OCS Study
BOEM 2018-029

Field Observations During Wind Turbine Foundation Installation at the Block Island Wind Farm, Rhode Island

Appendix C: Airborne Noise Monitoring Report

US Department of the Interior
Bureau of Ocean Energy Management
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Appendix C: Airborne Noise Monitoring Report

May 2018

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Measurement and assessment of airborne noise during construction at the Block Island Wind Farm, Rhode Island

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Executive Summary

As part of the Real-time Opportunity for Development of Environmental Observations (RODEO) program, Subacoustech Environmental Limited, under the team headed by HDR Inc., undertook a series of airborne noise measurements during the installation of the foundations for the Block Island Wind Farm (BIWF).

Few measurements of noise propagation over water from offshore construction exist, with most attention paid to propagation over land, or under water. The BIWF development provided an excellent opportunity to collect data to study primarily the attenuation of impulsive airborne noise over long distances offshore.

Five jacket-type frame foundation structures were placed and fixed off the coast of Block Island, Rhode Island over August, September and October 2015. This involved situating the frames by crane on the seabed and inserting long metal piles into the frame, which were then driven by impact piling – striking the top of the piles with a specialised piling hammer – to fix the frame in place. This process generates high noise levels both above and below the sea surface. The noise produced during piling was measured under a series of environmental conditions over ten separate piling events on five days. Noise measurement stations were situated at three locations on land surrounding BIWF, and also a mobile measurement station on a survey vessel, which moved on transects on different orientations and ranges from the pile under installation. The three coastal locations were the nearest point of land to the wind farm on Block Island, the Block Island Southeast Light, approximately three miles to the northwest; Balls Point North, on the east coast of Block Island, approximately seven miles north-northeast of BIWF; and at Point Judith, 17 miles to the north of BIWF and the nearest point on the mainland.

The results of measurements of the airborne noise emission during piling and its propagation have been analysed. In general, wind speeds, humidity temperature and sea states were reasonably consistent over the measurement periods, although the wind direction was changeable. The measurements demonstrate variations depending on the environmental conditions, with the main difference in noise propagation caused by changes in the wind direction relative to the direction of travel on the measurement transects.

The propagation of noise from the piling over water will change from a roughly spherical to cylindrical spreading pattern at a distance, but the location of this transition point is hard to identify. No measurements were possible closer than 500 yards from piling activities for safety reasons, limiting more detailed examination of this aspect. It is also reasonable to assume that there is no single transition 'point' and the change will be progressive over a range. This range will be dependent on environmental factors, particularly the wind direction. However, based on the information available the transition is estimated to occur around 800 m from the pile.

Based on extrapolations from measurements at a distance, a sound pressure level of approximately 127 dB $L_{Aeq,1s}$ re 20 µPa is estimated at 1 m from the pile, treating the piling as an effective point source. Due to the shortage of measurements within the 500 yard (460 m) exclusion zone around the piling there is significant uncertainty in this figure.

An estimate of the value of the geometric spreading loss was estimated for different relative wind directions within the cylindrical spreading zone. Measurements over long distance clearly demonstrated higher noise levels under downwind conditions than when the wind was against the direction of travel.

One short opportunity was available to sample noise propagation over water in flat calm conditions and measurements were taken between 710 m and 10 km from the source. Analysis of the results suggest that even a modest increase sea state will have an effect on the propagation of airborne noise over water.

Noise from piling was always clearly audible at the Southeast Light, three miles away, and sometimes audible at Balls Point North at seven miles under good conditions. Piling noise was never audible at Point Judith; although background noise levels were substantially raised by wave noise on the shore at Point Judith, no noise could be heard in breaks in wave noise nor would it be expected to be audible at this distance based on the audibility at sea. However, it is possible under certain environmental conditions that greater sound projection could occur.

While substantial data was acquired during piling for the foundations at Block Island Wind Farm, only a small number of repeated transects were possible, and all under identical environmental conditions (i.e. daytime, summer, clear, dry, temperature and humidity). Further investigations for offshore piling noise would ideally be under different conditions and it is likely that these would be available in a different location or time of year. The greatest data gaps exist for airborne noise measurements at close range (less than 500 yards, or 460 m) and at a greater range, particularly in excess of 8,000 m. Additionally, it was not possible to take samples of the noise level as it propagates long range over land, and so it would be useful to attempt to identify any changes in the propagation in the transition from water to land.

List of contents

1 Introduction

BOEM (Bureau of Ocean Energy Management) seeks to investigate the environmental impacts associated with the construction and operation of offshore wind farms sited. The Block Island Wind Farm (BIWF), situated off the coast of Rhode Island, is the first of its kind to be constructed in United States waters and provided an opportunity to directly observe and measure a variety of potential stressors on the local environment. The Real-time Opportunity for Development of Environmental Observations (RODEO) program was set up by BOEM to enable this.

The construction and operation of an offshore wind farm will necessarily generate noise. This noise will be produced from many sources, including those associated with the transportation of construction equipment and materials, the operation of construction equipment and the operation of the completed offshore wind turbines. As part of the RODEO program, Subacoustech Environmental Limited, as part of the team led by HDR Inc., planned and executed a survey around the construction site to measure the noise emitted both in the air and underwater.

This report has been prepared by Subacoustech Environmental Ltd for HDR, Inc. It presents the methodology and results of the airborne environmental noise survey undertaken during the installation of the first foundations for the BIWF offshore wind turbines in August and September 2015.

1.1 Study overview and site description

The Block Island Wind Farm is situated approximately three miles (~5 km) off the southeast coast of Block Island, and south of Point Judith, Rhode Island. The wind farm plan is comprised of five offshore wind turbines, each of a 6 MW output, to produce a 30 MW development designed to significantly reduce Block Island’s reliance on diesel fuelled electricity.

Table 1-1 shows the coordinates of the five turbines.

Turbine designation	North (degrees)	West (degrees)
WTG 1	41° 7’ 32.596”	71° 30’ 27.230”
WTG 2	41° 7’ 11.770”	71° 30’ 50.208”
WTG 3	41° 6’ 53.060”	71° 31’ 16.183”
WTG 4	41° 6’ 36.710”	71° 31’ 44.810”
WTG 5	41° 6’ 23.050”	71° 32’ 15.540”

Table 1-1 Block Island Wind Farm turbine coordinates

Figure 1-1 below shows the overview layout of BIWF relative to Block Island.

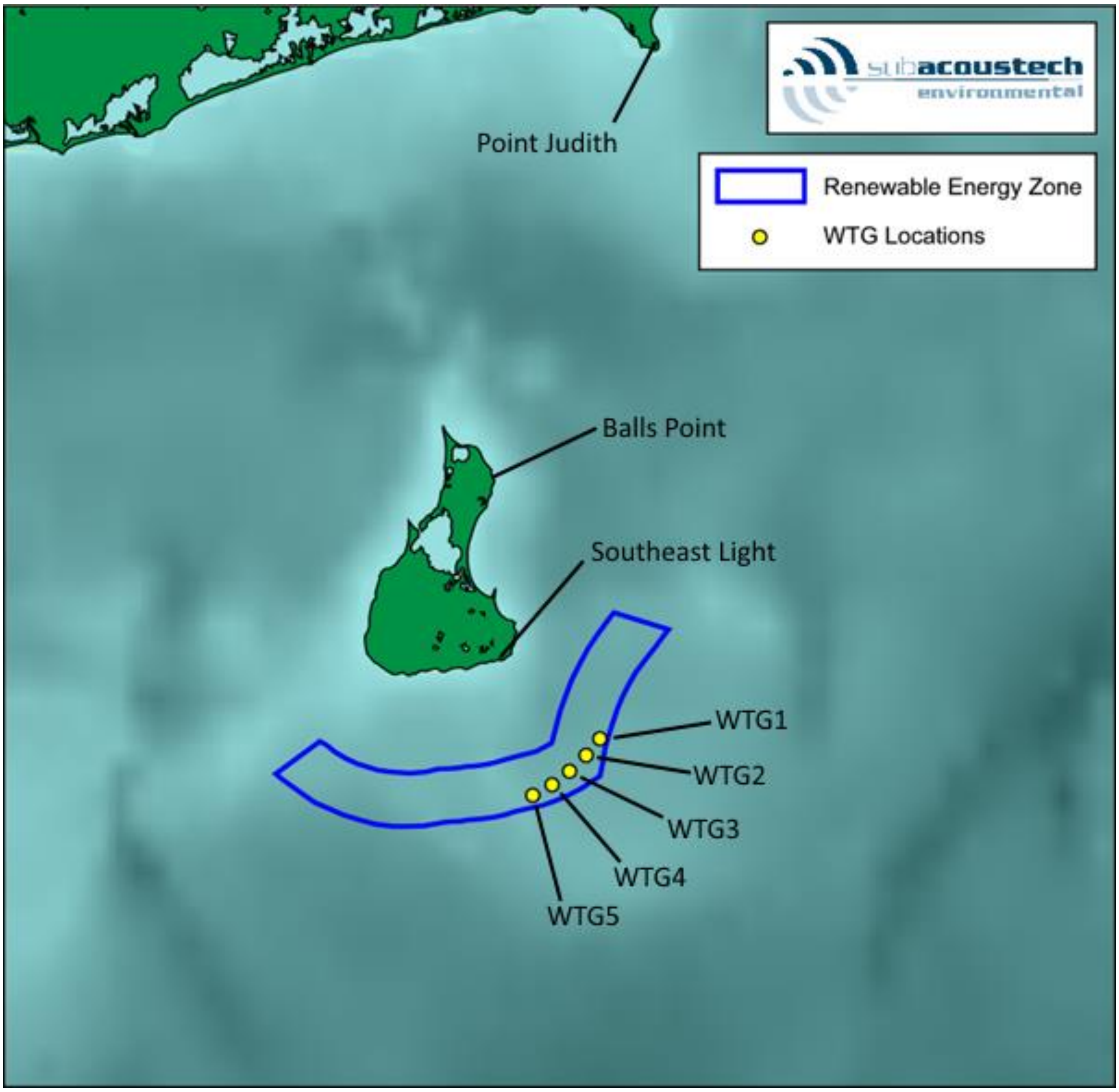

Figure 1-1 Location of the Block Island wind farm site

The wind turbines will each be situated on a 'jacket' frame foundation with a square profile. Each of the four corners is secured using a long steel tube, or 'pile', which is inserted by crane into each corner of the jacket and driven into the seabed using an impact pile driver supported by an adjacent barge.

The primary focus of this study was to observe and measure the levels of airborne noise produced during the installation of these piles. Airborne noise levels were sampled using a series of sound level meters (SLMs) set up at coastal locations and offshore attached to a survey vessel. These SLMs allowed noise levels to be captured simultaneously in fixed and mobile positions.

1.2 Construction machinery and foundation design

The five wind turbine generators will be installed on jacket frames, fixed to the seabed by four piles using an impact (percussive) pile driving technique. Two barge designs were employed on the BIWF site: a floating barge which was moored by a series of anchors during crane activity and a jack-up barge (see Figure 1-3). Most piles were installed using the jack-up. Each jacket was lowered by crane into the sea, and the piles lowered individually by crane into guide holes in each jacket corner. A piling hammer was set onto the top of one of the piles and driven incrementally into the seabed by a series of strikes. Piling for each leg typically took approximately 30 minutes. The depth of the sea was approximately 30 m at the BIWF location. Pile strikes were typically two to three seconds apart. The hammer, and therefore noise source, was approximately 35 m above sea level at its highest point and 6 m above sea level at its lowest, although the entire pile will radiate a certain amount of noise after a strike. Two piling hammers were utilized: Bauer-Pileco D280-22 (diesel) and Menck (hydraulic).

Once the four piles were driven, a second stage of piles were welded on and driven using the same procedure.

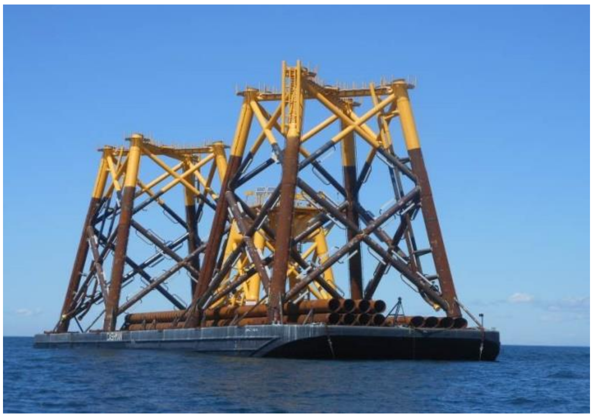

Figure 1-2 Jacket foundations and piles being transported by barge

Figure 1-3 Jack-up piling barge with four piles inserted, not driven, and hammer ready

Figure 1-4 Jacket with four driven piles

1.3 Scope of work

This report describes the results obtained from the underwater noise monitoring surveys for the jacket foundations 1, 2, 3, and 5. Also included within this report are descriptions of the methodology and data analysis performed. In summary, this report covers:

- Description of the methodology used to carry out the noise monitoring (Section 2)
- Measured background noise in and around the wind farm site (Section 3)
- Levels of noise measured during impact piling operations (Section 4)
- Interpretation of the levels of noise propagation and attenuation during construction, including the effect of wind direction (Section 5)
- Conclusions (Section 6)

2 Methodology

This section presents the methodology for the airborne noise surveys on and around Block Island. The equipment used is detailed, along with descriptions of the survey locations.

2.1 Measurement equipment

Three Larson David model 831 sound level meters (SLMs) were utilised in the monitoring during piling.

- LD 831 serial number 01152. Used offshore.
- LD 831 serial number 03417. Used at Point Judith on the Rhode Island mainland and Balls Point North, Block Island.
- LD 831 serial number 03605. Used at the lighthouse on Block Island.

Calibration certification for the equipment is provided in Appendix B, for the complete frequency range of the hydrophones, and confirmed before and after measurements using a field calibrator at 1000 Hz.

2.2 Measurement procedure

A series of airborne sound monitoring stations were set up both onshore and offshore to sample the noise produced during the construction of the offshore windfarm foundations, primarily by piling. All SLMs were calibrated with a field calibration device and clocks synchronized. Environmental and meteorological conditions were noted, including air temperature, wind speed and direction, precipitation, humidity, cloud cover, sea state and any other significant environmental features (e.g. fog).

2.2.1 Offshore measurement procedure

Airborne sound monitoring equipment was set up on the survey vessel URI *R/V McMaster*, operated by the University of Rhode Island, shown in Figure 2-1. Airborne sound monitoring equipment was set up on the survey vessel URI *R/V McMaster*, operated by the University of Rhode Island. A microphone and a high performance windscreen was fixed to a steel frame over the top of the vessel wheelhouse and connected to a sound level meter with a 5 m extension lead. The microphone was fixed to the top of the wheelhouse on the vessel (see Figure 2-2).

Figure 2-1 URI survey boat, R/V McMaster, used as the survey vessel for all transect measurements

Figure 2-2 McMaster deck showing microphone positioning and high performance windscreen (jack-up barge for piling in background)

The survey vessel's engines and other equipment which might have caused acoustic interference with the measurements were turned off and the boat was allowed to drift while measurements were taken.

The surveyors took measurements on a series of transects centred on the piling location. The transects were chosen either to coincide with one of the onshore monitoring stations (often heading northwest towards the Southeast Light, see Section 2.2.3) or coincident with a particular wind direction. The vessel was also used simultaneously for taking underwater noise measurements, and so the transects sometimes focused on directions pertinent to underwater conditions. A key element of the brief was to sample a range of conditions, especially transects under different wind directions relative to the transect direction.

Transects began at the edge of the offshore safety exclusion zone, 500 yards (460 m) from the piling location, and continued out until the vessel reached land or an impassable region of water, piling ended or piling noise was no longer audible or detectable. In practice the measurements typically continued beyond the range of audibility in air as the sound was detectable in water to a much greater distance.

At intervals starting at around 500 m and doubling in distance (500 m, 1 km, 2 km, 4 km, etc.) sound data was acquired on the computer, together with details of the boat's position and other relevant information. The boat's position was recorded on the computer system by sending the output from a GPS receiver to a USB port on the computer, which was logged with the acoustic data. This was used to determine the range to the piling from the survey vessel.

In general, airborne noise measurements were taken continuously during a piling event and so captured all noise during that period, including voices on the vessel and engine noise as the vessel moved.

A summary of the measurement details and conditions is given in Table 2-1.

Tran-sect ID	Date	Turbine foundation	Direction	Ranges	Time	Wind direction	Wind speed
1	18-Aug-15	WTG2	Northwest	450 - 700 m	15:53 - 16:11	SW	3-4.5 m/s
2	03-Sep-15	WTG2	Northwest	550 m - 4.85 km	09:56 - 10:20	WSW	3-3.5 m/s
3	03-Sep-15	WTG2	East	640 m – 12.0 km	11:14 - 15:11	WSW-S	3 m/s
4	17-Sep-15	WTG5	Northwest	470 m - 5.32 km	12:42 - 13:35	SW	3 m/s
5	17-Sep-15	WTG5	Northwest	590 m – 5.32 km	15:20 – 15:53	W	4 m/s
6	17-Sep-15	WTG5	Northwest	420 m – 5.32 km	16:39 – 17:21	W	3 m/s
7	18-Sep-15	WTG3	Southeast	730 m – 6.0 km	13.09 – 13:49	SW	2 m/s
8	18-Sep-15	WTG3	Southeast	500 m – 6.42 km	14:22 – 15:07	NW	3 m/s
9	19-Sep-15	WTG1	North	710 m – 10.5 km	08:37 – 08:55	NE	Calm
10	19-Sep-15	WTG1	North	3.9 km – 6.2 km	15:29 – 15:52	S	2 m/s

Table 2-1 Summary of underwater noise measurements of piling undertaken

2.2.2 <u>Onshore Sound Monitoring</u>

SLMs were fixed to tripods facing the direction of the site, and windscreens were fitted at all times. Wind speed, pressure, air temperature and relative humidity was taken at 3 m above sea level while offshore and at the measurement locations at the top of the cliffs on Block Island, approximately 80 m above sea level, 2 meters above ground level. There was no precipitation over the duration of the survey.

The onshore measurement locations were selected to be close to the coast, with nothing blocking line of site to the BIWF site and minimal propagation over land. It was attempted to acquire a location with a minimum of influence from other noise sources, primarily the presence of members of the public on foot and road noise. Account was taken of the prevailing wind direction in selection, southeast during the summer months.

Airborne noise levels were captured at three locations surrounding the BIWF site, representing a spread of distances to the site.

2.2.3 Southeast Light, Mohegan Bluffs, southeast Block Island

Noise measurements were undertaken at the Southeast Light for the majority of piling events. This location is approximately five kilometres (three miles) from the BIWF site. The SLM was situated on the south of the lighthouse land near the edge of the cliff, as far as possible from the public, with line of sight to the BIWF offshore site. Background noise was dominated by rustling foliage and distant waves, sporadic voices from members of the public and occasional light aircraft.

Figure 2-3 Photograph taken from the Southeast Light measurement location, showing the BIWF construction barge (circled) on the horizon

2.2.4 Balls Point North, northeast Block Island

The measurement location at Balls Point North was on the edge of a quiet footpath at the top of the cliff overlooking the site. This is approximately 11 kilometers (approximately seven miles) from the site. The background noise here was dominated by vegetation rustling in the wind and wave noise, and occasional light aircraft and vessels passing.

Figure 2-4 Onshore noise measurement location at Balls Point North, showing barge (circled) on the horizon.

2.2.5 Near Point Judith Lighthouse, Point Judith, Rhode Island mainland

The measurement location at Point Judith, on the Rhode Island mainland, was approximately 27 kilometers (17 miles) north of the BIWF site, on the coast. It was selected as an accessible position near the coast, as far as possible from the sea, without too much noise propagation over land, but which was unlikely to be disturbed by members of the public. The background noise was dominated by intermittent wave noise on the beach, which was impossible to avoid near to sea level.

Figure 2-5 Onshore measurement location near Point Judith Lighthouse. SLM was situated on the section of clear ground behind the large rock.

3 Background noise measurements

3.1 Introduction

Background noise readings were taken in all locations over periods outside of piling, in locations identical to those used during the measurements of construction noise. Although construction machinery was in position at all times, the activities being undertaken and the distances between the measurement location and the machinery were such that no appreciable noise from it could be detected or was audible outside of piling.

The background noise in each measurement location was dominated by specific sources in each case:

- Location 1 (mobile), at sea: waves and wave slap on the vessel. Vessel entirely shut down during measurements.
- Location 2, SE Light, Block Island: distant waves, rustling vegetation, members of the public, occasional vessel pass, light aircraft.
- Location 3, Balls Point North, Block Island: distant waves, occasional vessel pass.
- Location 4, Point Judith, RI mainland: wave noise on the shore.

3.2 Location 1 (mobile), background noise levels offshore

Background noise levels were sampled on the vessels outside of piling events. The background noise was typically caused by the movement of the seas and some wave slap to the side of the vessel. Background noise levels under typical offshore conditions during the August and September 2015 surveys are shown below.

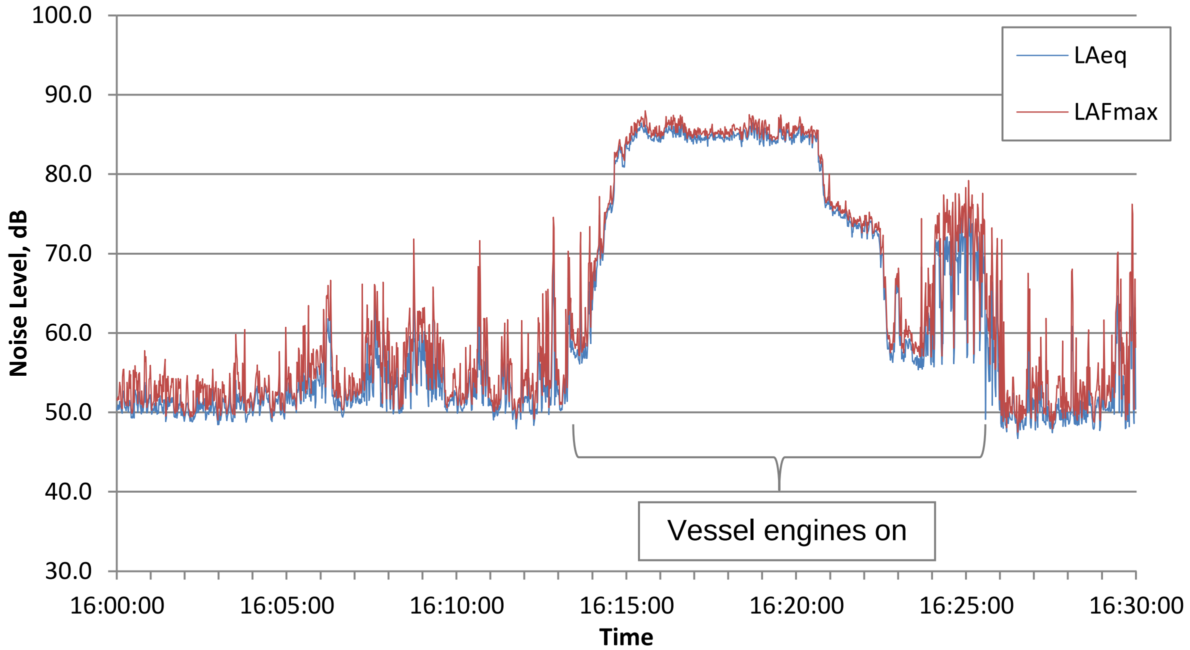

Figure 3-1 Typical sample background noise level measured offshore, August 25, 2015

Wind speed 2-3 m/s southwest, seas ~0.5 m.

	$L_{Aeq,10mins}$	L_{AFmax}	$L_{A90,10mins}$
16:00-16:10	53.3 dB	n/a	49.8 dB

Table 3-1 Summary of background noise level sample offshore (excluding engines)

Background noise levels offshore were entirely dependent on the sea state, and the orientation of the vessel to the waves. As the vessel had to be shut down for the duration of the measurement period the orientation was somewhat out of the control of the personnel on board. However, the sea state was fairly consistent throughout most of the surveys. There was also some influence from small creaks on the vessel and occasional radio transmissions, therefore the L_{Aeq} should be considered indicative and a valid L_{AFmax} cannot be stated.

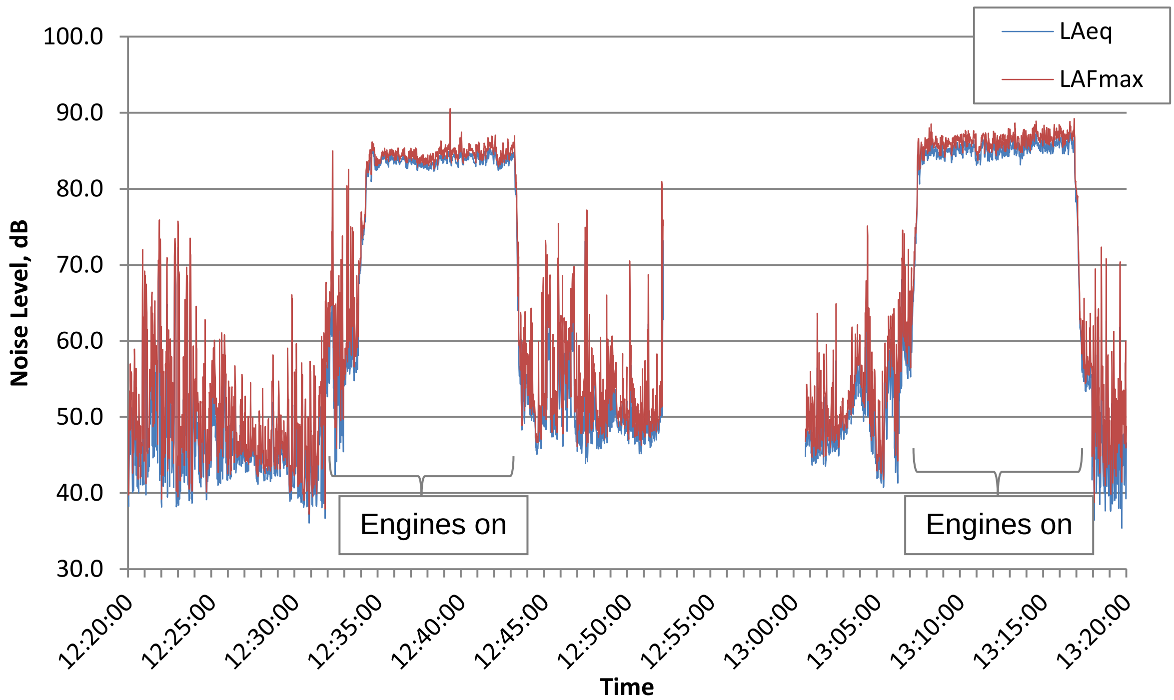

Figure 3-2 Comparative background noise level measured offshore, calm, September 19, 2015

Wind calm, sea still to <0.5 m

	$L_{Aeq,15mins}$	L_{AFmax}	$L_{A90,15mins}$
12:20-12:30, 12:45-12:50	56.6 dB	n/a	42.5 dB

Table 3-2 Summary of background noise level sampled offshore (excluding engines)

Figure 3-2 shows noise levels measured on September 19 when the wind and wave conditions were extremely calm and the sea, especially early in the sample, was glassy. The L_{A90} is around 7 dB lower than under the slightly choppy conditions normally present during the survey. As previously, influence from small vessel noises and radio transmissions cannot be excluded from the noise levels calculated.

3.3 Location 2, Southeast Light

A short-term indicative snapshot of background noise levels measured at the Southeast Light is shown below.

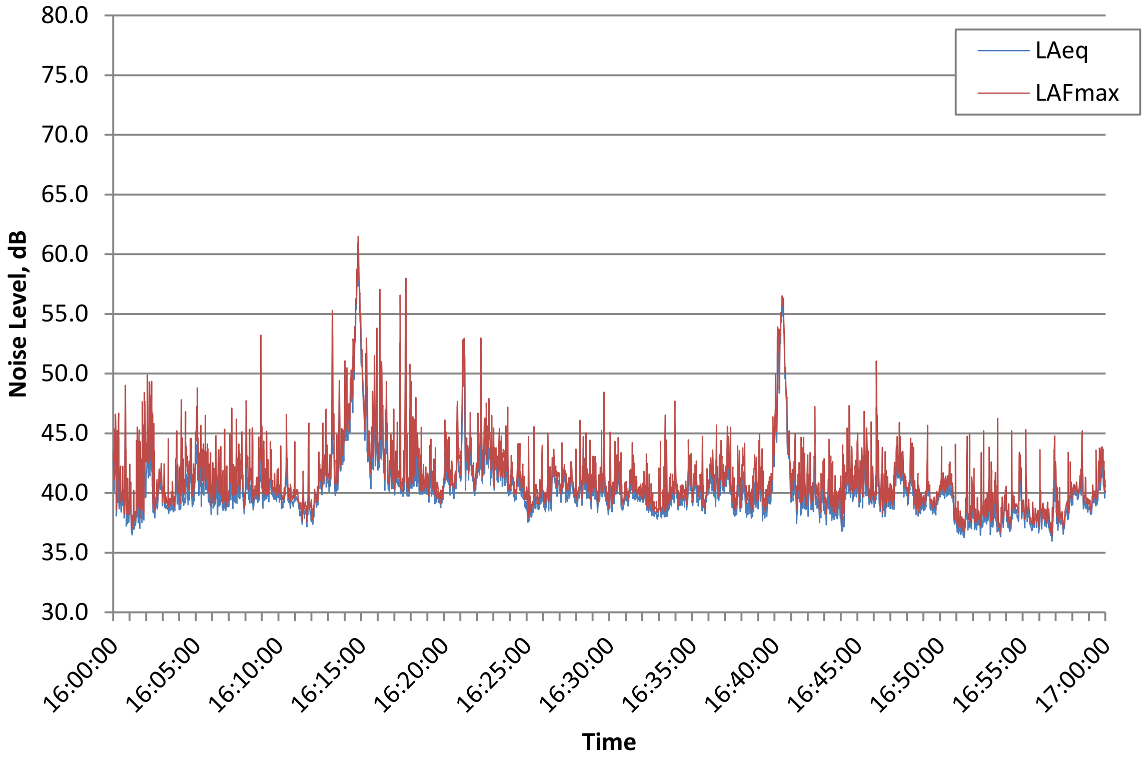

Figure 3-3 Typical sample background noise level measured at the Southeast Light, August 9, 2015

Average wind speed 9 m/s, northeast.

	$L_{Aeq,30mins}$	L_{AFmax}	$L_{A90,30mins}$
16:00 – 16:30	43.3 dB	61.5 dB	38.6 dB
16:30 – 17:00	41.1 dB	56.5 dB	37.5 dB

Table 3-3 Summary of background noise level sample at the Southeast Light, August 9, 2015

Noise levels were affected by members of the public talking and occasional light aircraft passes (for example see 16:15 in Figure 3-3 above).

A longer-term background noise survey was undertaken in January 2016, which sampled noise levels over day and night periods in the winter and at higher wind speeds, representative of more optimum wind turbine conditions. Note: due to the longer timescales, Figure 3-4 uses a 5-minute sample periods, as opposed to the 1-second sample periods used elsewhere.

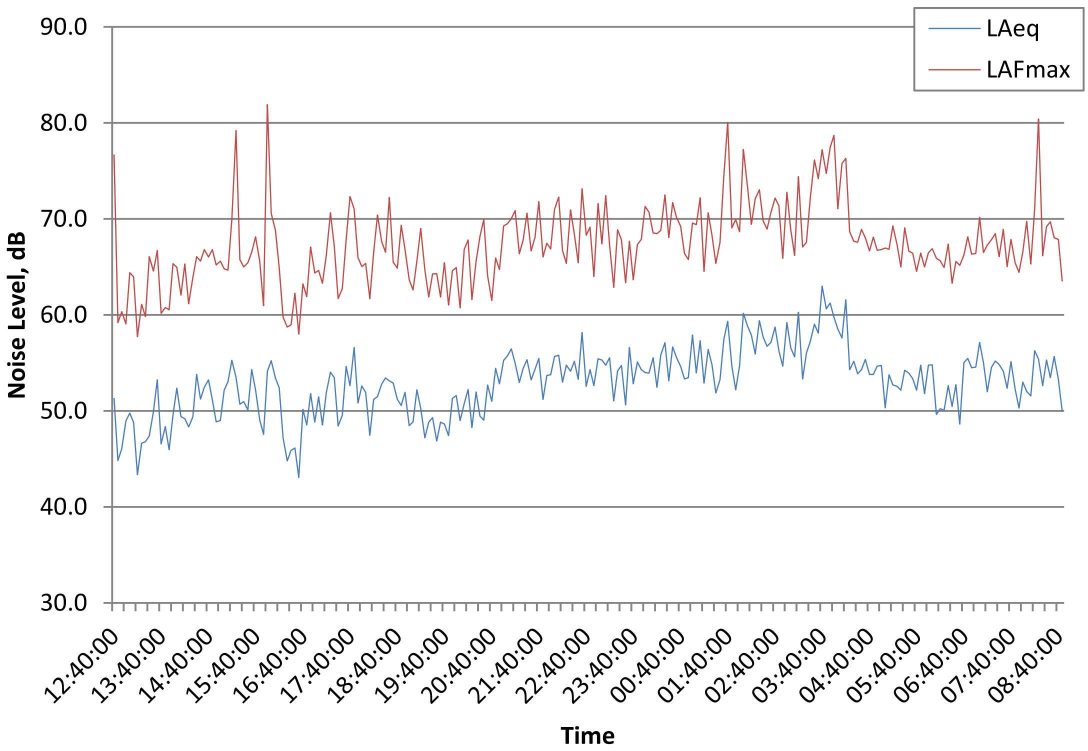

Figure 3-4 Sample background noise level measured at the Southeast Light, January 18-19, 2016

Wind speed range 6-12 m/s, northwest. The microphone was sheltered from strong winds in the shadow of the shed overlooking the sea. Noise levels were caused by wind in bare winter trees and correlated well with wind speed (shown in Figure 3-5 below).

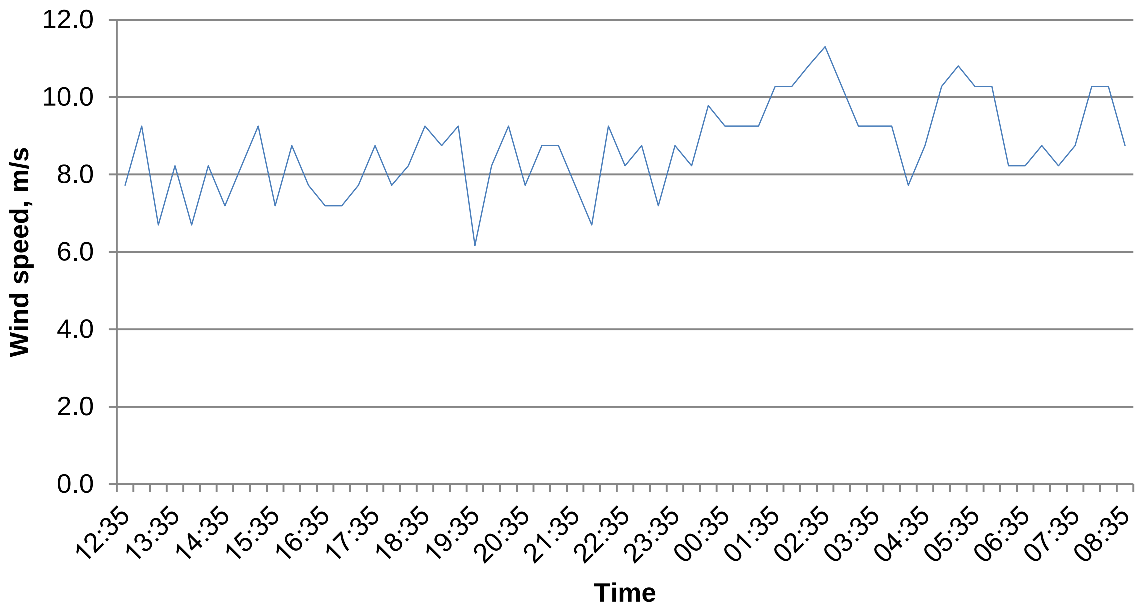

Figure 3-5 Wind speeds on Block Island, historic data from wunderground.com, Block Island Airport weather station, January 18-19, 2016

Note: wind speed data is not available with the same resolution as the noise data.

3.4 Location 3, Balls Point North

Background noise levels sampled at Balls Point North are shown in Figure 3-6 below. Problems with the SLM download mean that manual measurements must be used and thus this dataset uses a lower resolution to the other datasets. Note also that the noise levels recorded were L_{Cpeak} rather than L_{Amax} and not directly comparable with one another.

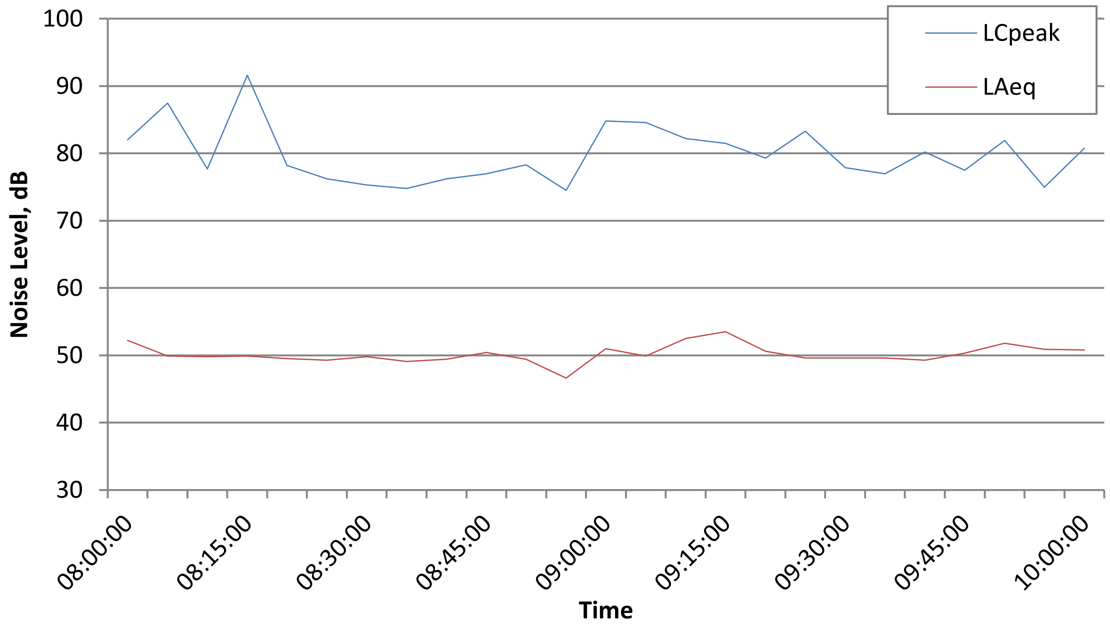

Figure 3-6 Typical sample background noise level measured at Balls Point North, August 13, 2015

	$L_{Aeq,30mins}$	$L_{Cpeak,30mins}$	$L_{A90,30mins}$
08:00 – 08:30	50.2 dB	91.6 dB	45.8 dB
08:30 – 09:00	49.3 dB	78.3 dB	45.5 dB
09:00 – 09:30	51.4 dB	84.8 dB	46.4 dB
09:30 – 10:00	50.3 dB	81.9 dB	46.0 dB

Table 3-4 Summary of background noise level sample at Balls Point North, August 9, 2015

Noise levels were caused by passing vessels, wave noise and rustling vegetation.

3.5 Location 4, Point Judith

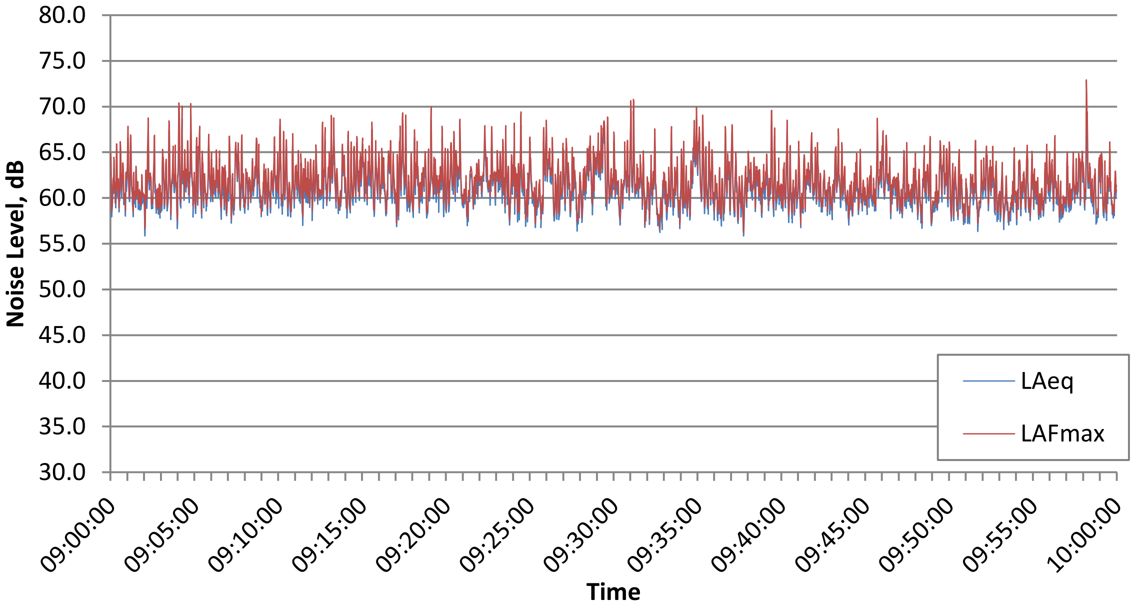

Figure 3-7 Typical sample background noise level measured at Point Judith, August 30, 2015

	$L_{Aeq,30mins}$	L_{AFmax}	$L_{A90,30mins}$
09:00 – 09:30	62.0 dB	70.4 dB	58.7 dB
09:30 – 10:00	61.3 dB	72.9 dB	58.2 dB

Table 3-5 Summary of background noise level sample at Point Judith, August 30, 2015

Noise levels are dominated by wave noise on the pebbly shore at Point Judith, which is continuous and reliable.

4 Piling noise measurement results

Measurements were taken offshore on the SLM set up on the *R/V McMaster* during all of the piling events.

Measurements were taken at the Southeast Light on Block Island during all piling events, with the exception of September 19th, where the monitor moved to Balls Point North. The results below show the results of the airborne noise measurements taken offshore alongside time histories taken at the Southeast Light, as the noise levels were reliably audible here and remained at a consistent location, unlike the measurements taken offshore. Measurements were taken at Point Judith on 18th and 3rd September. At no time during construction was piling audible and as such the noise measurements have only been reproduced in this report in Section 4.1.

The noise levels measured are variable strike-to-strike, and so a 30-second sample is provided of clear, continuous piling noise where it was unaffected by any other spurious noise source (for example public voices nearby, light aircraft overhead, bangs on the vessel). The 1-second $L_{Aeq,}$ L_{AFmax} and L_{Cpeak} value given was selected from the higher levels sampled of the pile strikes over a measurement period, typically the second highest measured within the period to avoid the risk of spurious spikes. As coastal measurement periods were much longer than those on the vessel, since the vessel had to move between locations and sometimes over significant distances, the measurement period chosen on the coast was selected to coincide with measurements taken offshore. This somewhat selective technique was deemed necessary to obtain the best quality comparable results due to the frequent presence of non-piling noise sources during the busy holiday period in which the works took place.

More detailed results from the surveys, including meteorological conditions at the time of piling and breakdowns of noise levels, are provided in Appendix A.

4.1 WTG2 – 18 August 2015

Piling work began on WTG2. A very brief piling event took place to begin to install the first corner pile before an element of the piling equipment failed and piling ceased. This event was captured on the SLMs offshore and at the Southeast Light on Block Island.

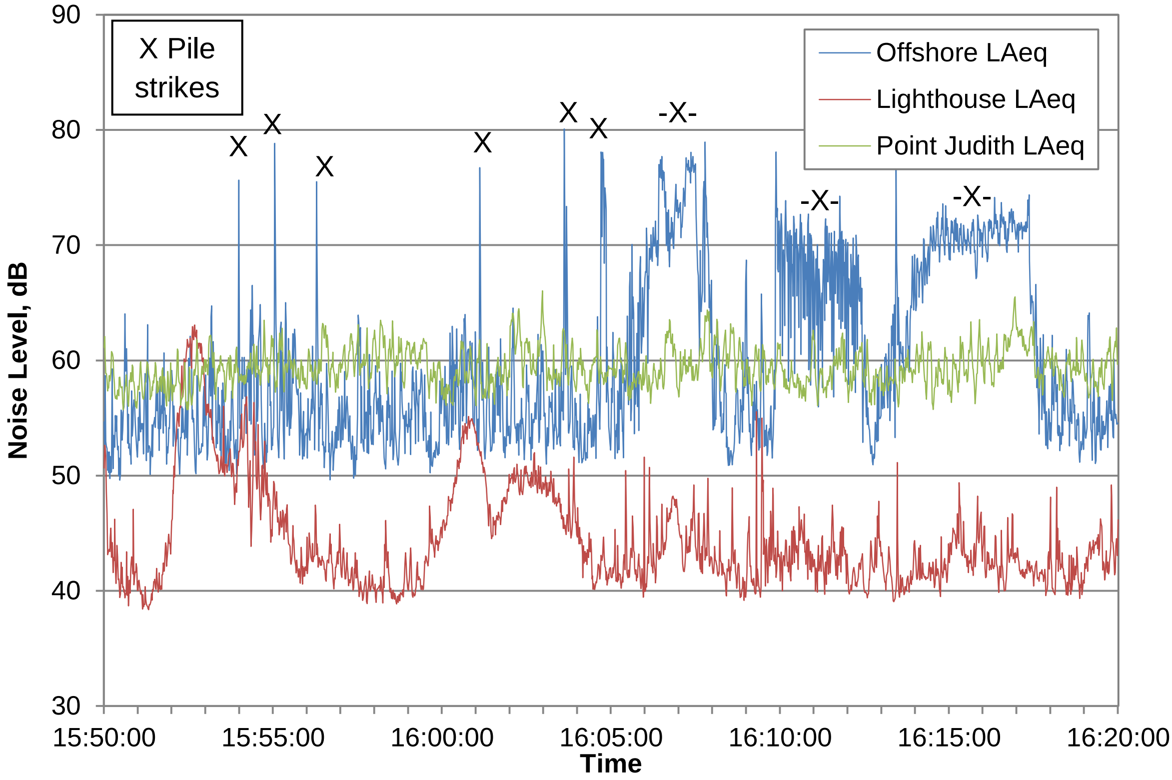

Figure 4-1 1s time history over the piling period, August 18, 2015

Figure 4-1 shows the time history over the piling period, which marks the pile strikes offshore, the variability of noise onshore at the Southeast Light and the noise levels at Point Judith.

Three initial pile strikes can be seen clearly at around 15:55, with a few sporadically before continuous piling for three distinct periods over the next 20 minutes. Piling can be detected in the Southeast Light time history and was clearly audible, although it is lost in frequent recreational light aircraft flybys (e.g. 15:53, 16:01). The noise level remains relatively high at Point Judith due to wave noise.

Although the noise appears somewhat continuous from the Point Judith time history, of course there were periods between waves when the ambient noise was effectively ‘quiet’ and pile strikes would be more audible. Subjectively, pile strikes were never audible at any time at Point Judith. This is as expected based on offshore samples taken at locations approaching Point Judith. For this reason Point Judith has been omitted in the rest of the main report.

4.2 WTG2 – 03 September 2015

Airborne noise measurements took place during the second stage of pile driving for the foundation WTG2 which took place on 3rd September 2015. The jacket foundation had previously been set and the first stage of pile driving had occurred. Three of the four second stage piles were sampled.

Throughout the driving of the second pile, measurements were carried out along an eastern transect between 640 m and 4.05 km. The second piling event began at 11:14 and ceased at 11:35.

In between the second and third piles being driven the survey vessel moved out to 7.6 km to continue measurements along the east transect. On commencement of piling for the third pile, measurements were taken between 7.6 km and 20 km.

The survey vessel continued to a distance of 30 km in between the third and fourth piles being driven for underwater measurements. The noise was inaudible in air at 20 km, and so no further measurements were taken at greater distances.

Measurements were taken onshore, at the Southeast Light and Point Judith. As previously, no noise from the piling was detected at Point Judith either subjectively or on the SLM at any time.

4.2.1 Pile 1 Northwest Transect

Figure 4-2 shows the time history data captured by the monitor onboard the survey vessel. The graph clearly displays four blocks which correspond to vessel operation; the SLM was not shut down during these periods and so these represent engine noise.

The figure shows the comparison between three common noise metrics that are used in environmental noise assessments. The time average is 1 second, equivalent to the 'slow' weighting for the L_{Aeq} metric.

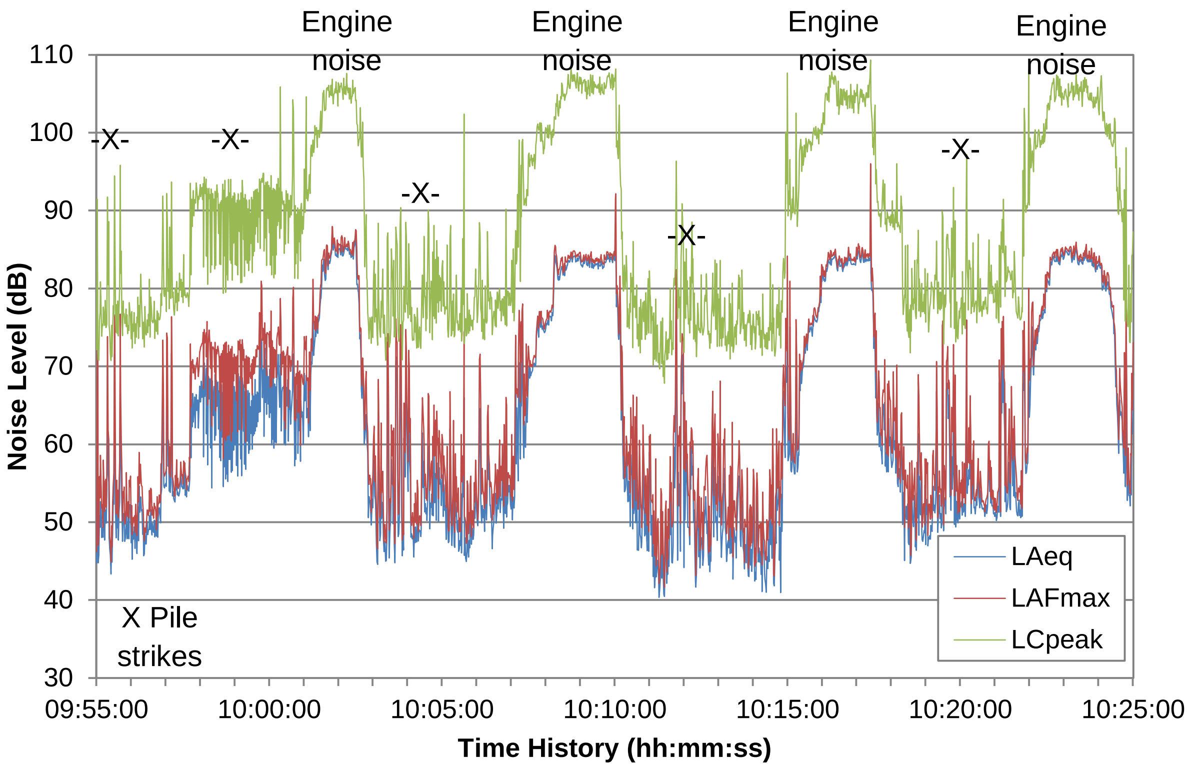

Figure 4-2 Time history plot of noise levels recorded offshore from WTG2 on 03 September 2015

Between vessel engine operation periods, Figure 4-2 shows a progressive reduction in noise levels clearly within the L_{Cpeak} trace as the vessel moves further from the noise source. The exception to this is the final measurement period around 10:20 at approximately 3,000 m, where the noise levels increase with no obvious explanation. This may be due to environmental conditions, such as a brief undocumented lull in wind or change in wind direction. No similar increase was observed in the underwater noise measurements at the same time, and no increase was noted on the time history for the Southeast Light (see Appendix A and Figure 4-3). A similar, apparently spurious, increase was also noted on the east transect at around 4,000 m. This is discussed further in Section 4.2.2.

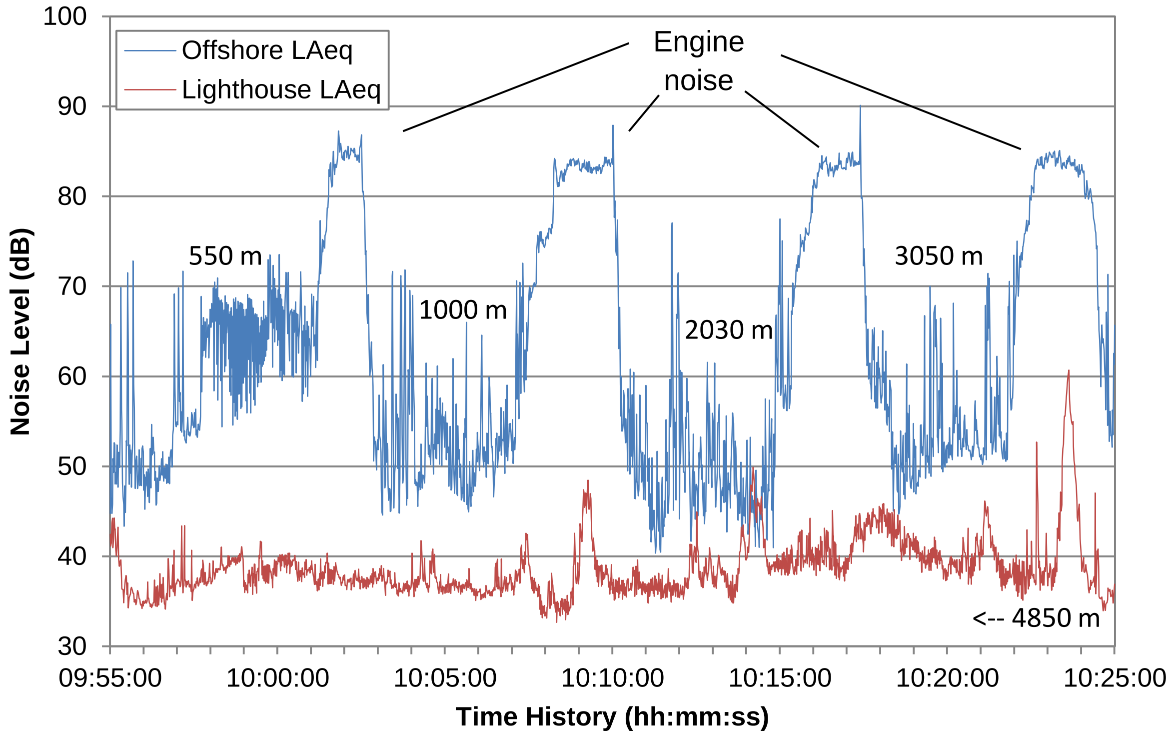

Figure 4-3 Comparative time history plot of noise levels recorded offshore and on the coast on an northwest transect, 03 September 2015, including range from piling

Figure 4-3 shows the same offshore time history as Figure 4-2 alongside the time history recorded at the Southeast Light. The transect was to the northwest and so the vessel was travelling towards the lighthouse.

4.2.2 Pile 2 and 3 East Transect

Measurements were taken along an east transect for two piling events. Figure 4-4 presents a summary of the data captured along the east transect. Noise events of pile strikes were recorded up to 12 km from the piling.

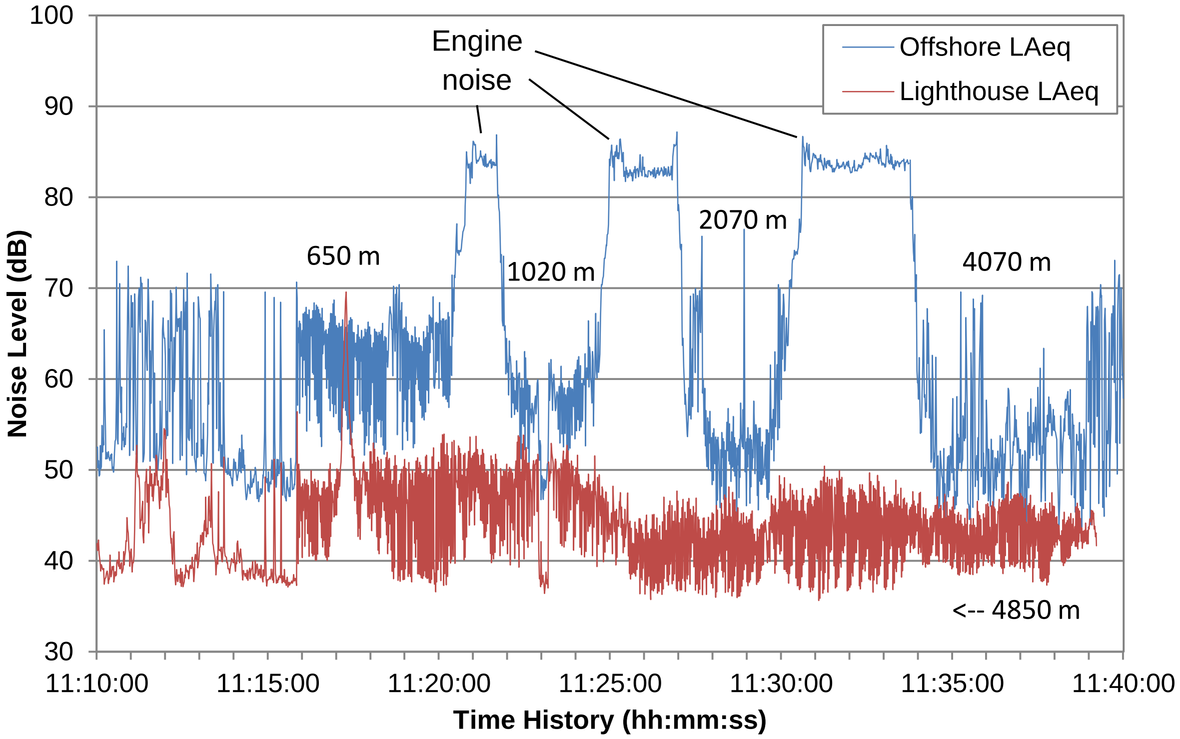

Figure 4-4 Time history plot of noise levels recorded offshore and on the coast on an east transect, 03 September 2015, including range from piling

As in Section 4.2.1, the offshore time history shows a progressive reduction over time, and therefore distance, around the periods of transit and high engine noise. There is also a clear reduction in the noise level received at the fixed lighthouse location at around 11:25, which cannot be explained.

In common with the measurements earlier in the day in Section 4.2.1, there is an unexpected increase in the noise level at around 11:35, 4.0 km from the piling. As the distances were similar but on different transects, it is possible that the increase is caused by atmospheric temperature variations, which can lead to a focussing of sound over a particular range. This cannot be confirmed.

4.3 WTG5 – 17 September 2015

Noise measurements were undertaken on 17 September 2015 offshore, at the Southeast Light and Point Judith. The pile driving was carried out on WTG5 foundation. The jacket structure of the foundation had been placed and the first stage of the four piles had been placed into the jacket.

4.3.1 Pile 2 – Northwest transect

Figure 4-5 shows a comparative time history of the airborne noise levels sampled offshore and at the Southeast Light. The survey vessel was on a heading directly towards the lighthouse.

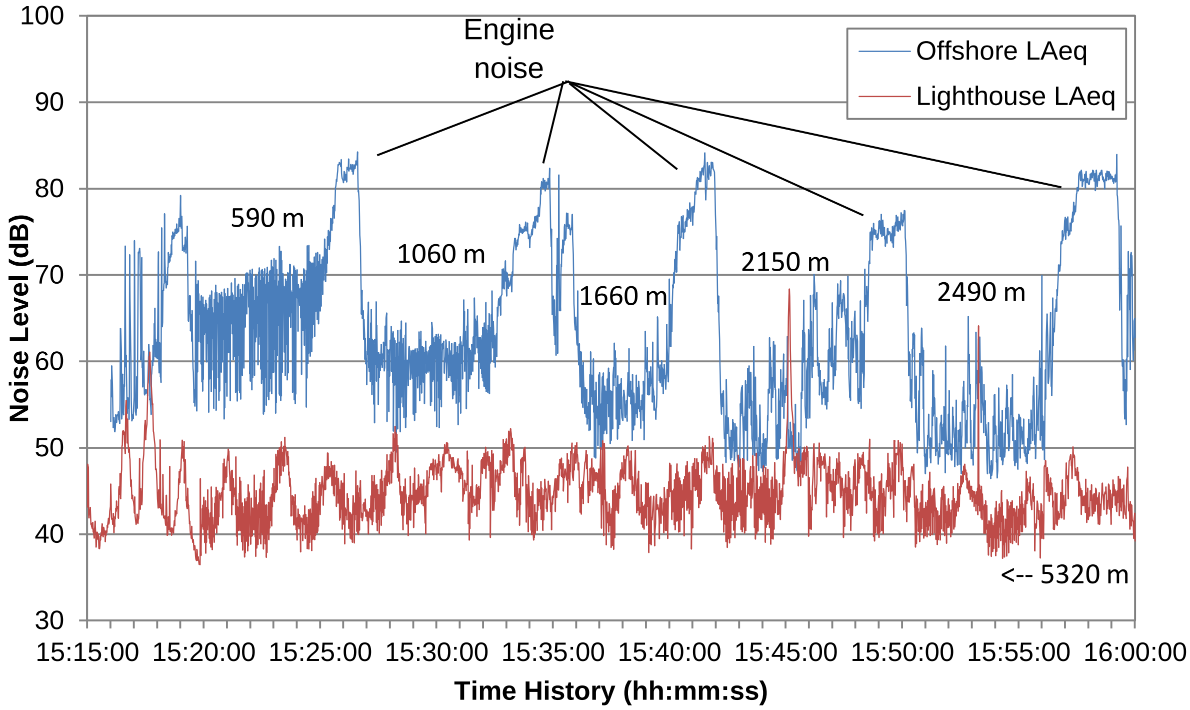

Figure 4-5 Time history plot of noise levels recorded offshore and on the coast on an northwest transect, 17th September 2015, including range from piling

The time history shows the initial soft start clearly at the beginning of the offshore trace, but is lost in the background noise onshore. After periods of engine noise with transiting of the survey vessel, progressive reductions in the noise level with time and distance are visible, although there is an increase around 15:47: piling noise was only just audible at this location and so this increase is due to other spurious factors most likely caused by talking on the vessel – underwater noise monitoring was also being conducted at this time – or other external source.

4.3.2 Pile 3 – Northwest transect

Figure 4-6 shows the comparative time histories between the offshore SLM taken on a northwest transect and the lighthouse. Five periods of vessel engine operation are clearly identifiable. The lighthouse monitor was started late.

The offshore noise levels decrease as expected after each transit until 17:35, where the vessel returns to 750 m, the same distance as at 16:50-16:55.

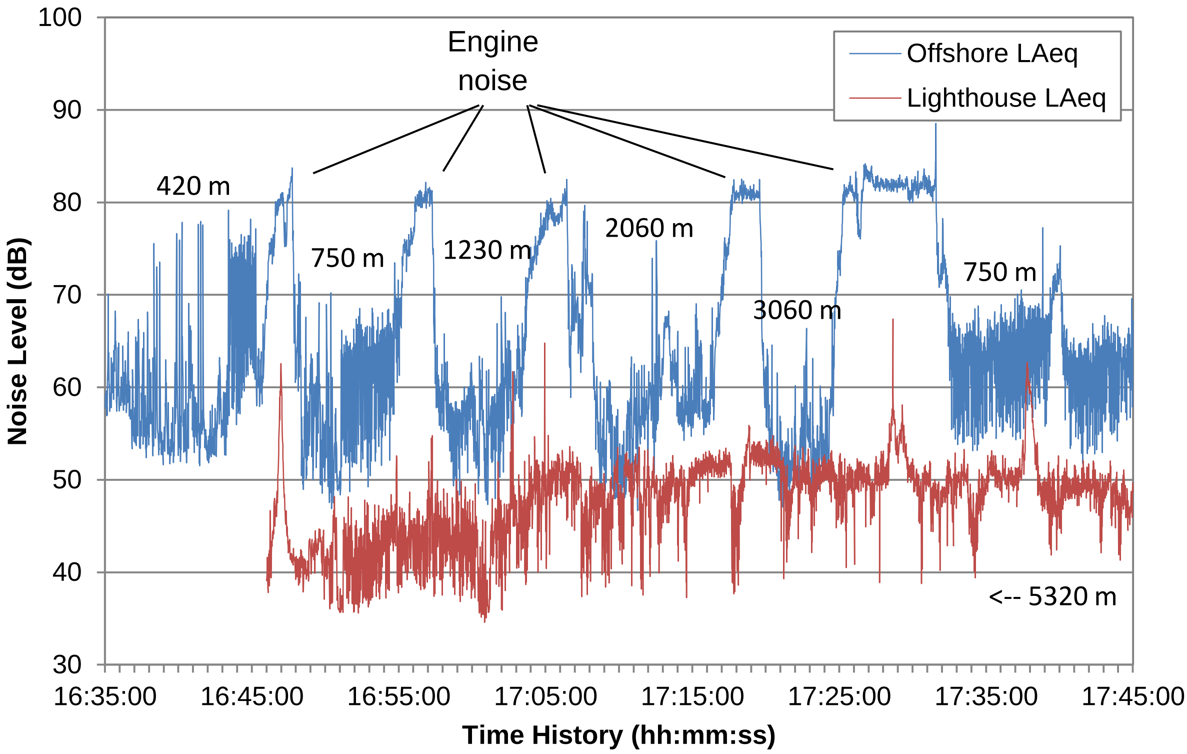

Figure 4-6 Time history plot of noise levels recorded offshore and on the coast on an northwest transect, 17th September 2015, including range from piling

The lighthouse time history shows a clear increase in the received noise level in the early stages of piling. This is also seen in the underwater fixed monitor and matches the ramp-up (i.e. progressive increase) in blow energy over the piling event. Energies increased from approximately 100 kJ to 170 kJ at 17:04 and from 170 kJ to 250 kJ at 17:18.

4.4 WTG3 – 18 September 2015

Noise measurements took place during the second stage of pile driving for the foundation WTG3 which took place on 18 September 2015. The jacket foundation had previously been set and the first stage of pile driving had occurred.

4.4.1 Pile 1 – Southeast transect

Airborne noise transect measurements were carried out during the pile driving along a transect to the southeast from WTG3, out into deeper waters. Three ranges were sampled offshore: 730 m, 3.1 km and 6.0 km. The offshore SLM was started slightly late.

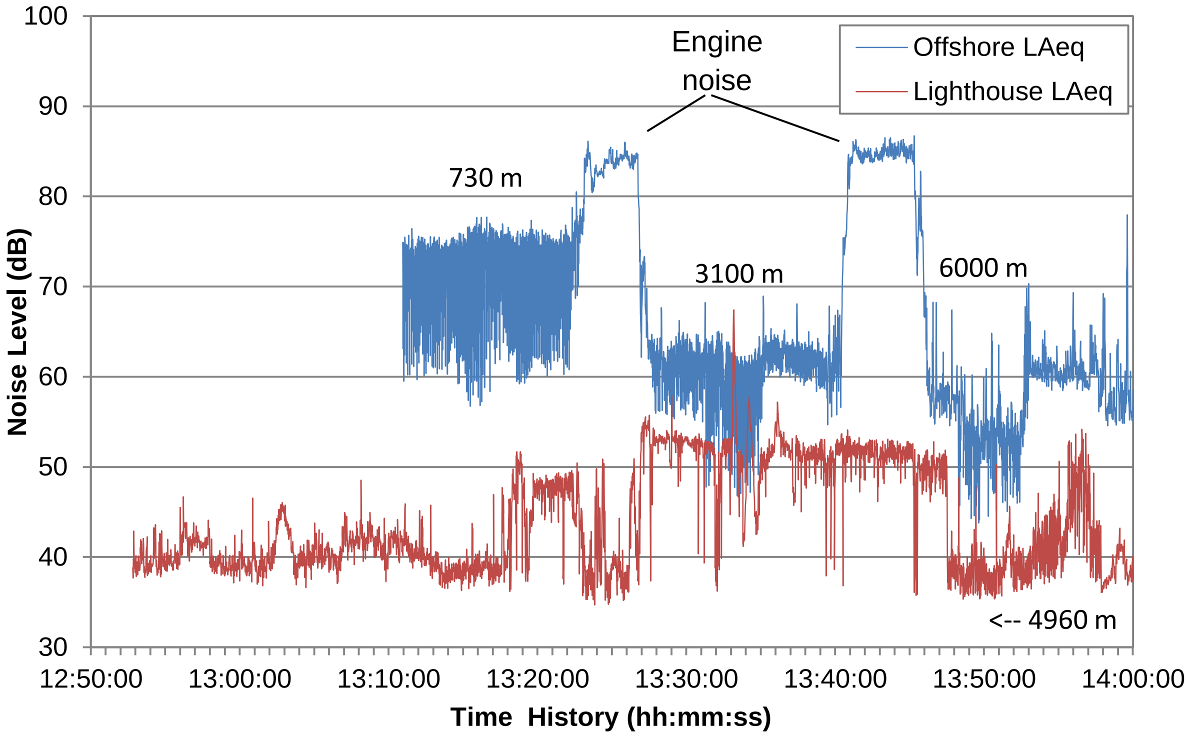

Figure 4-7 Comparative time history plot of sound level meters on September 18th 2015, including range from piling

A sudden drop in the noise level at the lighthouse can be observed at 13:47:30, and a few seconds later offshore due to the additional distance the sound has to travel. This can be seen in detail in the zoomed in chart in Appendix A. It appears to also be replicated in the fixed underwater noise monitor, and so would indicate a reduction in the noise level at source, possibly because of hitting a section of soft ground, rather than any external factor. The piling log shows no significant variation in blow energy at this time.

4.4.2 Pile 2 – Southeast transect

The second piling event sampled on September 18th is shown below. The transect was southeasterly, as per Figure 4-7 above, although in reverse, starting at 6.4 km and moving to just under 500 m just after 15:00.

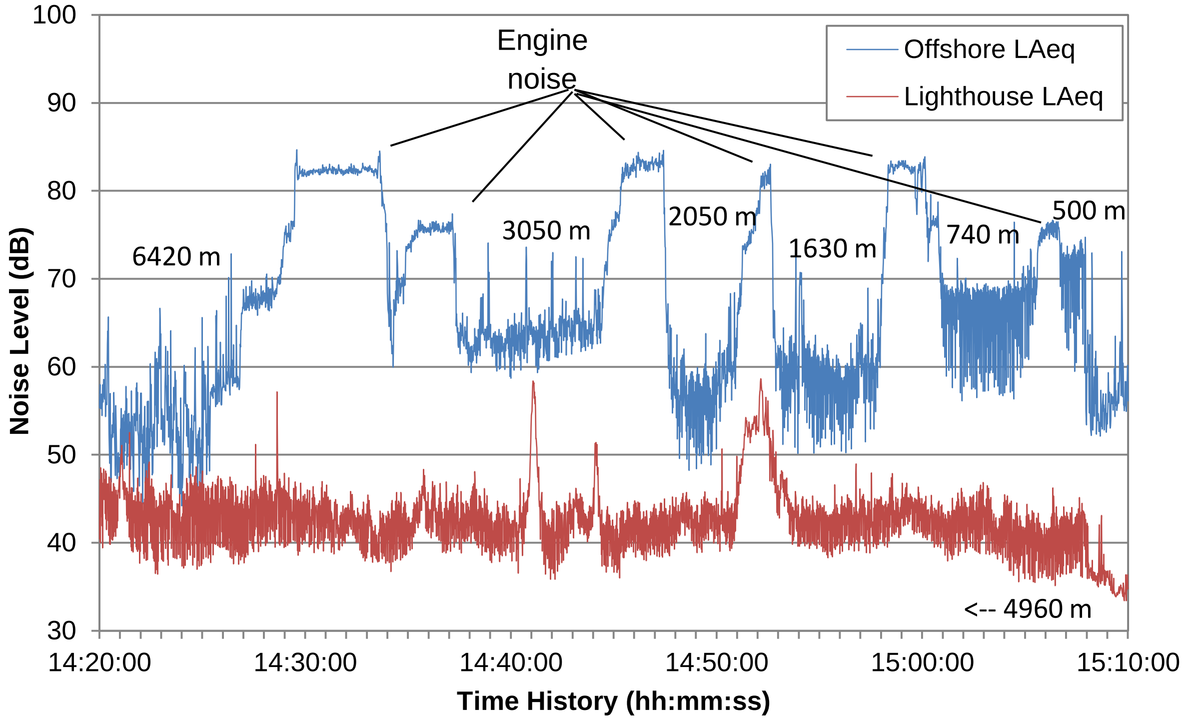

Figure 4-8 Time history plot of sound level meters on September 18th 2015, including range from piling

The piling noise levels follow the expected trend, becoming progressively louder after each vessel transit as the vessel moves closer to the piling with time. One notable exception is the period around 14:40 where the vessel was at 3.0 km. At this distance, the measured noise levels were at least 5 dB higher than the trend suggests, which can be seen clearly in Appendix A and also as the outlier in Figure 5-1. There is no clear explanation for this, although it does seem to follow a pattern of unexpectedly high noise levels around the 3.0 km to 4.0 km range, identified previously in Section 4.2.

4.5 WTG1 – 19 September 2015

Airborne noise measurements were taken offshore on a northerly transect towards Point Judith. The offshore transect was chosen so the vessel travelled past the Balls Point North monitoring location for corroboration. Pile driving for the first stage of the WTG1 foundation was carried out on 19 September 2015.

4.5.1 Pile 1 – North transect

Piling began at 8:30. Measurements were taken starting at 710 m from WTG1. The piling resumed on pile 1 at 12:25 and measurements were taken from the survey vessel at 12.4 km. The survey vessel then continued on the north transect in order to take measurements further out for the second pile. Pile strikes were recorded out to 24 km during the second pile being driven.

Piling was faintly audible on the survey vessel out to 6 km and also at Balls Point North, but only during the first piling event. The wind during this period was very calm and the water was still. Beyond this the winds picked up and piling was not generally audible on the coast. This may be in part due to slightly increased background noise caused by the wind in the vegetation.

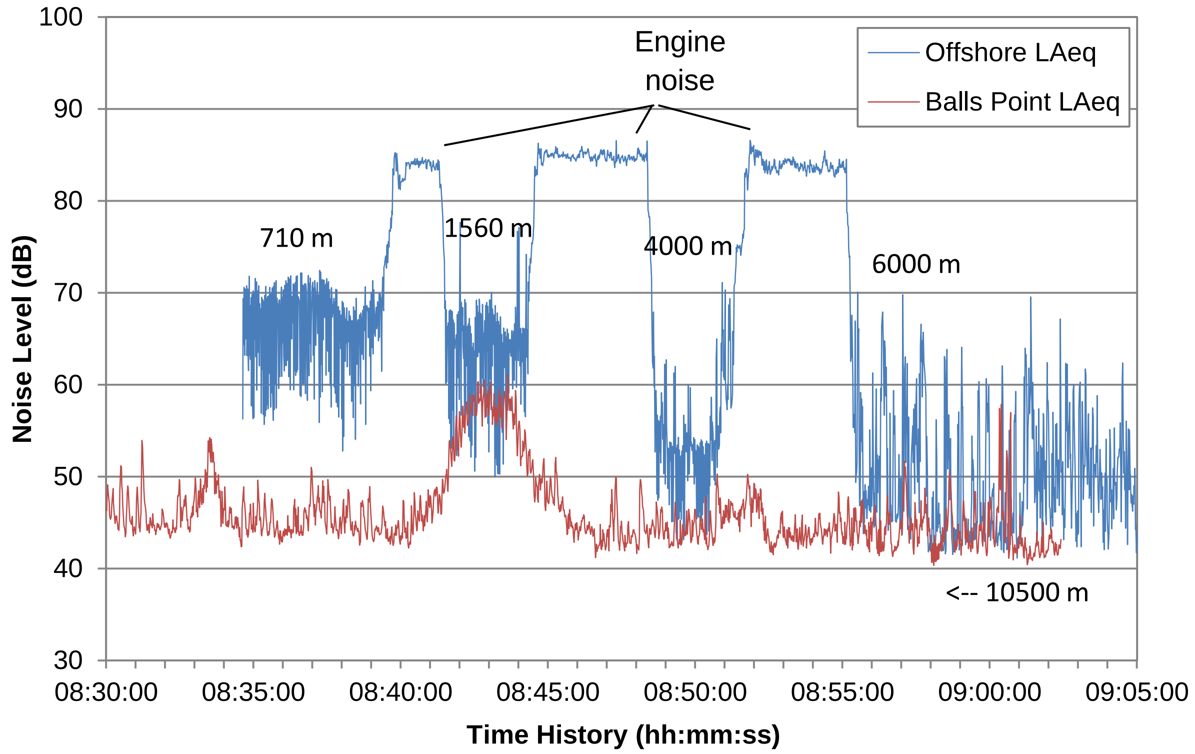

Figure 4-9 Comparative time history plot between SLM on the survey vessel and at Balls Point North on 19 September 2015, including range from piling

The offshore SLM was started slightly late. The large hump in the Balls Point North time history in Figure 4-9 was caused by a passing vessel close to the coast. At this time the survey vessel was nearly 10 km from the Balls Point North location. Piling finished very shortly after vessel stop at 08:55 and noise fluctuations after this were mostly due to speech on board the vessel and radio communications.

4.5.2 Pile 2 – North transect

Figure 4-10 below shows the same transect as in Figure 4-9 above, but at approximately 6.2 km before the vessel transit at 15:45, and 3.9 km after, moving towards the piling. Piling was clearly audible at both ranges. The winds had increased to approximately 2 m/s south, and the transect was therefore directly downwind.

Pile strikes can be observed in blocks up to 15:35, although they continue after this. Piling stops at 15:53, shortly after the vessel reaches 3.9 km and the strikes can be seen only briefly after the vessel engine noise between 15:45 and 15:49.

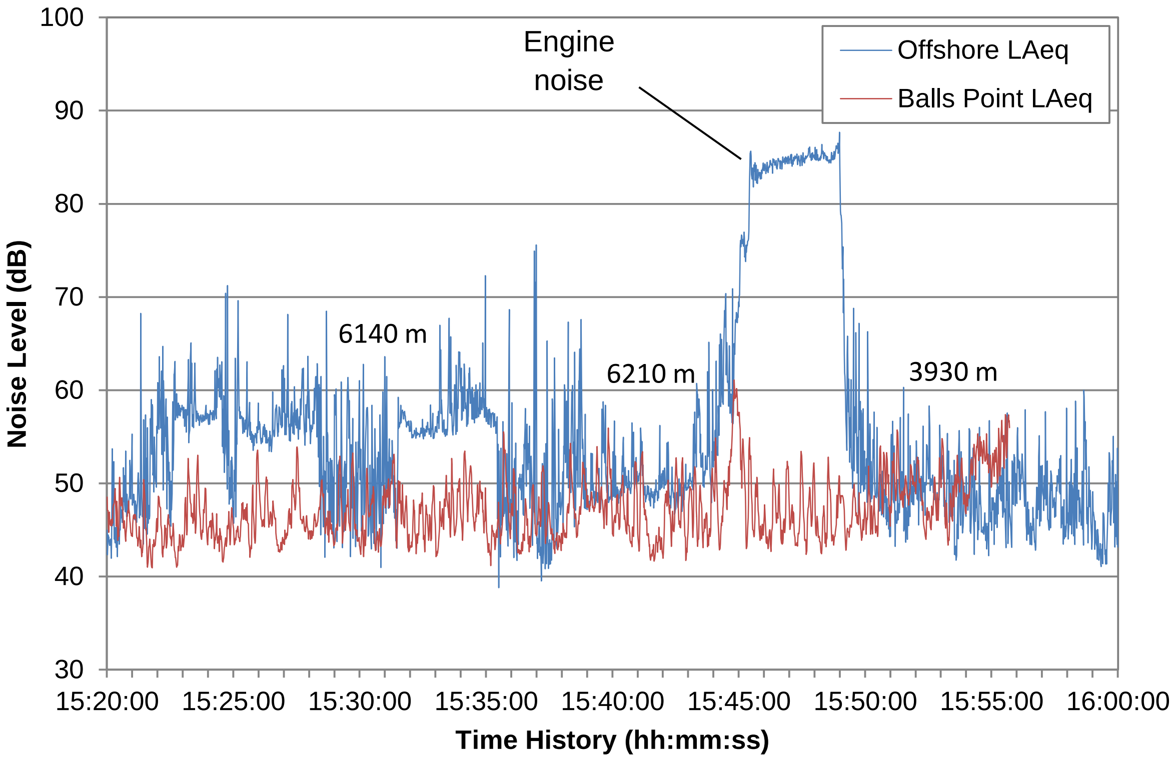

Figure 4-10 Comparative time history plot between SLM on the survey vessel and at Balls Point North on 19 September 2015, including range from piling

The pile strikes are indistinguishable from the background noise on the Balls Point North plot.

4.6 Discussion

In general the L_{Amax} was around 4.8 ±2 dB higher than the $L_{Aeq,1s}$ within approximately 1600 m, and closer to 3.9 ±3 dB beyond approximately 1600 m. Longer term $L_{Aeq,30s}$ readings vary relative to the short-term values according to the piling strike rate; the more rapid the strike rate, the more impulses occur within the thirty second period and consequently the $L_{Aeq,30s}$ will be higher.

5 Interpretation of results

5.1 Introduction

The airborne noise levels have been analysed to attempt to calculate the attenuation of airborne noise over water, taking into account the measurements taken on the survey vessel and at the onshore locations.

ISO 9613-2:1996 states that airborne environmental noise propagation over substantial distance tends to follow a basic equation where the noise level at a receiver position is affected by the level of noise at source, a directivity correction relating to any changes in noise emission dependent on the direction from the source and the attenuation with distance, which is a combination of multiple factors. As piling is effectively an 'omnidirectional' noise source, that is it radiates noise equally in all directions, directivity can be discounted. Discounting also factors that will not have an effect offshore (e.g. screening effects) and the equation for estimation of noise level at a receiver becomes:

$$RL = SL - N \log_{10} R - \alpha R$$

where RL is the noise level at the receiver, SL is the noise level at the source location, R is the range or distance from the source, N is a coefficient relating to the rate of geometric sound attenuation dependent on a number of factors, and α is the atmospheric absorption coefficient.

The primary purpose of this study is to observe the airborne noise emissions caused by impact piling during installation of the Block Island Wind Farm foundations. This analysis is designed to estimate an appropriate value for N coefficients based on the measured airborne noise levels as they propagate from piling over water, primarily as a function of wind speed and wind direction, relative to the direction of travel. This will help to predict received noise levels under similar situations in the future. It is acknowledged that other factors will have an impact on the attenuation of noise, such as scattering by the water surface, weather conditions (e.g. cloud/fog) or variations in temperature with altitude, but analysis to this level of detail is beyond the scope of this study.

The analysed data below will be split into three groups: where data was taken downwind, crosswind and upwind of the piling and also during flat calm conditions. Noise data sampled offshore has been combined with measurements onshore, primarily at the Southeast Light.

5.2 Factors affecting noise propagation in air

5.2.1 Source level

Critical to the calculation of the noise level at a receiver is the noise level at source. Subacoustech Environmental's previous measurements of offshore impact piling noise underwater has found that the source level is primarily related to the diameter of the pile and how hard the pile is struck (the blow energy of the hammer in use). While other factors will have an effect on the noise produced (e.g. material type and thickness, properties of the ground and properties of the pile), the source noise emission can be described adequately by the diameter of the pile and blow energy.

As the pile size and hammer used for the installation of foundations at the BIWF, the source level is likely to change only by the energy used in each strike.

It should be noted that for the purposes of this study, the source level is defined as a theoretical sound level at 1 m from the noise source. This assumes that the source itself is effectively a point source, as it will appear at the distances at which the measurements were taken.

5.2.2 N coefficient

Also known as geometric spreading, the value of N defines how quickly the noise at source reduces over distance and is primarily related to how the noise 'spreads out'. However, this value changes with the shape of the source (i.e. if the source is a 'point', a 'line' or an 'area'), how far the receiver is from the source, weather conditions, changes in the atmosphere, reflective surfaces and others. Typically a simple assumption of a sound spreading spherically from the source in ideal conditions provides a value of N of 20, and real world conditions lead to variations around this value depending on the exact situation. For example, downwind conditions might be expected to lead to slower attenuation of noise and a slightly lower value of N, but upwind the sound will attenuate more quickly and the value of N will be greater.

Depending on the value of N, the real reduction in noise tends to vary between 3 and 6 dB per doubling of distance from the noise source.

5.2.3 Absorption coefficient, α

While the N coefficient causes a reduction in the noise level with every doubling of distance, the absorption coefficient (α) applies a small reduction with every unit of distance, due to absorption in the medium in which the noise is travelling. The consequence of this is that the overall attenuation of noise is controlled by N when near the noise source, and α becomes more significant at a greater distance.

Like N, the value of α depends on a large number of factors, including the frequency of the noise and the environmental conditions, such as temperature and humidity, where the noise travels through air. Detailed tables showing the values of α under a variety of environmental conditions can be found in ISO 9613-1:1993 *Acoustics - Attenuation of sound during propagation outdoors* and for the purposes of this study are considered to be a known quantity.

5.3 Analysed data – wind direction

The airborne noise data sampled during the piling for the BIWF, ten piling events, have been sorted in respect of the wind direction under which they were taken. Where events occurred under the same wind direction, the various distances, including measurements taken at the coast, at which noise level samples were taken were combined to provide a level vs. range plot.

It should be noted that the sea state, wind speed, temperature, pressure and humidity remained fairly consistent throughout measurements in each group. For more information on conditions at the time of survey, see Table 2-1 and the detailed descriptions in Appendix A.

All analysis assumes there are two values of the N coefficient: one which exists close to the piling and one at a greater distance. Due to safety reasons, as the number of measurements close to the pile were insufficient to empirically establish a trend in the nearfield measurements, spherical spreading (i.e. N = 20) was assumed. The limited nearfield data also makes it difficult to determine the transition point between the nearfield and far-field spreading zones. The best fits to the data were achieved where a range of 800 m was used as the transition point in the analysis; that is, the calculations assumed spherical spreading (N = 20) at ranges of 800 meters or less. This is similar to the conclusion reached by Boué (2007) in a report to the Swedish Energy Agency for Vindforsk, which identifies a transition point of 700 m, based on data from a noise measurement programme in the Baltic Sea.

Analysis initially consisted of applying a line of best fit using a sum-of-squares technique to the 1-second L_{Aeq} ($L_{Aeq,1s}$) data. The $L_{Aeq,1s}$ rather than the 30-second average was used in the analysis as it is independent of piling strike rate, which was variable. Changing the strike rate would affect the longer-term average, despite the source level remaining unchanged.

Coefficients of N (>800 m) and the source noise level were then altered manually until data (at 200 m intervals) most closely matched the line of best fit. The effect of blow energy on the apparent source noise level is considered in section 5.5 but in general the same source level fitted the data throughout. There were two exceptions: measurements taken under slightly upwind conditions (wind at 67.5°) and under calm conditions. These are described in the relevant sections below.

The range axes are all on a logarithmic scale.

5.3.1 Receiver downwind of the piling

Two piling events took place with measurements taken under a downwind transect: one on September 18th and one on September 19th. The level vs. range plot, with reference to 1 m, is shown in below.

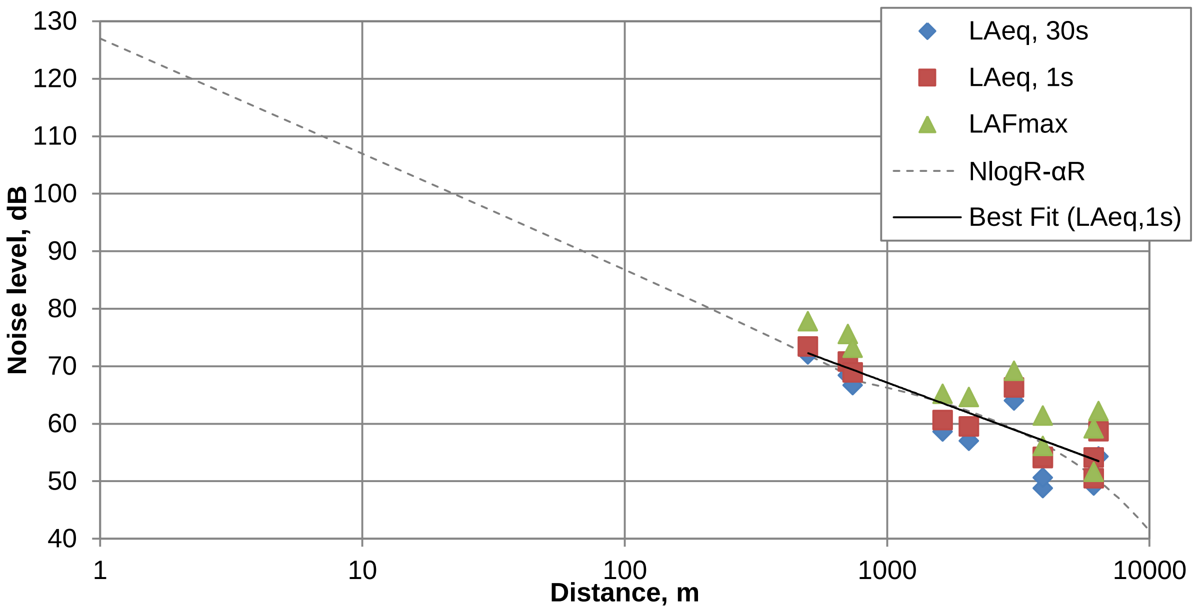

Figure 5-1 Level vs range plot for winds at 180° (downwind) to the direction of travel

Receiver Level [R>800m]: N = 6, α = 0.0021

The source noise level was calculated to be 127 dB $L_{Aeq,1s}$, a figure remarkably close to the estimate, "129 dBA", reported in "In-Air Acoustic Report" prepared by TetraTech EC, Inc. for Deepwater Wind. The 'tail' at the end of the NlogR-αR points represents a greater influence of the absorption coefficient over large ranges.

5.3.2 Receiver crosswind of the piling

Data in the 90° crosswind analysis was extracted from samples taken on three piling events, which occurred on September 3rd, 17th and 18th.

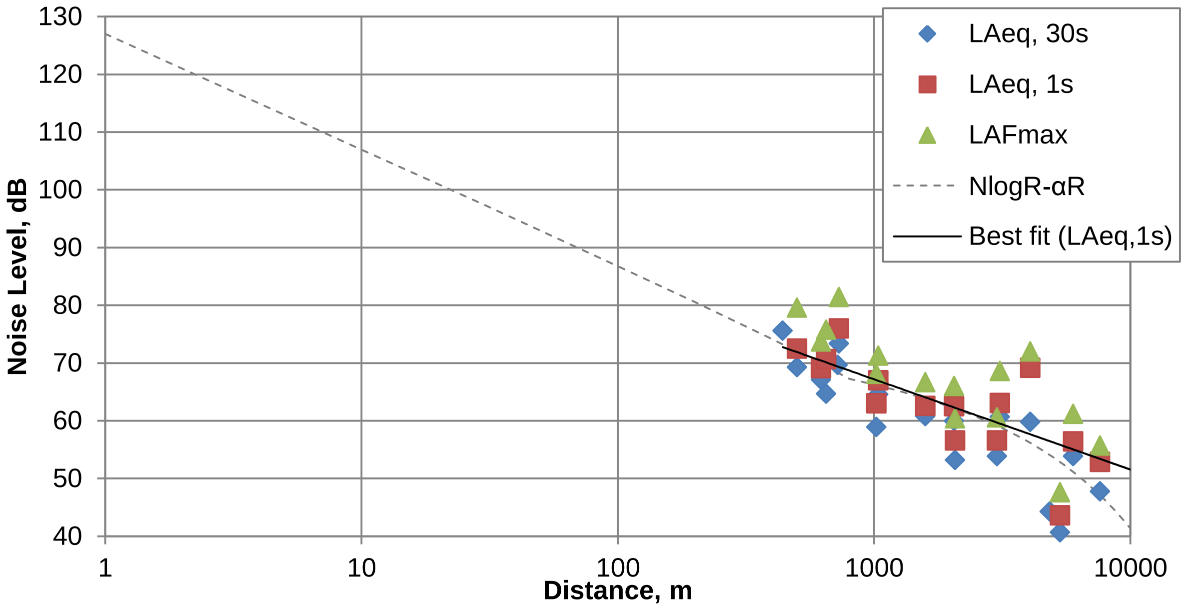

Figure 5-2 Level vs range plot for winds at 90° to the direction of travel

Receiver Level [R>800m]: N = 6, α = 0.0021

There is a lower correlation between the line of best fit and samples beyond 3000 m; all samples were included in the best fit calculation. Although the line of best fit is best matched by N = 6 for ranges in excess of 800 m, values of up to N = 12 show a progressive steepening of the curve which remains visually within the trend, especially if the sample at 4.1 km is considered a spurious outlier. It is suggested that there is likely to be greater variation in crosswinds than under an entirely upwind or downwind condition and that a slightly higher value of N would be reasonable, especially in light of the analysis for the 67.5° winds noted in Section 5.3.3 below.

The source level remains at 127 dB $L_{Aeq,1s}$.

5.3.3 Receiver upwind of the piling

Most events occurred during measurements taken under winds with an upwind component.

There were two piling events where the wind was at 45° to the transect, both on September 17th, and data combined show an excellent correlation to the line of best fit between 400 m and 5 km.

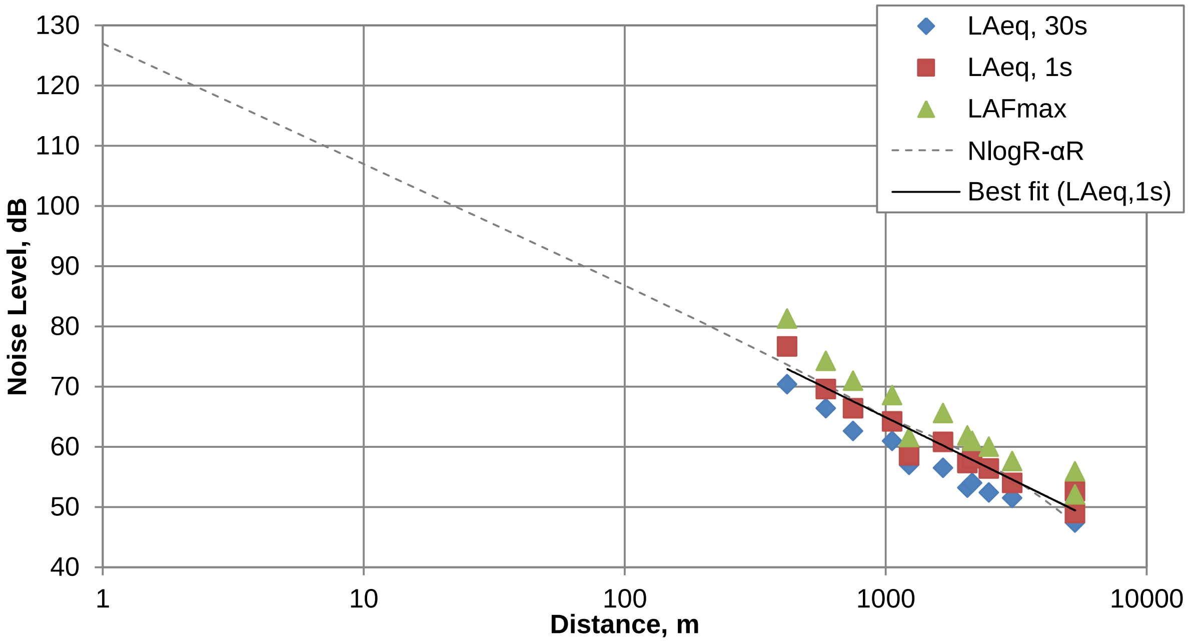

Figure 5-3 Level vs range plot for winds at 45° to the direction of travel

Receiver Level [R>800m]: N = 12, α = 0.0021

The NlogR-αR points fit the line well at N=12, i.e. a slightly faster attenuation with distance than the standard N=10 for cylindrical spreading. This is to be expected, as the adverse winds lead to greater reductions in noise. The absorption coefficient remains as previously at 0.0021 and the source noise level at 127 dB $L_{Aeq,1s}$.

The 67.5°, or just beyond crosswind conditions, was only sampled briefly over one event four points on September 3rd. However the line of best fit remains at N=12 for R>800m.

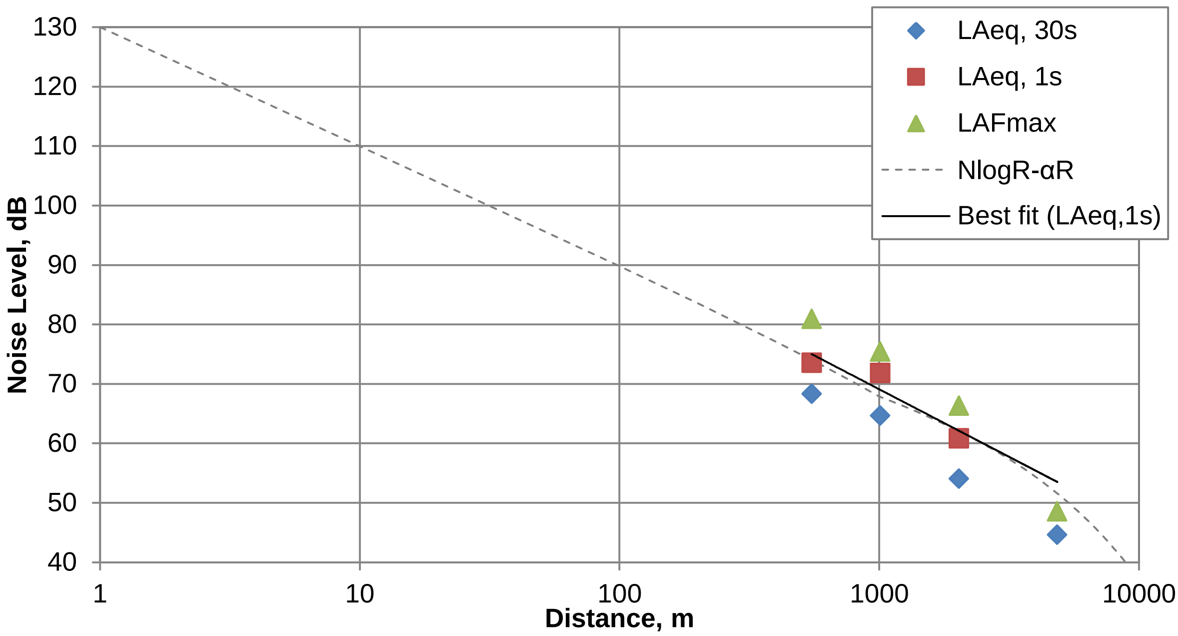

Figure 5-4 Level vs range plot for winds at 67.5° to the direction of travel

Receiver Level [R>800m]: N = 12, α = 0.0021

It is worth noting that for the event when the wind is at 67.5° from the direction of travel, the standard N=20 (R<800m) and α coefficients only fitted the data when the source level was increased by 3 dB to 130 dB $L_{Aeq,1s}$. The data would also fit if the source level remained constant and the value of N in the nearfield range reduced to 19, although it seems more plausible that environmental conditions remain consistent and there was an increase in the overall noise output during this event. Piling logs do not show a notably high blow energy at this time (energy was 60 kJ to 100 kJ over this period, which is representative of most sampled periods) and so the apparently higher source noise level may be caused by the relatively low number of measurements taken over this wind condition.

5.3.4 Calm wind and seas

On the final day of measurement, the wind dropped completely with flat calm seas. Only one short transect was possible under these conditions.

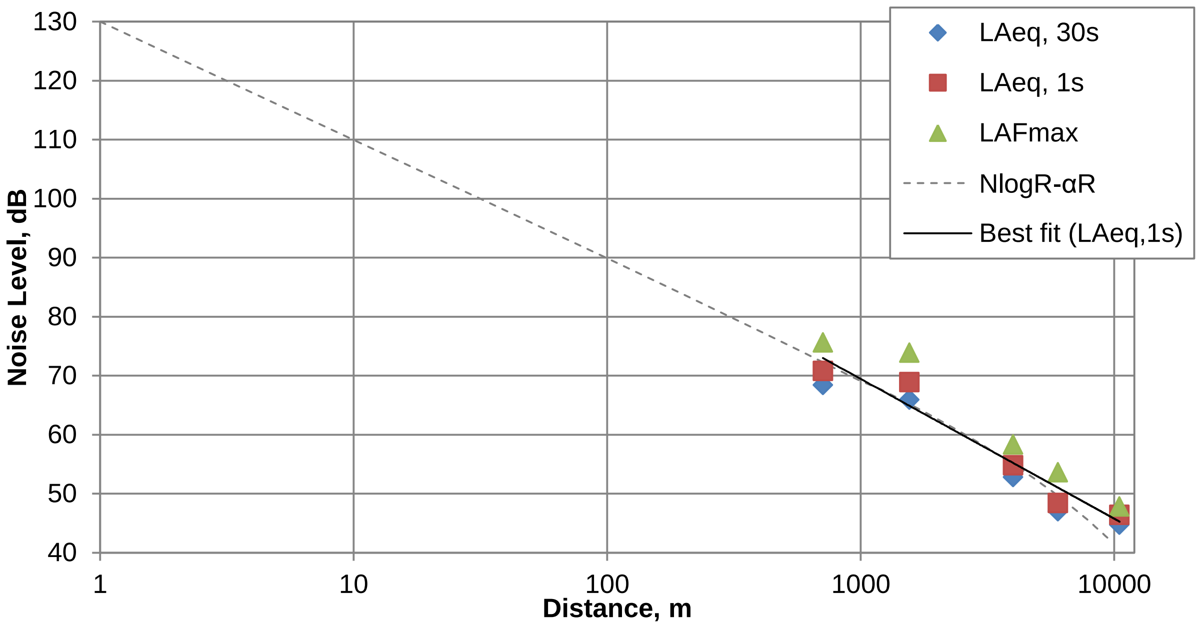

Figure 5-5 Level vs range plot for calm winds and seas

Receiver Level [R>800m]: N = 19, α = 0.001

Under entirely calm conditions, the propagation of sound in the far-field behaved somewhat differently to all other wind and sea states. There appears to be no significant transition from spherical (N=20) to cylindrical (N≈10) spreading, with the data sampled between 700 m and 10 km fitting N=19. All other conditions have much slower attenuations with N=12 or less. This may be due to flat seas scattering sound less and reflecting more to the atmosphere.

The measurements under calm conditions also required a lower attenuation coefficient (α) of 0.00063, instead of 0.0021 to keep the trendline from deviating from the measured noise levels.

As with the results where the wind is at 67.5° from the direction of travel, the standard N=20 and α coefficients only fitted the data when the source level was increased by 3 dB to 130 dB $L_{Aeq,1s}$. An investigation of the piling logs showed that there was an increase in the blow energy at the time when the two shortest range measurements (710 m and 1.6 km) where taken, representing a near doubling in energy for this short period. A higher source noise level was also noted in the concurrent underwater noise measurements compared to other piling events on the same day.

A doubling of blow energy could reasonably represent a 3 dB increase in the source noise level, and so applying a reduction of 3 dB to the first two data points reduces the line of best fit to a source level of 127 dB $L_{Aeq,1s}$, in consensus with the other wind condition trends, but the high N=19 remains. To best fit the data, an absorption coefficient of α = 0.00063 dB/km, considerably lower than most other conditions and equivalent to the ISO 9613 air absorption at 200 Hz, is required.

5.4 Analysed data – frequency analysis

All pile strikes will have a frequency 'signature', which will be dependent on numerous factors including pile material and dimensions, position, type and force of strike, seabed properties, and numerous others. For future analyses, the most useful frequency data will that taken close to the pile, as any distance between source and receiver will be a function of the environment in which the sound travels, and this will affect every frequency band slightly differently, high frequencies generally being attenuated more quickly than low frequencies.

While detailed analysis of sound propagation in individual frequency bands will provide detailed and accurate data for that specific band, it is considered more useful to analyse the data as a whole, particularly as almost all criteria used in environmental noise assessments are denoted in A-weighted decibels. However, 1/3rd octave band spectra have been acquired and can be reanalysed at a later date.

The frequency spectra for each piling event are provided in Appendix A. Below is a sample of the spectra under an upwind and downwind condition, and under calm conditions.

5.4.1 Frequency spectra downwind

Taken on a southeast transect, with northwesterly winds at 3 m/s.

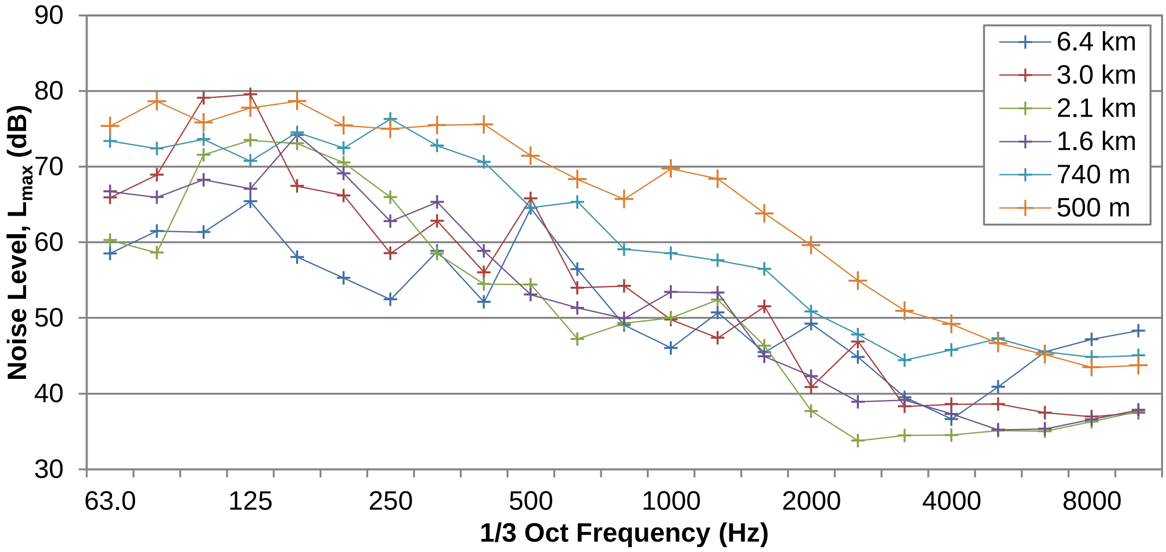

Figure 5-6 1/3rd octave band L_{max} spectra taken under downwind conditions on September 18th 2015

Most of the energy in the strikes is at low frequency and primarily below 400 Hz, although the spectra are clearly broadband in nature.

5.4.2 Frequency spectra upwind

The spectra were taken on a westerly transect, with a northwesterly wind (i.e. taken on 45° upwind conditions).

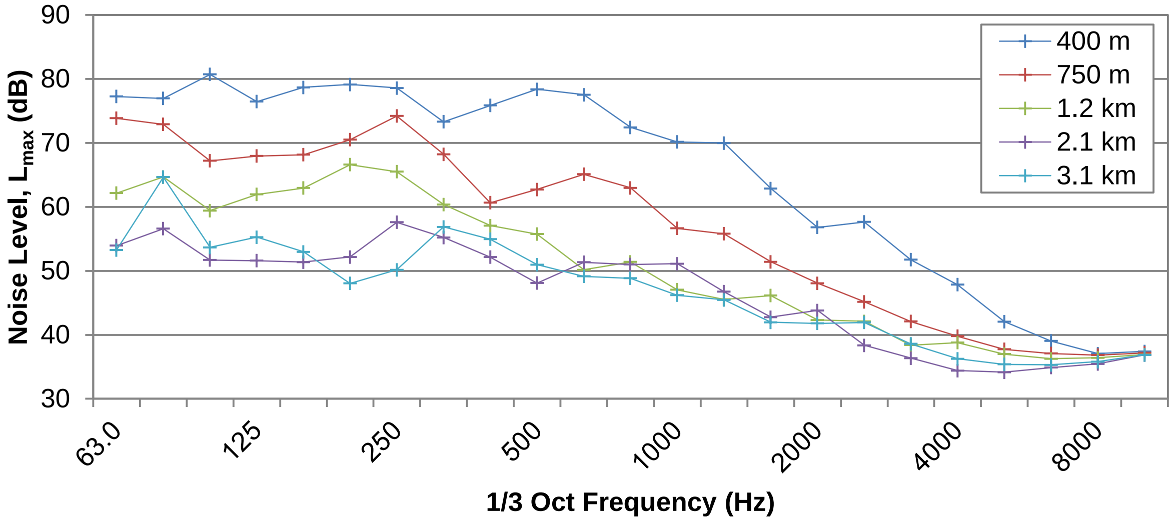

Figure 5-7 1/3rd octave band L_{max} spectra taken under upwind conditions on September 17th 2015

A sample was taken closer to the piling here than on the downwind sample in Figure 5-6, and it showed a spectrum at 400 m reaching the 630 Hz 1/3rd octave band before any significant drop in energy occurs. After little more than 1 km most of the energy in frequency bands over 630 Hz has been lost. It is interesting to note the consistency between Figure 5-6 and Figure 5-7 where the spectrum at 740/750 m both start to drop off above 250 Hz.

5.4.3 Frequency spectra, calm winds

Taken on a northerly transect.

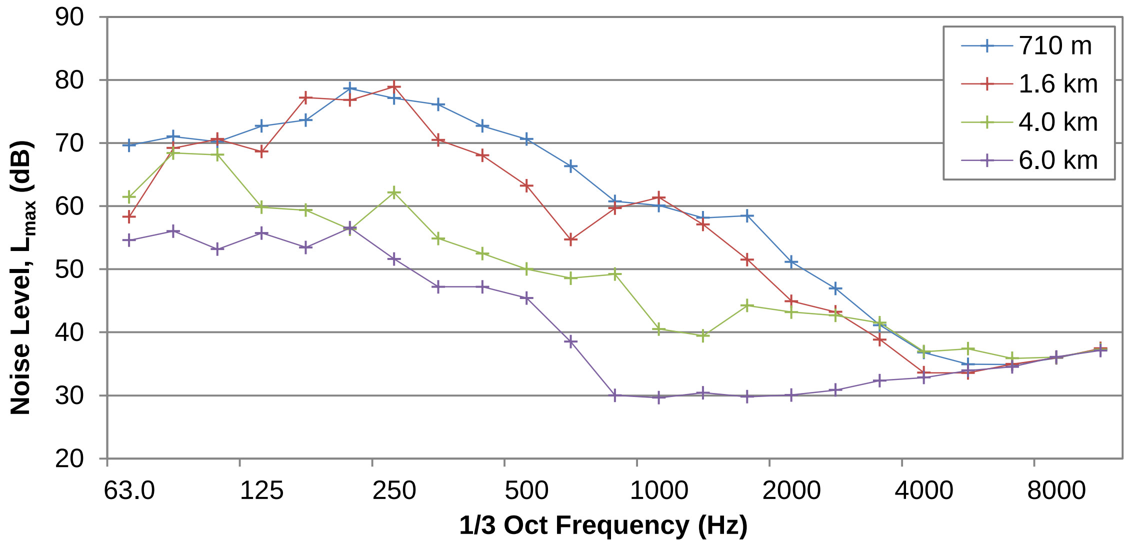

Figure 5-8 1/3rd octave band L_{max} spectra taken under upwind conditions on September 19th 2015

Though there are fewer positions on Figure 5-8, this demonstrates clear reductions in all frequencies below 6300 Hz band, suggesting that little energy is produced by piling above this frequency, or it attenuates so quickly that little arrives at 710 m. However, data reproduced in Figure 5-6 indicates that higher frequencies are present closer to the pile.

5.5 Analysed data – piling blow energy and source noise level

The airborne source noise level of the piling has been calculated based on a 20 logR + αR spreading attenuation. An absorption coefficient of α = 2.1 has been set based on the typical results and analysis in Section 5.3. Only airborne noise levels measured at 750 m or less from the pile have been included in the analysis to reduce the influence of wind and other far-field factors.

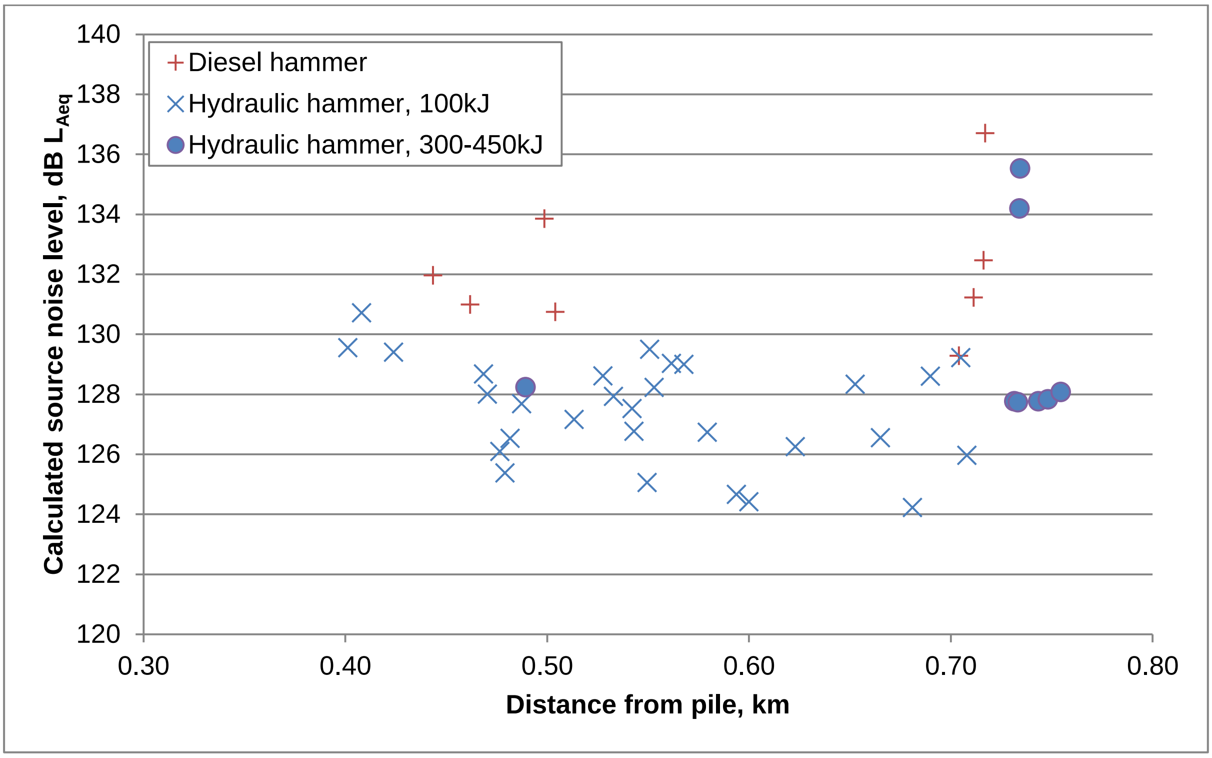

Figure 5-9 Scatter chart of calculated source noise levels from the diesel and hydraulic piling hammer

Figure 5-9 shows the results of the analysis by the distance from piling. Results are broken down in the chart by hammer type: the Menck hydraulic hammer in blue (September 3 and 17, the last two at 710 m on Sep 19) and the Bauer-Pileco D280-22 diesel hammer in red (Aug 18). The piling logs for the Bauer-Pileco hammer did not include energy-per-blow data. However, the hammer's technical specifications state energy per blow of 485-933 kJ, which is significantly greater than that used with the Menck, logged between 60 and 500 kJ. (Bauer-Pileco data from http://www.bauerpileco.com/en/products/hammers/diesel_hammers/d280-22, last downloaded February 22, 2016.)

The diesel hammer clearly demonstrates higher calculated source noise levels, with the noise levels typically being above 130 dB $L_{Aeq,1s}$. The hydraulic hammer typically produces noise levels lower than 130 dB $L_{Aeq,1s}$. Results show little correlation with distance suggesting that the simple 20 logR + αR propagation loss produces reasonable results over this range. That the small collection of closest measurements (~400 m) is also among the highest, however, is noted; also that these three samples occurred during soft start on September 17th at around 16:40. Slightly higher noise levels during soft start were also noted in the underwater measurements, despite lower blow energies.

It is possible that there are three 'bands' within the blue x results at 124-126 dB, 126-128 dB and 128-130 dB, with a gentle decline with range. The data points that make up these 'bands' are scattered and do not follow a particular day, time or wind direction. The gentle decline may however reflect a slightly higher value of α may in fact be more appropriate and investigations with the least-squares line of best fit shows α = 0.009 provides the 'flattest' trend. This corresponds with a 1/3 octave band centre frequency of 1600 Hz, which is much higher than where most of the energy is contained in the signal, even at close range (see section 5.4), and so this seems unlikely to be the explanation.

All results denoted with a blue x occurred with a blow energy of approximately 100 kJ. The blue spots denoted energies of 300 or 450 kJ with the two results between 134 and 136 dB $L_{Aeq,1s}$ are at the higher 450 kJ energy. It is notable that the results at 300 kJ did not appear to be significantly louder than those at the typical lower 100 kJ, where the 450 kJ stood clearly out. The block of blue spot results in excess of 700 m at approximately 128 dB $L_{Aeq,1s}$ were all taken under downwind conditions and so wind is unlikely to have caused any lowering effect.

The Menck hydraulic hammer produced an arithmetic average source level of 127.4 dB $L_{Aeq,1s}$ and the diesel hammer averaged 132.2 dB $L_{Aeq,1s}$. In the absence of any explanation for the variation in noise emission with the same hammer under the same energy, there appears to be a 'natural' source noise level spread of ±3 dB across each hammer type.

5.6 Discussion

The data acquired during the surveys generally follows the expected trend for far-field noise propagation, with a transition from spherical to cylindrical spreading, and more rapid attenuation with distance in upwind conditions. The following table provides a summary of the coefficients that best fit the measured data under different wind conditions. Note that 0° would denote upwind conditions, 180° denotes downwind conditions and the transition between nearfield and far-field is 800 m.

Wind bearing	Nearfield N value	Far-field N value	Absorption coefficient, α
45°	20	12	0.0021
67.5°	20	12	0.0021
90°	20	6	0.0021
180°	20	6	0.0021
Calm	20	19	0.0010

Table 5-1 Summary of noise attenuation coefficients under different wind and sea conditions

The data fits the theory well, with greater than cylindrical spreading (N=10) under upwind conditions and lower than cylindrical spreading downwind. Also, perhaps surprisingly, the data under crosswinds (90°) shows a better agreement with the line of best fit where N is equivalent to that of downwind spreading. However, correlation with the line of best fit under crosswinds is weaker than with the upwind or downwind conditions and so the confidence in this conclusion is somewhat lower.

Noise levels normalized by distance from piling measured showed that the diesel hammer was louder than the hydraulic hammer by an average of 5 dB, which agrees with subjective observations by the surveyor at the Southeast Light. The average calculated source noise level for the diesel hammer was 132 dB $L_{Aeq,1s}$ at 1 m, compared with the hydraulic hammer at 127 dB $L_{Aeq,1s}$ at 1 m based on measurements between 400 and 750 m. There was no clear correlation between source noise level and blow energy for the hydraulic hammer at blow energies 300 kJ and under. However, an average source noise level of 135 dB $L_{Aeq,1s}$ at 1 m was calculated where the blow energy increased to 450 kJ. No blow energy data for the diesel hammer was available but generic specifications for it show its minimum blow energy was similar to the maximum used for the hydraulic hammer.

To simplify the assessment, only an overall A-weighted value for the received noise levels and a single-figure value of α has been used, rather than the more robust technique of breaking down the individual frequency components of the measured noise levels. It is acknowledged that a much deeper analysis of the data would provide more accurate conclusions as the value of α would no longer be a selection. However, this simplified approach has produced a generally good agreement with the measured results across a long range.

This study primarily utilises A-weighted metrics, in keeping with international standards for the assessment of airborne environmental noise. The A-weighting of sound is designed to correct for the sensitivity of human hearing. The effect of this is to reduce the significance of sound frequencies progressively below and above 2000 Hz, as this is the frequency of peak sensitivity. This avoids any undue emphasis on very low (and very high) frequencies to which humans are not sensitive. The analysis of the frequency data for the samples of piling noise show that the majority of the energy in the received noise levels at a distance are dominated by low frequencies.

The consequence of this is that the A-weighting effectively attenuates some of the energy in the received noise levels and this is a consequence of the standards used across the majority of environmental noise assessments. Despite this, the fact that the data does appear to follow the theory and suggests that the A-weighting does not eliminate the useful information.

For future studies, it may be worth investigating the data in terms of a criterion that takes better account of low frequency characteristics, such as the C-weighting, an unweighted metric or investigation of a single frequency band. However, this may be of limited use when it comes to comparison with environmental criteria and it is recommended that the A-weighting continue to be the primary metric in the airborne data analysis.

6 Conclusions

Airborne noise levels have been sampled during the installation of the foundation piles for the Block Island Wind Farm in August and September 2015. Measurement stations were located on three coastal locations facing BIWF and on a mobile survey vessel that transited on transects around the foundations during piling.

A total of ten piling events were sampled, with a piling event consisting of a single period of pile driving of duration around 30 minutes. Pile strikes were typically 2-3 seconds apart. Conditions during the surveys were ideal for environmental noise measurement, sunny and dry, with temperatures around 25°C (77°F) and relative humidity 80% remaining fairly consistent day to day. Wind direction was variable but typically remained between 2 and 4 m/s. Seas were less than 1 m and usually between one and three feet. Completely calm conditions were present over one piling event. All measurements were undertaken in daylight hours.

Noise during piling was always audible at the closest coastal measurement station, five kilometers (three miles) from the offshore wind farm. At the furthest location, 27 kilometers (17 miles) from the piling, the noise was never audible. A further coastal location at eleven kilometres (seven miles) from the piling was visited for a short period and it was found that the piling was only intermittently audible under totally calm conditions and no longer audible shortly afterwards under light, downwind conditions.

The mobile measuring station on a survey vessel sampled noise levels at various distances from the piling, between 420 m at the closest and 12 km at the furthest. No measurements were possible closer to the piling than this for safety reasons.

The measured noise levels were used to calculate the rate at which the sound attenuates over water. It was found that sound attenuated independently of any weather conditions in a spherical manner, i.e. 20 log(R) or a 6 dB attenuation per doubling of distance, up to approximately 800 m from the source, where R is the distance in meters from the pile. Beyond that point, the attenuation changed to a cylindrical character and wind direction was critical, with attenuations of 6 log(R) under downwind conditions and 12 log(R) under upwind conditions best fitting the measured data. An attenuation of 6 log(R) best fitted the crosswind condition line of best fit, although the received noise levels showed a much greater deviation from the line of best fit and so there is a consequently a lower confidence in this value.

The attenuation changed significantly under the brief calm condition, demonstrating approximately spherical spreading in both the near and far-field. Measurements were possible up to 6 km from the foundation; only a single sample of this situation was possible.

Frequency spectra of the measurements showed that most of the energy in the received pulses was below the 630 Hz 1/3rd octave band at distances up to 400 m from the piling, and below 250 Hz at distances beyond 2000 Hz.

Future studies should attempt to investigate noise levels closer to the pile to verify the initial spherical spreading assumption and improve confidence in the source noise levels. It is likely the source noise level will change with the piles and piling equipment in use, so this is important bearing in mind the large variety of foundations currently in use or proposed for offshore wind turbines. This could be done either by vessel, where safe to do so or by potentially setting up a sound level meter on the deck of the piling barge.

7 References

Boué M. 2007. *Long-range sound propagation over the sea with application to wind turbine noise*. Final report for the Swedish Energy Agency project 21597-3. TRITA-AVE 2007:22 ISSN 1651-7660

ISO 9613-1:1993 Acoustics - Attenuation of Sound during propagation outdoors: Part 1: Calculation of the absorption of Sound by the atmosphere. International Organization for Standardization.

ISO 9613-2:1993 Acoustics - Attenuation of Sound during propagation outdoors: Part 2: A general method of calculation. International Organization for Standardization.

Institute of Acoustics. 2013. A good practice guide to the application of ETSU-R-97 for the assessment and rating of wind turbine noise.

Institute of Acoustics. 2013. Supplementary guidance note 6: Noise propagation over water. For on-shore wind turbines.

Appendix A Detailed results

Appendix B Calibration certificates

CERTIFICATE OF CALIBRATION

Issued by: **MTS Calibration Ltd**

Laboratory address: 17 Elvington Close
Billingham TS23 3YS
England

Telephone: +44 (0)1642 876 410

Please note delivery address below

UKAS CALIBRATION 0607

Date of Issue:	12 January 2015	Certificate Number:	23211U

Sound Level Meter Periodic Tests to BS EN 61672-3: 2006 Class 1

Client: PC Environmental Ltd.
Units 1/2 Claylands Road Industrial Estate
Bishop's Waltham
Southampton, SO32 1BH

Instrument Make:	Larson Davis	*Microphone Make:*	PCB
Instrument Model:	831	*Microphone Model:*	377B02
Serial Number:	1152	*Serial Number:*	103031
Preamplifier Make:	Larson Davis	*Calibrator Make:*	Larson Davis
Preamplifier Model:	PRM831	*Calibrator Model:*	CAL200
Serial Number:	0365	*Calibrator Serial Number:*	4418
		Calibrator Adaptor:	none
		Calibrator Certification Ref:	23214U

Other Accessories supplied:

MTS Calibration Ltd has obtained evidence which is generally available to the public that an independent testing organisation responsible for pattern approvals has demonstrated that this model of sound level meter has successfully completed the pattern evaluation tests of IEC 61672-2: 2003. This instrument, which was constructed to the requirements of BS EN 61672-1:2002 Class 1, has been tested using the procedures for periodic testing as specified in BS EN 61672-3: 2006.

The sound level meter submitted for testing has successfully completed the Class 1 periodic tests of IEC 61672-3: 2006 for the environmental conditions under which the tests were performed. As public evidence was available, from an independent testing organisation responsible for approving the results of pattern evaluation tests performed in accordance with IEC 61672-2: 2003, to demonstrate that the model of sound level meter fully conformed to the requirements in IEC 61672-1: 2002, the sound level meter submitted for testing conforms to the Class 1 requirement s of IEC 61672-1: 2002

In conducting these measurements, it was necessary to use manufacturer's data. This was taken from the instruction manual of the instrument.	I831.01 Rev J

The instrument was within the above specification as received - no modifications were made

Ambient Temperature at Calibration (deg C)	22.9	Calibration check frequency (Hz)	1000.1
Ambient Pressure at Calibration (mPa)	996.25	Reference Sound Pressure Level (dBA)	114.0
Ambient Relative Humidity at Calibration (%)	36.6	Reference Level Range dB	Normal

Test Equipment:

Equipment	Manufacturer	Model	Serial No.	Traceability Ref.	Cal. Due
Condenser Microphone	Larson Davis	2541	4295	TE 102	Nov-15
Acoustic Calibrator 1kHz	Larson Davis	CAL200	9175	TE 208	Aug-15
Acoustic Calibrator	Brüel & Kjær	4226	2141963	TE 206	Sep-15
Signal Generator (set 2)	Agilent	33120A	MY40007806	TE 160	Aug-15
Real-Time Frequency Analyser (set 3)	Larson Davis	2900	0510	TE 165	Aug-15

Authorised signatory:

Date of Receipt:	7 January 2015		
Date of Periodic Test	12 January 2015	Page:	1
Date of Certificate:	12 January 2015	of:	12

Tony Sherris

MTS Calibration Ltd
The Grange Business Centre, Belasis Avenue, Billingham TS23 1LG
Telephone: 01642 876410 **Fax:** 01642 876411 **E-Mail:** dmarsh@slmcal.co.uk **or** tsherris@slmcal.co.uk

PCB PIEZOTRONICS
A PCB GROUP COMPANY

Certificate of Calibration and Conformance

Certificate Number 2013-180305

Instrument Model 831, Serial Number 0003417, was calibrated on 03OCT2013. The instrument meets factory specifications per Procedure D0001.8310, ANSI S1.4-1983 (R 2006) Type 1; S1.4A-1985 ; S1.43-1997 Type 1; S1.11-2004 Octave Band Class 1; S1.25-1991; IEC 61672-2002 Class 1; 60651-2001 Type 1; 60804-2000 Type 1; 61260-2001 Class 1; 61252-2002.

New Instrument
Date Calibrated: 03OCT2013
Calibration due:

Calibration Standards Used

MANUFACTURER	MODEL	SERIAL NUMBER	INTERVAL	CAL. DUE	TRACEABILITY NO.
Stanford Research Systems	DS360	61889	12 Months	30JAN2014	61889-013013

Reference Standards are traceable to the National Institute of Standards and Technology (NIST)

Calibration Environmental Conditions

Temperature: 23 ° Centigrade

Relative Humidity: 31 %

Affirmations

This Certificate attests that this instrument has been calibrated under the stated conditions with Measurement and Test Equipment (M&TE) Standards traceable to the U.S. National Institute of Standards and Technology (NIST). All of the Measurement Standards have been calibrated to their manufacturers' specified accuracy / uncertainty. Evidence of traceability and accuracy is on file at Provo Engineering & Manufacturing Center. An acceptable accuracy ratio between the Standard(s) and the item calibrated has been maintained. This instrument meets or exceeds the manufacturer's published specification unless noted.

The collective uncertainty of the Measurement Standard used does not exceed 25% of the applicable tolerance for each characteristic calibrated unless otherwise noted.

The results documented in this certificate relate only to the item(s) calibrated or tested. A one year calibration is recommended, however calibration interval assignment and adjustment are the responsibility of the end user. This certificate may not be reproduced, except in full, without the written approval of the issuer.

Tested with PRM831-026043

Signed: Ron Harris
Technician: Ron Harris

Page 1 of 1

Provo Engineering and Manufacturing Center, 1681 West 820 North, Provo, Utah 84601
Toll Free: 888.258.3222 Telephone: 716.926.8243 Fax: 716.926.8215
ISO 9001-2008 Certified

Calibration Certificate

Certificate Number **2014000714**

Customer:

Larson Davis, a division of PCB Piezotronics, Inc.
1681 West 820 North
Provo UT, 84601, US
716-684-0001

Model Number	831	***Procedure Number***	D0001.8378		
Serial Number	0003605	***Technician***	Ron Harris		
Test Results	**Pass**	***Calibration Date***	22 Apr 2014		
Initial Condition	As Manufactured	***Calibration Due***			
		Temperature	23.05	°C	± 0.01 °C
Description	Larson Davis Model 831	***Humidity***	50.7	%RH	± 0.5 %RH
		Static Pressure	85.4	kPa	± 0.03 kPa

Evaluation Method Tested electrically using PRM831 S/N 029415 and a 12.0 pF capacitor to simulate microphone capacitance. Data reported in dB re 20 μPa assuming a microphone sensitivity of 50.0 mV/Pa.

Compliance Standards Compliant to Manufacturer Specifications and the following standards:

IEC 60651:2001 Type 1	ANSI S1.4 (R2006) Type 1
IEC 60804:2000 Type 1	ANSI S1.11 (R2009) Class 1
IEC 61252:2002	ANSI S1.25 (R2007)
IEC 61260:2001 Class 1	ANSI S1.43 (R2007) Type 1
IEC 61672:2013 Class 1	

Larson Davis, a division of PCB Piezotronics, Inc. certifies that the instrument described above meets or exceeds all specifications as stated in the referenced procedure (unless otherwise noted). It has been calibrated using measurement standards traceable to the SI through the National Institute of Standards and Technology (NIST), or other national measurement institutes.

The quality system is registered to ISO 9001:2008.

This calibration is a direct comparison of the unit under test to the listed reference standards and did not involve any sampling plans to complete. No allowance has been made for the instability of the test device due to use, time, etc. Such allowances will be made by the customer as needed.

The uncertainties were computed in accordance with the ISO Guide to the Expression of Uncertainty in Measurement (GUM). A coverage factor of approximately 2 sigma (k=2) has been applied to the standard uncertainty to express the expanded uncertainty at approximately 95% confidence level.

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Standards Used

Description	Cal Date	Cal Due	Cal Standard
SRS DS360 Ultra Low Distortion Generator	07/10/2013	07/10/2014	006311
Hart Scientific 2626-H Temperature Probe	05/07/2013	05/07/2014	006767
Barometric Pressure Sensor	08/14/2013	08/14/2014	007130

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Provo UT, 84601, US
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4/22/2014 10:43:09AM

Page 1 of 7

Report documentation page

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Document No.	Draft	Date	Details of change
E494R0200	08	11/25/2015	Initial writing and internal review
E494R0201	04	01/17/2016	Issue to HDR
E494R0202	-	02/25/2016	Amendments and reissue to HDR

Originator's current report number	E494R0202
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Report classification and caveats in use	COMMERCIAL IN CONFIDENCE
Date written	November 2015 – February 2016
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Translation/Conference details (if translation, give foreign title/if part of a conference, give conference particulars)	
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Descriptors/keywords	
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