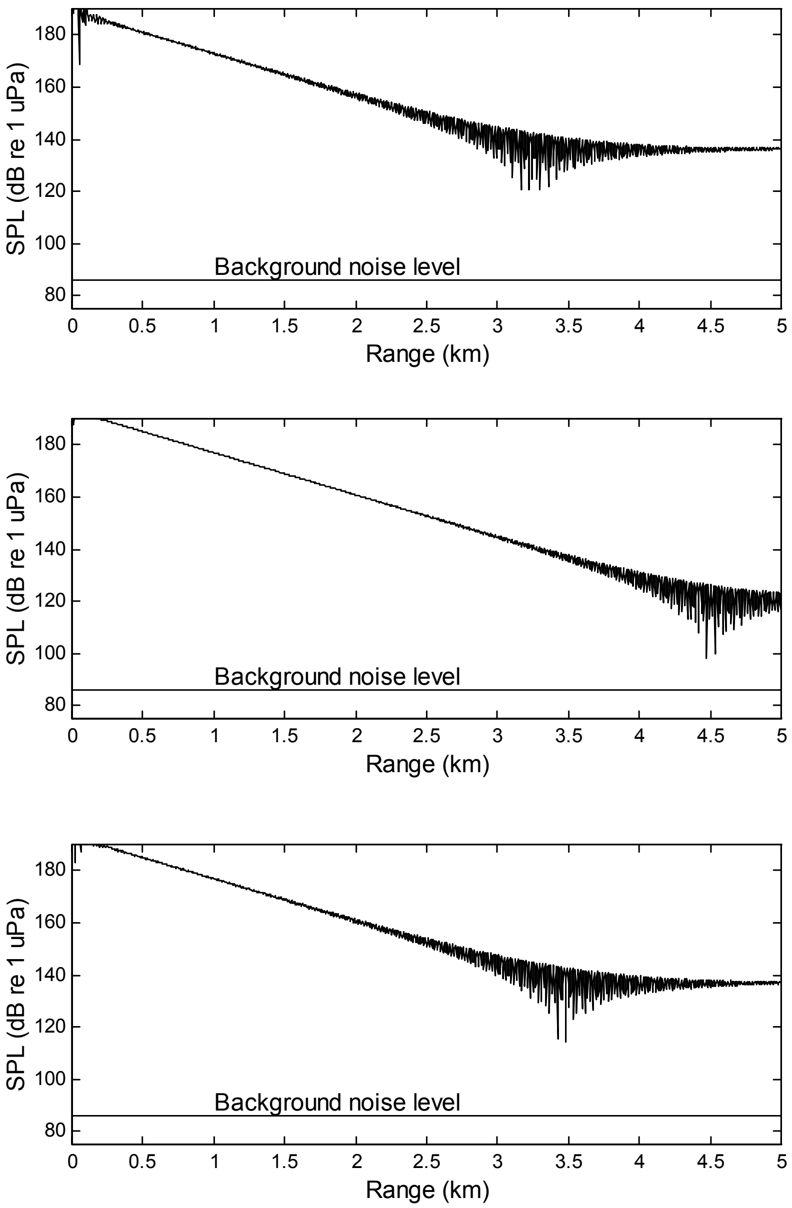


*Figure 8a: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 0 m below the seabed*

## Piling operation - 140 Hz component

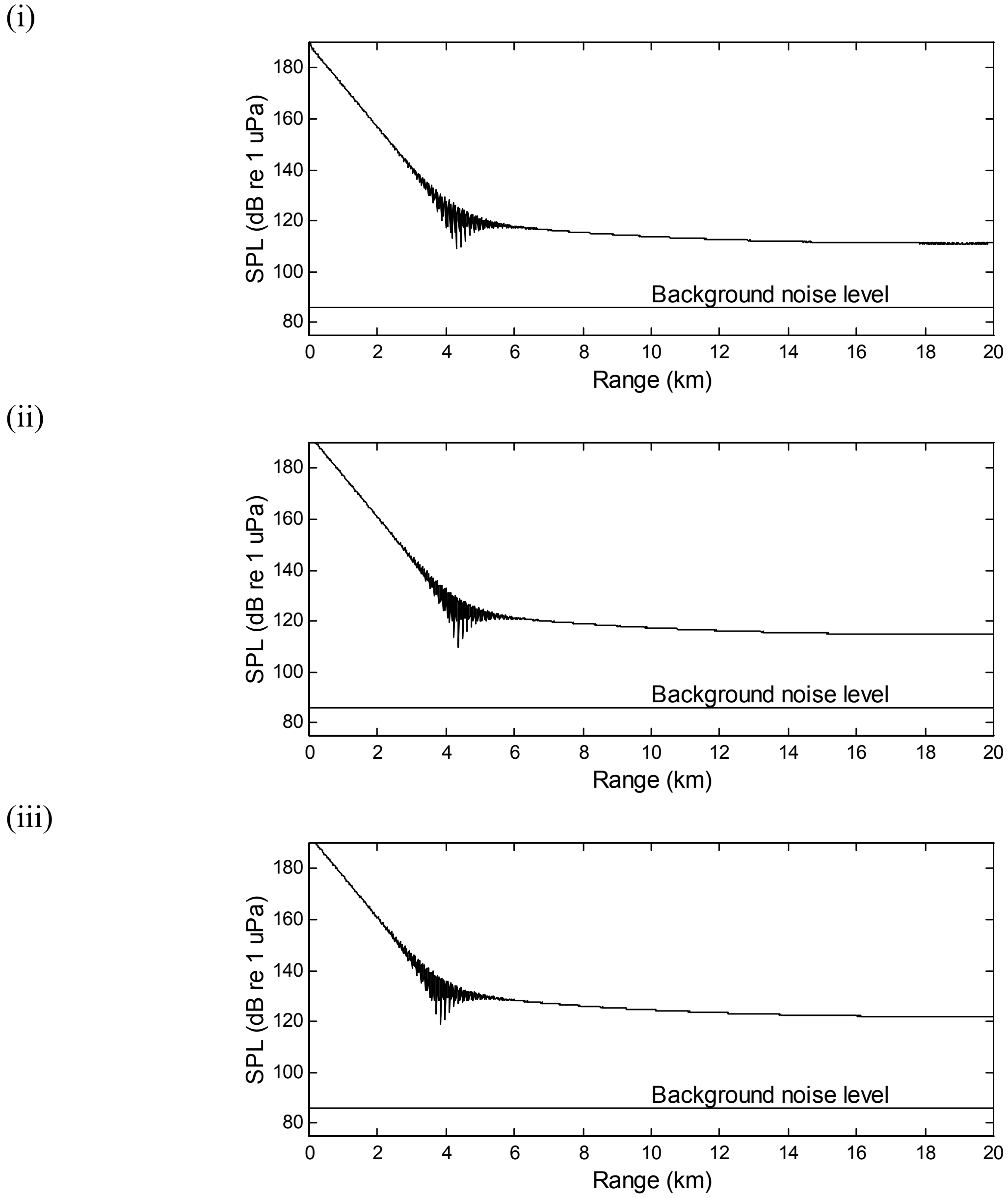


*Figure 9: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 2 m below the seabed*

## Piling operation - 140 Hz component

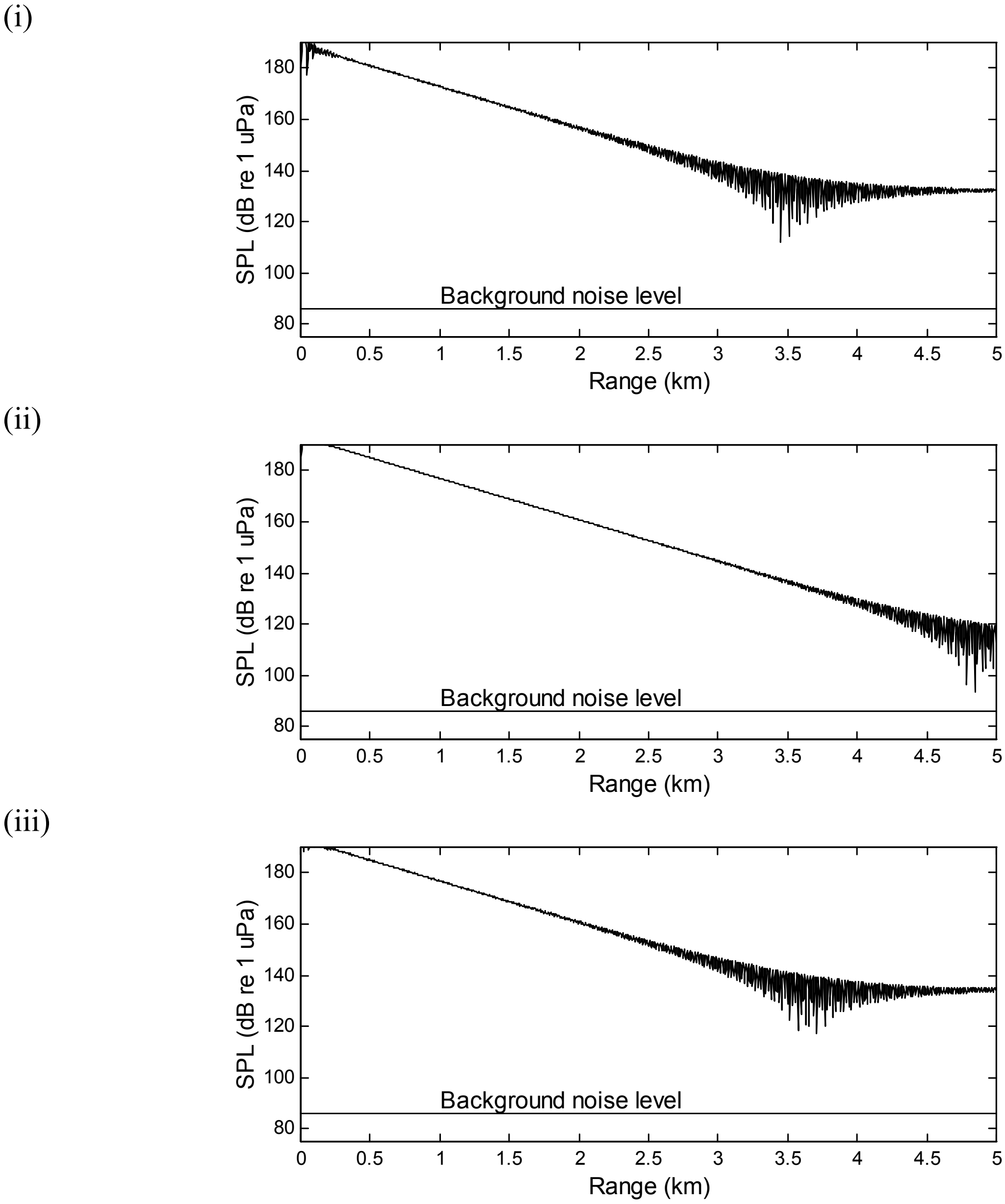
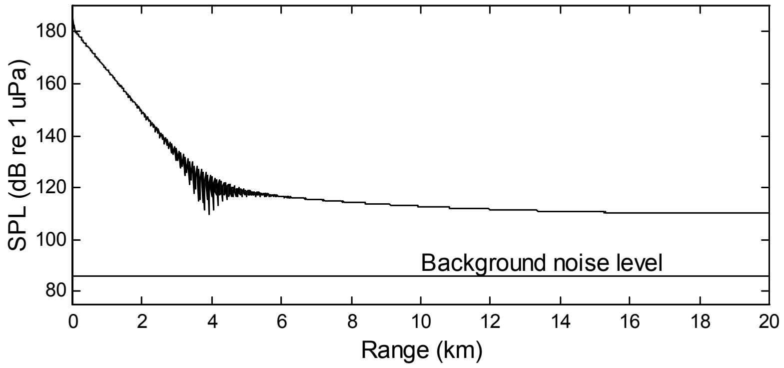


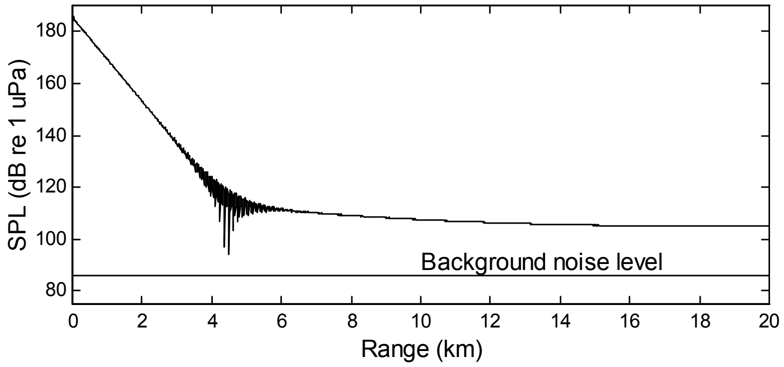
*Figure 9a: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 2 m below the seabed*

## Piling operation - 140 Hz component

(i)



(ii)



(iii)

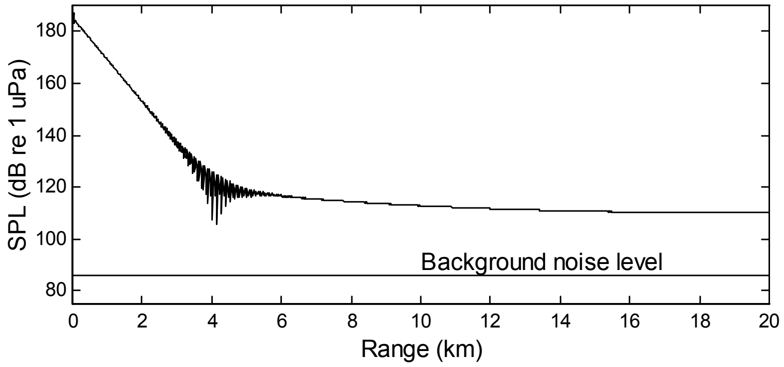
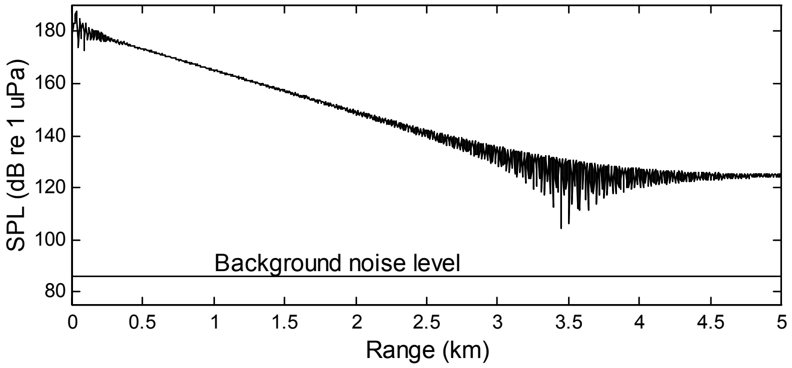


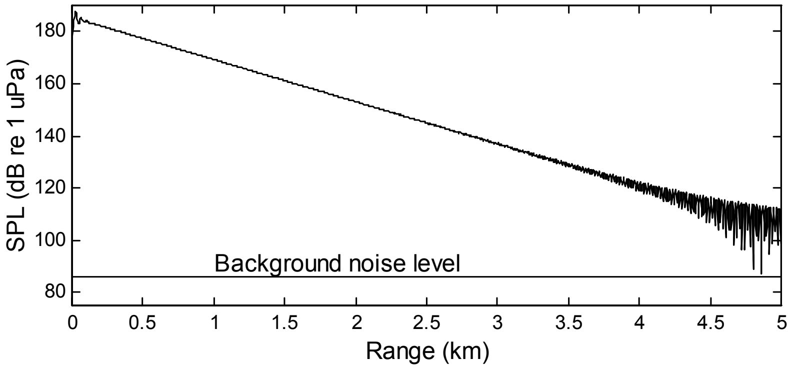
*Figure 10: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 4 m below the seabed*

## Piling operation - 140 Hz component

(i)



(ii)



(iii)

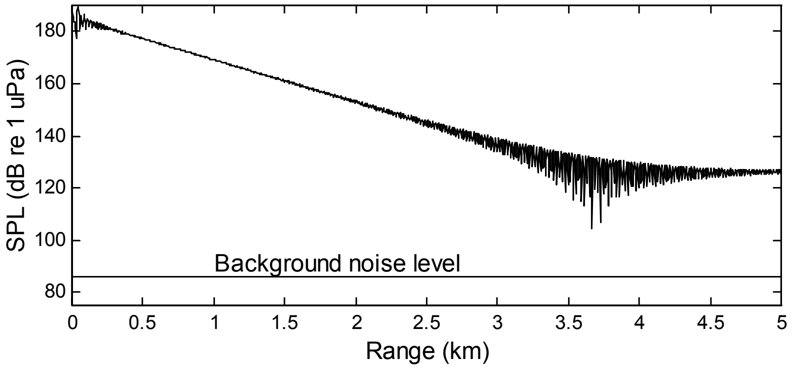
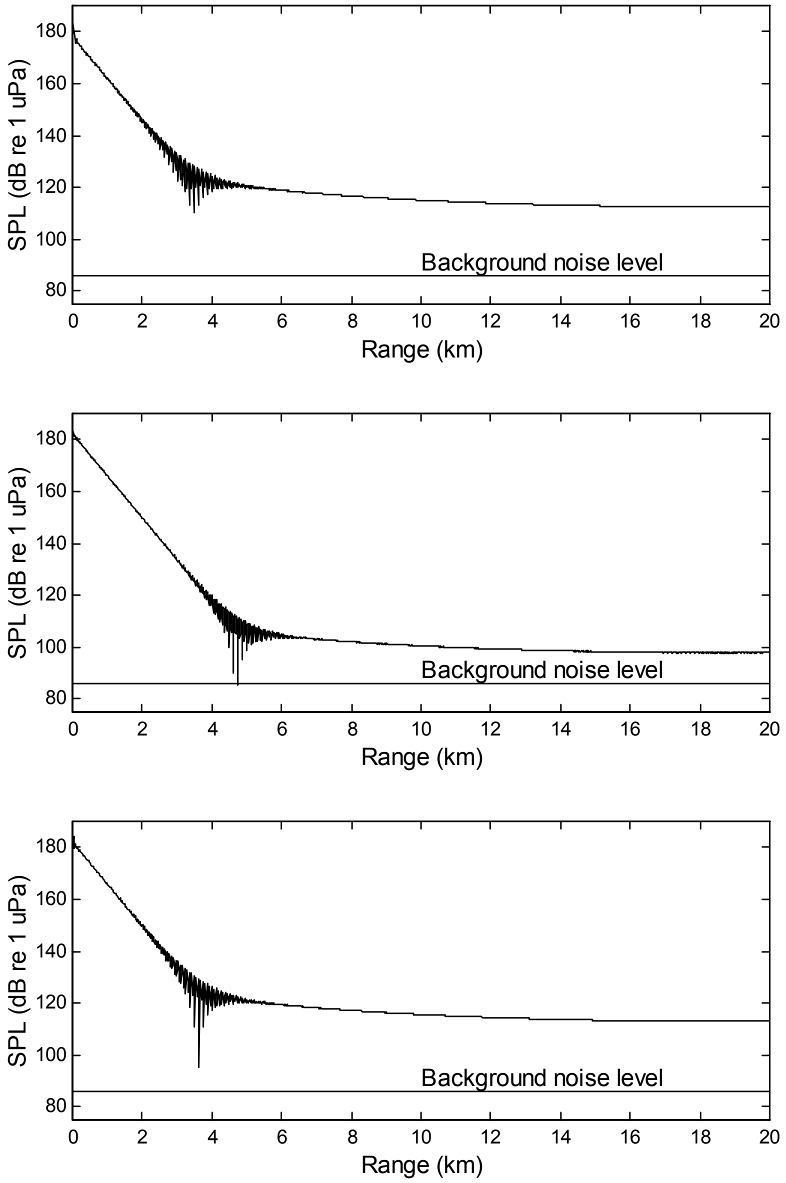


*Figure 10a: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 4 m below the seabed*

## Piling operation - 140 Hz component



(i)

(ii)

(iii)

*Figure 11: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 6 m below the seabed*

## Piling operation - 140 Hz component

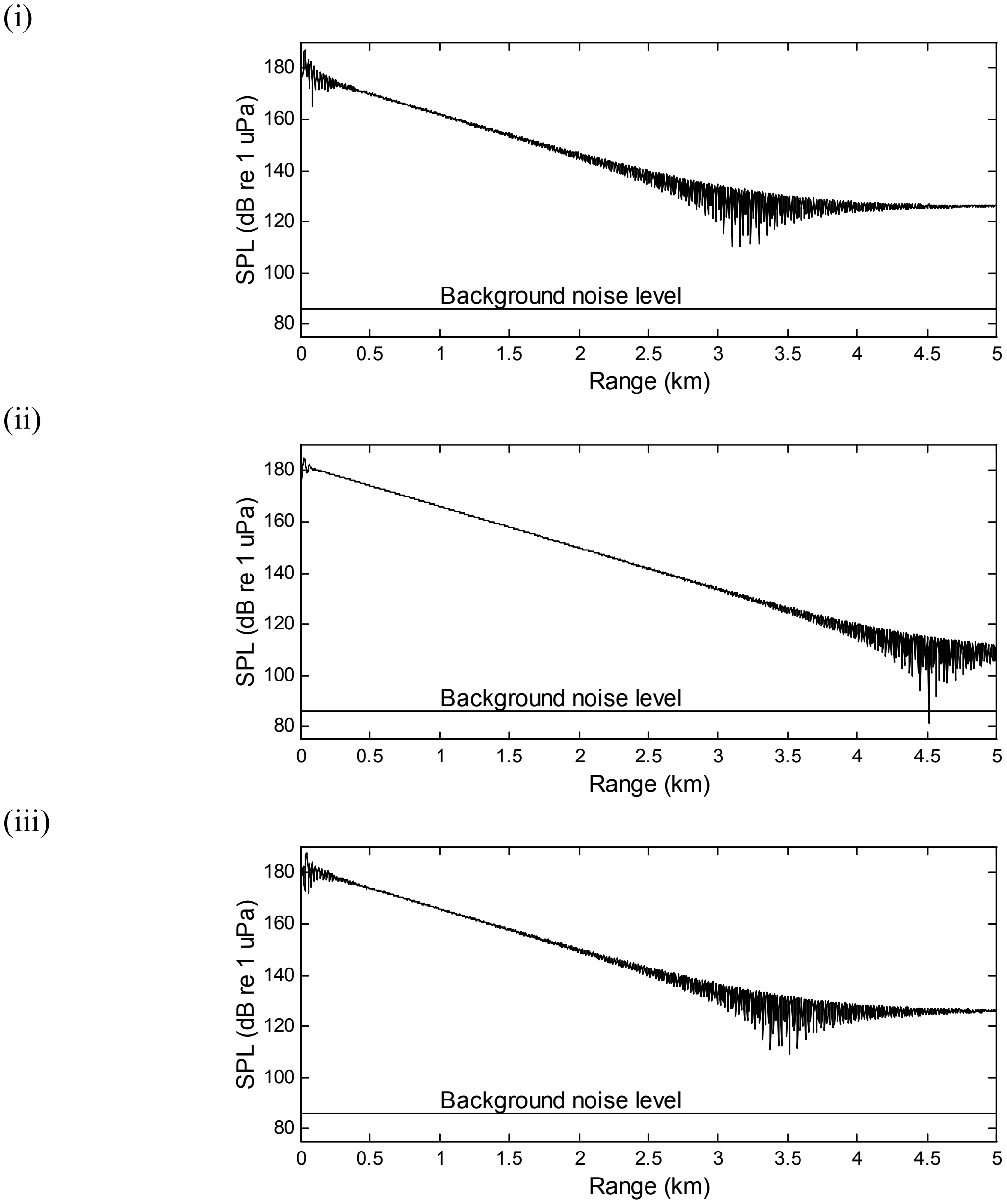


*Figure 11a: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 6 m below the seabed*

## Piling operation - 150 Hz component

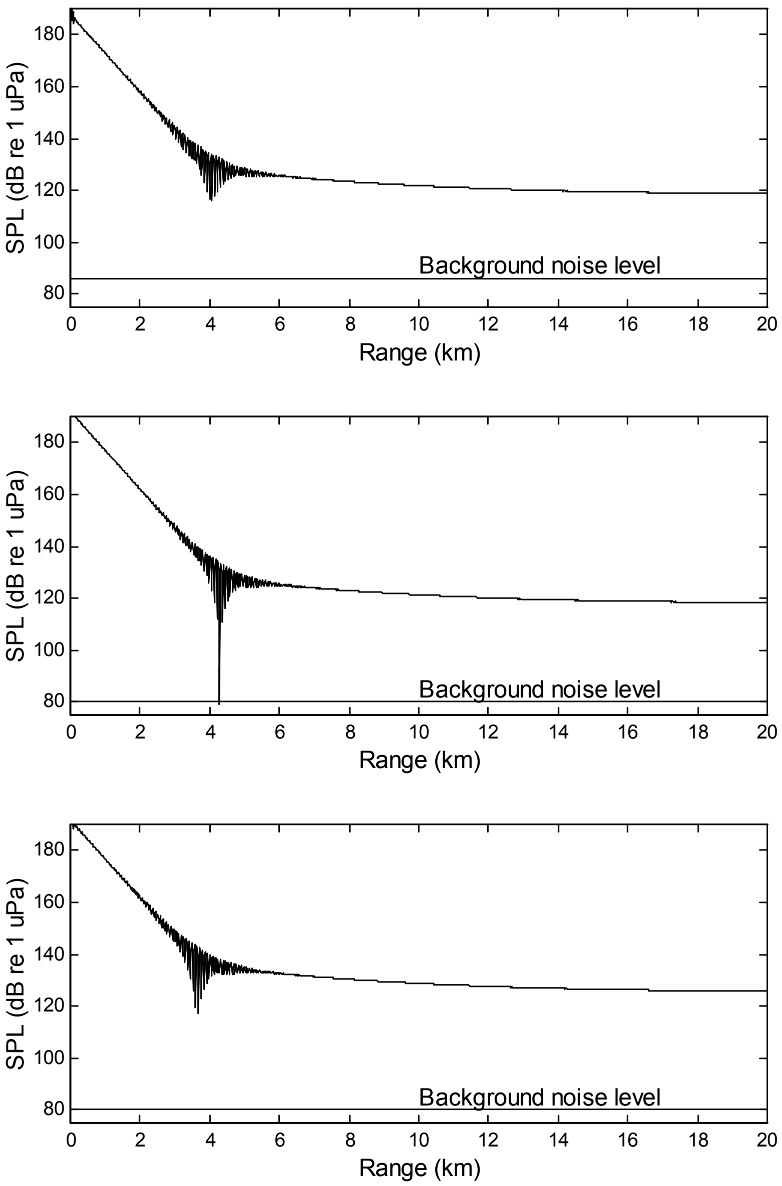


*Figure 12: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 0 m below the seabed*

## Piling operation - 150 Hz component

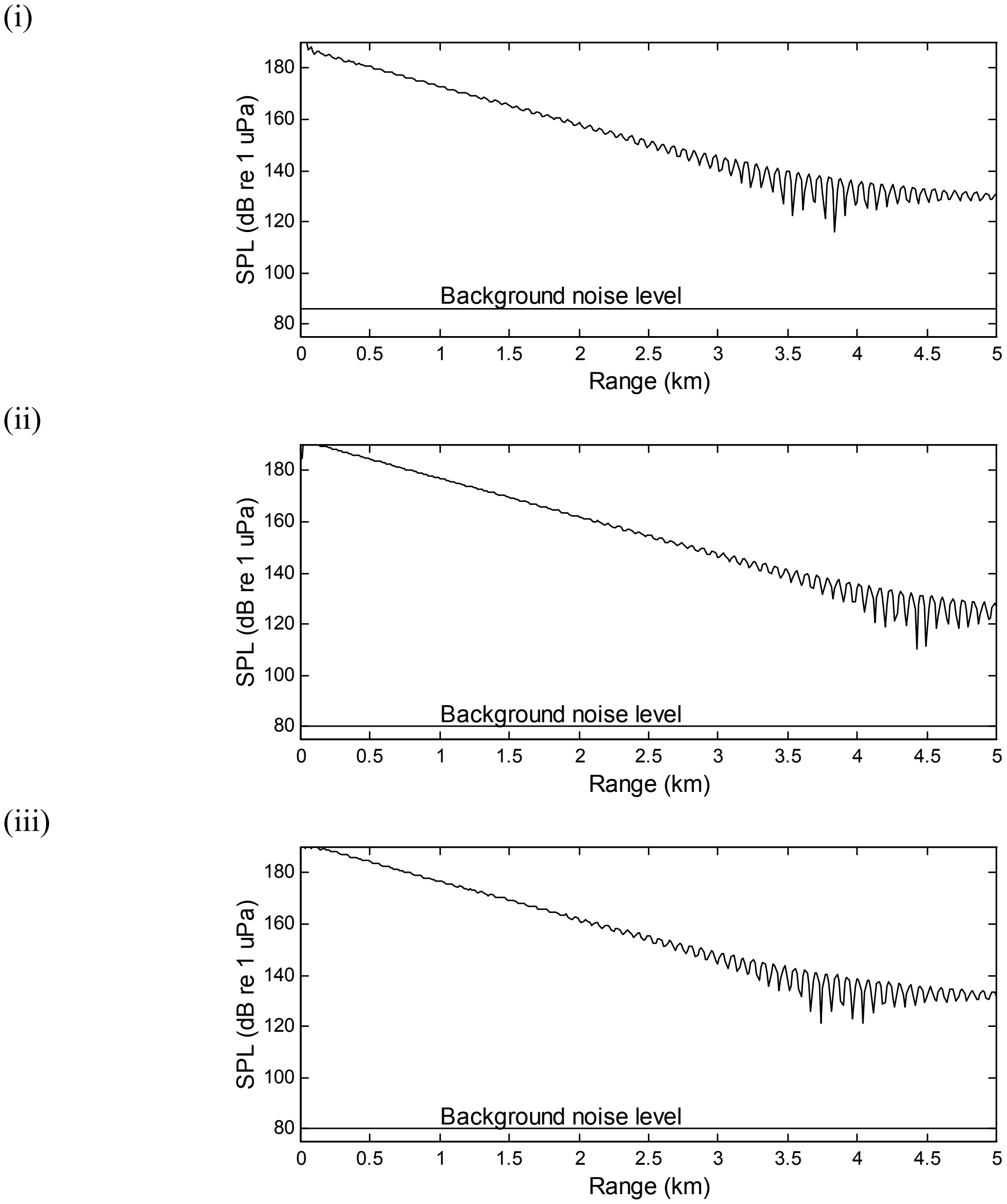


*Figure 12a: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 0 m below the seabed*

## Piling operation - 150 Hz component

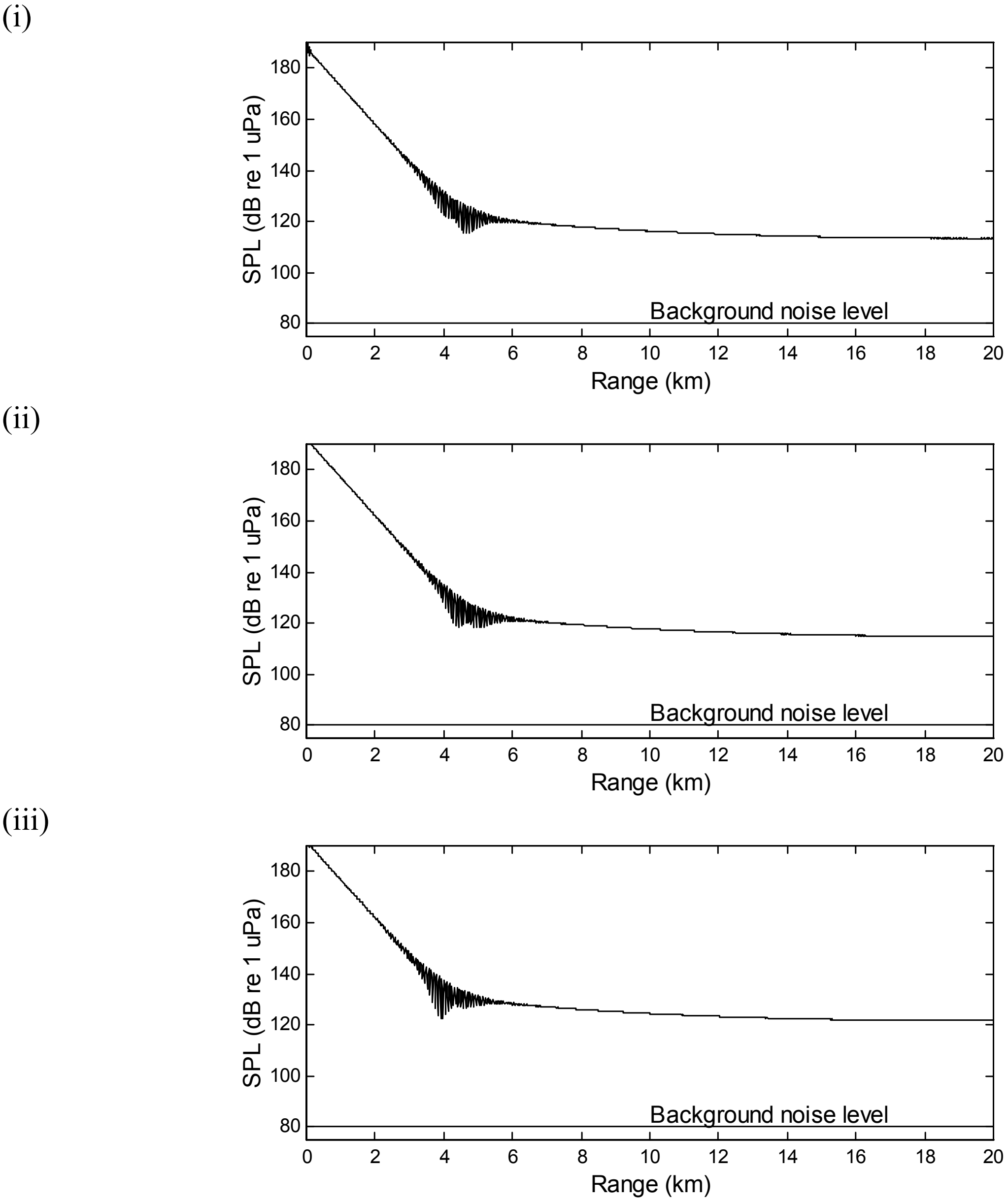


*Figure 13: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 2 m below the seabed*

## Piling operation - 150 Hz component

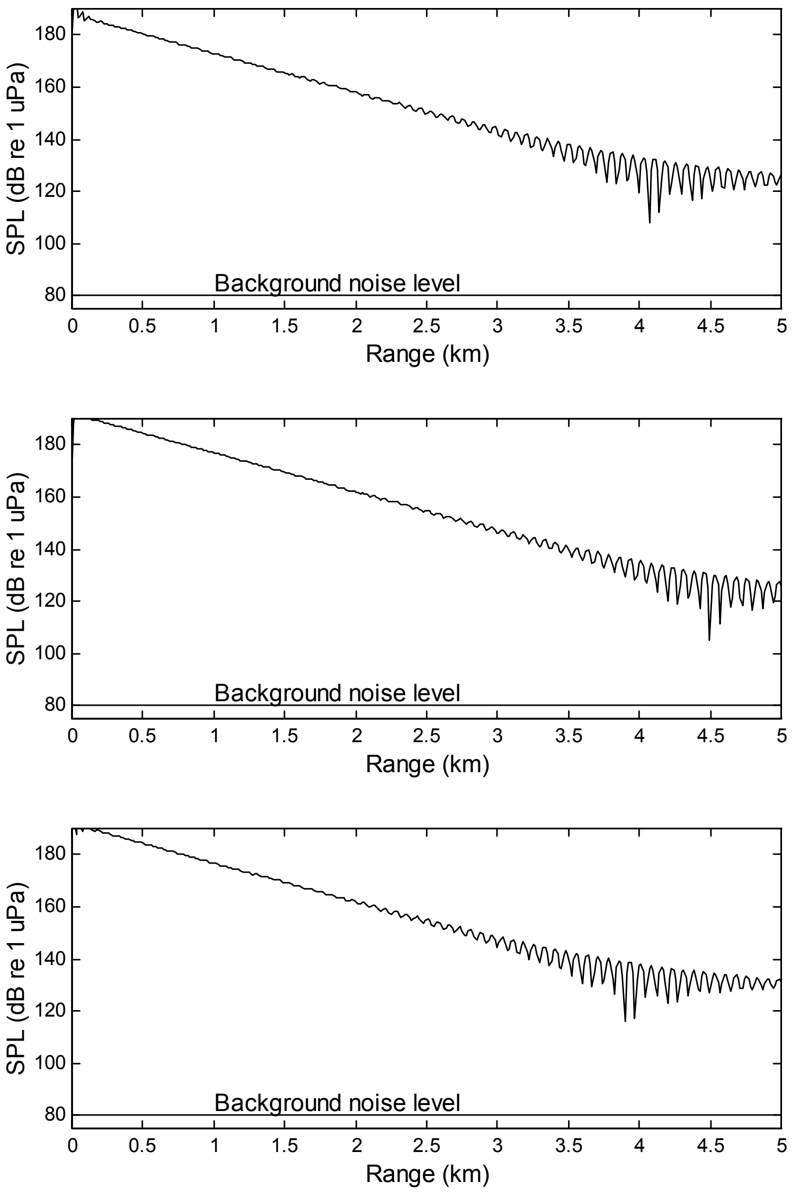


*Figure 13a: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 2 m below the seabed*

## Piling operation - 150 Hz component

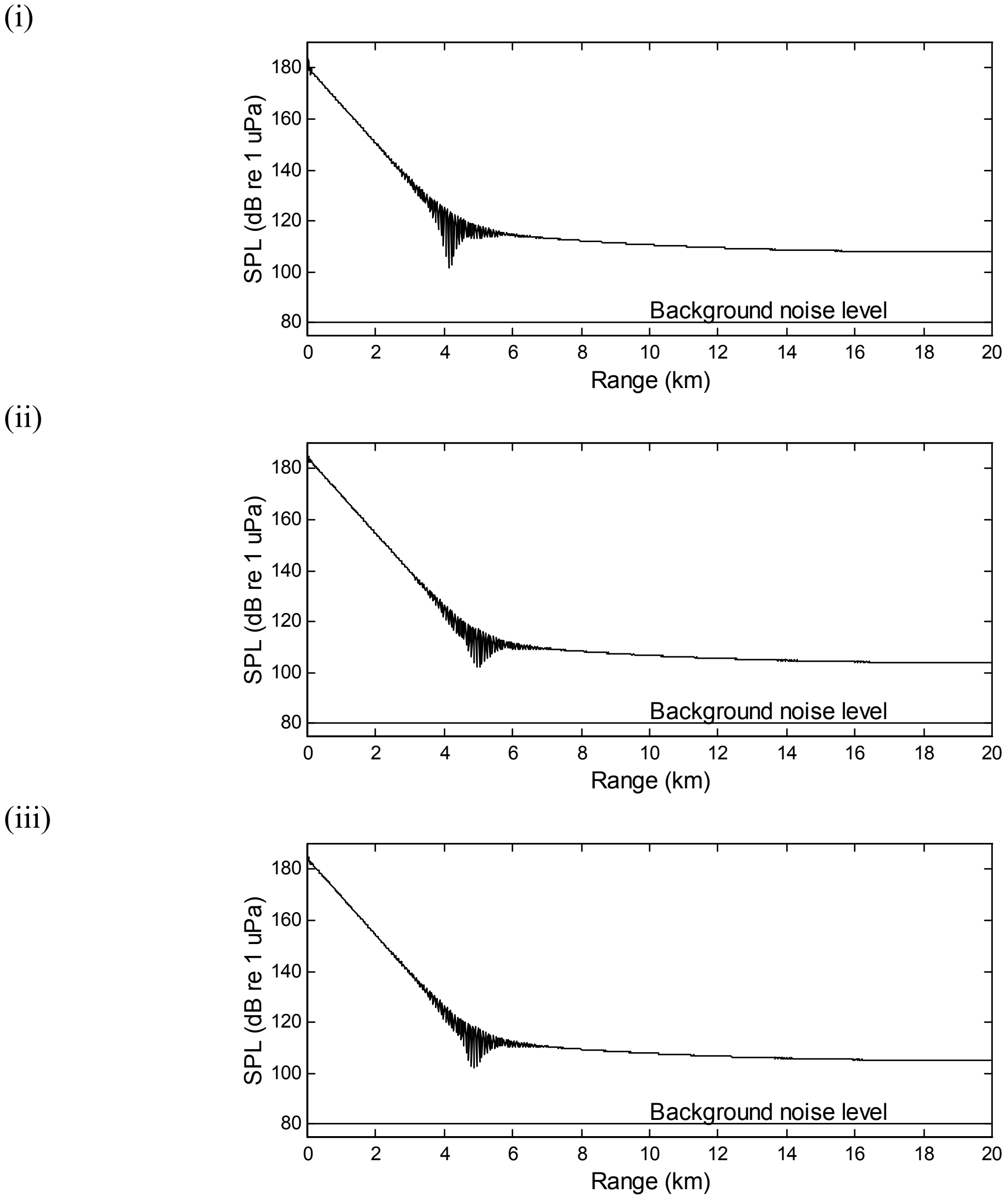


*Figure 14: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 4 m below the seabed*

### Piling operation - 150 Hz component

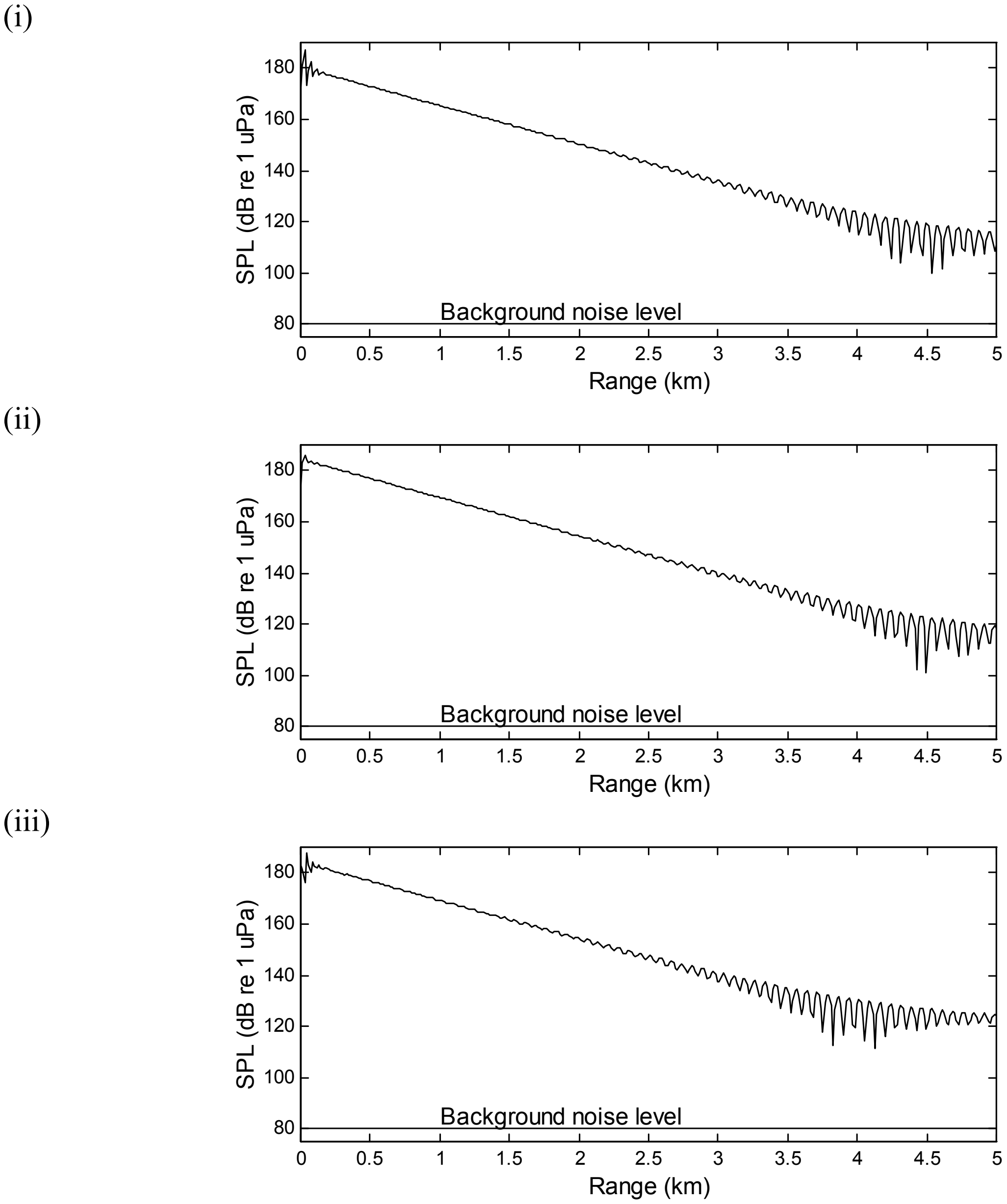


*Figure 14a: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 4 m below the seabed*

## Piling operation - 150 Hz component

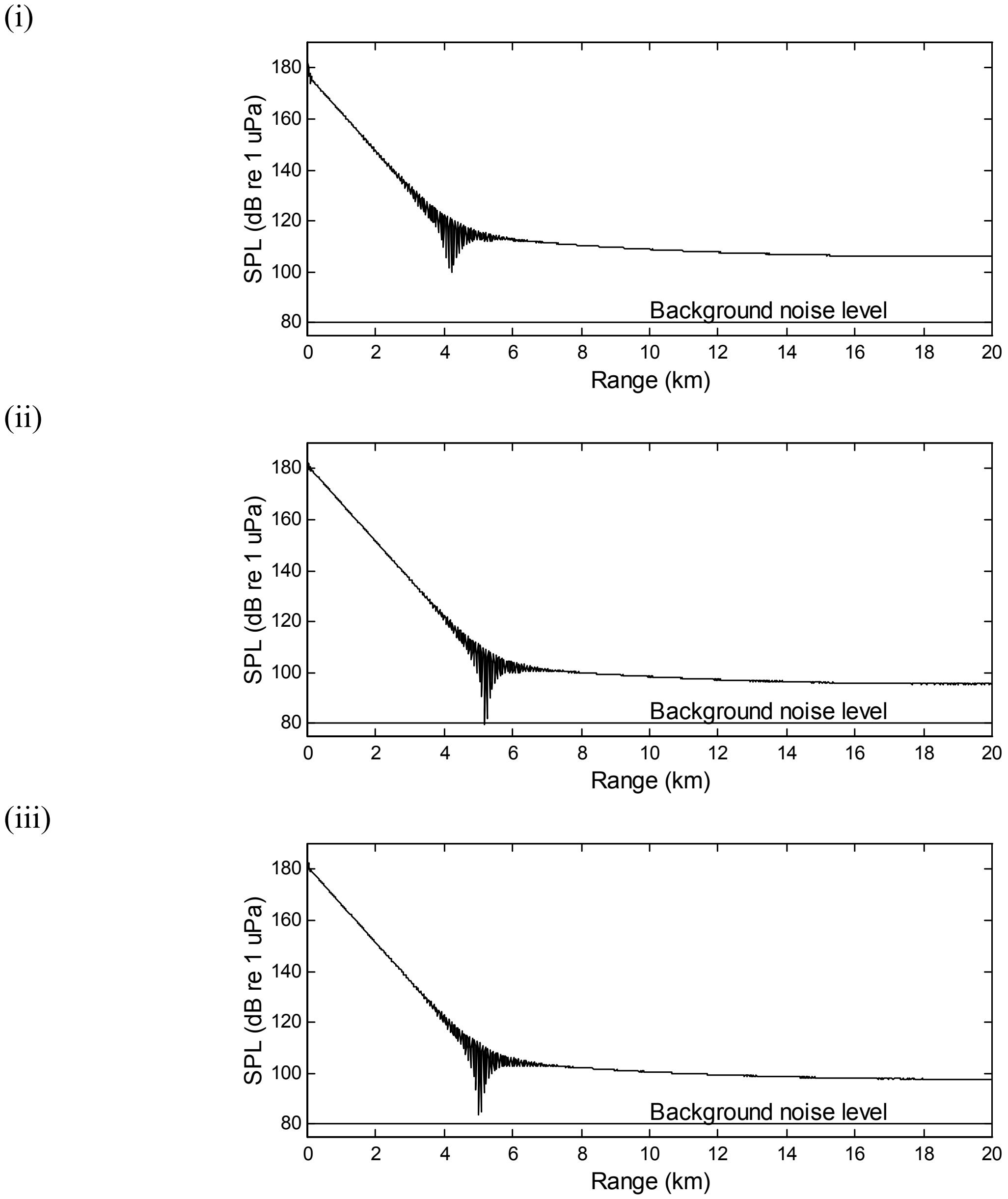


*Figure 15: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 6 m below the seabed*

## Piling operation - 150 Hz component

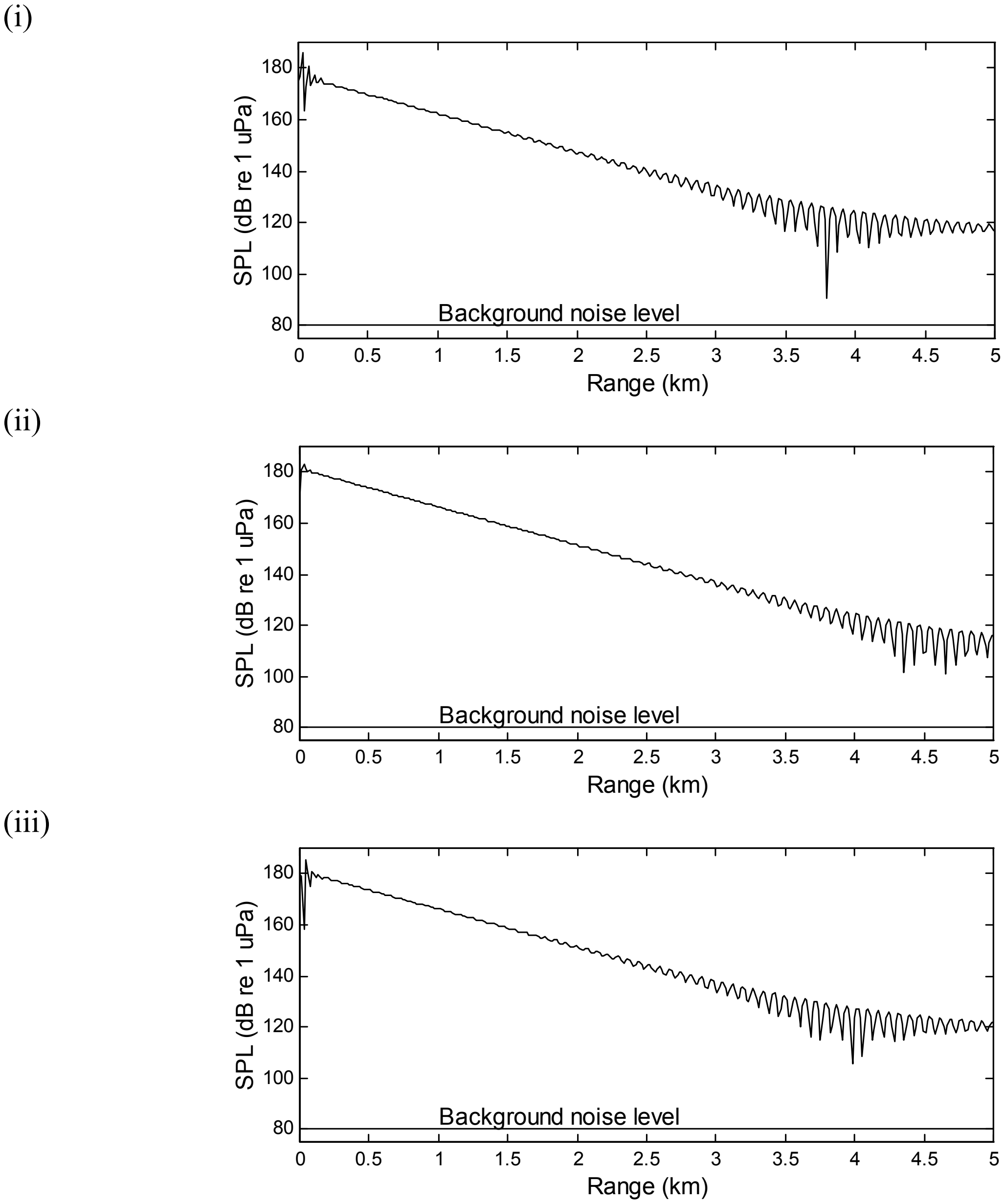


*Figure 15a: Underwater sound pressure level as a function of range at depths i) 3m, ii) 6m, iii) 9m for a piling depth of 6 m below the seabed*

## Wind turbine in operation

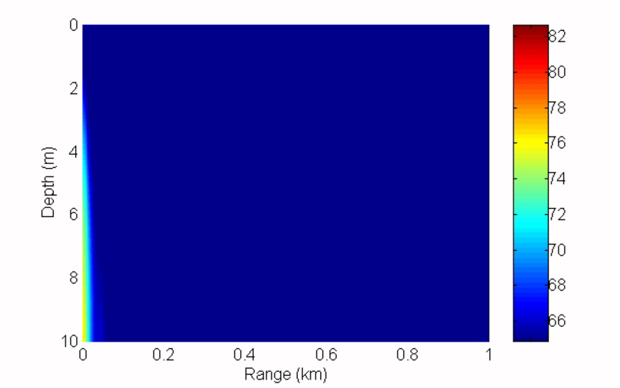


*Figure 16: Contour plot in range and depth of sound pressure level (dB re 1 μPa) in water for wind tower vibrational frequency of 30 Hz*

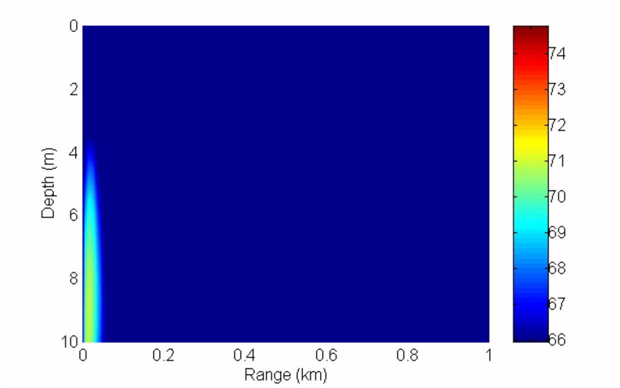


*Figure 17: Contour plot in range and depth of sound pressure level (dB re 1 μPa) in water for wind tower vibrational frequency of 50 Hz*

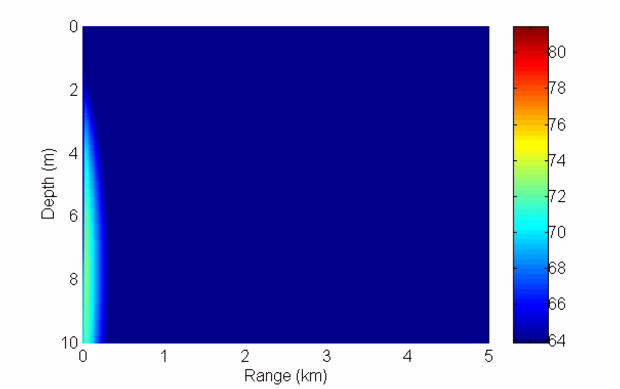


*Figure 18: Contour plot in range and depth of sound pressure level (dB re 1 μPa) in water for wind tower vibrational frequency of 70 Hz*

## Wind turbine in operation

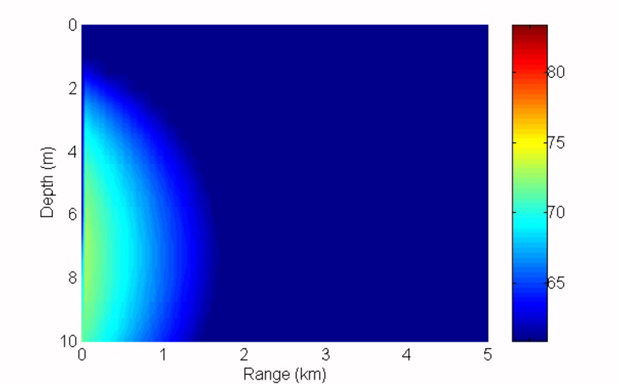


*Figure 19: Contour plot in range and depth of sound pressure level (dB re 1 μPa) in water for wind tower vibrational frequency of 90 Hz*

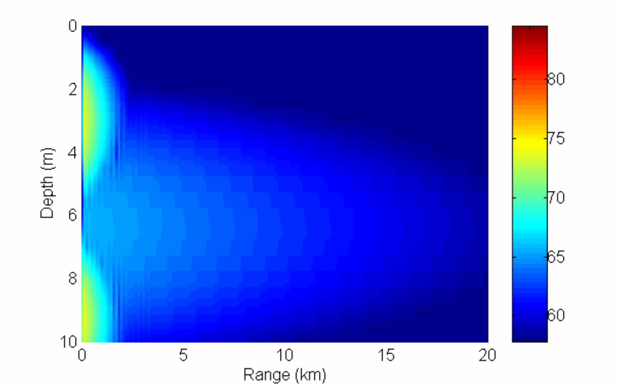


*Figure 20: Contour plot in range and depth of sound pressure level (dB re 1 μPa) in water for wind tower vibrational frequency of 160 Hz*

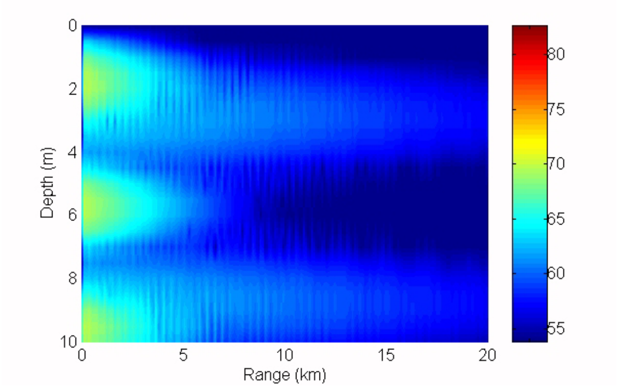


*Figure 21: Contour plot in range and depth of sound pressure level (dB re 1 μPa) in water for wind tower vibrational frequency of 250 Hz*

## Wind turbine in operation

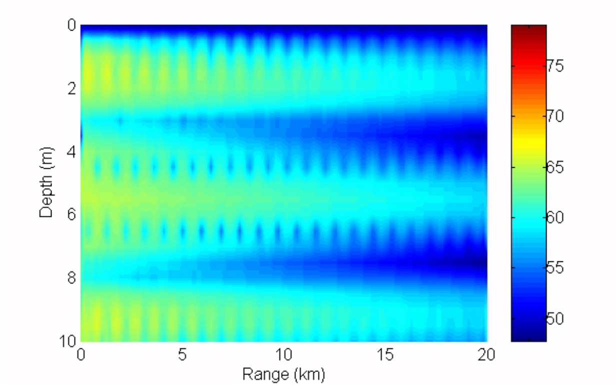


*Figure 22: Contour plot in range and depth of sound pressure level (dB re 1 μPa) in water for wind tower vibrational frequency of 400 Hz*

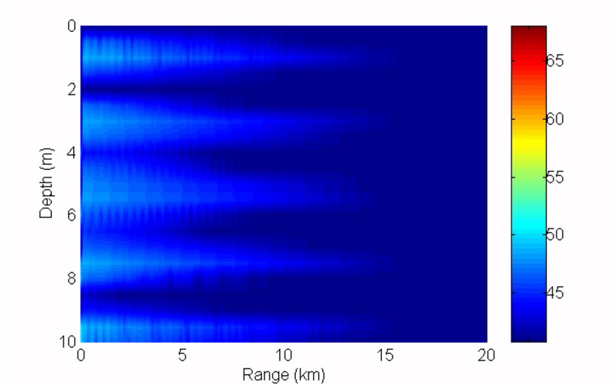


*Figure 23: Contour plot in range and depth of sound pressure level (dB re 1 μPa) in water for wind tower vibrational frequency of 600 Hz*

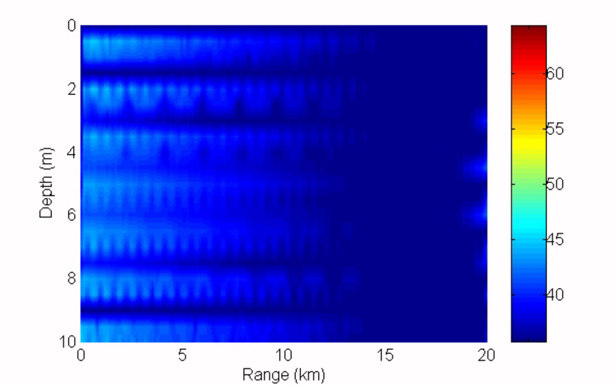


*Figure 24: Contour plot in range and depth of sound pressure level (dB re 1 μPa) in water for wind tower vibrational frequency of 800 Hz*

### Wind turbine in operation

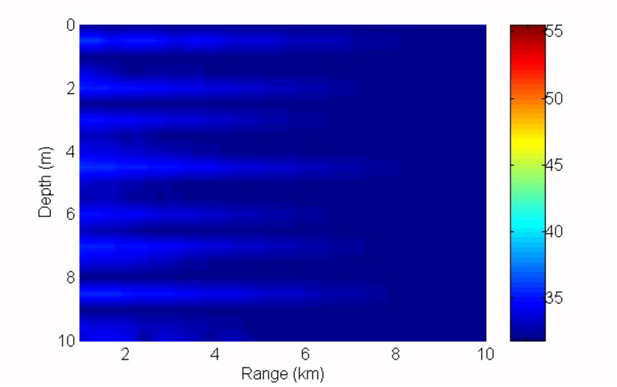


*Figure 25: Contour plot in range and depth of sound pressure level (dB re 1 μPa) in water for wind tower vibrational frequency of 1000 Hz*

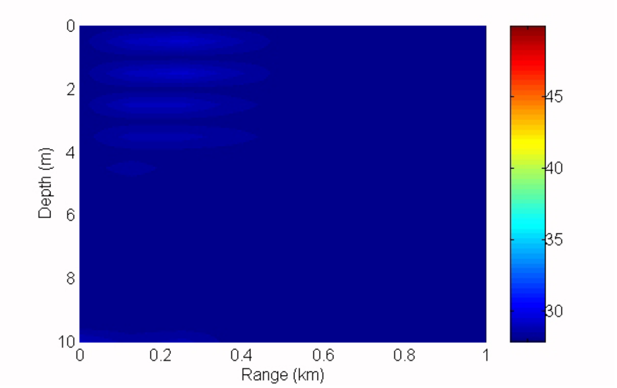


*Figure 26: Contour plot in range and depth of sound pressure level (dB re 1 μPa) in water for wind tower vibrational frequency of 1200 Hz*

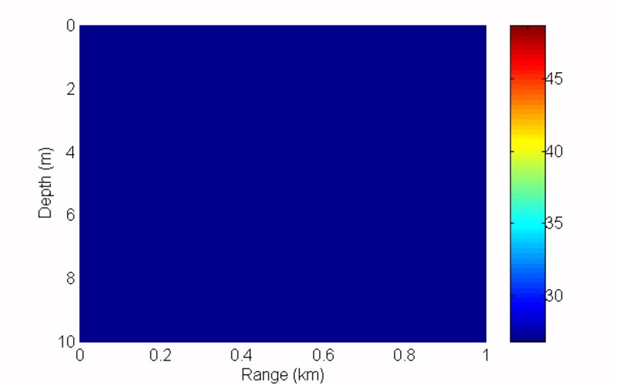


*Figure 27: Contour plot in range and depth of sound pressure level (dB re 1 μPa) in water for wind tower vibrational frequency of 1400 Hz*

## Wind turbine in operation

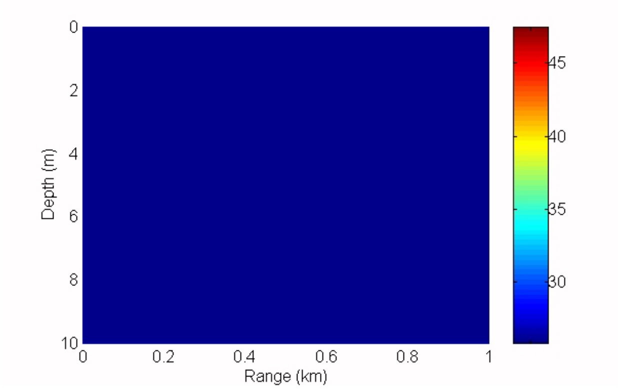


*Figure 28: Contour plot in range and depth of sound pressure level (dB re 1 µPa) in water for wind tower vibrational frequency of 1600 Hz*

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## Report documentation page

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10a. Abstract. (An abstract should aim to give an informative and concise summary of the report in up to 300 words).

QinetiQ has been tasked by Hayes-McKenzie Partnership to report on predicted underwater sound pressure levels during two stages in the development of an offshore wind farm in North Wales. The stages are the piledriving operation and the subsequent post-commission operation of the wind turbines. In addition, a high level mitigation strategy has been produced in order to assist in the minimisation of any potential impacts on the environment during the development of the wind farm.

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| 10b. Abstract classification: Commercial | FORM MEETS DRIC 1000 ISSUE 5 |

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