OCS Study
BOEM 2018-029

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

**US Department of the Interior**
**Bureau of Ocean Energy Management**
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## DISCLAIMER

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## ABOUT THE COVER

Cover photo: Block Island Wind Farm Facility Wind Turbine 3 Foundation Construction. Courtesy of HDR RODEO Team. Used with permission. 

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## List of Abbreviations and Acronyms

| | |
|---|---|
| 3D | three-dimensional |
| AWAC | acoustic wave and current profiler |
| BIWF | Block Island Wind Farm |
| BOEM | Bureau of Ocean Energy Management |
| cm | centimeter(s) |
| dB | decibel(s) |
| DTM | digital terrain model |
| Hz | Hertz |
| km | kilometer(s) |
| kJ | kilojoules |
| m | meter(s) |
| $m^2$ | square meter(s) |
| mi | mile(s) |
| mm/s | millimeter(s)per second |
| mm | millimeter(s) |
| m/s | meter(s)/second |
| PPV | peak particle velocity |
| RMS | root mean square |
| RODEO | Real-Time Opportunity for Development Environmental Observations |
| SHRU | Several Hydrophone Receiving Unit |
| SL | source level |
| SLM | sound level meter |
| SPL | sound pressure level |
| VLA | vertical arrays |
| WGS84 | World Geodetic System, 1984 |
| WTG | wind turbine generator |

## Editorial Notes

- All coordinates used in this report are referenced to WGS84 unless stated otherwise.
- Current direction is the direction towards which the current is flowing.

## Executive Summary

Methods, data, observations, results, and findings from real-time environmental monitoring surveys conducted in and around the Block Island Wind Farm (BIWF) Project Area during the installation of the wind turbine foundations are presented in this report. The monitoring was conducted under the United States (U.S.) Department of the Interior's Bureau of Ocean Energy Management's (BOEM) Real-Time Opportunity for Development Environmental Observations (RODEO) Program.

The five-turbine, 30-megawatt BIWF is the nation's first offshore wind facility, and is located 4.5 kilometers (km) (2.8 miles [mi]) from Block Island, Rhode Island, in the Atlantic Ocean. Water column depth in the wind farm area is approximately 30 meters (m) (98.4 feet [ft]). BIWF construction was completed in two phases. During Phase 1, five steel jacket foundations were installed on the seabed; Phase 2 involved installation of the turbines on the foundations and laying of the submarine power transmission cables. The real-time construction monitoring included the following:

- Construction Phase 1
  - visual monitoring of construction activities from onshore and offshore locations
  - onshore and offshore airborne noise monitoring
  - near- and far-field underwater sound monitoring
  - seafloor disturbance and recovery monitoring
  - turbine foundation scour monitoring.
- Construction Phase 2
  - visual monitoring of submarine cable laying activities from onshore and offshore locations[1]
  - visual monitoring of construction activities from onshore and offshore locations
  - onshore and offshore airborne noise monitoring
  - seafloor disturbance and recovery monitoring.

The monitoring data will provide additional information necessary for BOEM's evaluation of environmental effects of future facilities and generate data to improve the accuracy of models and analysis criteria employed to establish monitoring controls and mitigations. Key observations and significant findings from the various types of monitoring conducted during the BIWF Phase 1 construction phase are summarized below[2].

**Visual Monitoring** – The purpose of the visual monitoring was 1) to document visibility of Phase 1 construction activities from selected onshore and offshore locations and 2) generate a real-time record of the Phase 1 construction-related impact-producing activities, and where possible, quantify such activities. Phase 1 construction, which initially was planned to be completed over a period of 5 weeks, actually was completed over a period of 18 weeks. The first jacket was set in the water on 26 July 2015, and the final pile was driven on 26 October 2015. The delay was largely a result of equipment issues and adverse weather conditions.

The visual monitoring team was onsite from 10 August to 21 September (37 days versus the planned 14 days) for observing and documenting construction activities. During this period, data were collected for 15 pile driving operations. Of the two hammers utilized for pile driving, the Menck hydraulic hammer was more effective than the Bauer-Pileco D280-22 diesel hammer. Of the two construction platforms used, the jack-up vessel L/B Roberts, which provided a more stable platform as compared to the Weeks

[1] See Elliott et al. (2017).

[2] Observations and significant findings from the various types of monitoring conducted during the BIWF Phase 2 construction phase will be separately presented.

barges and tugs, was more effective. The construction project moved faster after the initial learning curve. For example, on 1 September 2015, with calm seas and low wind, one pile was driven in the foundation for Wind Turbine Generator (WTG) 3 in less than 1 hour, compared to earlier attempts, which in some cases took up to a day to drive one pile.

**Airborne Noise Monitoring** – Construction of an offshore wind farm is expected to generate noise from sources such as transportation and mobilization of construction equipment and materials, and operation of construction equipment, including pile driving. Of all of the construction-related sources of noise, pile driving generates the highest levels. Airborne noise monitoring was therefore conducted during active construction periods to observe and measure levels of airborne noise produced during the installation of the WTG foundations.

Airborne noise levels were measured and recorded at selected onshore and offshore locations using a series of sound level meters. Noise levels were recorded during periods of active pile driving and outside of the active pile driving (to establish background levels). For onshore noise monitoring, data were recorded at three onshore locations, namely the Southeast Lighthouse at the Mohegan Bluffs (4.8 km [3 mi] from the WTG 3, Balls Point North on the northeast corner of Block Island (10.5 km [6.5 mi] from the WTG 1), and near Point Judith on the Rhode Island mainland (26.4 km [16.4 mi] from WTG 1).

Offshore noise monitoring was conducted from a strategically located vessel. Measurements were recorded on a series of transects centered on the piling location. Transects were chosen either to coincide with one of the onshore monitoring stations, heading northwest towards the Southeast Lighthouse, or coincident with a particular wind direction. The monitoring data were analyzed to determine the attenuation of sound as it propagates from the piling position over water, primarily as a function of wind speed and wind direction relative to the direction of travel. This analysis will help predict received sound levels under similar situations in the future.

Noise monitoring data analyses indicated that the noise from the pile driving was clearly audible at the Southeast Lighthouse, but was not detected at Point Judith on the mainland. Over water, the piling noise was barely audible at 11.3 km (7 mi) downwind (127 decibels [dB] weighted energy-averaged sound level ($L_{Aeq}$) at 1.6 km [1 mi] from the pile [estimated]). Clear differences were noted in airborne noise transmission between upwind and downwind conditions. The hum from the construction barge was just audible beyond 3.2 km (2 mi) over water under downwind conditions.

**Underwater Sound Monitoring** – was conducted in parallel with airborne noise monitoring to detect and record underwater acoustic and sediment-borne signals generated by the impact pile driving. Two parallel underwater monitoring studies were conducted by two groups of researchers[3]. While complementary, the monitoring approaches adopted by the two groups were different, and therefore results from the two studies are reported separately. The first study involved using stationary and towed arrays and a sensor-equipped geosled. In the second study, 1) a fixed, continuously monitoring hydrophone station was placed at 750 m (2,460.6 ft) from the foundation, and 2) a single drifting hydrophone was deployed to record underwater sound at two depths and seabed vibration monitoring.

Results from preliminary data analyses[4] showed that pile driving sound was above background sound levels at ranges in excess of 20 km (12.4 mi); received levels of approximately 120 dB re 1 μPa root mean square [RMS]. Background sound levels at distances of 20 to 30 km (12.4 to 18.6 mi) from the construction site were recorded from 97.7 dB to a 125.7 dB (mean of 107.4 dB). Based on models calibrated with measured data, the sound levels were a function of water depth, which varied based on

[3] The first group included a joint team of acoustic experts from Marine Acoustics, Inc., the University of Rhode Island, and Woods Hole Oceanographic Institution and the second group was Subacoustech Environmental.

[4] Detailed analyses are ongoing and will be presented in a subsequent report.

direction away from the pile. Overall, underwater sound levels were lower in deep waters and higher in shallow waters; the difference between the two could be as large as 10 dB. Sound levels were also shown to be dependent upon the orientation of the pile to the recording vessel. The piles are driven at an angle (13.3° relative to perpendicular). A 10 or 15 dB difference in sound levels resulted depending on whether the pile was angled towards, perpendicular, or away from the measuring vessel. Particle motion, which is important to demersal fish and megabenthos, was greater at the sea floor compared to higher in the water column.

**Seafloor disturbance and recovery monitoring** – Three rounds of bathymetry surveys were conducted to monitor seafloor disturbances caused by Phase 1 and Phase 2 construction and to track seabed recovery (healing) over time. The first survey was conducted on 11 and 12 May 2016, approximately 8 months after completion of the Phase 1 construction in October 2015. The second survey was conducted from 2 to 5 October 2016, 2 months after the completion of Phase 2 construction activities in August 2016. The third survey was conducted on 18 and 19 May 2017, approximately 18 months after the completion of Phase 1 construction. Survey data were used to characterize four different types of seafloor disturbance features. Documented features were tracked over a 12-month period to assess rate of recovery.

During the first survey, 160 seafloor disturbance features, which resulted from Phase 1 construction activities, were interpreted. Collectively, these scar features impacted approximately 11,570 square meters ($m^2$). Data from the second survey showed 103 new seafloor disturbance features, which had resulted from Phase 2 construction activities were observed. Collectively, these 103 new scars impacted approximately 6,876 $m^2$. New seafloor disturbance features associated with the Phase 2 construction were concentrated around each of the five WTG locations and along the inter-array cable route.

Data from the third survey indicated that 75 and 60 disturbance features from Construction Phases 1 and 2, respectively were completely healed. In addition, all disturbance features appeared to be undergoing either infilling and/or a decrease in size, albeit at varying rates. Survey 3 data also indicated that of the 160 disturbance features noted during the first survey, 64 features had partially healed, and 75 were completely healed. Also, of the 103 disturbance features noted from the Survey 2 data, Survey 3 data indicated that 34 features had partially healed and 68 were completely healed. Fifty-six of the 68 features that have completely healed were in or adjacent to areas comprised predominantly of fine-grained sand. The other 15 features were in areas comprised of predominantly medium- to coarse-grained sand. Long term trends indicate that the seabed level changed by approximately 0.2 m (0.7 ft) and monthly variations were up to 0.6 m (2 ft). Scour pits appeared to exhibit deepening and infilling during the measurement period. Deepening events corresponded to storm events (as expected) but also appear to reflect seasonal variations.

Survey 3 data also identified 12 new scour features that had developed around the concrete mats placed to protect the cable at the turbine entry points. Cable sections near the wind turbines were intentionally left unburied until the cables were pulled into the wind turbines. After the cable pulls, concrete mats were placed on the unburied sections of cables for protection. This scour development was only observed on turbines 1 and 2. These disturbance features comprised an area of approximately 844 $m^2$. Scour appears to be notably deeper and wider on the northwestern side of the mats, which potentially indicates there was a dominate bottom current flow direction.

Comparison of data from the three surveys identified changes in seafloor bedforms that indicate the seafloor was active during the time between surveys. Ripple fields changed in spatial extent and ripples also changed in orientation and size between Surveys 1 and 2 and then again between Surveys 2 and 3. Ripples were two times taller in Surveys 1 and 3 (conducted at the end of winter) than observed in Survey 2 (conducted at the end of summer). This is expected, as the winter wave climate is typically characterized by shorter wavelength, higher frequency and higher amplitude waves than the calmer, longer swells typical of summer months.

Seafloor recovery rates generally correspond to seabed mobility. Based on data collected during the three surveys, the seafloor within the Project Area was classified into three zones (Zones 1, 2 and 3) and two subzones (Zones 1a and 2a). Seafloor mobility was observed to be the highest within Zone 1, moderate in Zone 2, and low in Zone 3. In general, the zones of higher seafloor mobility correlated with higher sediment infill/seafloor disturbance recovery rates.

**Turbine foundation scour monitoring** – A pair of scour monitors were also tested at the BIWF. The monitors were installed on the WTG 3 foundation for measuring and recording in real-time changes in seabed elevations at a distance of up to 10 m (32.8 ft) from the foundation. A near continuous seabed elevation dataset was collected over the course of 14 months and 19 days. A seabed-mounted acoustic wave and current profiler was also installed nearby to provide data on oceanographic conditions (water levels, currents, and waves).

Evaluation of the data collected by scour monitors indicated that changes in the seabed elevation were seen to occur at three distinct periods: 1) less than 1 day, consistent with the periodicity of the local tidal forcing, 2) over the course of one week to one month, appearing to coincide with perturbations to the tidal current flow resulting from increased wave energy; and 3) a seasonal signal consistent with increased wave activity in the winter months, and calmer conditions in the summer months. The orientation of the acoustic beams allowed for observation of the variation in seabed level with distance from the foundation, and response of the seabed to physical oceanographic forcing.

The scour monitors provide a long-term time series of seabed elevations at specific points close to the foundation that can be used to enhance the understanding of the variation in seabed levels. Data collected by the monitors cannot be duplicated by bathymetry surveys. For future projects, the scour monitors could be used to generate data to support design assumptions about seabed mobility, or if scour occurs under specific circumstances then appropriate preventative intervention can be designed and actioned to maximize the life of the structures.

The data, findings, and recommendations presented in this report were generated for BOEM by the HDR RODEO Team under IDIQ Contract M15PC00002, Task Order M15PD00031.

# 1 Introduction

This report presents methods, data, observations, results, and findings from real-time environmental monitoring surveys conducted in and around the Block Island Wind Farm (BIWF) Project Area (**Figure 1**) during the installation of wind turbine foundations. This monitoring was conducted under the Bureau of Ocean Energy Management's (BOEM) Real-Time for Opportunity Development Environmental Observations (RODEO) Program. This report focuses on visual observations, airborne and underwater sound, seafloor disturbance and recovery, and scour monitoring.

## 1.1 The RODEO Program

The purpose of the RODEO Program is to make direct, real-time measurements of the nature, intensity, and duration of potential stressors during the construction and initial operations of selected proposed offshore wind facilities. The purpose also includes recording direct observations during the testing of different types of equipment that may be used during future offshore development to measure or monitor activities and their impact producing factors.

Data collected under the RODEO Program may be used as input to analyses or models that are used to evaluate effects or impacts from future offshore activities. This Program is not intended to duplicate or substitute for any monitoring that may otherwise be required to be conducted by the developers of the proposed projects. Also, RODEO Program monitoring is coordinated with the industry and is not intended to interfere with or result in delay of industry activities.

The BIWF is the first facility to be monitored under the RODEO Program. All monitoring surveys were implemented in accordance with a pre-approved field sampling plan, which included a project-specific health and safety plan (**Appendix A**). **Table 1** identifies the types of field data collected under the RODEO Program during construction and/or initial operations of this facility.

## 1.2 The BIWF

The BIWF is the nation's first offshore wind farm, and it is located 4.5 kilometers (km) (2.8 mi [mi]) from Block Island, Rhode Island, in the Atlantic Ocean. Water column depth in the wind farm area is approximately 30 meters (m) (98.4 feet [ft]). The five-turbine, 30-megawatt facility is owned and operated by Deepwater Wind Block Island, LLC. Power from the turbines is transmitted to Block Island. A 32 km (19.9 mi) transmission submarine power cable transfers excess power from Block Island to the mainland. This cable is buried under the ocean floor and makes landfall on the mainland, north of Scarborough Beach at Narragansett.

BIWF construction began in July 2015, and was completed in a phased manner by the end of November 2016. During the first phase, five turbine foundations were installed on the seabed from 26 July to 26 October 2015. These turbines were designated as wind turbine generator (WTG) 1 to WTG 5. Phase 2 construction was initiated in January 2016, and it included laying of the submarine power transmission cables, and installation of the turbine towers, blades, and nacelles on the foundations. Phase 2 components included the following:

- an inter-array submarine cable connecting the five turbines
- an export cable connecting northernmost WTG to Block Island
- the Block Island substation, located near New Shoreham on Block Island, includes approximately 1.3 km (0.8 mi) of underground cable from the beach to the new substation
- the Block Island Transmission System, which includes a bi-directional 32.1 km (19.6 mi) submarine cable from Block Island to Scarborough State Beach in Narragansett and 5.6 km (3.5 mi) of underground cable from Scarborough State Beach to the Dillon's Corner substation.


**Figure 1. BIWF project area.**

Operational testing of the facility was conducted from August through November 2016, and the initial operations commenced on 2 December 2016.

**Table 1. RODEO Program monitoring conducted at the BIWF.**

| Phase | Key Activities | Dates | Monitoring Surveys | Comment |
|---|---|---|---|---|
| Construction Phase 1 | • Steel jacket foundations were installed on the seabed using two different types of hammers. Both derrick barges and a lift boat were used as construction platforms. Piles were installed with a 13.27° rake from the vertical. | 26 July 2015–26 October 2015. | • Visual observations and documentation of the construction activities.<br>• Airborne noise monitoring associated with the pile driving.<br>• Underwater sound monitoring associated with the pile driving.<br>• Seafloor sediment disturbance and recovery monitoring through bathymetry surveys conducted immediately after construction was completed and in approximately 3-month intervals for one year.<br>• Turbine platform scour monitoring through installation of two scour monitoring devices on selected WTG foundations.<br>• An Acoustic Wave and Current Profiler was also deployed within the project area. | Results, finding, and recommendations from Construction Phase 1 monitoring are presented in this report. |
| Construction Phase 2 | • WTGs were installed on the steel foundations. | 13 May 2016–18 August 2016. | • Airborne noise monitoring.<br>• Visual observations and documentation of activities. | Results, finding, and recommendations from Phase 2 Construction Monitoring will be presented in a separate report, which is tentatively titled ”*Field Observations during Phase 2 Construction, Operational Testing, and Initial Operations at the Block Island Wind Farm, Rhode Island*”[1] |

| Phase | Key Activities | Dates | Monitoring Surveys | Comment |
|---|---|---|---|---|
| | • Submarine transmission power cables connecting Block Island and mainland were laid using a jet plowing in the offshore portions and horizontal directional drilling in the near shore area. | 3 June 2016–26 June 2016. | • Visual observations and documentation of the cable laying activities and of turbine installation from both on shore and off shore locations.<br>• Still photography and filming of portions of trenching operations for cable laying.<br>• Seafloor sediment disturbance monitoring.<br>• Post-construction seafloor recovery through bathymetry surveys. | See report entitled: "*Observing Cable Laying and Particle Settlement During the Construction of the Block Island Wind Farm*" for detailed information on Construction Phase 2 monitoring (Elliott et al. 2017). |
| Operational Phase | • Testing of the newly installed turbines.<br>• Testing of the submarine transmission power cables. | Operational testing conducted from 29 August 2016–30 November 2016. | • Visual observations of the operational wind farm from varied distances on shore and off shore locations. | Results, finding, and recommendations from monitoring conducted during operational testing and initial operations will be presented in a separate report, which is tentatively titled "*Field Observations during Phase 2 Construction, Operational Testing, and Initial Operations at the Block Island Wind Farm, Rhode Island*"[1] |
| | • Facility operations. | Wind Farm operation began on 2 December 2016. | • Airborne noise monitoring.<br>• Underwater sound monitoring.<br>• Seafloor sediment disturbance and recovery monitoring.<br>• Benthic monitoring. | |

[1] This report is currently under preparation.

## 1.3 Phase 1 Construction Activity Characterization

Phase 1 construction covered installation of the turbine foundations on the seafloor. Each foundation consisted of a larger steel jacket and a smaller transition deck. The jackets and decks were fabricated by Gulf Island Fabrication at their facility in Houma, Louisiana, and shipped via barge to a mobilization area approximately 4.8 km (3 mi) from Block Island (**Figure 2**). The distance to the project area from Houma, Louisiana, is approximately 3,379.6 km (2,100 mi) and it took the derrick barges approximately 3 weeks to cover the distance. The steel jackets consist of a lattice structure with four hollow leg structures around the perimeter and they are designed to withstand a CAT III Hurricane. Each jacket weighs over 1,500 tons and its base measures 24.4 × 24.4 m (80 × 80 ft).


**Figure 2. WTG foundations en route to Block Island Work Area.**

During construction, each steel jacket was lowered by a crane onto the seabed and then individual piles, which measured between 1.4 to 1.7 m (4.6 to 5.6 ft) in diameter, were lowered by a crane into the guide holes at jacket corners. Impact (percussive) pile driving was used to drive the piles incrementally into the seabed. The piles were driven to their final penetration design depth of 76.2 m (250 ft) or until refusal, whichever came first.

In each corner of the jacket, there are guide holes (tubes) into which the piles are placed by crane and then driven by impact pile driving. Once the first set of piles were driven into each corner, a second set of piles (and in some cases a third set) were welded on and driven into the foundation jacket guide holes using the same procedure. Once all the piles were hammered into place and the steel jacket was firmly anchored, the transition deck was placed on top of the steel jacket and bolted in place to complete the foundation. **Figure 3** is a schematic showing a completely assembled turbine foundation. **Figure 4** shows the completed WTG 5 foundation.

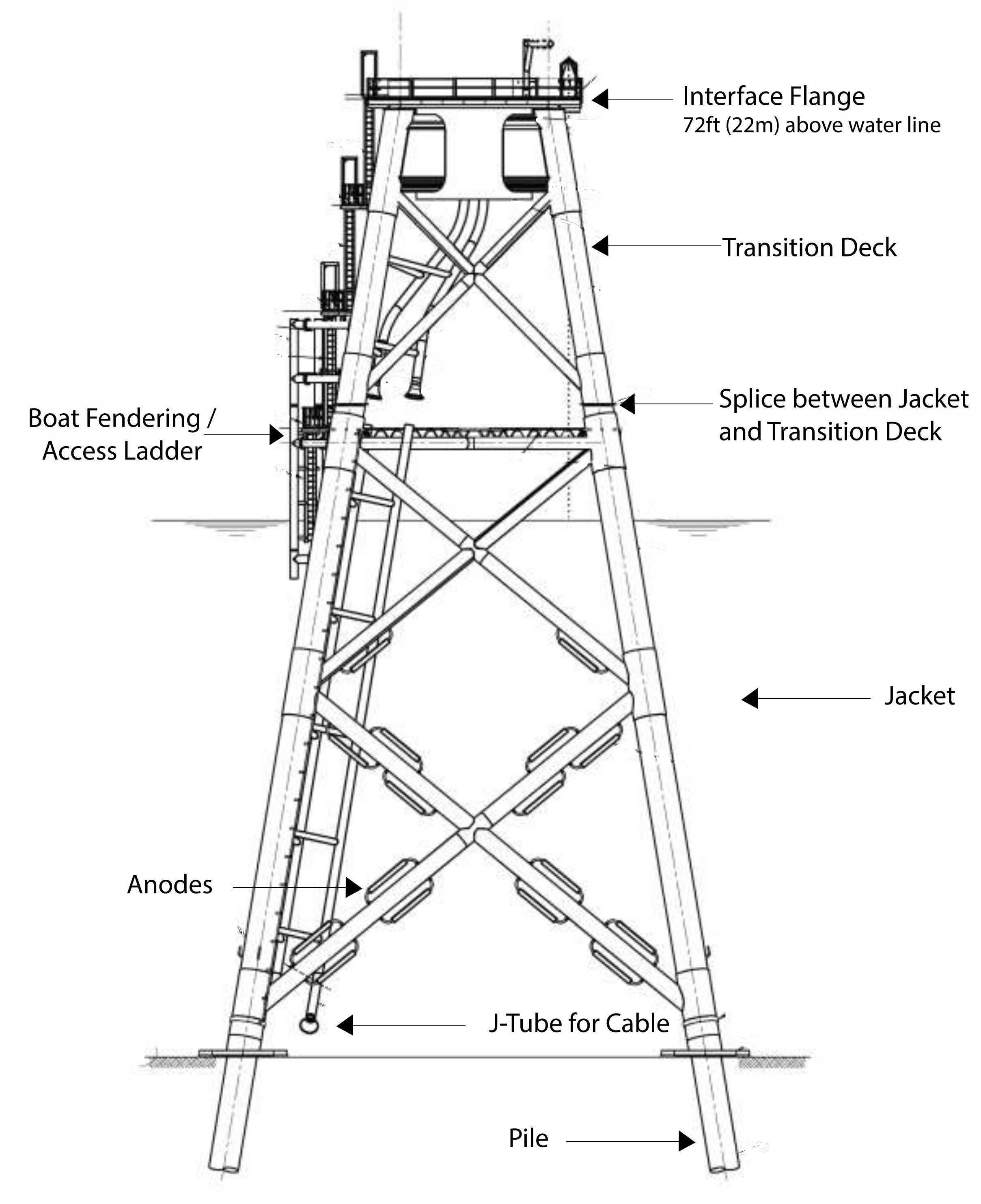



**Figure 3. Schematic showing a fully assembled turbine foundation (courtesy Deepwater Wind).**

**Figure 4. Completed foundation for WTG 5.**

The WTG 1 foundation was damaged the last week of July 2015 when one of the barges bumped into the foundation and dented one of the foundation's tubular legs. WTG 1was removed from the water and shipped to New Jersey for repair. The foundation was repaired and replaced back in the water in mid-September 2015.

Two types of barge designs were used for the pile driving: a floating barge, which was moored by a series of anchors during crane activity; and a jack-up barge. The jack-up barge proved to be more effective, and most piles were driven using this approach. Two piling hammers were used: Bauer-Pileco D280-22 (diesel) and Menck (hydraulic). Of the two, the hydraulic hammer was more effective. At its highest, the hammer was approximately 35 m (114.8 ft) above sea level, and at its lowest, was approximately 6 m (19.7 fee) above sea level. Piling typically took approximately 30 minutes for each driven pile. Pile strikes were typically two to three seconds apart. Pile driving logs for each individual turbine are shown in **Table 2**.

Real-time, Phase 1 construction environmental monitoring included the following:

- onshore and offshore visual monitoring of construction activities
- onshore and offshore airborne noise monitoring
- near- and far-field underwater sound monitoring
- seafloor disturbance and recovery monitoring
- turbine foundation scour monitoring.

**Table 2. BIWF pile driving log.**

| Foundation | Pile Type | Leg | Name | Date | Start Time | End Time | Duration | Vessel |
|---|---|---|---|---|---|---|---|---|
| WTG 1 | P1 | A1 | J1P1A1 | 2015-09-19 | 13:00 | 13:37 | 0:37 | L/B Robert |
| | | A2 | J1P1A2 | 2015-09-19 | 15:10 | 15:53 | 0:43 | L/B Robert |
| | | B1 | J1P1B1 | 2015-09-19 | 8:28 | 12:40 | 4:12 | L/B Robert |
| | | B2 | J1P1B2 | 2015-09-19 | 13:56 | 14:44 | 0:48 | L/B Robert |
| | P2 | A1 | J1P2A1 | 2015-10-17 | 13:37 | 14:11 | 0:34 | L/B Robert |
| | | A2 | J1P2A2 | 2015-10-17 | 12:39 | 13:25 | 0:45 | L/B Robert |
| | | B1 | J1P2B1 | 2015-10-17 | 14:17 | 14:49 | 0:32 | L/B Robert |
| | | B2 | J1P2B2 | 2015-10-17 | 11:39 | 12:32 | 0:53 | L/B Robert |
| | P3 | A1 | J1P3A1 | 2015-10-21 | 10:16 | 11:09 | 0:53 | L/B Robert |
| | | A2 | J1P3A2 | 2015-10-21 | 9:10 | 10:10 | 1:00 | L/B Robert |
| | | B1 | J1P3B1 | 2015-10-19 | 16:25 | 17:15 | 0:50 | L/B Robert |
| | | B2 | J1P3B2 | 2015-10-19 | 15:05 | 16:10 | 1:05 | L/B Robert |
| WTG 2 | P1 | B2 | J2P1B2 | 2015-08-18 | 16:05 | 16:12 | 0:05 | W533 |
| | P1 | A1 | J2P1A1 | 2015-09-03 | 11:13 | 11:41 | 0:28 | W533 |
| | | A2 | J2P1A2 | 2015-09-03 | 9:55 | 10:22 | 0:27 | W533 |
| | | B1 | J2P1B1 | 2015-09-03 | 14:40 | 15:15 | 0:35 | W533 |
| | | B2 | J2P1B2 | 2015-09-03 | 16:49 | 17:17 | 0:28 | W533 |
| | P2/P3 | A1 | J2P2A1 | 2015-10-11 | 12:43 | 13:47 | 0:48 | W533 |
| | | A2 | J2P2A2 | 2015-10-11 | 14:55 | 15:45 | 0:50 | W533 |
| | | B1 | J2P2B1 | 2015-10-11 | 16:14 | 17:22 | 1:08 | W533 |
| | | B2 | J2P2B2 | 2015-10-11 | 9:53 | 10:51 | 0:58 | W533 |
| WTG 3 | P1 | A1 | J3P1A1 | 2015-08-30 | 9:23 | 10:25 | 1:03 | W533 |
| | | A2 | J3P1A2 | 2015-09-02 | 12:40 | 13:38 | 0:58 | W533 |
| | | B1 | J3P1B1 | 2015-09-01 | 15:39 | 16:47 | 1:08 | W533 |
| | | B2 | J3P1B2 | 2015-09-02 | 10:21 | 11:07 | 0:46 | W533 |
| | P2 | A1 | J3P2A1 | 2015-09-18 | 10:01 | 10:49 | 0:48 | W533 |
| | | A2 | J3P2A2 | 2015-09-18 | 14:17 | 15:08 | 0:51 | W533 |
| | | B1 | J3P2B1 | 2015-09-18 | 8:36 | 9:38 | 1:02 | W533 |
| | | B2 | J3P2B2 | 2015-09-18 | 12:52 | 13:58 | 1:06 | W533 |
| WTG 4 | P1 | B1 | J4P1B1 | 2015-09-20 | 8:16 | 8:22 | 0:06 | L/B Robert |
| | P1 | A1 | J4P1A1 | 2015-10-08 | 10:09 | 12:25 | 2:16 | L/B Robert |

| Foundation | Pile Type | Leg | Name | Date | Start Time | End Time | Duration | Vessel |
|---|---|---|---|---|---|---|---|---|
| | | A2 | J4P1A2 | 2015-10-09 | 16:40 | 17:36 | 0:56 | L/B Robert |
| | | B1 | J4P1B1 | 2015-10-08 | 8:57 | 9:26 | 0:27 | L/B Robert |
| | | B2 | J4P1B2 | 2015-10-10 | 9:30 | 10:37 | 1:07 | L/B Robert |
| | P2 | A1 | J4P2A1 | 2015-10-12 | 16:25 | 16:54 | 0:29 | W533 |
| | | A2 | J4P2A2 | 2015-10-12 | 17:36 | 18:07 | 0:31 | W533 |
| | | B1 | J4P2B1 | 2015-10-13 | 9:23 | 9:45 | 0:22 | W533 |
| | | B2 | J4P2B2 | 2015-10-13 | 9:58 | 10:14 | 0:16 | W533 |
| | P3 | A1 | J4P3A1 | 2015-10-26 | 4:09 | 5:12 | 1:03 | W526, L/B Robert |
| | | A2 | J4P3A2 | 2015-10-25 | 14:36 | 15:46 | 1:10 | W526, L/B Robert |
| | | B1 | J4P3B1 | 2015-10-25 | 12:15 | 13:06 | 0:51 | W526, L/B Robert |
| | | B2 | J4P3B2 | 2015-10-25 | 13:20 | 14:17 | 0:57 | W526, L/B Robert |
| WTG 5 | P1 | A1 | J5P1A1 | 2015-09-17 | 12:30 | 13:40 | 1:10 | L/B Robert |
| | | A2 | J5P1A2 | 2015-09-17 | 15:16 | 16:13 | 0:57 | L/B Robert |
| | | B1 | J5P1B1 | 2015-09-17 | 18:06 | 19:02 | 0:56 | L/B Robert |
| | | B2 | J5P1B2 | 2015-09-17 | 16:38 | 17:51 | 1:13 | L/B Robert |
| | P2 | A1 | J5P2A1 | 2015-10-08 | 15:58 | 16:52 | 0:54 | W533 |
| | | A2 | J5P2A2 | 2015-10-08 | 5:42, 8:22 | 9:26 | 1:42 | W533 |
| | | B1 | J5P2B1 | 2015-10-09 | 12:45 | 13:32 | 0:47 | W533 |
| | | B2 | J5P2B2 | 2015-10-09 | 11:18 | 12:18 | 1:00 | W533 |

Note: Data provided by Deepwater Wind.

## 1.4 Report Organization

Key results, major observations, and conclusions from each type of environmental monitoring are summarized in individual sections in this report. Raw data and detailed discussions from each type of monitoring are contained in technical reports, which are provided as digital appendices to this summary report:

- **Section 1** presented an overview of the BIWF Facility and the RODEO Program and included a summary description of the construction activities conducted during the two phases.
- Methods and key observations from the onshore and offshore visual monitoring conducted during construction Phase 1 are presented in **Section 2**.
- **Section 3** contains a description of the onshore and offshore airborne noise monitoring.

- Underwater sound monitoring methods and findings from preliminary acoustic data analyses are presented in **Section 4**.
- Seafloor disturbances and recovery monitoring from three rounds of bathymetry surveys are described in **Section 5**. This section also contains information on the turbine scour monitors that were field tested under the RODEO Program.
- References cited in the report are listed in **Section 6**.

# 2 Visual Monitoring

The purpose of visual monitoring was 1) to document visibility of Phase 1 construction activities from selected onshore and offshore locations, and 2) generate a real-time record of the Phase 1 construction-related impact-producing activities, and where possible, quantify such activities. Visual monitoring surveys were accordingly conducted from selected onshore and offshore locations during the installation of WTG 2 and WTG 3 foundations over a 14-day period. Relevant information on size, type and number of vessels, pile-driving activities and duration, and other impact-producing factors were recorded during 14 days of real-time field observations in accordance with a pre-approved Phase 1 construction activity monitoring plan. Meteorological conditions that affected visibility during construction were also noted (**Appendix B**).

The monitoring team mobilized to Block Island on 7 August 2015. Site reconnaissance was conducted on 8 and 9 August 2015 to select the most optimal onshore monitoring location. On-site training was conducted for all field observers to ensure consistency in describing activities and recording observations. Monitoring was initiated on 10 August and completed on 21 September 2015. Key observations and significant findings from the monitoring are discussed in the subsections below; additional information is contained in the Visual Monitoring Logs contained in **Appendix B**.

## 2.1 Survey Approach and Methods

Visual surveys were conducted by a team of dedicated observers to document visibility of Phase 1 construction activities from selected onshore and offshore locations. The onshore observer also served as the field safety coordinator and maintained contact with the construction vessel via VHF communications.

### 2.1.1 Onshore Monitoring

The most strategic location for recording visual observations from the Block Island shoreline was determined to be the Southeast Lighthouse (**Figure 1** and **Figure 5**). This lighthouse is situated on top of Mohegan Bluff at the southeastern corner of the island at an elevation of approximately 75 m (246 ft) above mean sea level and approximately 4.8 km (3 mi) away from the BIWF construction site. From the lighthouse grounds, the survey team had a clear uninterrupted view of the turbines as they were brought to the site and placed on the seabed. Access to the lighthouse grounds was coordinated through Ms. Lisa Nolan, Executive Director of the Southeast Lighthouse Foundation.

Construction observations were made from a fixed location on the lighthouse grounds (N 41º09º.17’, W 071º33.097’). The monitoring location was adjacent to the wooden boundary fence along the southern edge of the lighthouse grounds and provided direct line of sight to the construction site (**Figure 6**). The WTG coordinates and their distance from Block Island are listed in **Table 3**.

**Table 3. WTG coordinates and distance from Block Island.**

| WTG | Latitude (Deepwater Wind 2016) | Longitude (Deepwater Wind 2016) | Distance from Block Island |
|---|---|---|---|
| 1 | 41° 7.546’ N | 71° 30.451’ W | 4.55 km (2.83 mi) |
| 2 | 41° 7.193’ N | 71° 30.837’ W | 4.69 km (2.91 mi) |
| 3 | 41° 6.883’ N | 71° 31.270’ W | 4.81 km (2.99 mi) |
| 4 | 41° 6.609’ N | 71° 31.744’ W | 4.97 km (3.09 mi) |
| 5 | 41°6.380’ N | 71°32.258’ W | 5.17 km (3.21 mi) |

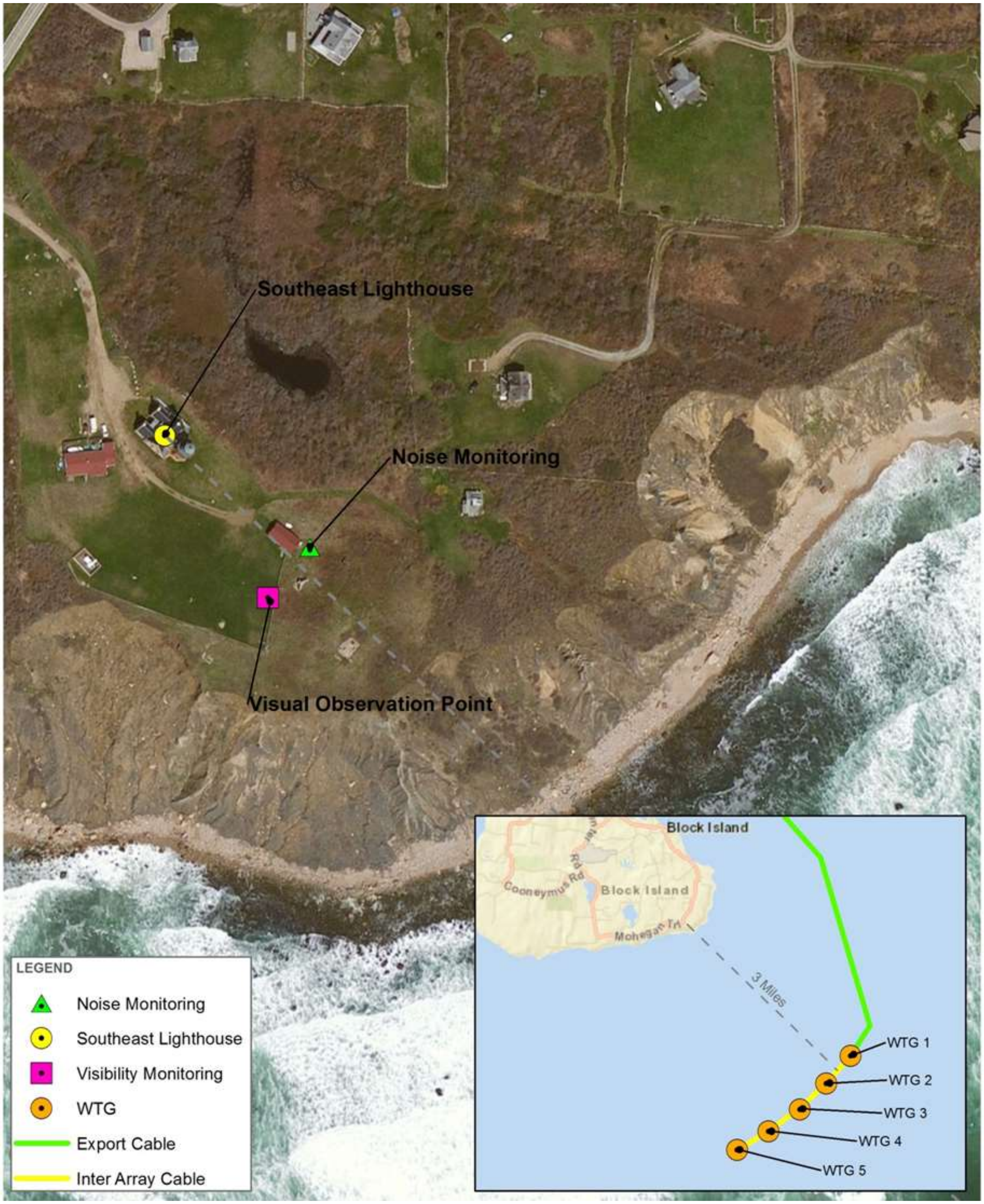



**Figure 5. Location of visual monitoring station on the Southeast Lighthouse grounds.**

**Figure 6. Fixed monitoring location on Southeast Lighthouse.**

Visual observations of construction activities were recorded in the morning, mid-day, sunset, and during significant changes in meteorological conditions (e.g., rain, fog, etc.). During each recording event, a set of still photographs and high-resolution video of turbines and construction activities were taken from the monitoring location using a Canon 5D Mark III camera with a 70- to 200-millimeter (mm) telephoto lens. The telephoto lens was wide enough to capture ambient lighting and environmental conditions and had the capability of zooming in for closer images. To ensure that photographs taken at different times could be compared side-by-side, the same camera angle and a constant zoom setting was used, and the camera was mounted on a tripod to maintain image consistency.

During each monitoring event, observations were recorded using a customized iPad application (app), which was specially created for this project using the database platform FileMaker Go. The app was field tested prior to being used for the monitoring. Standardized data entry procedures were used for data entry to ensure consistency among the field observers. Observers took a photograph and then recorded the photo frame number along with notes on activity observed, time, and weather conditions. Meteorological data recorded included wind direction, wind speed, sea state, cloud cover, and humidity. These data were verified, quality checked, edited if needed, and synchronized with a dedicated hard drive at the end of each day. **Figure 7** shows an example of the iPad app input screen.

### 2.1.2 Significant Events Affecting Documentation of Visual Observations

The project area experienced heavy fog on 25 August, 2 September, and 9 September; this limited visibility from the shoreline and affected visual observations. In addition, on several mornings there was a slight haze around the foundations, which affected the quality of images captured. The view of the WTGs from the Southeast Lighthouse monitoring station under foggy and clear weather conditions (as observed on 2 September 2015) is compared side-by-side in **Figure 8**. As seen in this figure, the foundation and Derrick barge are not visible from shore during the morning foggy conditions, but were clearly visible once fog dissipated in the early afternoon.


**Figure 7. Sample data log screen.**

**Figure 8. View from the Southeast Lighthouse monitoring station foggy and clear conditions.**

Weather and sea state also impacted onshore visual observations. **Figure 9** shows the WTGs under foggy and clear conditions from a distance of 500 m (1,640.4 ft). These images were taken in parallel with the images shown in **Figure 8**.

**Figure 9. Comparison of offshore areas under foggy versus clear conditions (approximately 457.2 m [500 yards, 1,500 ft]).**

### 2.1.3 Offshore Monitoring

In parallel with onshore monitoring, a small vessel was deployed to record visual observations from an offshore location. This allowed documentation of construction activities from a closer range. Two different vessels were used for the offshore monitoring. The R/V Whale Researcher, which is owned and operated by HDR, is a Willard Marine Sea Force 730 LE 23-foot-long vessel with twin outboard Mercury 200HP engines (**Figure 10**). This vessel has an open deck and covered console as well as an onboard navigation system, depth sounder, EPIRB, and additional U.S. Coast Guard-approved safety equipment. As necessary, a locally chartered vessel (F/V Hula Dog) was deployed. The Hula Dog is a 27-foot-long vessel equipped with a center console outfitted onboard navigation system, depth sounder, and U.S. Coast Guard-approved safety equipment (**Figure 11**).

The daily offshore monitoring schedule was based on information received from Deepwater Wind and the Notice to Mariners published by the Rhode Island Coastal Resources Management Council. The notice typically listed planned construction activities for the following day and was distributed daily via email to stakeholders, local fisherman, and recreational boaters.

The U.S. Coast Guard had established an approximately 457.2 m (1,500 ft or 500 yards) safety zone around each foundation site. All vessel traffic not directly supporting construction was prohibited from entering this area. The offshore monitoring vessel accordingly stayed outside the safety zone and did not interfere with transit of construction vessels. The safety zone was in effect while construction vessels and associated equipment were present. The first notice of the safety zone was issued on 17 July 2005 and was in effect until first week of October 2016. The LB Roberts arrived to the project site on 17 September 2016 and the final pile was driven approximately 39 days later on 26 October 2016.

Fujinon 10 × 50 marine binoculars were used to observe the construction site. Still photographs and high resolution video were recorded using a Canon 5D EOS with a 100 to 400 mm lens. The telephoto lens allowed the observers to see and photograph names and features of the construction vessels and construction activities at close quarters. ICOM M36 portable VHF radios were used for monitoring construction activities, weather, and maintaining communication among the onshore and offshore observers.

The offshore monitoring team maintained a visual record of types and number of vessels deployed, chronology and duration of activities, and other relevant information for use in evaluating impact-producing factors. Meteorological conditions that affected visibility of the construction activities were also noted. Incidental observations of recreational boat traffic (fishing vessel, yachts, etc.) and marine mammal sightings were also noted by the offshore observers. All construction activity observations were recorded using an iPad in a customized database as described in **Section 2.1.1**.

**Figure 10. The R/V Whale Researcher.**

**Figure 11. Charter Vessel F/V Hula Dog.**

## 2.2 Visual Monitoring Observations Summary

**Figure 12** shows the WTG 1 steel jacket being lowered into the sea. Placement of the first section of piles into the steel jacket corner guide holes can be seen in **Figures 13** and **14**. A Pileco diesel hammer was used on the first day of pile driving (**Figure 15**), but was discontinued because of poor success and multiple problems encountered. A Menck hydraulic hammer (**Figure 16**) was mobilized to the site to replace the diesel hammer, and proved to be more effective for pile driving.

Two vessel platforms were used during construction. Initially, a Derrick barge was maneuvered into place with tugs and anchored next to the foundations. The barge was equipped with two deck cranes used for placing the piles into the jackets and subsequently hosting the hammer above the piles to drive them into the seafloor, as shown in **Figure 17**. The barge-mounted crane platform was not stable, and progress was slow, especially during bad weather and rough sea states.

In September 2016, the barge-mounted crane platform was replaced by a more stable vessel platform, namely the jack-up offshore support vessel L/B Roberts. This platform has a self-elevating hull with three legs, 306 m (1,004 ft) in length. The platform can be raised up to 219 m (718.5 ft) above sea level, and is equipped with four cranes on deck; it also includes living quarters for up to 152 workers (**Figure 18**). The L/B Roberts was used for both pile driving and placement of the transition deck on top of the anchored jackets (**Figure 19**). On the highly stable L/B Roberts platform's first day of deployment, crews were able to complete driving of three piles, which was a substantial improvement on progress made with the barge-mounted crane platform.

A total of 16 different vessels were observed during Phase 1 construction; the number of vessels on site on a given day varied with weather and the nature of activities being conducted. Vessel anchoring within the work zone is likely to contribute to seabed scarring.

On a typical day, Derrick barges Weeks 533 and Weeks 526, along with LB Roberts, were generally positioned next to the jackets. The Weeks 533 and Weeks 526 barges were used primarily to place the piles into the jacket corners and for welding operations. Tug support for the Derrick barges was provided by two tugs. One tug would be attached to the barge and the other would provide anchoring support as needed. Cranes on the L/B Roberts would transfer a pile to the jacket and then commence pile driving using the Menck hydraulic hammer.

Crews and supplies were brought in to the work site daily from Galilee and Quonset aboard the Rosemary Miller and Sorenson Miller, respectively. The Project Management Team typically used the F/V Lindsey E for transport to the work site. Other vessels on site included the R/V Heather Lynn, which was used for environmental monitoring conducted prior to the start of pile driving.

A summary of significant events that occurred during the Phase 1 construction period is presented in **Table 4** (for August 2015) and **Table 5** (for September 2015). A complete list of vessels observed during the construction period and their known functions is shown in **Table 6**.

During the visual monitoring, over 4,500 photographs were taken from Southeast Light House and research vessels. These photographs provide visual examples of the types of activities that occurred during construction. They were provided to BOEM on a DVD and are available upon request.

Selected high-quality photographs, which are illustrative of the construction activities described in this report, are presented in the photolog below. Key observations recorded during onshore and offshore visual monitoring are summarized in **Sections 2.1** and **2.2**, respectively. These two sections also include a key for the photographs stored on the DVD that has been provided to BOEM. **Section 2.3** describes meteorological observations recorded during the visual monitoring.

**Figure 12. Lowering of the WTG 1 steel jacket into the sea.**

**Figure 13. Placing of piles into the WTG 3 steel jacket guide holes.**

**Figure 14. Piles inserted into jacket prior to pile driving.**

**Figure 15. Pileco diesel hammer attempting to drive piles at WTG 2.**


**Figure 16. Menck hydraulic hammer.**

**Figure 17. L/B Roberts hammering piles at WTG 1.**

**Figure 18. Transition deck installation.**

**Figure 19. Support vessels at WTG 2 to WTG 5.**

**Table 4. August 2015 significant events.**

| Date | Pile Driving | Significant Events |
|---|---|---|
| 8/18 | Yes | 1513 first strike heard at SE Lighthouse from piling at WTG 2. Soft start till 1600. 1610 Continuous hammering occurs for approximately 3 minutes then stops. Hammer was damaged and day ended with only one partially driven pile. |
| 8/23 | No | Expected pile driving at WTG 2 in late afternoon. Two tugs positioned Weeks 526 next to WTG 2 but never hammered. Weeks 533 next to WTG 3 stabbing 3$^{rd}$ pile which Subacoustech Environmental captured acoustics and reported in **Section 3**. |
| 8/24 | No | Expected pile driving at WTG 2. Cable broke on hammer once set on pile. Pile driving did not occur. |
| 8/25 | No | Expected pile driving at WTG 2. Heavy fog limited visual. Lifted hammer and placed on barge deck, then removed hammer. Weeks Barge requested a welder so assume problem with rigging. |
| 8/26 | No | Winch is broken on crane. Onshore observer captured whale breach near WTG 3. |
| 8/27 | No | Weeks barge is not stable enough to accurately and consistently drive the piles. Weeks engineers coming from Louisiana to assess. |
| 8/28 | No | Hammer placed on WTG 3 and became jammed. Caliper and winch damaged. |
| 8/29 | No | Placed hammer on pile at WTG 3 and it got stuck again. |
| 8/30 | Yes | First pile on WTG 3 driven. Soft start began on 0923. 0931 Start hammering consistently. 1026 Hammer stops. 1530 hammer put on deck to readjust anchors. |
| 8/31 | No | No activity due to adverse weather conditions. |

**Table 5. September 2015 significant events.**

| Date | Hammer | Summary of Activity |
|---|---|---|
| 9/1 | Yes | Piling occurred at WTG 3. Second pile was driven in 58 minutes. Sound easily detectable at SE Lighthouse. URI Santa Rose pulling towed array and reported in **Section 4**. |
| 9/2 | Yes | 2 piles driven at WTG 3. URI captured acoustics for both which is described in **Section 4**. Heavy fog in morning created poor visibility for onshore observer. |
| 9/3 | Yes | 4 piles driven at WTG 2 by Weeks 533 Crane. |
| 9/4 thru 9/16 | No | DW safety inspection. No piling. Team demobilized. 2 jackets in the water. Hammer moved to LB Roberts. |
| 9/16 | No | Team mobilized back to BI. |
| 9/17 | Yes | L/B Roberts onsite. 3 piles driven at WTG 5. Also stabbing piles at WTG 2. Subacoustech captured underwater sound on 2 piles. Attached GoPro to particle motion as described in **Section 4.6**. |
| 9/18 | Yes. | Hammered 4 piles at WTG 3. Welding second set of piles at WTG 5. Remaining work consists of second set of piles at WTG 5, 2, and 1. WTG 4 will need both sets of piles driven: |
| 9/19 | Yes | 4 piles driven at WTG 1. Drove first pile to approximately 75% complete and had hydraulic leak on hammer. Repairs made and finished all piles. Piles are taking just under an hour to drive. Barge onsite with top piece for jackets. Weeks Barge installing platforms on foundations. |
| 9/20 | No | WTG 4 While on pile 1 at WTG 4, the pile hit a soft spot on ocean bottom and slid down quickly causing the hammer to come off. The hammer was striking air at that point and concern is that it may have damaged crane from the force. They are having the crane inspected at Quonset today. They got approximately one-third of the way through the first pile before incident. |
| 9/21 | | Team demobilized. |

**Table 6. Vessels supporting jacket installation.**

| Vessels | Length | Breadth | Function |
|---|---|---|---|
| W533 (Weeks/Manson) | 94.5 m (310 ft) | 30.3 m (99.4 ft) | Derrick Crane Barge |
| W526 (Weeks/Manson) | 89.0 m (292 ft) | 24.4 m (80.1 ft) | Derrick Crane Barge |
| F/V Reed Danos | 32.0 m (105 ft) | 9.1 m (29.9 ft) | Tug used to transport jackets from Louisiana to Block Island |
| R/V Heather Lynn | 25.0 m (82 ft) | 7.3 m (24 ft) | Environmental Monitoring |
| F/V Sorenson Miller | 33.5 m (110 ft) | 7.6 m (24.9 ft) | Supply Vessel |
| F/V Rosemary Miller | 95.5 m (313.3 ft) | 21.5 m (70.5 ft) | Crew Transport from Galilee, Quonset, WTGs |
| R/V McMaster | 9.1 m (29.9 ft) | Unknown | URI Research (Acoustics) |
| R/V Shanna Rose | 12.8 m (42 ft) | 4.5 m (14.7 ft) | URI Research (Acoustics) |
| F/V Iona McAlister | 33.2 m (108.9 ft) | 10.1 m (33.1 ft) | Tug |
| L/B Roberts | 56.4 m (185 ft) | 41.1 m (134.8 ft) | Lift boat |
| F/V Elizabeth | 23.5 m (77.1ft) | 7.9 m (25.9 ft) | Tug |
| L/B Robert | 24.7 m (81 ft) | 8.5 m (27.9 ft) | Tug |
| F/V Stephanie Dann | 26.1 m (85.6 ft) | 8.5 m (27.9 ft) | Tug |
| F/V Josephine K Miller | 57.9 m (190 ft) | 9.1 m (29.9 ft) | Supply Vessel |
| F/V Lindsey E | 11.0 m (36.1 ft) | 4.2 m (13.8 ft) | Crew Transport between Block Island and WTGs |
| F/V Hula Dog | 8.2 m (26.9 ft) | 2.8 m (9.2 ft) | Visual Observation Vessel |

## 2.3 Visual Observations: Highlights and Lessons Learned

- On bright, clear days, construction activities and associated vessel traffic were visible up to 3 mi away.
- Phase 1 construction, which was planned to be completed over 5 weeks, was actually completed over 18 weeks. The first jacket was set in the water on 26 July 2015, and the final pile was driven on 26 October 2015. Adverse weather conditions and equipment issues were the primary causes for that delay.
- The Monitoring Team was on site from 10 August to 21 September (37 days versus the planned 14 days). During this period, data were collected for 15 pile driving operations and are broken down as follows:
  - 18 August 2015 – WTG 2, partial piling event on pile 1
  - 1 to 3 September 2015 – Piling at WTG 3 and WTG 2
  - 17 September – Piling at WTG 5
  - 18 September – WTG 3, second section of piling
  - 19 September – WTG 1
- Of the two hammers mobilized for pile driving, the Menck hydraulic hammer was far more effective than the Bauer-Pileco D280-22 diesel hammer.
- Of the two construction platforms used, the jack-up vessel L/B Roberts provided a stable platform as compared to the Weeks barges and tugs.
- The construction project moved at a faster pace after the initial learning curve. For example, on 1 September 2015, with calm seas and low wind, one pile was driven at WTG 3 in less than 1 hour (**Table 7**), which was a significant improvement over earlier attempts, which in some cases were not even successful in driving a pile and had to be abandoned.

**Table 7. Selected pile driving times.**

| Date | WTG No. | PILE | Start Time | End Time | Elapsed Time | Total Blows |
|---|---|---|---|---|---|---|
| 9/3/2015 | WTG 2 | P1-A1 | 11:13 | 11:41 | 0:28 | 766 |
| 9/3/2015 | WTG 2 | P1- A2 | 9:55 | 10:22 | 0:27 | 741 |
| 9/3/2015 | WTG 2 | P1-B1 | 14:14 | 15:17 | 1:03 | 906 |
| 9/3/2015 | WTG 2 | P1-B2 | 16:39 | 17:17 | 0:38 | 733 |
| 9/17/2015 | WTG 5 | P2-A1 | 12:30 | 13:39 | 1:09 | 1697 |
| 9/17/2015 | WTG 5 | P2-B1 | 18:06 | 19:02 | 0:56 | 1905 |
| 9/17/2015 | WTG 5 | P2-B2 | 16:38 | 17:51 | 1:13 | 2178 |
| 9/18/2016 | WTG 3 | P2-B2 | 10:01 | 10:49 | 0:48 | 1639 |
| 9/18/2016 | WTG 3 | P2-A2 | 14:17 | 15:07 | 0:50 | 1767 |
| 9/18/2016 | WTG 3 | P2-A1 | 12:52 | 13:57 | 1:05 | 2278 |
| 9/18/2015 | WTG 3 | P2 -B1 | 8:36 | 9:37 | 1:01 | 2128 |
| 9/19/2015 | WTG 1 | P1-A1 | 13:00 | 13:37 | 0:37 | 1295 |
| 9/19/2015 | WTG 1 | P1-A2 | 15:00 | 15:52 | 0:52 | 1364 |
| 9/19/2015 | WTG 1 | P1-B1 | 8:28 | 12:39 | 4:11* | 1110 |
| 9/19/2015 | WTG 1 | P1-B2 | 13:56 | 14:43 | 0:47 | 1471 |

*halted hammering to repair hydraulic line

Note: The sampling of days listed in this table was selected to indicate typical progress during cooperative weather windows and no mechanical delays. The average time to hammer a pile was 51 minutes. This average does not include WTG 1 P1-B1 which took over 4 hours because of a broken hydraulic hose.

# 3 Airborne Noise Monitoring

Construction of an offshore wind farm is expected to generate noise from sources such as transportation and mobilization of construction equipment and materials, and operation of construction equipment, including pile driving. Of all of the construction-related sources of noise, pile driving generates the highest levels. During BIWF Phase 1 construction, airborne noise monitoring was conducted during active construction periods to observe and measure levels of airborne noise produced during the installation of the WTG foundations. Noise levels were sampled both on land and on the water. The monitoring data were analyzed to determine the attenuation of noise as it propagates from the piling position over water, primarily as a function of wind speed and wind direction relative to the direction of travel. This analysis will help predict received noise levels under similar situations in the future.

Major results and significant findings from the monitoring and data analyses are discussed in the subsections below; additional information is contained in the Airborne Noise Monitoring Report (**Appendix C**).

## 3.1 Monitoring Approach and Methods

Airborne noise levels were sampled at selected onshore and offshore locations using a series of sound level meters (SLMs). Noise levels were recorded during periods of active pile driving and outside of the active pile driving (to establish background levels).

### 3.1.1 Onshore Monitoring

For onshore noise monitoring, 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 were measured while offshore at 3 m (9.8 ft) above sea level, and at the measurement locations at the top of the cliffs on Block Island, approximately 80 m (262.5 ft) above sea level, and 2 m (6.6 ft) above ground level. There was no precipitation over the duration of the survey.

Data were recorded at three onshore locations, namely the Southeast Lighthouse at the Mohegan Bluffs (4.8 km [3.1 mi] from the WTG 3, Balls Point North on the northeast corner of Block Island (10.5 km [6.5 mi] from the WTG 1), and near Point Judith on the Rhode Island mainland (26.4 km [16.4 mi] from WTG 1) (**Figure 1**). At the Southeast lighthouse monitoring station, the SLM was located south of the lighthouse near the edge of the cliff. This location was as far as possible from public use areas and had a clear line of sight to the BIWF work area. Background noise at his location was dominated by rustling foliage and distant waves, sporadic voices from members of the public and occasional light aircraft.

Measurements at Balls Point North were recorded on the edge of a quiet footpath at the top of the cliff overlooking the site. The background noise at this location was dominated by vegetation rustling in the wind and wave sound, and occasional light aircraft and vessels passing. At Point Judith the SLM was located at an accessible but relatively-remote point on the coastline. The background noise at this location was dominated by intermittent wave action at the beach.

### 3.1.2 Offshore Monitoring

For offshore noise monitoring, surveyors took measurements on a series of transects centered on the piling location. Transects were chosen either to coincide with one of the onshore monitoring stations, heading northwest towards the Southeast Lighthouse, or coincident with a particular wind direction. The monitoring vessel also was used simultaneously for taking underwater sound measurements; accordingly, transects also occasionally focused on directions pertinent to underwater conditions. A key element of the scope of work was to sample a range of conditions, especially transects under different wind directions relative to the transect direction.

A weather-protected microphone was set up on the survey vessel R/V McMaster, which was fixed to a frame in a position that selected to minimize reflections and noise shielding from vessel structures. The microphone was approximately 3 m (9.8 ft) above sea level.

Transects began at the edge of the offshore safety exclusion zone–457.2 m (0.29 mi [500 yards]) from the piling location—and continued out until the vessel reached land, piling ended, or piling noise was no longer audible or detectable because of distance. In practice, the measurements typically continued beyond the range of audibility both 1) in air and 2) underwater, where the sound was detectable to a much greater distance.

Noise data was acquired at intervals starting at approximately 500 m (1,640.4 ft) and doubling in distance (1 km [0.6 mi], 2 km [1.2 mi), and 4 km [2.5 mi]), 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 a computer. This was used to determine the range to the piling from the survey vessel.

## 3.2 Airborne Noise Equation Terms

### 3.2.1 Introduction

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

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

where, RL is the sound level at the receiver, SL is the sound 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.

### 3.2.2 Source Level (SL)

Critical to the calculation of the sound level at a receiver is the sound level at source. Previous offshore impact piling noise underwater monitoring has shown 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) (See the Technical Report in **Appendix C**). While other factors will also have an effect on the sound produced (e.g. material type and thickness, properties of the ground and properties of the pile), the source sound 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 remained the same, 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 (3.3 ft) from the sound 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.

### 3.2.3 N Coefficient

Also known as geometric spreading, the value of N defines how quickly the sound at source reduces over distance and is primarily related to how the sound '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 sound 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 sound tends to vary between 3 and 6 dB per doubling of distance from the sound source.

### 3.2.4 Absorption Coefficient, α

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

Like N, the value of α depends on many factors, including the frequency of the sound and the environmental conditions, such as air temperature and humidity. 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.

This analysis is designed to estimate an appropriate value for N and α coefficients based on the measured airborne sound levels. It is acknowledged that other factors will have an impact on the attenuation of sound, such as scattering by the water surface, weather conditions (e.g., clouds/fog) or variations in temperature with altitude, but analysis to this level of detail is beyond the scope of this study.

### 3.2.5 Sound Metrics

**$L_{Aeq,t}$** – the A-weighted, Equivalent Average Sound Pressure Level (or Energy-Averaged Sound Level). It indicates the decibel level of a constant sound source that would have the same total acoustical energy over the same time interval as the actual time-varying sound condition being measured or estimated. $L_{eq}$ values must be associated with an explicit or implicit averaging time “t” in order to have practical meaning.

**$L_{AFmax,t}$** – the A-weighted Maximum Sound Pressure Level measured with a fast 125 millisecond time constant and associated with an averaging time “t.”

**$L_{A90,t}$** – the A-weighted Sound Pressure Level Sound exceeded for 90 percent of the measurement period “t.”

**$L_{CPeak}$** – the C-weighted, largest absolute value of the instantaneous sound pressure.

**A Weighting** – a weighting applied to received sound pressure level spectra designed to filter out the lower and higher frequencies that the average person cannot hear.

**C Weighting** – similar to A-weighting, C-weighting filters less of the lower frequencies of received sound pressure levels.

### 3.2.6 Spherical and Cylindrical Spreading

This relates to the manner in which the sound spreads from the source, and depends on the distance from the source and the shape of the source. Assuming the source appears to be a single point, at certain distances the sound behaves as if it is spreading out in an approximately spherical shape, and this leads to a theoretical reduction of 6 dB per doubling of distance (as per **Section 3.2.3**). In other situations, the sound can spread in a cylindrical shape, leading to a theoretical reduction of 3 dB per doubling of distance. In practice, the conditions are rarely this well-defined.

In this situation, the noise spreading tends to be approximately spherical near to the sound source then transitions to a more cylindrical pattern at a greater distance.

## 3.3 Background Noise Measurements

Background noise readings were taken outside of active pile-driving periods at the same onshore and offshore locations. Although construction machinery was in position at all times, the activities 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.

### 3.3.1 Onshore

#### 3.3.1.1 Southeast Lighthouse

Background noise levels measured at the **Southeast Lighthouse** on 9 August 2015 are shown in **Table 8**. Average wind speed was 9 meter/second (m/s), northeast. Noise levels were predominantly anthropogenic. The microphone was located in a location that was sheltered from the effects of wind noise.

**Table 8. Summary of background noise level sample at the Southeast Light, 9 August 2015.**

| | $L_{Aeq,30mins}$ | $L_{AFmax}$ | $L_{A90,30mins}$ |
|---|---|---|---|
| 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 |

A longer-duration background noise survey was undertaken at this location in January 2016 (table not provided), which sampled noise levels over day and night periods at higher wind speeds, more indicative of optimum wind turbine conditions. Wind speeds ranged from 6 to 12 m/s, northwest. Noise levels were caused by wind in bare winter trees and correlated well with wind speed.

#### 3.3.1.2 Balls Point North

Background noise levels sampled at **Balls Point North** are shown in **Table 9**. Note that the noise levels recorded were $L_{Cpeak}$ rather than $L_{AFmax}$ and not directly comparable with one another. Noise levels were caused by passing vessels, wave noise, and rustling vegetation.

**Table 9. Summary of background noise level sample at Balls Point North, 9 August 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 |

Background noise levels sampled at **Point Judith** are shown in **Table 10**. Noise levels were dominated by the continuous wave noise on the pebbly shore.

**Table 10. Summary of background noise level sample at Point Judith, 30 August 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 |

### 3.3.2 Offshore

Background noise levels **offshore** were entirely dependent on the sea state and the orientation of the vessel to the waves (**Table 11**). As the vessel was shut down for the duration of the measurement period, the orientation was somewhat out of the control of the personnel on board. There was also some influence from small creaks on the vessel and occasional radio transmissions, therefore the background $L_{Aeq}$ should be considered indicative and a valid $L_{AFmax}$ cannot be stated. For 25 August, the winds were calm and the wave height <0.5 m (1.6 ft).

**Table 11. August 25, 2015 Summary of background noise level sample offshore (excluding engines).**

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

**Table 12** displays noise levels measured on 19 September when the wind and wave conditions were extremely calm and the sea, especially early in the sample, was glassy. The $L_{A90}$ is approximately 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.

**Table 12. 19 September 2015 Summary of background noise level sampled offshore (excluding engines).**

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

## 3.4 Monitoring Results

Measurements taken offshore using the SLM set up on the R/V McMaster during all of the piling events are detailed in **Table 13**. Onshore measurements were taken for all piling events at the Southeast Lighthouse on Block Island except for events on 19 September, where the monitor moved to Balls Point North.

As the noise levels measured were variable from pile strike to pile strike, 30-second samples of continuous piling noise were recorded. Levels were discounted if obviously affected by spurious noise sources, such as a nearby vessel or aircraft passing. One second $L_{Aeq}$, $L_{AFmax}$ and $L_{Cpeak}$ values were selected from the higher levels sampled of the pile strikes over a measurement period. The reported value typically was the second highest measured within the period to avoid the risk of spurious spikes. Short, selective samples of pile strikes were used as longer periods were subject to variability in pile strike rate.

**Table 13. Summary of piling event airborne noise measurements.**

| Transect ID | Date | Turbine foundation | Transect Direction | Ranges | Time | Wind direction | Wind speed |
|---|---|---|---|---|---|---|---|
| 1 | 18-Aug-15 | WTG 2 | Northwest | 450 m – 700 m (1,476.4 ft – 2,296.6 ft) | 15:53 – 16:11 | SW | 3–4.5 m/s |
| 2 | 03-Sep-15 | WTG 2 | Northwest | 550 m – 4.9 km (1,804.5 ft – 3 mi) | 09:56 – 10:20 | WSW | 3–3.5 m/s |
| 3 | 03-Sep-15 | WTG 2 | East | 640 m – 12.0 km (2,099.7 ft – 7.5 mi) | 11:14 – 15:11 | WSW-S | 3 m/s |
| 4 | 17-Sep-15 | WTG 5 | Northwest | 470 m – 5.3 km (1,542 ft – 3.3 mi) | 12:42 – 13:35 | SW | 3 m/s |
| 5 | 17-Sep-15 | WTG 5 | Northwest | 590 m – 5.3 km (1,935.7 ft – 3.3 mi) | 15:20 – 15:53 | W | 4 m/s |
| 6 | 17-Sep-15 | WTG 5 | Northwest | 420 m – 5.3 km (1,378 ft – 3.3 mi) | 16:39 – 17:21 | W | 3 m/s |
| 7 | 18-Sep-15 | WTG 3 | Southeast | 730 m – 6.0 km (2,395 ft – 3.7 mi) | 13.09 – 13:49 | SW | 2 m/s |
| 8 | 18-Sep-15 | WTG 3 | Southeast | 500 m – 6.4 km (1,640.4 ft – 4 mi) | 14:22 – 15:07 | NW | 3 m/s |
| 9 | 19-Sep-15 | WTG 1 | North | 710 m – 10.5 km (2,329.4 ft – 6.5 mi) | 08:37 – 08:55 | NE | Calm |
| 10 | 19-Sep-15 | WTG 1 | North | 3.9 km – 6.2 km (2.4 mi – 3.9 mi) | 15:29 – 15:52 | S | 2 m/s |

The monitoring vessel had to move between locations, sometimes over significant distances. To ensure that the offshore measurement periods overlapped with the onshore measure periods, the length of the onshore measure period was appropriately extended. This somewhat selective technique was deemed necessary to obtain the best quality comparable results because of the frequent presence of local non-piling noise sources during the busy holiday period.

Two examples of piling event noise metric trends are provided. Coinciding 18 August $L_{Aeq,}$ data histories recorded at the R/V McMaster, the Southeast Lighthouse and Point Judith are shown in **Figure 20**. Three initial pile strikes can be seen clearly at approximately 15:55, followed by a few sporadically before continuous piling for three distinct periods over the next 20 minutes.

Piling can be detected in the lighthouse time history and was clearly audible, although it is frequently lost in recreational light aircraft flybys (e.g., 15:53, 16:01). The noise level remains high at Point Judith because of noise of waves on the shore. Subjectively, pile strikes were never audible at any time at Point Judith.

**Figure 21** shows a summary of the data captured along the east transect. Noise events of pile strikes were recorded up to 12 km (7.46 mi) from the piling at WTG 2 on 3 September 2015. The chart clearly displays three 'blocks' which correspond to survey vessel operation and so these represent engine noise (i.e., self-noise), which can be discounted. The SLM was not shut down during these periods. The time average assigned is 1 second for the $L_{Aeq}$ metric.

The offshore time history shows a progressive reduction over time, and therefore distance, outside 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 approximately 11:25, which cannot be explained but may be due to a variation in wind conditions as there was no obvious change in piling in the logs.

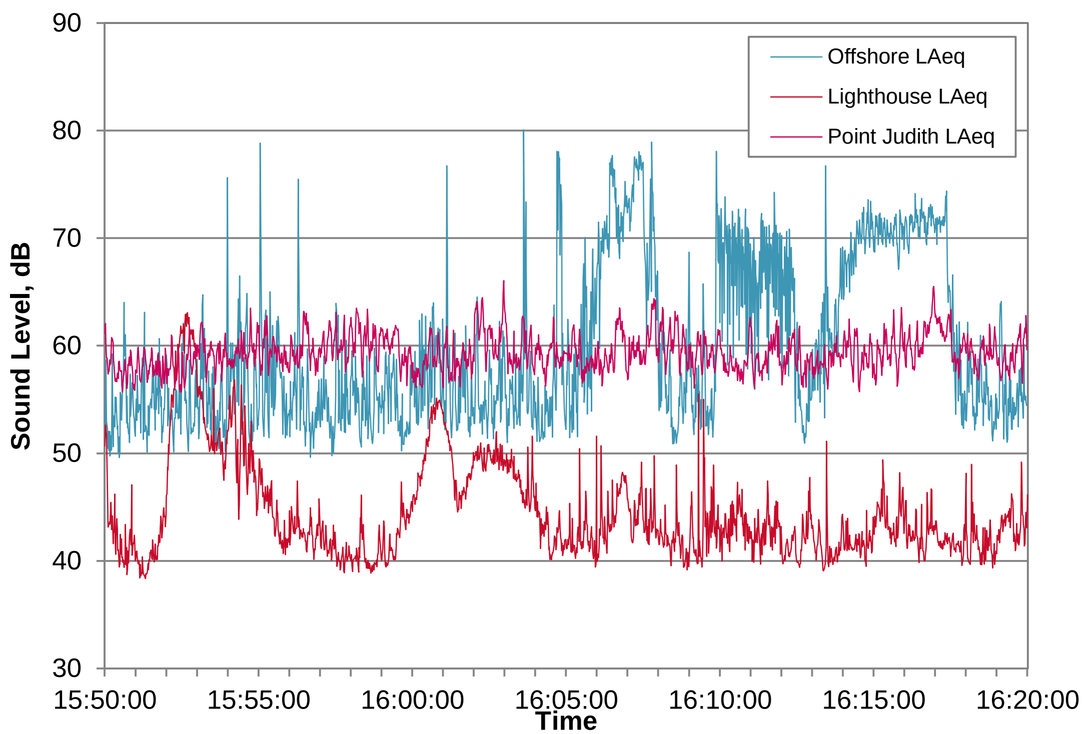



**Figure 20. Offshore Southeast Lighthouse and Point Judith $L_{Aeq,1s}$ noise levels versus time recorded during pile driving of WTG 2 on 18 August 2015.**

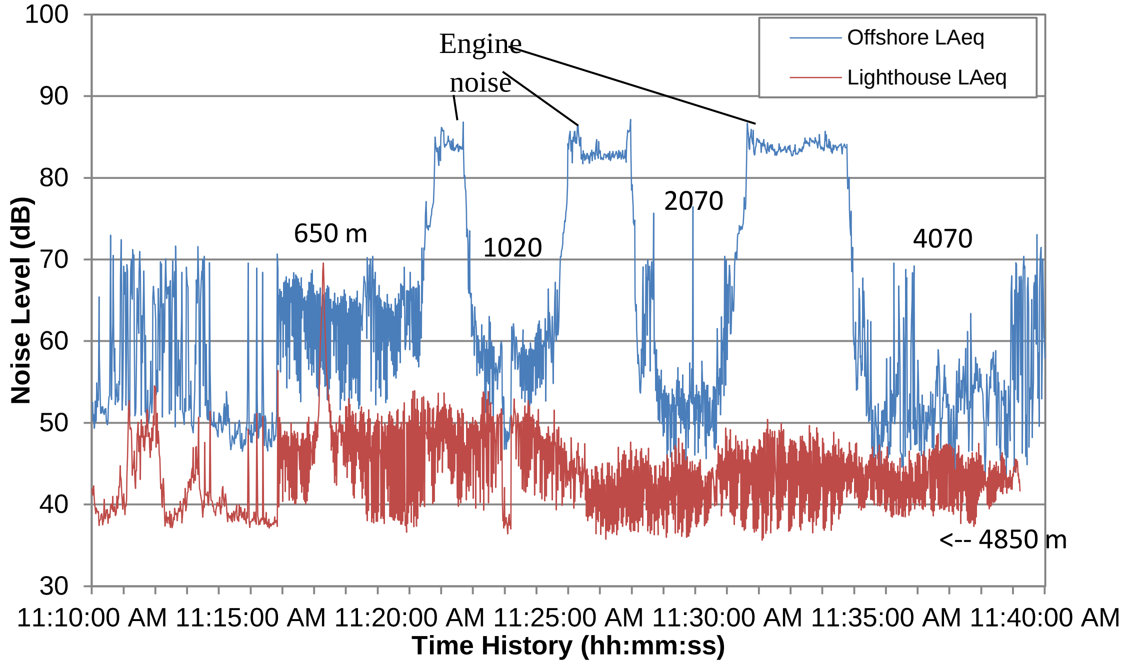



**Figure 21. Offshore noise levels versus time (1-second increments) recorded during pile driving of WTG 2 on 3 September 2015.**

There is an unexpected increase in the noise level at approximately 11:35, 4.0 km (2.49 mi) 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 focusing of noise over a particular range. This cannot be confirmed. At the beginning of piling, the noise level sampled at the lighthouse was approximately 50 dB $L_{Aeq}$, over 10 dB above the background noise level.

## 3.5 Data Analyses

Recorded noise monitoring data were analyzed separately for key aspects; findings are discussed below.

### 3.5.1 Wind Direction

The airborne noise data sampled during the piling for the 10 BIWF 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 at which noise level samples were taken, including measurements taken at the coast, were combined to provide a level versus range plot.

It should be noted that the sea state, wind speed, temperature, pressure and humidity remained fairly consistent throughout measurements in each group.

All analyses assume there are two values of the N coefficient: one which exists close to the piling (nearfield) and one at a greater distance (far field). As the number of measurements close to the pile were insufficient to empirically establish a trend in the nearfield measurements because of safety restrictions, 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 (2,624.7 ft) was used as the transition point in the analyses; that is, the calculations assumed spherical spreading (N = 20) at ranges of 800 m (2,624.7 ft) 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 (2,296.6 ft), based on data from a noise measurement program 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 (30-second) average, despite the source level remaining unchanged.

Coefficients of N in excess of >800 m (2,624.5 ft) and the source noise level were then altered manually until data points at 200 m (656.2 ft) intervals most closely matched the line of best fit.

The effect of blow energy on the apparent source noise level is discussed in **Section 3.7**, 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.

### 3.5.2 Receiver Downwind of the Piling

Two piling events took place with measurements taken under a downwind transect: one on 18 September and one on 19 September. The level versus range plot, with reference to 1 m (3.3 ft), is shown in **Figure 22**. The source noise level (at 1 m (3.3 ft) from the source position) was calculated to be 127 dB $L_{Aeq,1s}$, a figure remarkably close to the estimated "129 dBA" reported in "In-Air Acoustic Report" prepared by TetraTech EC, Inc. for Deepwater Wind.

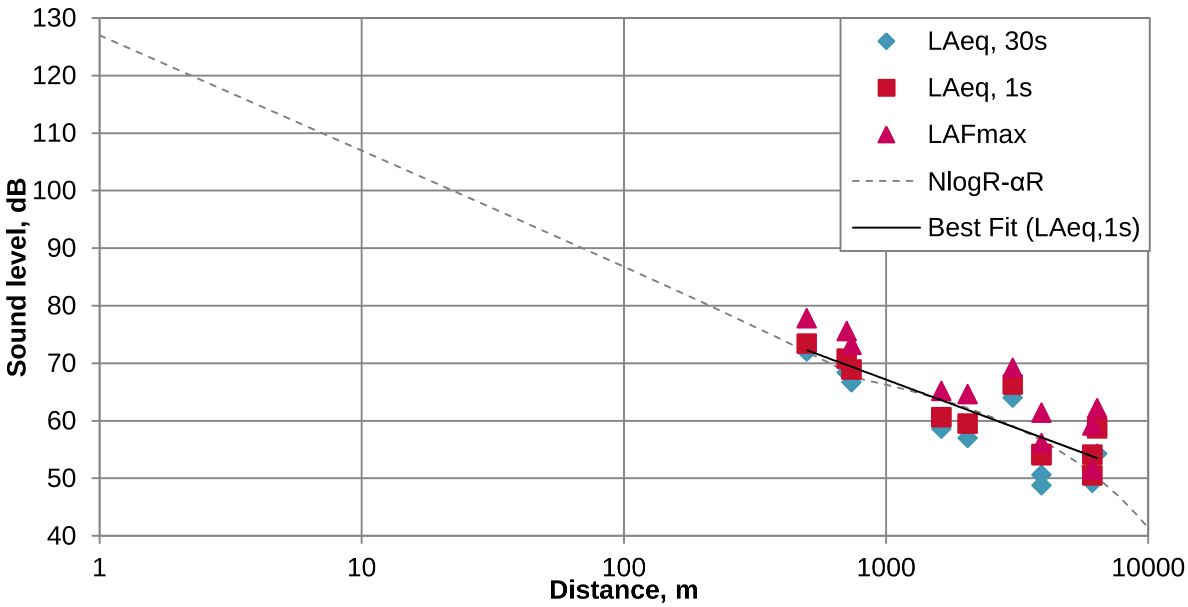



**Figure 22. Level vs range plot for winds at 180° (downwind) to the direction of travel. Far-field [R>800m] coefficients: N = 6, α = 0.0021.**

### 3.5.3 Receiver Crosswind of the Piling

Data in the 90° crosswind analysis were extracted from samples taken on three piling events, which occurred on 3, 17 and 18 September. There is a weaker correlation between the line of best fit and samples beyond 3,000 m (9,842.5 ft); all samples were included in the best-fit calculation (**Figure 23**). Although the line of best fit is best matched by N = 6 for ranges in excess of 800 m (2,624.7 ft), 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 (2.6 mi) is considered a spurious outlier.

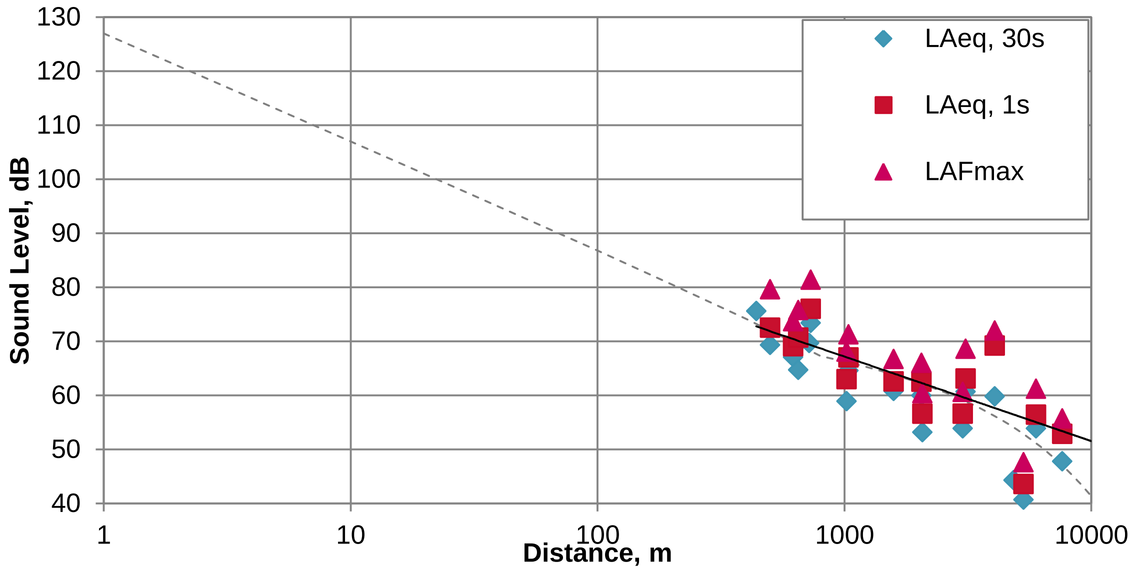



**Figure 23. Level vs range plot for winds at 90° to the direction of travel. Far-field coefficients [R>800 m (2,624.7 ft)]: N = 6, α = 0.0021.**

It is suggested that there is likely to be greater variation in crosswind than under an entirely upwind or downwind condition, as a small variation in direction would change the condition to a potentially upwind or downwind situation. A slightly higher value of N would be reasonable, especially considering the analysis for the 67.5° winds discussed in Section 3.5.4. There is also a confounding factor in that the measurements taken on 3 September are under foggy conditions, which will affect the noise propagation over long range and is likely to have influenced the outliers at 4-5 km (2.49–3.11 mi). The source level remains at 127 dB $L_{Aeq,1s}$.

### 3.5.4 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 17 September, and data combined show an excellent correlation to the line of best fit between 400 m (1,312.3 ft) and 5 km (3.1 mi) (**Figure 24**). The NlogR-αR points fit the line well at N = 12, i.e., a 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 source noise level remains as previously at 127 dB $L_{Aeq,1s}$.

The 67.5° transect, or just beyond crosswind conditions, was only sampled briefly over one event at four points on 3 September; however, the line of best fit remains at N = 12 for R>800 m (2,624.7 ft) (**Figure 25**).

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<800 m [(2,624.7 ft)]) and α coefficients only fitted the data when the apparent source level was 130 dB $L_{Aeq,1s}$. The data also would fit if the source level remained constant and the value of N in the near field 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 to 100 kilojoules (kJ) over this period, which is representative of most sampled periods), and so the apparently higher source noise level may be caused by the small sample size taken over this wind condition.

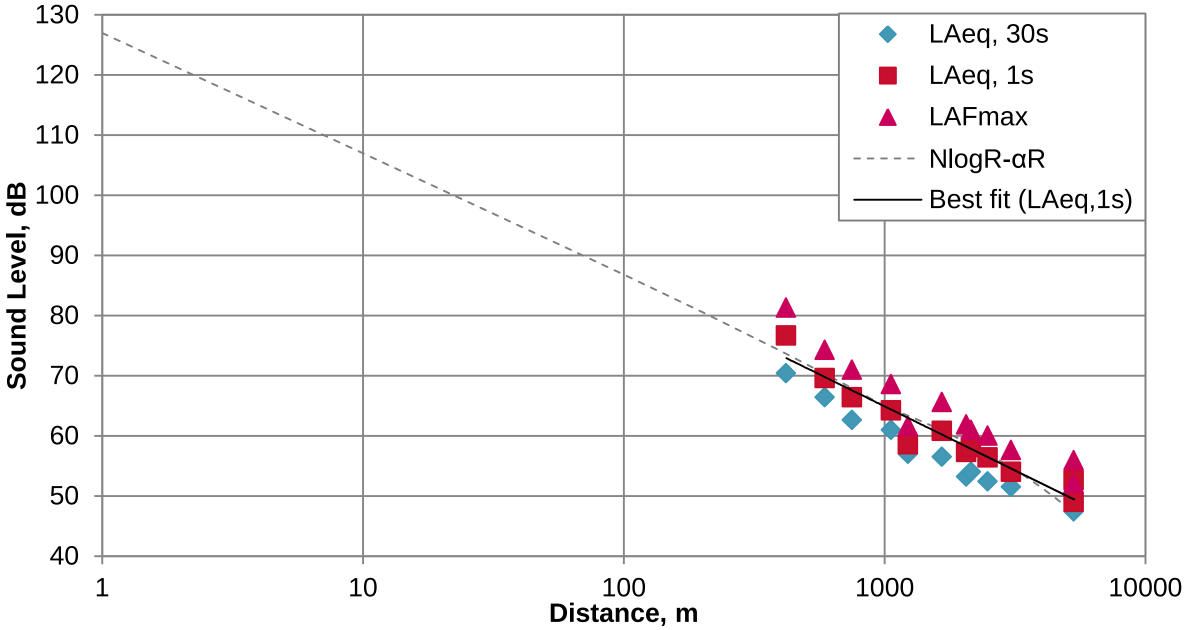



**Figure 24. Level vs range plot for winds at 45° to the direction of travel. Far-field coefficients [R>800m]: N = 12, α = 0.0021.**

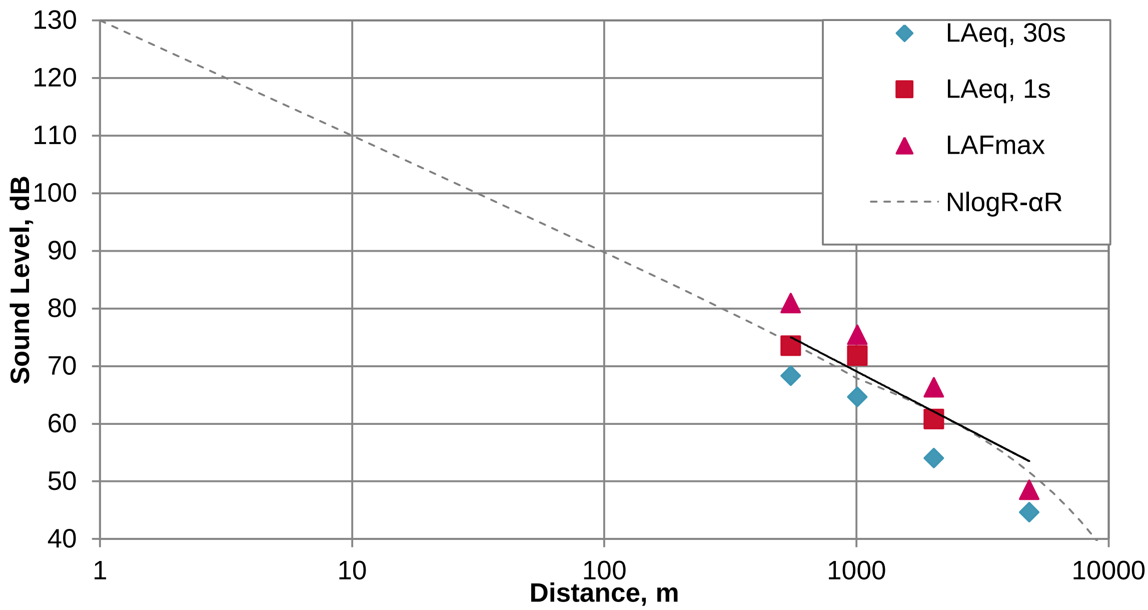



**Figure 25. Level vs range plot for winds at 67.5° to the direction of travel. Far-field coefficients [R>800 m (2,624.7 ft)]: N = 12, α = 0.0021.**

### 3.5.5 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. Under entirely calm conditions, the propagation of noise 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 (2,296.6 ft and 6.2 mi) fitting N = 19 (**Figure 26**). All other conditions (i.e., with any wind present) have much slower attenuations with N = 12 or less. This may be due to flat seas scattering noise less and reflecting more to the atmosphere, or effects on the layering of the atmosphere.

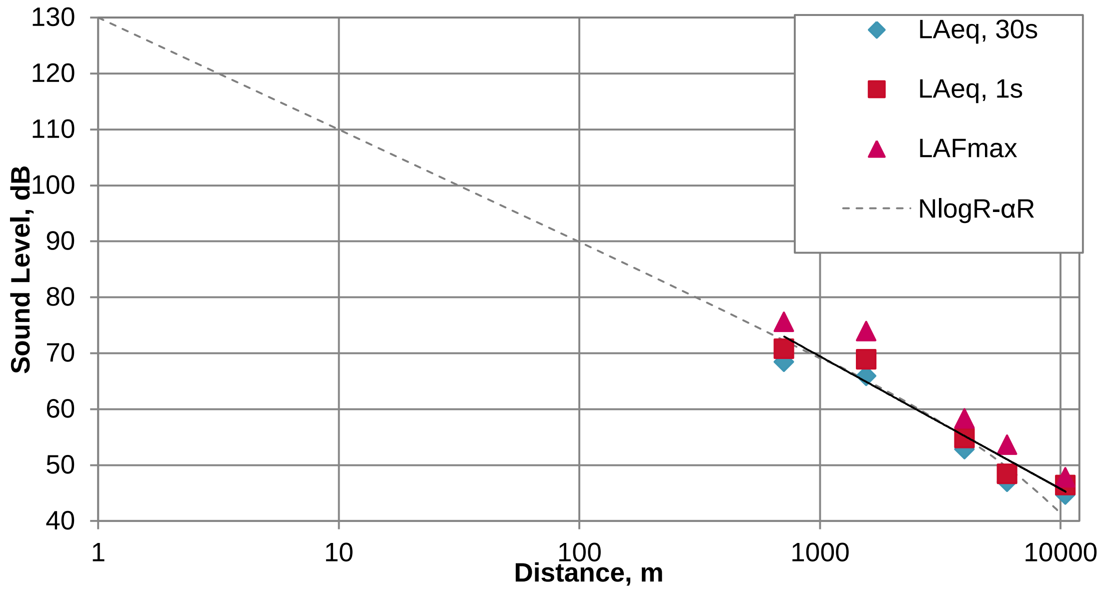



**Figure 26. Level vs. range plot for calm winds and seas. Far-field coefficients [R>800m]: N = 19, α = 0.00063.**

The measurements under calm conditions also required a lower attenuation coefficient (α) of 0.00063, instead of 0.0021 to keep the trend line 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 [2,329.4 ft and 1 mi]) were taken, and were nearly double the energy for this short period. A higher source noise level was also noted in the results of 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 best-fit line to a source level of 127 dB $L_{Aeq,1s}$, in consensus with the other wind condition trends, but the high N = 19 remains.

## 3.6 Frequency Spectra

All pile strikes will have a frequency signature, which will be dependent on 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 be that taken close to the pile, as any variation over the distance between source and receiver will be a function of the environment in which the noise travels. This will affect every frequency band slightly differently, high frequencies generally being attenuated more quickly than low frequencies.

While analysis of noise propagation in individual frequency bands will provide detailed and accurate data for that specific band, it is considered more useful to analyze and present the data as single overall values, particularly as almost all criteria used in environmental noise assessments are denoted in A-weighted decibels. However, one-third octave band spectra have been acquired and can be reanalyzed at a later date.

The frequency spectra for each piling event are provided in Appendix A of the Airborne Noise Monitoring Technical Report (**Appendix C**). Below is a sample of the spectra under upwind, downwind, and calm conditions.

### 3.6.1 Frequency Spectra Downwind

Taken on a southeast transect, with north-westerly winds at 3 m/s (**Figure 27**). Most of the energy received in the strikes is at low frequency and primarily below 400 Hertz (Hz), although the spectra are clearly broadband (non-tonal) in nature.

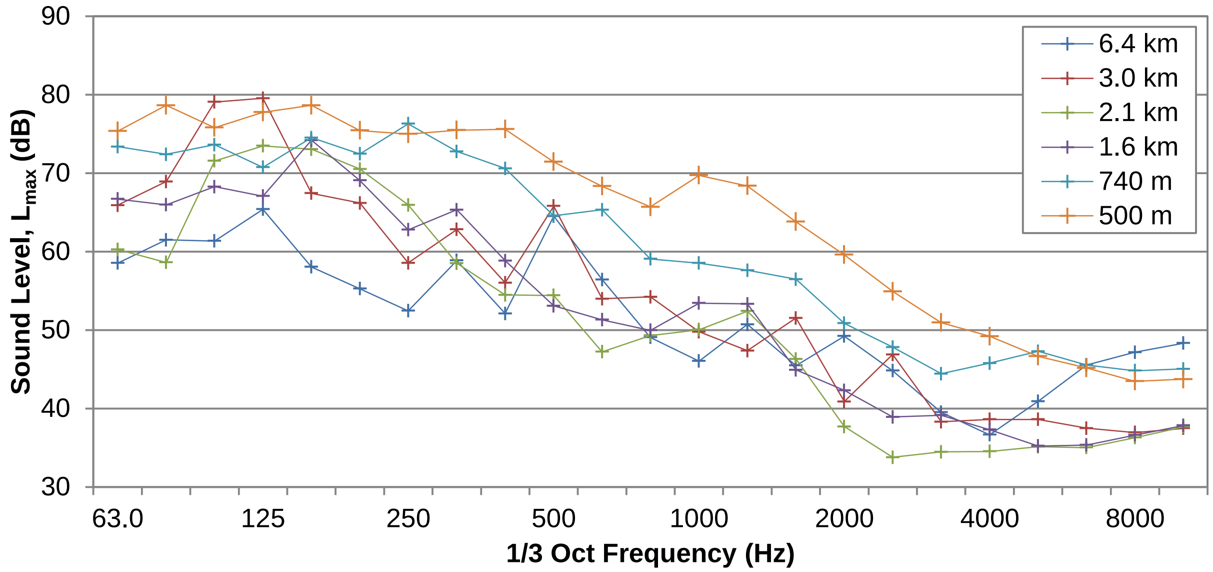



**Figure 27. One-third octave band $L_{max}$ spectra taken under downwind conditions on 18 September 2015.**

### 3.6.2 Frequency Spectra Upwind

The spectra were taken on a westerly transect, with a north-westerly wind (i.e. taken on 45° upwind conditions). A sample was taken closer to the piling here than on the downwind sample in **Figure 28**. After little more than 1 km (0.6 mi) most of the energy in frequency bands over 630 Hz has been lost. The consistency between **Figures 28** and **29** where the spectrum at 740/750 m (2,427.8/2,460.6 ft) both start to drop off above 250 Hz.

## 3.7 Piling Blow Energy and Noise Source Levels

The airborne source noise level of the piling has been calculated based on a 20 logR + αR spreading attenuation and using measurements made closest to the pile. An absorption coefficient of $\alpha = 2.1$ has been set based on the results presented in **Section 3.5**. Only airborne noise levels measured at 750 m (2,460.6 ft) from the pile or less have been included in the analysis to reduce the influence of wind and other far-field factors.

**Figure 30** shows the results of the analysis by the distance from piling, to help identify any influence the distance has on calculated source levels, i.e., noise levels normalized to 1 m (3.3 ft). Results are broken down in the chart by hammer type: the Menck hydraulic hammer in blue (3 and 17 September, the last two at 710 m (2,329.4 ft) on 19 September) and the Bauer-Pileco D280-22 diesel hammer in red (18 August).

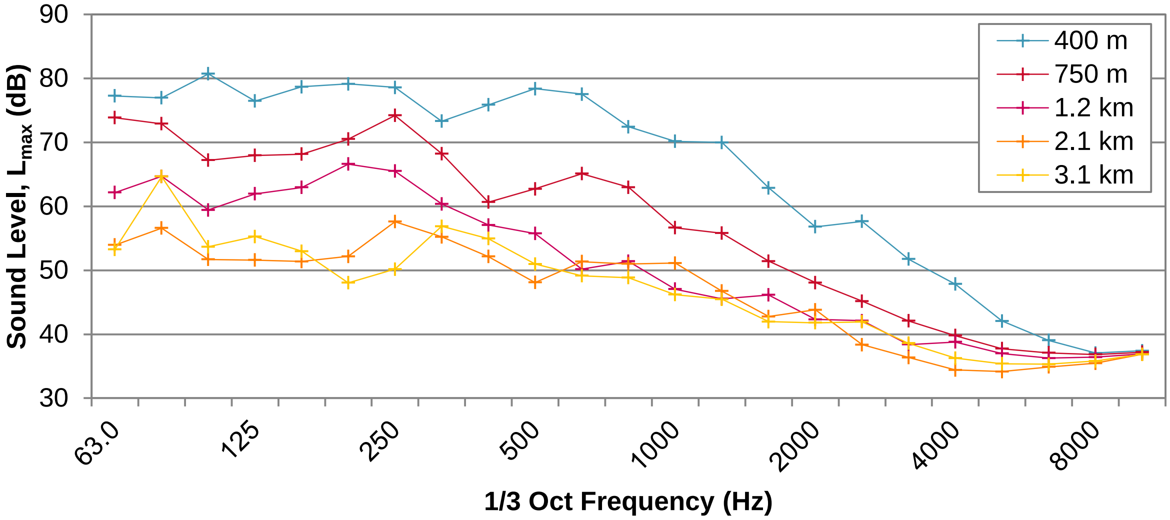



**Figure 28. One-third octave band $L_{max}$ spectra taken under upwind conditions on 17 September 2015.**

### 3.7.1 Frequency Spectra Calm Winds

Taken on a northerly transect. Although there are fewer positions on **Figure 29**, this demonstrates clear reductions in all frequencies below 6,300 Hz band, suggesting that little energy is produced by piling above this frequency, or it attenuates so quickly that little arrives at 710 m (2,329.4 ft). However, data presented in **Figure 29** indicate that higher frequencies are present closer to the pile.

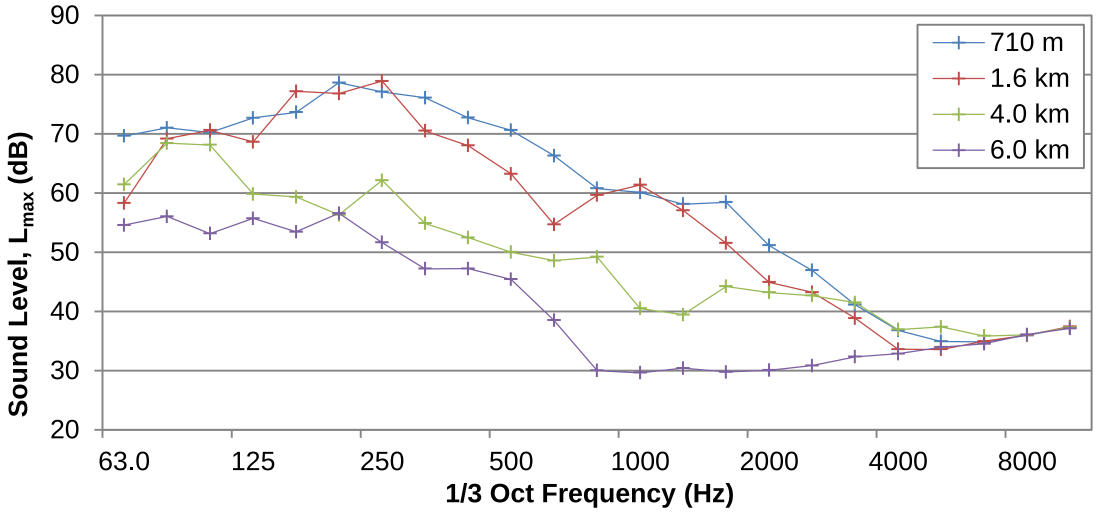



**Figure 29. One-third octave band $L_{max}$ spectra taken under upwind conditions on 19 September 2015.**

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 to 933 kJ, which is significantly greater than that used with the Menck, logged between 60 and 500 kJ[5].

[5] Bauer-Pileco data from http://www.bauerpileco.com/ en/products/hammers/diesel_hammers/d280-22, last downloaded 22 February 2016

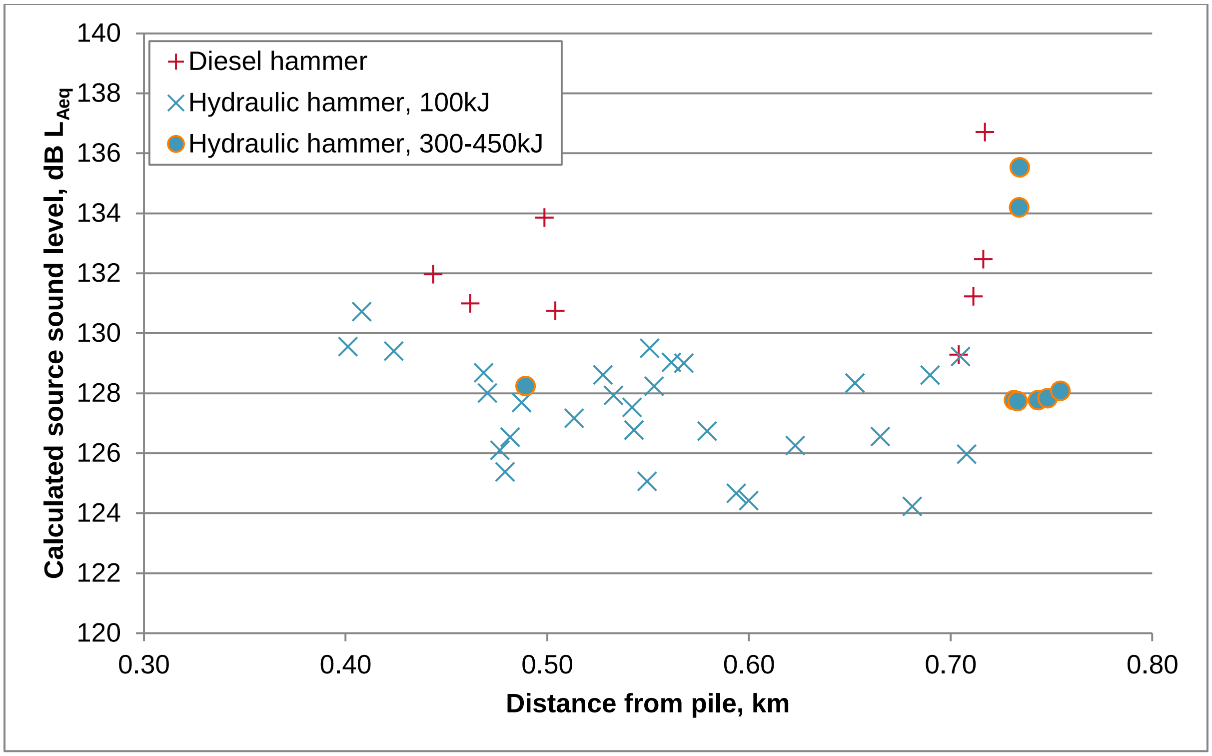



**Figure 30. Scatter chart of calculated source noise levels from the diesel and hydraulic piling hammer.**

The diesel hammer clearly shows higher calculated source noise levels, than the hydraulic hammer at 100 kJ, with the noise levels typically being above 130 dB $L_{Aeq,1s}$. With one exception, the hydraulic hammer at lower energy produced source noise levels lower than 130 dB $L_{Aeq,1s}$. The high energy hydraulic hammer strikes were some of the loudest at 134 to 136 dB LAeq,1s. Results show little correlation with distance, except possibly a small downward trend, suggesting that the simple 20 logR + αR propagation loss produces reasonable results over this range. Natural' strike-to-strike variability in source level is greater than the effects of range. It should be noted that the small collection of closest measurements (approximately 400 m (1,312.3 ft)) are also among the highest. Also note that these three samples occurred during soft start on 17 September at approximately 16:40. Slightly higher noise levels during soft start also were noted in the underwater measurements, despite lower blow energies. The reason of this is unknown.

It is possible that there are three 'bands' within the blue X results at 124 to 126 dB, 126 to 128 dB and 128 to 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 could reflect a slightly higher value of α that 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 one-third octave band center frequency of 1,600 Hz, which is much higher than where most of the energy is contained in the signal, even at close range (refer to **Section 3.6**), and so this seems unlikely to be the explanation.

All results denoted with a blue X (in **Figure 30**) 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 $L_{Aeq,1s}$ 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, but the 450 kJ stood clearly out. The block of blue spot results in excess of 700 m (2,296.6 ft) 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’ noise level spread of ± 3 dB across each hammer type.

## 3.8 Discussion

The data acquired during the surveys generally follow 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. **Table 14** 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 at 800 m (2,624.7 ft) from the pile.

**Table 14. Summary of noise attenuation coefficients under different wind and sea conditions.**

| 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 | 0.00063 |

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 showed that the diesel hammer was louder than the hydraulic hammer (at 100 kJ) by an average of 5 dB, which agrees with subjective observations by the surveyor at the Southeast Lighthouse. The average calculated source noise level for the diesel hammer was 132 dB $L_{Aeq,1s}$ at 1 m (3.3 ft), compared with the hydraulic hammer at 127 dB $L_{Aeq,1s}$ at 1 m (3.3 ft) based on measurements between 400 and 750 m (1,312.3 and 2,460.6 ft). 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 (3.3 ft) 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.

The offshore background noise level, at between 42 dB and 50 dB $L_{A90}$ (depending on sea state) was in general sufficiently below the measured piling noise impulses so as not to influence the measured levels, up to the order of 6,000 m (19,685 ft) from the pile. Beyond that range there tends to be a small upward deviation from the NlogR-αR line, which could indicate that the received noise levels are close to background. Most measurements, however, are closer to the piling than this.

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. A 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 good agreement with the measured results across a long range.

This study primarily utilized A-weighted metrics, in keeping with international standards for the assessment of airborne environmental noise. The A-weighting of noise is designed to correct for the sensitivity of human hearing. The effect of this is to reduce the significance of noise frequencies progressively below and above 2,000 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 most of the energy in the received noise levels at a distance is 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 most environmental noise assessments. Despite this, the fact that the data do appear to follow the theory suggests that the A-weighting does not eliminate 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.

## 3.9 Conclusions

The results of measurements of the airborne noise emission during piling and its propagation have been analyzed. In general, wind speed, 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. Access was restricted closer than 500 yards (457.2 m [1,500.2 ft]) 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 approximately 800 m (2,624.7 ft) from the pile.

Extrapolations from measurements at a distance show a noise pressure level of approximately 127 dB $L_{Aeq,1s}$ re 20 µPa calculated at 1 m (3.3 ft) from the pile, treating the piling as an effective point source when viewed from a long distance. Because of the limited measurements within the 500-yard (457.2 m [1,500 ft]) exclusion zone around the piling, there is significant uncertainty (± 3 dB) 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 (2,329.4 ft and 6.2 mi) from the source. Analysis of the results suggest that even a modest increase in sea state will have an effect on the propagation of airborne noise over water. The noise was also affected on the one day where conditions were foggy, which is reasonable to expect because of effect of humidity on noise attenuation.

Noise from piling was always clearly audible at the Southeast Lighthouse, 4.8 km (3 mi) away, and sometimes just audible at Balls Point North at 11.3 km (7 mi) under ideal conditions. At the lighthouse, noise levels were measured at over 50 dB LAeq,1s, more than 10 dB above background noise levels, which were typically of the order of 39 dB $L_{A90}$ and dominated by rustling vegetation. 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 noise 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 most under similar environmental conditions (i.e., daytime, summer, clear, dry, temperature and humidity). Further investigations of offshore piling noise over water 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, i.e. within the 500-yard (457.2 m [1,500 ft] security exclusion zone and at a greater range, particularly in excess of 8,000 m (26,246.7 ft). In addition, 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.

## 3.10 Summary

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 at three coastal locations facing BIWF and on a mobile survey vessel that transited on transects around the foundations during piling.

A total of 10 piling events were sampled, with a piling event consisting of a single period of pile driving of approximately 30 minutes in duration. Pile strikes were typically 2 to 3 seconds apart. Conditions during the surveys were ideal for environmental noise measurement, sunny and dry, with temperatures at approximately 25 degrees Celsius (77 degrees Fahrenheit) and relative humidity 80 percent 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 (3.3 ft) and usually between 0.3 and 0.9 m (0.9 and 3 ft). Completely calm conditions were present during one piling event. All measurements were undertaken in daylight hours.

Noise during piling was always audible at the closest coastal measurement station, 5 km (3.1 mi) from the offshore wind farm. At the furthest location, 27 km (17 mi) from the piling, the noise was never audible. A mid-point coastal location at 11 km (7 mi) from the piling was visited for a short period and it was found that the piling was only intermittently audible under totally calm conditions, with minimal background noise, 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 (1,378 ft) at the closest and 12 km (7.5 mi) 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 noise attenuates over water. It was found that noise 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 (2,624.7 ft) from the source, where R is the distance in meters from the pile. Beyond that point, the attenuation changed to a cylindrical pattern 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 data, although the received noise levels showed a poorer correlation with the line of best fit and so there is consequently a lower confidence in this value.

The attenuation changed significantly under calm conditions, demonstrating approximately spherical spreading in both the near and far-field. Measurements were possible up to 6 km (3.7 mi) from the foundation; only a single event in these conditions could be sampled.

Frequency spectra of the measurements showed that most of the energy in the received pulses was below the 630 Hz one-third octave band at distances up to 400 m (1,312.3 ft) from the piling, and below 250 Hz at distances beyond 2 km (1.3 mi).

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 to bear in mind with the variety of foundations currently in use or proposed for offshore wind turbines. Close range measurements could be done either by vessel, where safe to do so, or by potentially setting up an SLM on the deck of the piling barge.

# 4 Underwater Sound Monitoring

Underwater sound monitoring was conducted in parallel with airborne noise monitoring during Phase 1 construction to detect and record underwater acoustic and sediment-borne signals generated by the impact pile driving. Two parallel monitoring studies were conducted as follows:

1. Underwater sound monitoring using **stationary and towed arrays** and a **sensor-equipped geosled**. This monitoring was conducted by a joint team of acousticians from the University of Rhode Island, the Woods Hole Oceanographic Institution, and Marine Acoustics, Inc. The approach, methods, results, findings, and recommendations from this monitoring study are summarized in **Section 4.1**. An electronic copy of the monitoring report from this study is included in **Appendix D**.

2. **Single drifting sensor** (hydrophone) underwater sound at two depths and **seabed vibration monitoring**. A fixed, continuously monitoring hydrophone station was located at 750 m (2,460.6 ft) from the foundation. This monitoring was conducted by Subacoustech Environmental Ltd. The approach, methods, results, findings, and recommendations from this monitoring study are summarized in **Section 4.2**. An electronic copy of the monitoring report from this study is included in **Appendix D**.

## 4.1 Stationary and Towed Array Monitoring

### 4.1.1 Approach

Acoustic and seismic signals were measured and recorded using the following fixed and mobile monitoring systems:

- An eight-hydrophone towed array was deployed over two separate days from the R/V Shanna Rose. The hydrophones were used to measure sound pressure.
- Two vertical arrays (VLA) moorings, each equipped with Several Hydrophone Receiving Units (SHRUs), were deployed for 4 weeks at a distance of 7.5 and 15 km (4.7 and 9.3 mi) from the turbines. Each SHRU consisted of four hydrophones.
- A stationary geophysical sled was deployed for 4 weeks approximately 500 m (1,640.4 ft) from WTG 3 and WTG 4 at a depth of 26 m (85.3 ft). This sled carried the following monitors:
  - a 4-hydrophone tetrahedral array for measurement of acoustic particle velocity, and
  - a geophone sensor package with a 3-axis geophone and a co-located low sensitivity hydrophone for the measurement of sediment motion and acoustic pressure on the seabed.

Monitoring data were analyzed to estimate peak-to-peak Sound Pressure Levels (SPLs) and kurtosis values for pile driving hammer strikes. Kurtosis is the shape of the distribution of measurements (Zar 1984). High kurtosis indicates that variance is due to infrequent, extreme deviations from the mean as opposed to frequent, modestly sized deviations. Data were also plotted against range to examine how the values changed with distance from the pile driving location. Individual piles being driven were analyzed separately and the different piles were compared against each other. Monitoring data were also used to estimate acoustic particle accelerations and particle velocity, and test a preliminary numerical three-dimensional (3D) underwater sound propagation model. Fin whale vocalizations recorded during the monitoring were also evaluated.

**Table 15** shows the dates on which data were collected using different types of sensors. Deployment locations and depths of the stationary sensors are shown in **Table 16**. The relative positions of the various sensors deployed within the study area are shown in **Figures 31**, **32**, and **33**.

**Table 15. Underwater acoustic monitoring summary.**

| Sensor Type | 18 Aug | 30 Aug | 1 Sept | 2 Sept | 3 Sept | 17 Sept | 18 Sept | 19 Sept | 12 Oct | 13 Oct | 14 Oct | 15 Oct | 16Oct | 17 Oct | 18 Oct | 19 Oct | 20 Oct | 21 Oct | 22 Oct | 23 Oct | 24 Oct | 25 Oct | 26 Oct |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Towed Array | | | | √ | | √ | | | | | | | | | | | | | | | | | |
| Vertical Line Arrays | | | | | | | | | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ |
| Geophysical Sled | | | | | | | | | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ | √ |

Note: Pile driving was completed on 26 October 2015; stationary moorings were retrieved on 4 November 2015, which provided one week of post-construction ambient background sound measurements.

**Table 16. Stationary sensors locations and depth.**

| Mooring | Latitude (Degrees N) | Longitude (Degrees W) | Depth |
|---|---|---|---|
| Geophysical Sled (with Geophone 917 and Tetrahedral Array 918) | 41.1110 | 71.5225 | 26 m (85.3 ft) |
| VLA SHRU 913 | 41.0127 | 71.4044 | 40 m (131.2 ft) |
| VLA SHRU 919 | 41.0664 | 71.4590 | 41 m (134.5 ft) |

Note: The 750 m (2,460.6 ft) fixed monitoring station was conducted in conjunction with the dipped hydrophone measurement transect and its location was in line with the direction of travel during that pile installation.

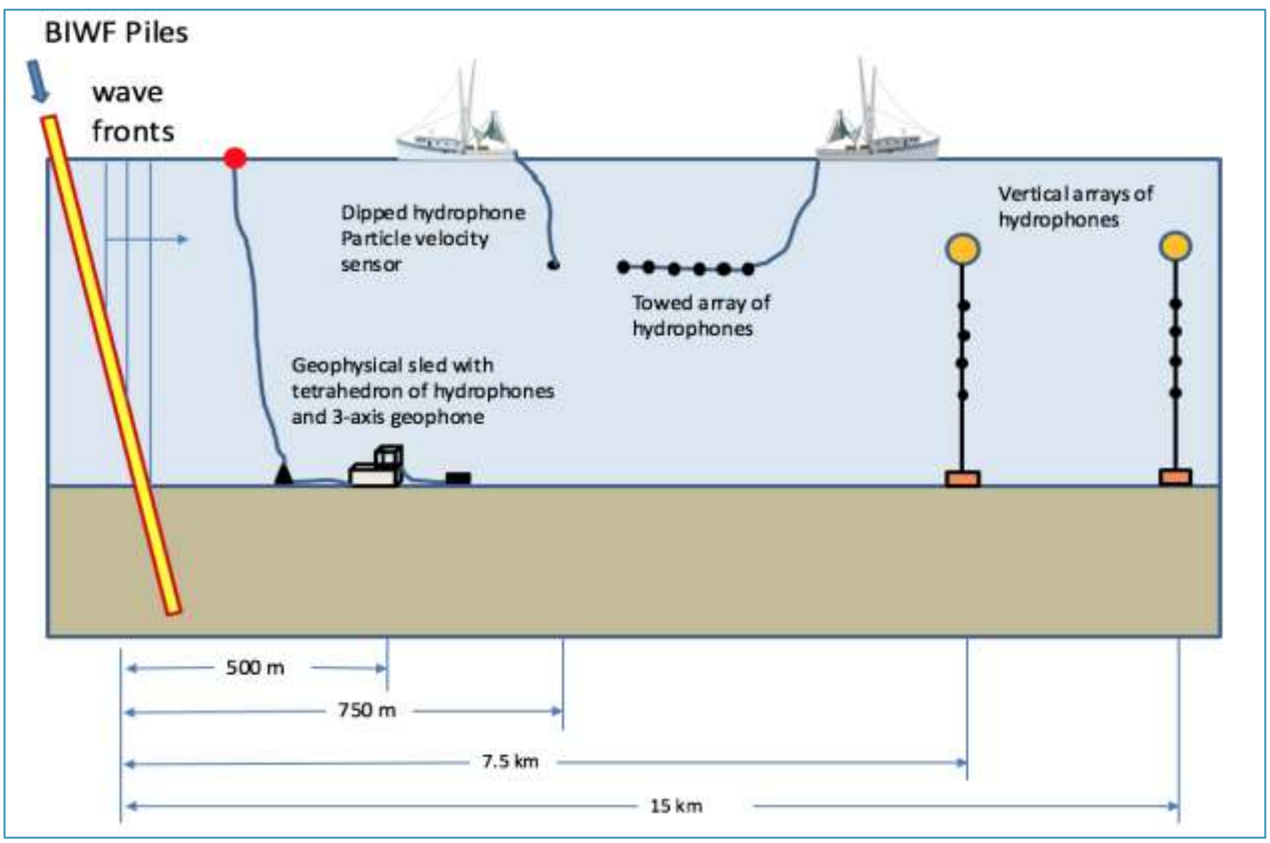



**Figure 31. Overview of the various measurements of acoustic and seismic signals from pile driving for the Block Island Wind Farm along with nominal ranges.**

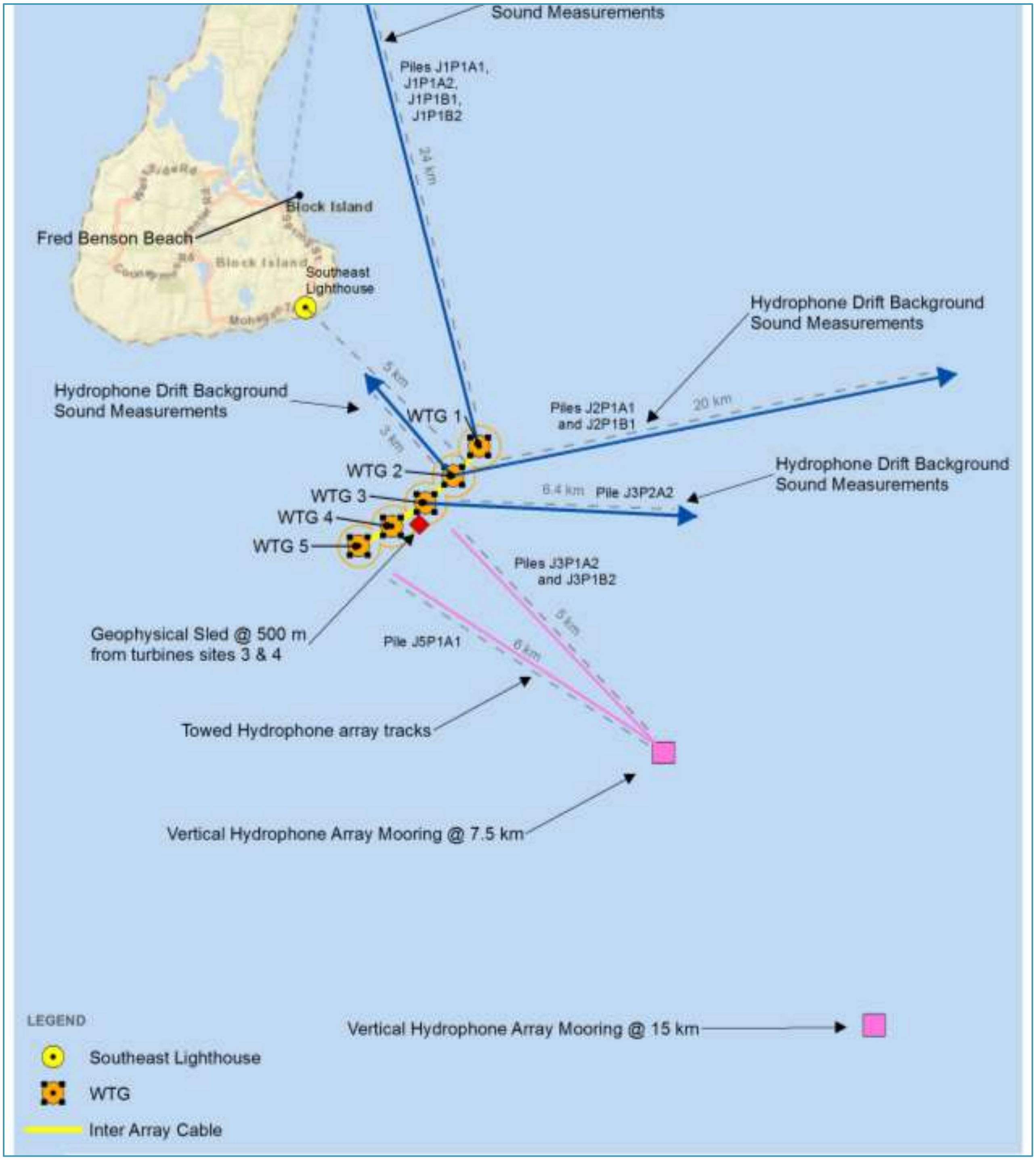



**Figure 32. Pile driving underwater sound monitoring summary.**

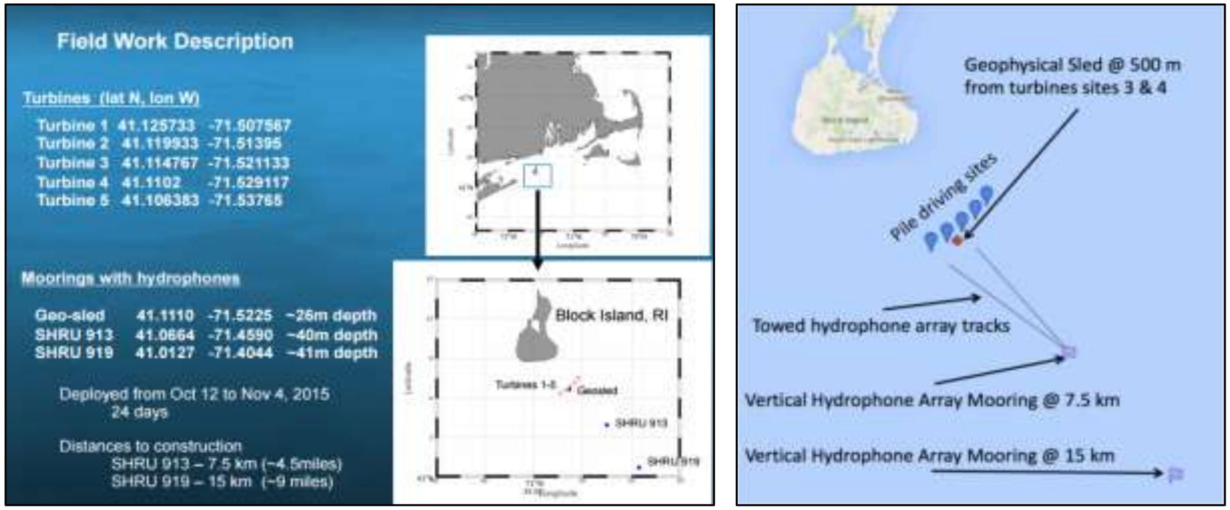



**Figure 33. Field work description (left) and summary of geophysical sled, vertical hydrophone array and towed hydrophone array tracks (right).**

### 4.1.2 Monitoring Methods and Results

#### 4.1.2.1 Towed Hydrophone Array

The following pile-driving events were monitored using a towed hydrophone array:

- On 2 September 2015, the towed array system recorded two separate piles being driven on WTG 3 (**Figure 34**). The first recording was of the piling of the P1 segment of the B2 leg and the second recording was the piling of the P1 segment of the A2 leg. The array was towed along a track at ranges from 1 km (0.6 mi) out to 6 km (3.7 mi) from the piles. Depth sensors were placed at two points along the array and recorded the sensors on the array being towed at depths between 9 and 12 m (29.5 and 39.4 ft) during the pile driving. The speed of the vessel and location of the sensors along the array contributed to the fluctuation in sensors depths.
- On 17 September 2015, the towed array system recorded the pile driving of the P1 segment of leg A1 on WTG 5 from a range of 1 to 8 km (0.6 to 5 mi) from the pile. The tracks (**Figure 35**) on both days were in a southeast direction from the WTG location. Depth sensors were placed at three points along the array and recorded the sensors on the array being towed at depths between 3 and 12 m (9.5 and 39.4 ft) during the pile driving. The speed of the vessel and location of the sensors along the array contributed to the fluctuation in sensor depths.

Data were monitored in real-time using Cornell University's Raven 1.5 software[6] and recorded as consecutive 30 second duration files that were later processed on shore. On the first pile driving day, 145 data files were collected, for a total of 4.08 GB of data. On the second pile driving day, 342 files were collected, culminating in 9.76 GB of data. Representative time series and spectrogram displays (**Figure 36**) show a series of hammer strikes recorded 5.3 km (3.3 mi) from leg A2 on WTG 3 on 2 September 2015. Individual strikes of the hammer pile are seen below 5 kilohertz (kHz) and the signal to sound ratio is high.

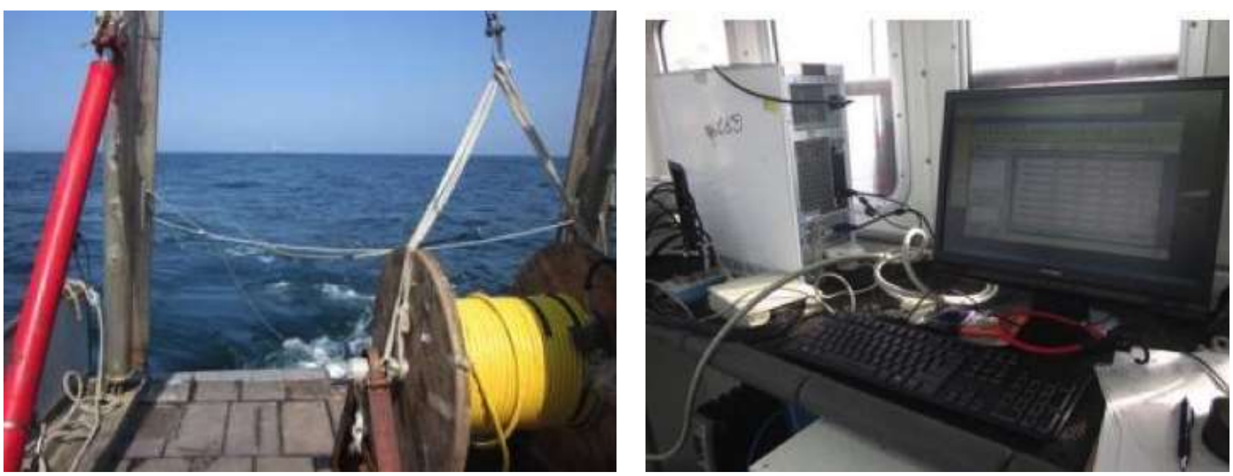
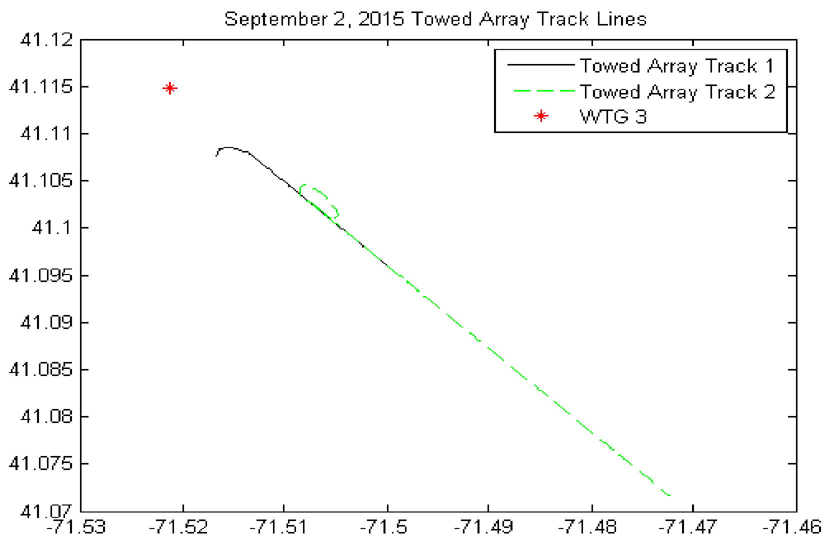
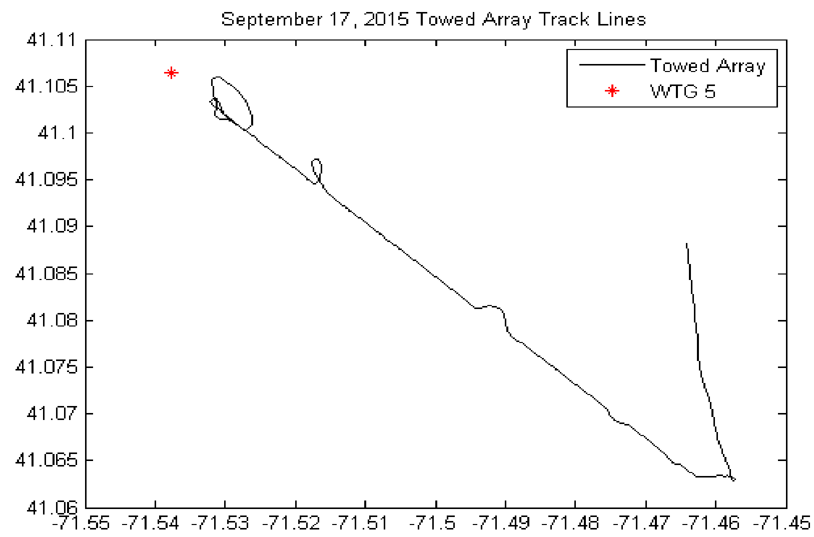


**Figure 34. Towed array spool configuration (left) and data collection station installed in the vessel lab (right).**

[6] http://www.birds.cornell.edu/brp/raven/RavenVersions.html




Note: Track 1 relates to the first recording of pile driving on this day and Track 2 relates to the second recording. Decimal degrees of latitude and longitude correspond to the vertical and horizontal axes respectively.

**Figure 35. Track lines from 2 September 2015 (left); track lines from 17 September 2015 (right).**

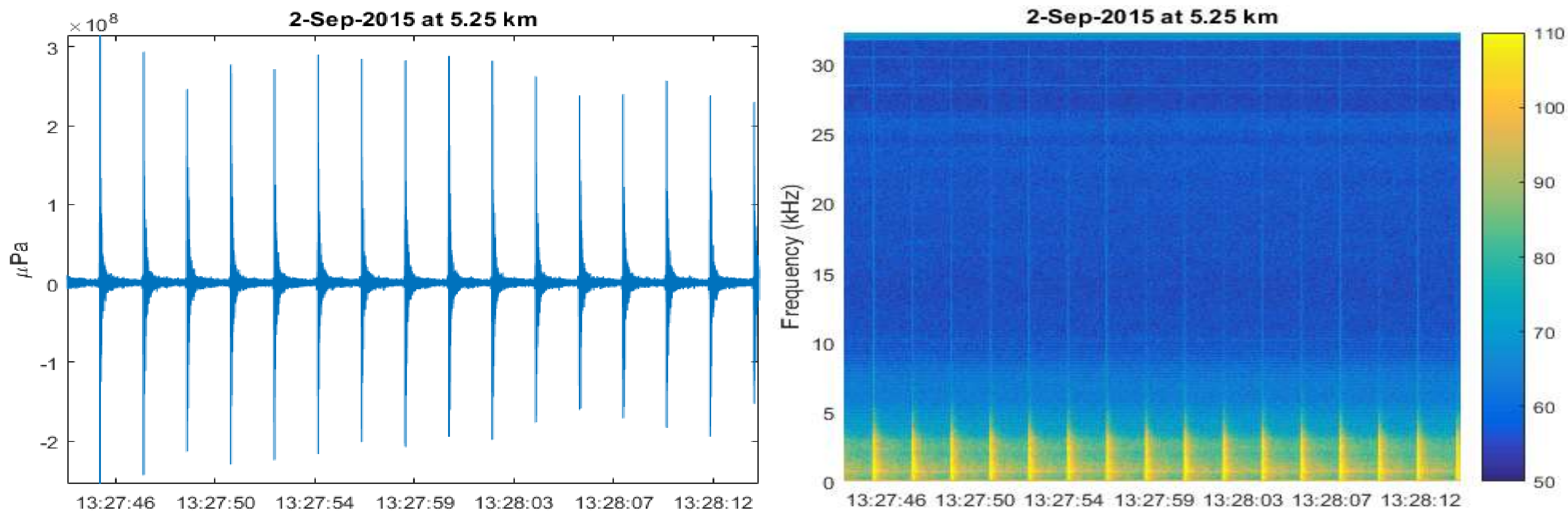



**Figure 36. Time series (left) and spectrogram (right color bars show decibel rms) taken from a 30-second file, with x-axis as local time, when the vessel was 5.25 km (3.3 mi) from pile driving of leg A2 on WTG 3 on 2 September 2015.**

The peak-to-peak SPL level (RL) and kurtosis values were determined for each hammer strike. Kurtosis is the shape of the distribution of measurements (Zar 1984). It is calculated from a scaled version of the fourth power of the deviations from mean, giving a unitless quantity (Zar 1984, p. 82 Equation 7.13). High kurtosis indicates that variance is due to infrequent, extreme deviations from the mean as opposed to frequent, modestly-sized deviations. These metrics were plotted against range to examine how the values changed with distance from the pile driving location. Each pile driving recording was analyzed separately and then compared.

Preliminary results from the analysis show that all channels on the hydrophone array functioned as expected and collected data for the entire deployment. **Figure 37** presents calculations of the peak to peak received level for all of the hammer strikes from the three pile driving recordings. The blue dots represent the hammer strikes from the pile driving on WTG 5 recorded on 17 September and the black and red dots represent the data from 2 September for WTG 3. The depth of the array on 17 September was between 3 to 12 m (39.4 ft) and the depth of the array on September 2 was between 9 and 12 m (29.5 and 39.4 ft). The received levels for each day exhibit a similar trend where the received level decreases as the range from the pile driving increases. The outliers with received levels at approximately 140 dB at distances between 2 and 4 km (1.2 and 2.5 mi) in the 17 September data are being investigated as part of the ongoing analysis.

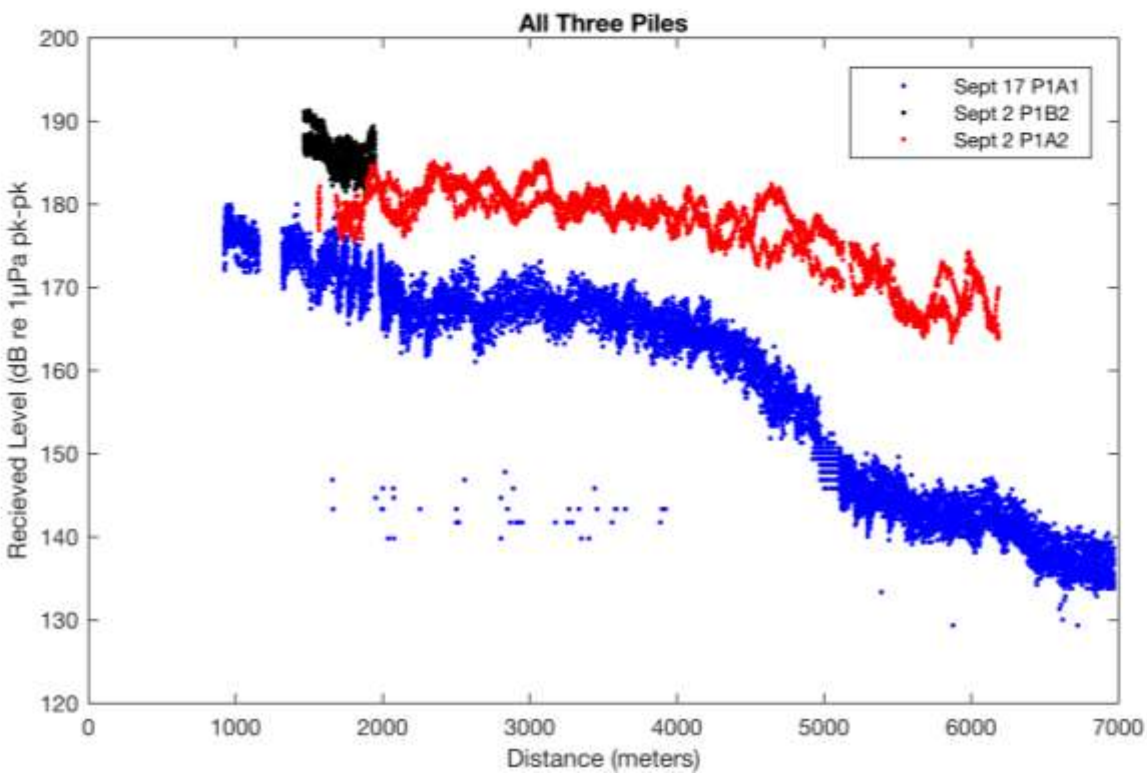
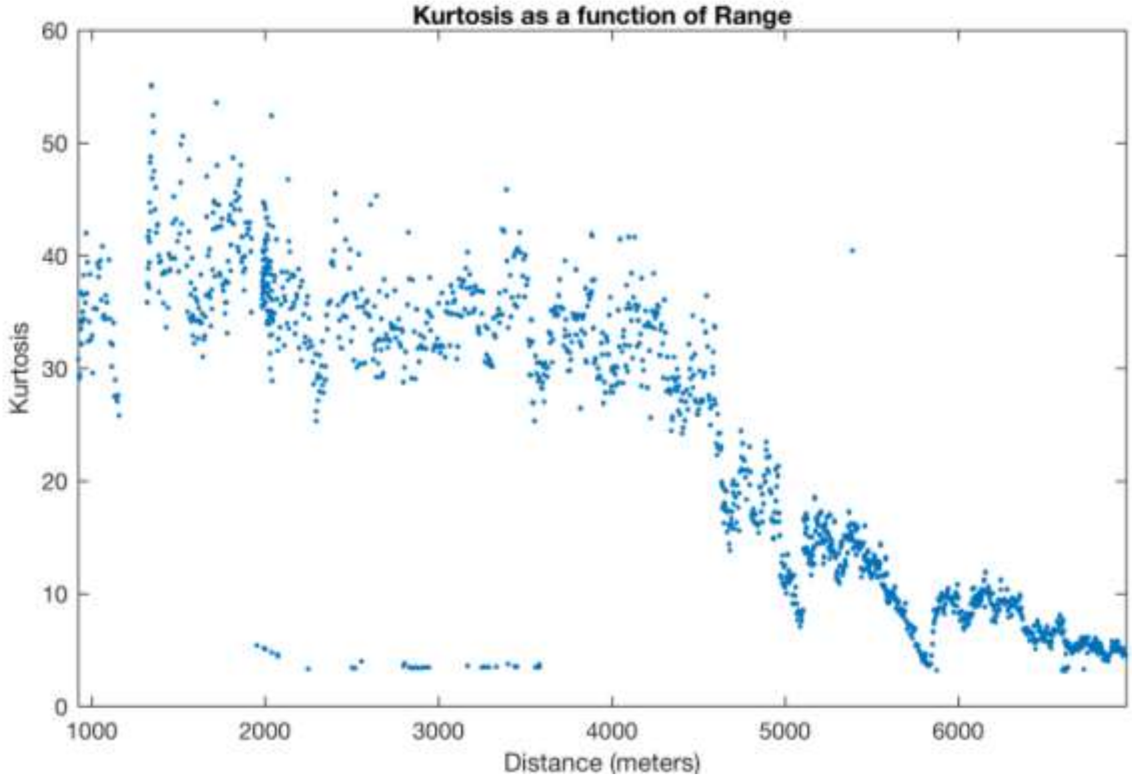



**Figure 37. Peak to peak received level calculated for all of the hammer strikes from the three different pile driving recordings plotted against distance of the array from the turbine.**

**Figure 38** presents calculations of kurtosis for the pile driving of segment P1 on leg A1 from WTG 5 that was recorded on 17 September 2015. The trend toward decreased kurtosis with range is suggestive that this metric can be applied successfully to field data to better characterize the temporal nature of the received signals. However, further analyses and replication are needed.




Note: additional detailed analyses of the towed array monitoring data are still ongoing and updated results will be presented in one or more peer-reviewed technical publications at a future date.

**Figure 38. Kurtosis calculated using 17 September 2015 data, presented as a function of distance from WTG 5.**

#### 4.1.2.2 Vertical Array SHRUs

Two vertical sound pressure hydrophone array moorings with SHRUs (Several Hydrophone Receiving Units) were deployed at 7.5 and 15 km (4.7 and 9.3 mi) from the turbines. The mooring configuration is shown in **Figure 39**. Each array had four hydrophones; the top and third hydrophones had a normal gain of 26 dB, while the second and bottom phones had a lower gain of 6 dB. The different gains were used to assure that the peak pressure from the pile driving would not clip the received signals.

An example time series of the acoustic pile-driving signal recorded with the VLA is shown in **Figure 40**. In the top panel, a single pile-driving recording is shown from SHRU 913 deployed at 7.5 km (4.7 mi) from WTG 3. While some clipping is evident in the high gain hydrophones, none was experienced with the low gain channel.

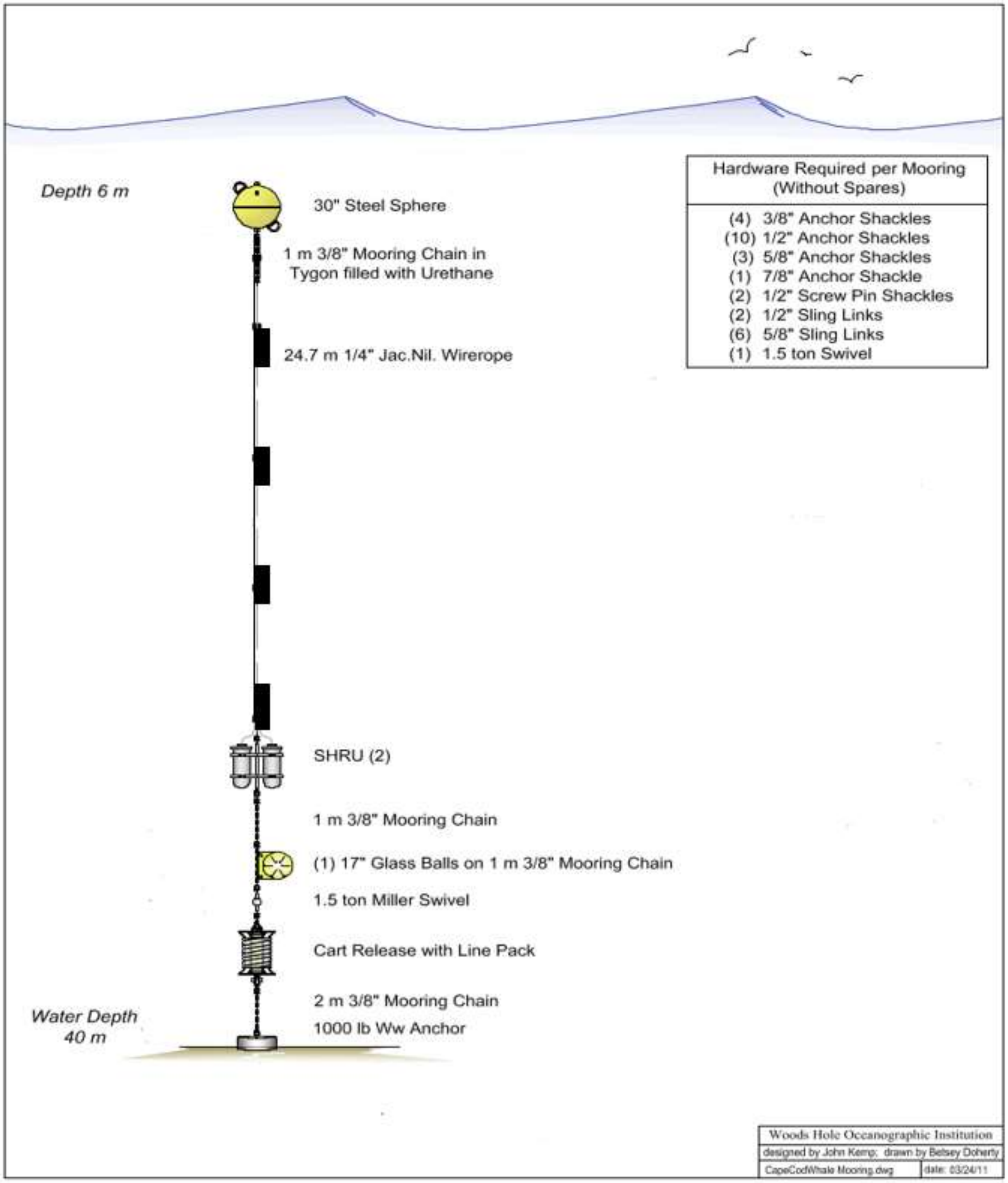
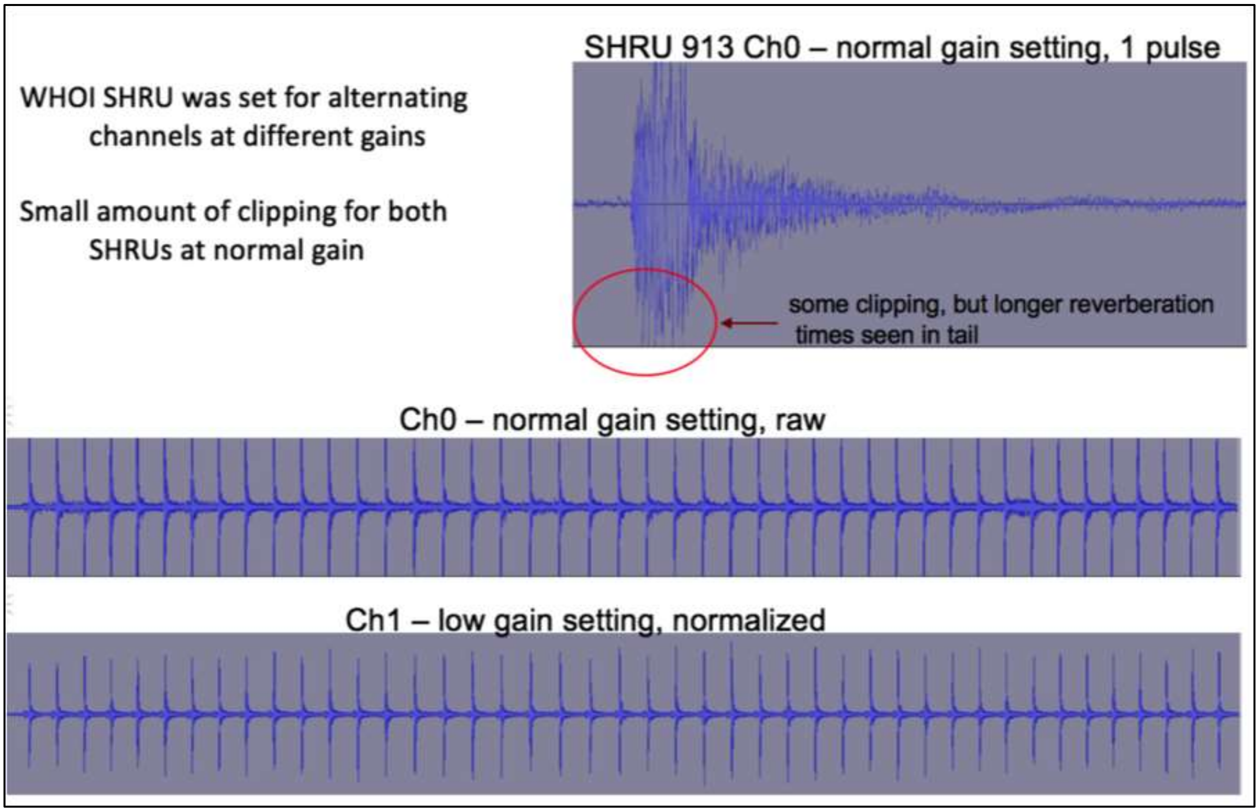



**Figure 39. Mooring design for the 7.5 km (4.7 mi) and 15 km (9.3 mi) vertical hydrophone arrays.**




Note: While some clipping is evident in the high gain hydrophones, the low gain hydrophone (lower time series shows no clipping.

**Figure 40. A recording of pile driving signals is shown from SHRU 913 deployed at 7.5 km (4.7 mi) from WTG 3; the duration of the recording is 1 minute 45 seconds with approximately 2 seconds between each strike.**

#### 4.1.2.3 Geophysical Sled

A geophysical sled with a 4 sound pressure hydrophone tetrahedral array (for measurement of acoustic pressure and particle velocity near the seabed) and a 3-axis geophone with low sensitivity sound pressure hydrophone (for the measurement of sediment motion and acoustic pressure on the seabed) was deployed approximately 500 m (1,640.4 ft) from WTG 3 and 4 at 41° 6’ 39.7152” N latitude 71° 31’ 21.0258” W longitude in approximately 26 m (85.3 ft) of water (**Figure 41**). The sound pressure hydrophones had a spacing of 0.5 m (1.6 ft). In **Figure 41**, the right panel shows the surface floats for the geophysical sled; the middle and left panel shows the geophysical sled before deployment.

When the sled was deployed, it landed on its side (**Figure 42)**. However, the photograph taken by a GoPro camera mounted on the bow of the sled showed that the hydrophone array maintained its tetrahedral shape.

**Tetrahedral Array Results** – An example spectrogram of the data collected on one of the sound pressure channels of the tetrahedral array is shown in the left panel of **Figure 43**. The x-axis for both plots is referenced to an arbitrary start time. The peak-to-peak SPL for these signals was approximately 185 dB re 1 µPa. The array was deployed approximately 500 m (1,640.4 ft) from WTG 3 and 4 in approximately 26 m of water. Pile-driving signals from 25 October 2015 from all four hydrophones of the tetrahedral array are shown in the right panel. Data from tetrahedral array 500 m (1,640.4 ft) from pile driving is to be used to calculate particle velocity for fish studies (Potty et al. 2018).

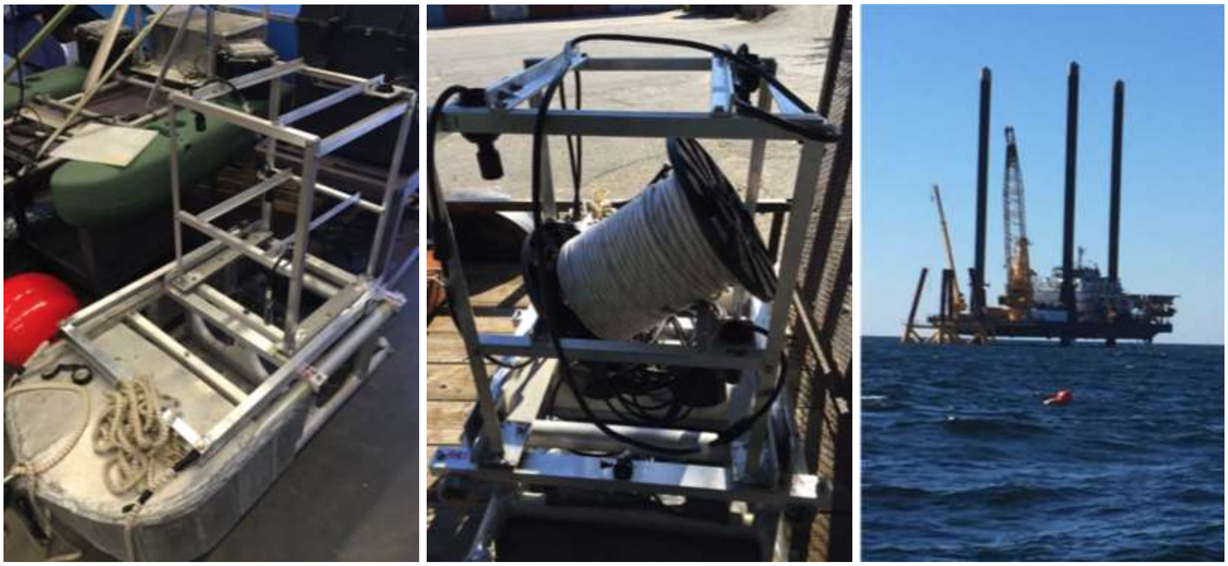


**Figure 41. Images of the geophysical sled before deployment (left and center). These two photographs show the tetrahedral array of hydrophones with a spacing of 0.5 m (1.6 ft). Photo of the surface floats for the sled with WTG 4 in the background (right).**

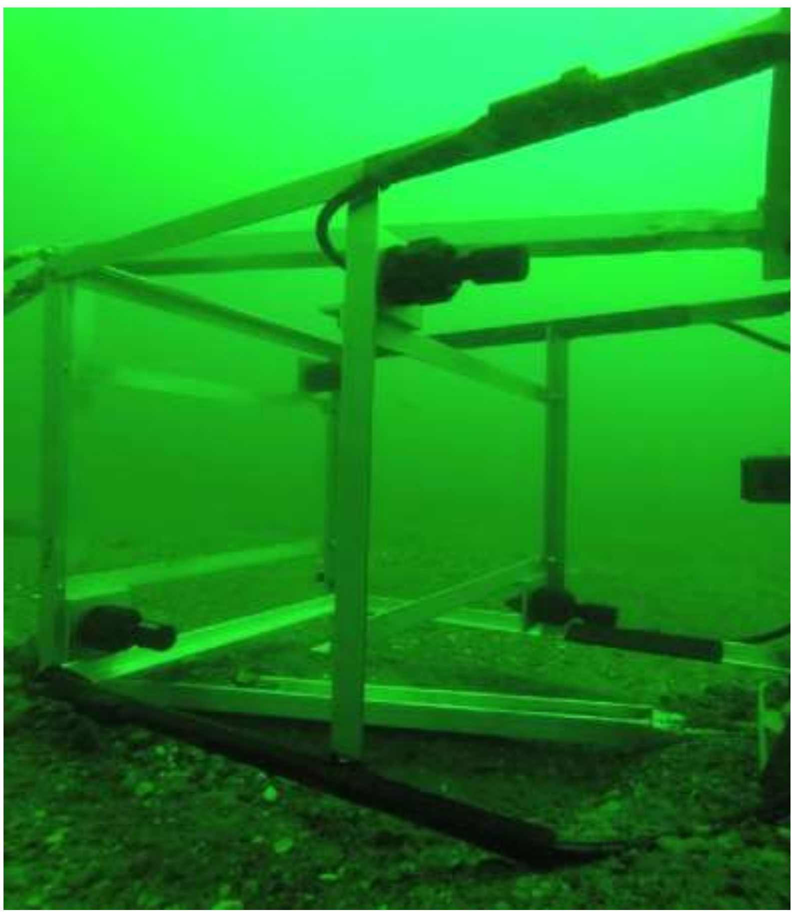


**Figure 42. An underwater photo captured via a GoPro camera mounted on the bow of the sled shows the tetrahedral array of hydrophones is maintained despite the sled landing on its side.**

As noted earlier, for the hammer strike data shown in **Figure 43**, the peak-to-peak SPL at the sled was found to be approximately 185 dB re 1 μPa. Assuming only spherical spreading attenuation form source to receiver, the peak-to-peak source level of the pile driving signal was estimated to be approximately 239 dB re 1 μPa at 1 m (3.3 ft).

The **acoustic particle accelerations** can be computed from the gradient of the acoustic pressures using the following equation:

$$-\nabla p = \rho \frac{\partial \vec{u}}{\partial t}$$

$p$ acoustic pressure

$\vec{u}$ acoustic particle velocity

$\rho$ density

The **particle velocity** can be estimated from the above equation by numerically integrating the particle accelerations. An example of the particle acceleration and velocity calculated for a hammer strike is shown in **Figure 44**.

**3D Geophone Results** – An example of the data from the 3-axis geophone deployed off the geophysical sled is shown in **Figure 45**. The figure shows the particle velocity along vertical and two horizontal directions (left panel) and pressure (right panel) generated by a single impact pile driving at a range of 500 m (1,640.4 ft)from WTG 3 and 4. These data were recorded on 25 October 2015 at approximately 2:58 p.m. The pile driving signals had a high signal-to-noise ratio, no clipping, and the time series has complexity that may be ascribed to the pile driving mechanisms. The velocities are shown in mm/s and the pressure in kPa. The peak–to–peak SPLs are comparable to the levels measured in the hydrophones in the tetrahedral array. The magnitudes of the velocities are higher compared to values calculated using the tetrahedral array data. This will be discussed later in this section.

**Figure 46** shows two clips of sound data (time on the x-axis is arbitrary) with the particle velocity magnitude of the total velocity (vector sum) in dB re nm/s measured at the seabed using the geophone (left panel). Right panel shows the particle velocity in the water column (same units), 1 m (3.3 ft) from the seabed, calculated using the tetrahedral array data. There is an approximate 10 dB difference in peak velocities (dB re nm/s).

The spectral distribution of the energy in the geophone and co-located hydrophone is shown in **Figure 47**. The difference in frequency content between the hydrophone and geophone response is apparent in the figure. This indicates that the response of the geophone and hydrophone are possibly dominated by different wave types. The geophones measure the ground motions whereas the tetrahedral array estimates the particle velocities above the ground in the water column (approximately 1 m (3.3 ft) from the bottom). The single sound pressure hydrophone measures the compressional waves in the water whereas the geophone measures the motion generated by shear and interface (Scholte) waves in addition to the motion associated with compressional waves. Particle motions produced by interface waves (Scholte waves) are likely to dominate the geophone signal. These motions decay exponentially away from the interface (seabed).

Previous studies have shown that signals recorded on seismic sensors on the seafloor are found to be more complicated than on co-located hydrophones (Bibee 2011). The differences were attributed to the response of the seismometer sensors to shear waves in the seafloor and interface waves at the water-sediment boundary. It is conjectured that differences between particle velocities measured at the bottom and in the water column can be different because shear and interface waves can contribute (in addition to compressional waves) in the sediment medium as opposed to compressional waves alone in the water medium.

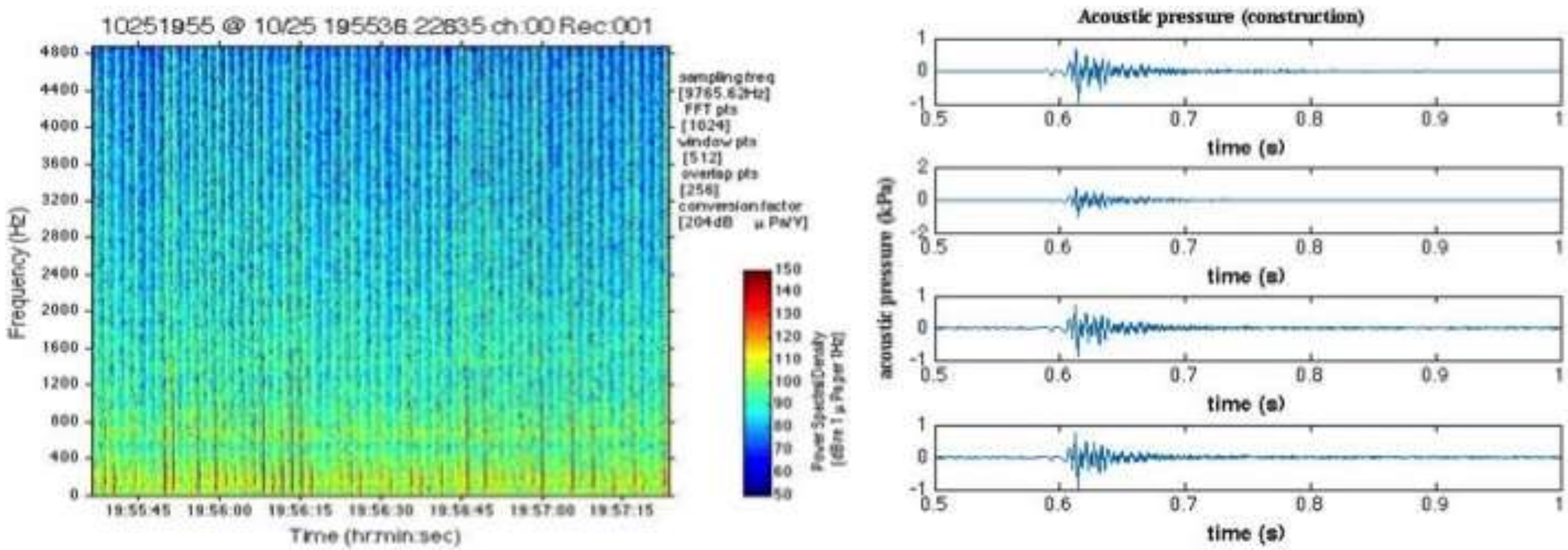



**Figure 43. Spectrogram of data from a single tetrahedral array hydrophone (left) and acoustic pressure signals on the four channels of the tetrahedral array (right) collected on 25 October 2015.**

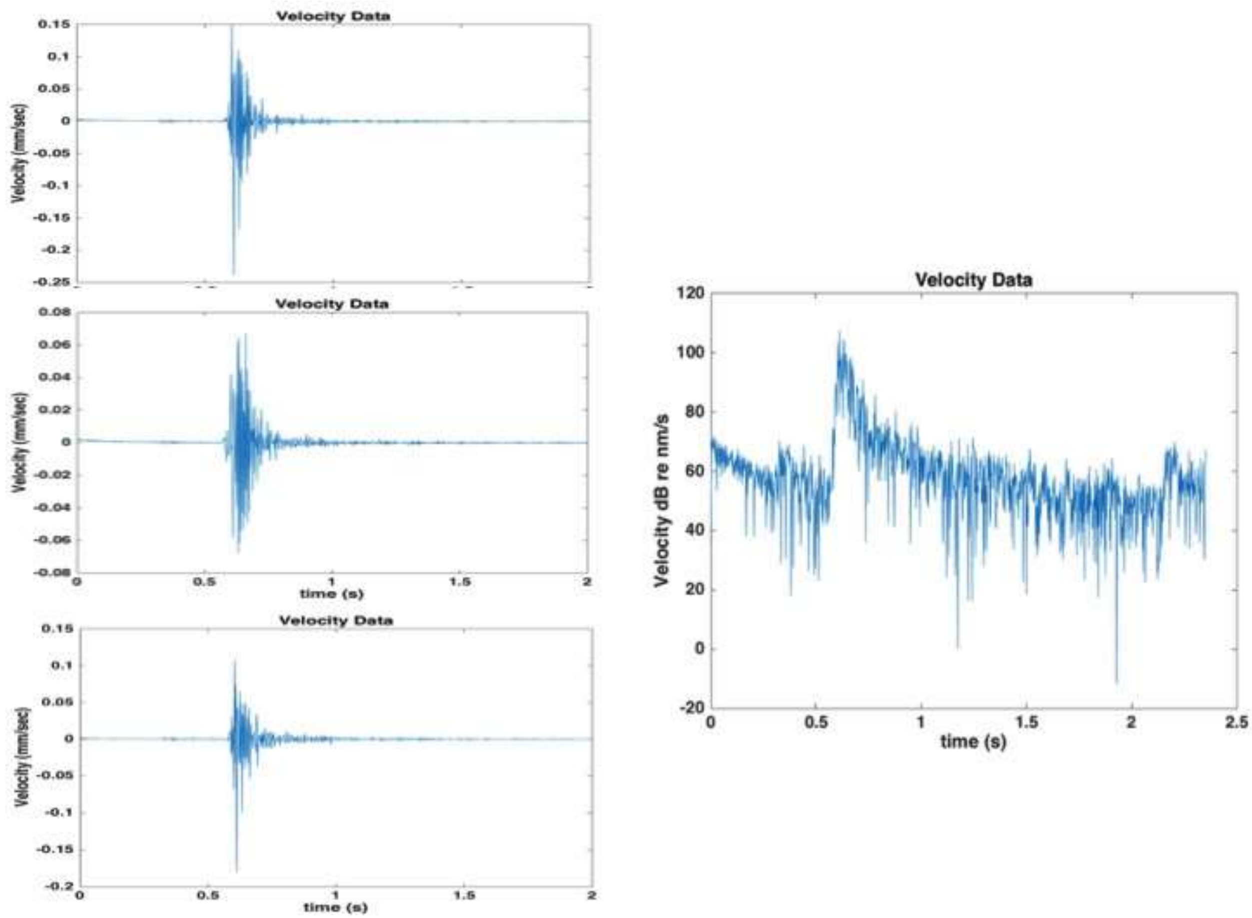



**Figure 44. Particle velocity calculated from the sound pressure gradients for one hammer strike. Left panel shows the values in mm/s and the right panel shows the magnitude of the total velocity (vector sum) in dB re nm/s.**

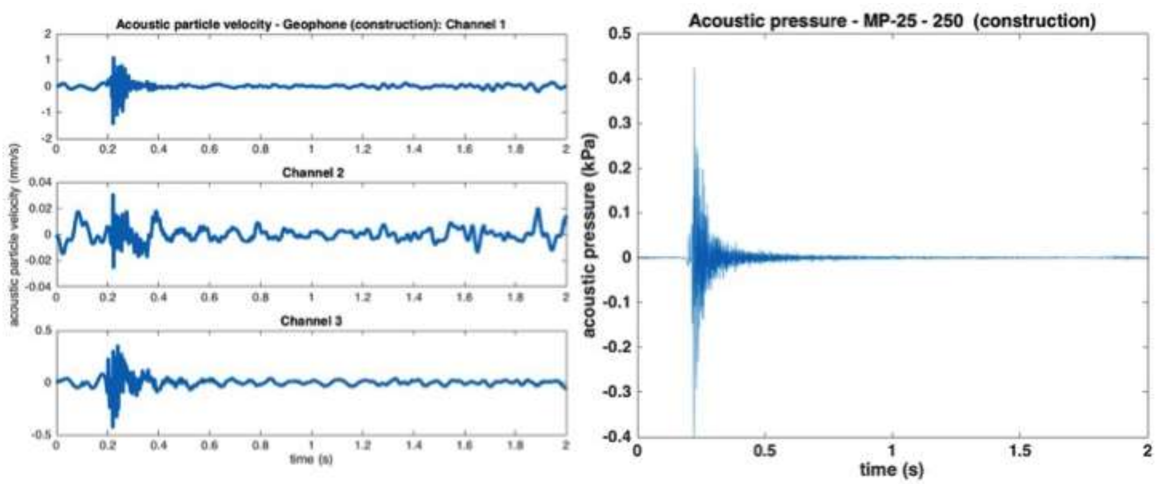



**Figure 45. An example of the particle velocity data (in mm/s in three mutually perpendicular directions) from the 3-axis geophone deployed off the geophysical sled (left panel). Right panel shows the acoustic pressure measured by the hydrophone co-located with the geophone.**

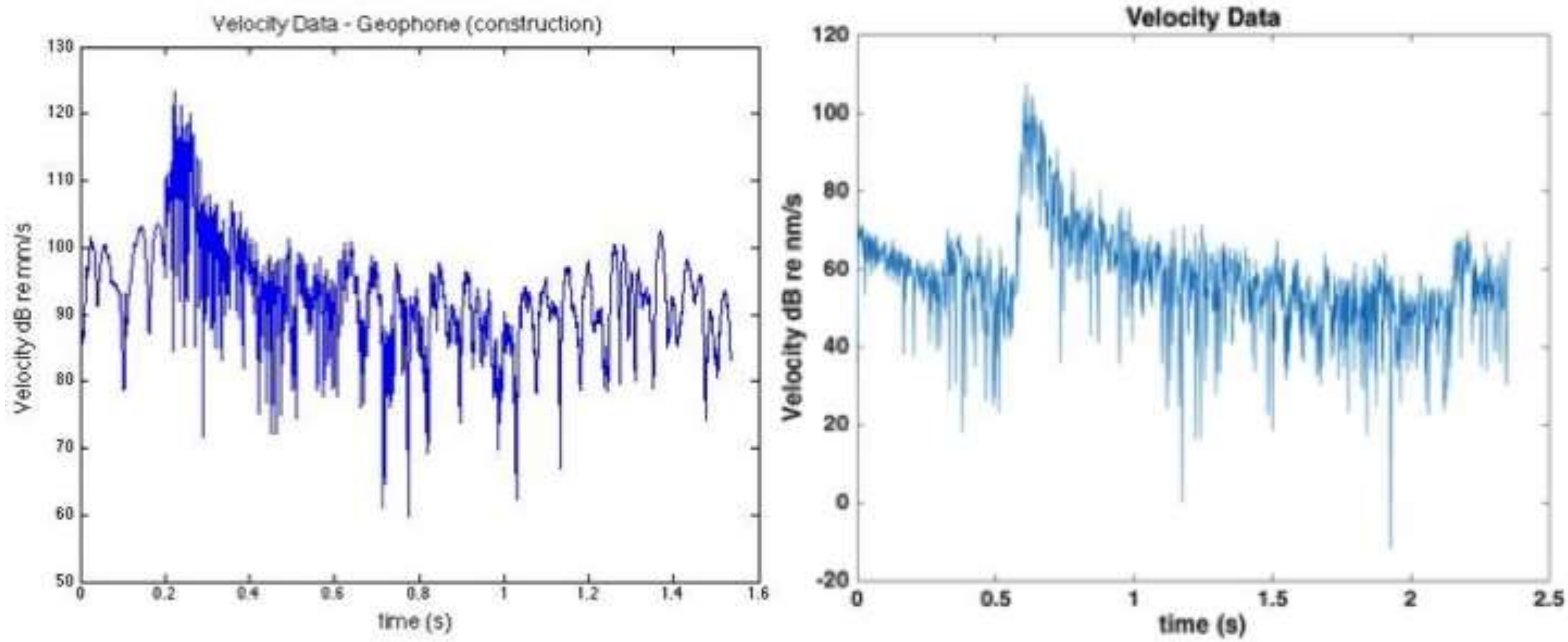



**Figure 46. Particle velocity magnitude of the total velocity (vector sum) in dB re nm/s measured by the geophone (left panel). Right panel shows the magnitude of the total velocity (vector sum) calculated from the tetrahedral array data. Note that the start times (x-axis) are arbitrary.**

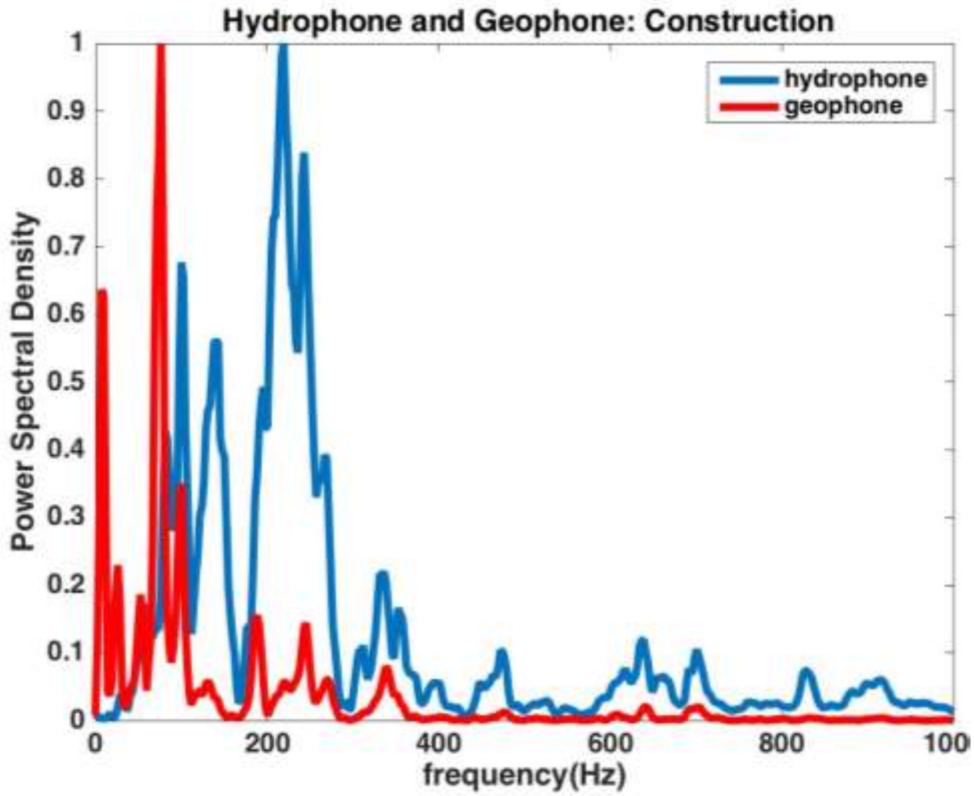



**Figure 47. Spectra of the particle velocity (red) and acoustic pressure (blue) measured on the seabed using the co-located geophone and hydrophone. Note that the amplitudes are normalized using the peak values. The difference in frequency content between the hydrophone and geophone response is apparent.**

#### 4.1.3 Acoustic 3D Modeling

##### 4.1.3.1 Previous Studies/Results

There have been several offshore wind farms constructed in Europe and underwater sound monitoring is typically undertaken during the construction phase to monitor underwater sound levels. Betke (2006) and his colleagues at ITAP in Oldenberg, Germany measured sound from construction and operation of a monopile wind turbine. In particular, they showed the variability of radiated sound from the turbine with various power production levels and wind speeds as shown in **Figure 48**.

Reinhall and Dahl (2011) have reported on modeling and measurement of vertical pile driving. They reported that when the hammer strikes the pile, a compression wave produces a local radial deformation because of Poisson’s effect. This radial deformation propagates down the pile. The speed of the wave in the steel shell of the pile that is surrounded by water is approximately 5,015 m/s and much greater than water sound speed of 1,500 m/s. The pile driving creates a Mach wave in the water and sediment with an angle of 17$^{o}$ from the vertical. This phenomenon is displayed in **Figure 49.**

Kim et al. (2012) and Kim (2014) modeled the effect of pile driving on an elastic seabed. The higher the angle of the Mach wave, the more energy is absorbed by the seafloor. **Figure 50** shows Kim’s (2014) results and the resultant compressional wave in the water and bottom, shear wave in the bottom and interface wave at the seafloor.

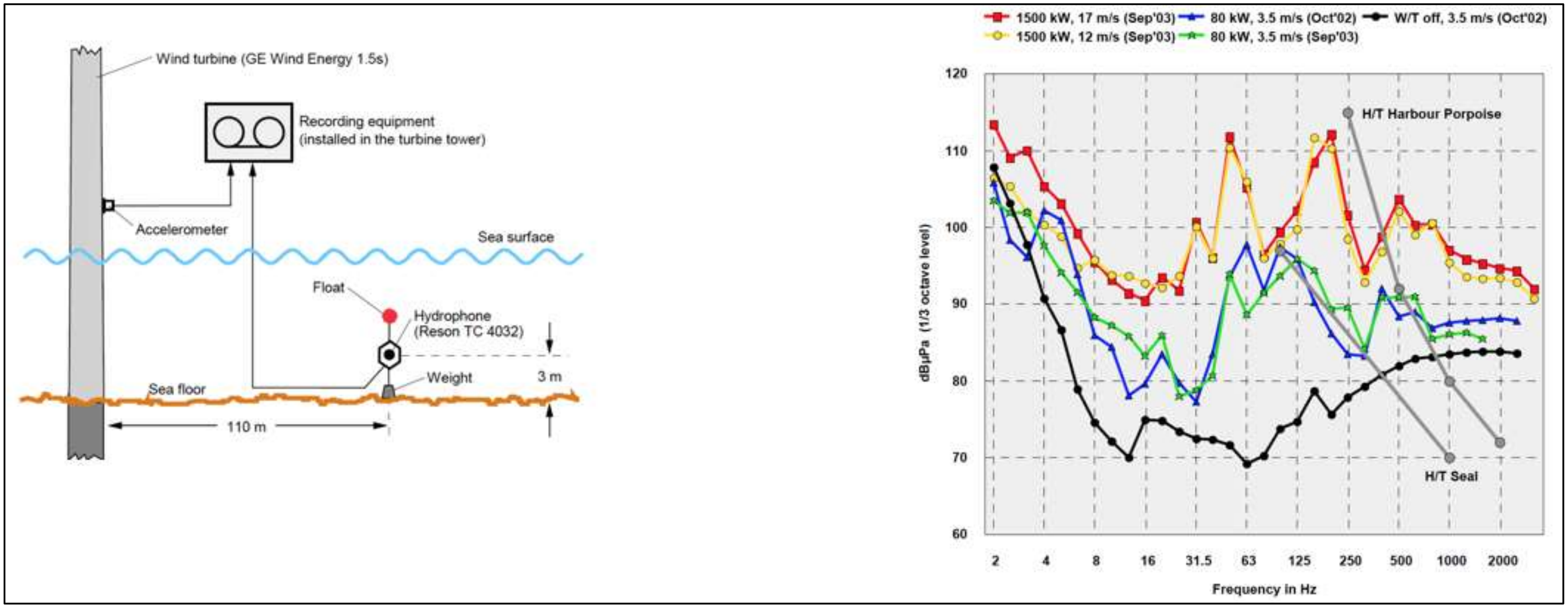



**Figure 48. Measurement setup as described by Betke (2004) for monitoring underwater sound from an offshore wind turbine in water 10 m (32.8 ft) deep (left). One-third octave band levels measured 110 m (360.9 ft) from the turbine for different operating conditions (right). Wind speeds are measured at the hub height.**

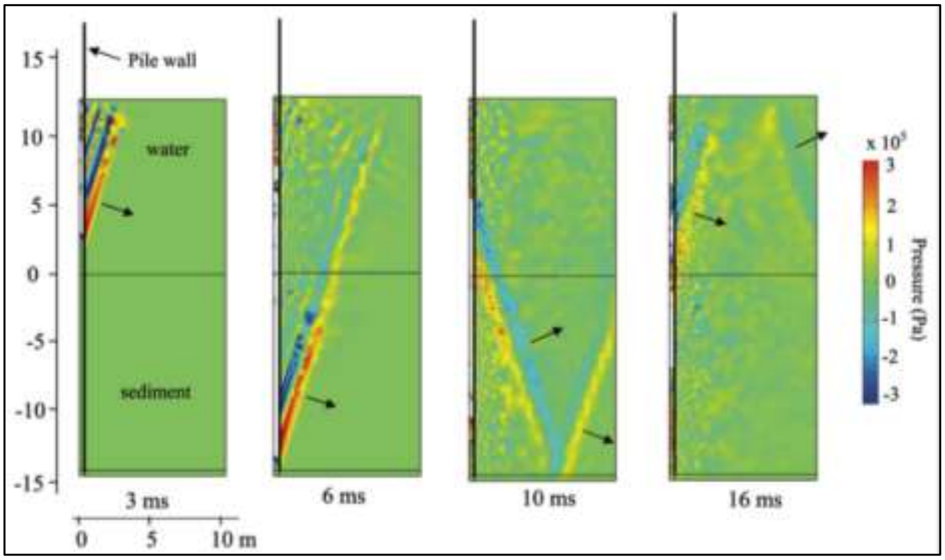
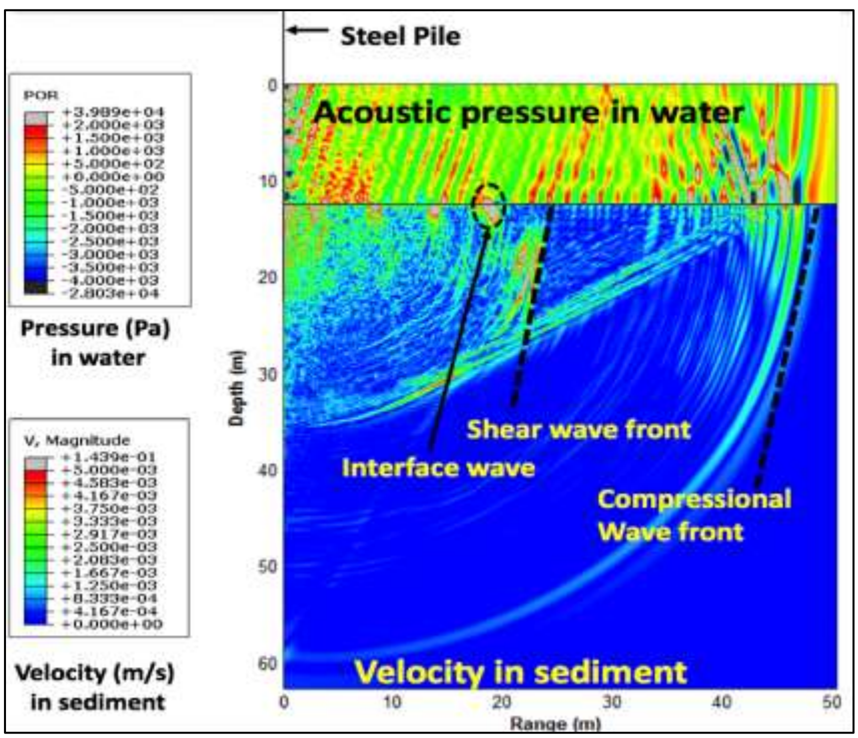



**Figure 49. Reinhall and Dahl (2011) modeled the creation of an acoustic wave in the water from a vertical pile. The speed of the wave in the pile is approximately 5,015 m/s and much greater than the water sound speed of approximately 1,500 m/s. This creates a Mach wave which propagates at an angle of approximately 17$^{o}$ from the vertical.**




Note: The water depth is approximately 12 m (39.4 ft) and chosen to match the scenario modelled in Reinhall and Dahl (2011). The y-axis is depth below the water. The x-axis is range in meters. The pressure field is plotted in the water between -4 and +2 kPa. Pressures above 2 kPa are shown in grey and pressures below -4 kPa are shown in black. The magnitude of the particle velocity in sediment is shown between 0 and 0.005 m/s. Particle velocity magnitudes greater 0.005 m/s are shown in grey.

**Figure 50. A finite element simulation using ABAQUS of the acoustic effects of impact pile driving into an elastic sea bottom is shown.**

#### 4.1.3.2 BIWF Monitoring Data 3D Modeling

The piles used for anchoring the turbine foundations to the sea bottom were not vertical but raked at a 13.27$^{o}$ angle. Acoustic energy radiated underwater during the pile driving is highly directional and 3D modeling effort is currently ongoing in collaboration with Sandia National Laboratory to provide data for improving understanding of the directionality aspects of the underwater sound.

Preliminary results from the 3D modeling indicated that the rake angle caused a directional dependence to the pile driving signals. Measurements using the towed hydrophone array showed 10 to 15 dB differences between levels on different days for piles being driven at different angles. As shown in **Figures 49** and **50**, the Mach wave travels at an angle of approximately 17°. When recording pile driving signals from a pile oriented away from the receiver, the wave is close to vertical and travels efficiently down the underwater acoustic channel formed by the sea surface and seabed. When recording pile driving signals from a pile oriented toward the receiver, the wave is oriented at the sum of the rake and Mach angle, driving most of the energy into the seafloor where it is absorbed. Differences of up to 35 dB were observed for different piles and associated rake angles.

In addition to the directional dependence, the pile driving sound pressure levels were generally lower at longer range as expected. Levels were observed at 155 to 165 dB re 1 μPa peak-to-peak at a range of 15 km (9.3 mi). Particle velocity measurements were taken by a tetrahedral array of hydrophones and by geophones placed on the seafloor approximately 500 m (1,640.4 ft) from the pile driving. Levels of particle velocity were found to be less than the levels which will cause mortality or injury at 500 m (1,640.4 ft). Based on limited behavioral audiograms available, it was observed that fish who inhabit depths close to the bottom will be impacted more compared to fish who spend most of their times away from the bottom.

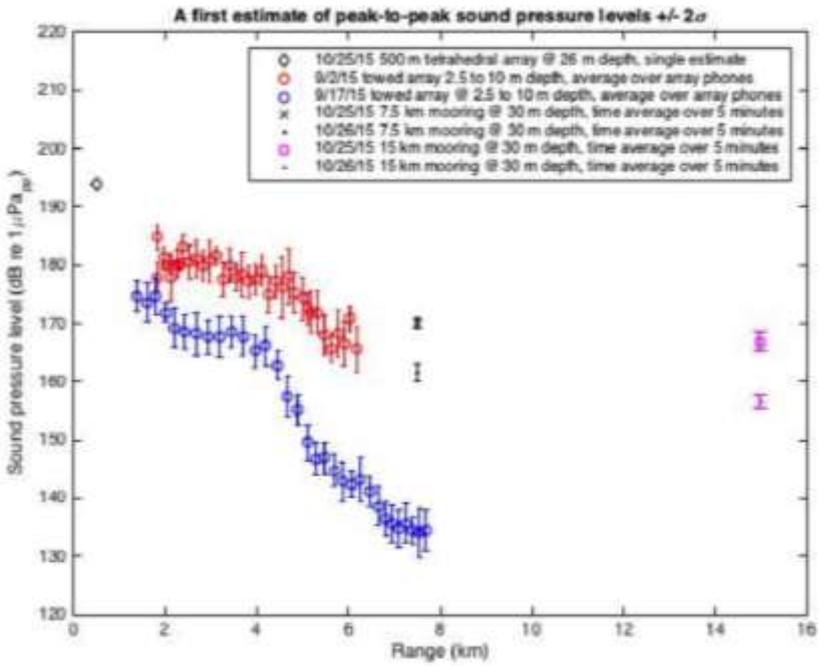
### 4.1.4 Stationary and Towed Array Monitoring Summary

A summary of the peak-to-peak SPL results for the towed array, geophysical sled and moorings are shown in **Figure 51**. The variability of the SPL is thought to be a function of the rake or angle of the piles (shown in the left panel) as oriented to the seafloor and receiving sensor. Legs A2 and B2 of WTG 3 were driven during the towed array data collection on 2 September and Leg A1 of WTG 5 was driven on 17 September 2015. As the towed array course was approximately to the southeast on both days, it is clear that the three pile drives resulted in remarkably different water column and sediment sound transmissions.

### 4.1.5 Fish Hearing and Effect of Sound and Particle Motion

Fishes show extensive variability in their behavior, ecology, and physiology. Moreover, fish vary in their abilities to detect and utilize sounds, and likely also vary in their potential susceptibility to damage by sound. Particle motion plays a critical role in the fish sensory mechanism. The auditory regions of fish ears consist of otolith organs. Each otolith organ contains a dense calcareous mass lying close to the sensory epithelium which functions much as an accelerometer. Otolith organs of all fishes respond to particle motion of the surrounding fluid. Many fish also detect sound pressure via the gas bladder or other gas-filled structures that re-radiate energy, in the form of particle motion, to the otolith organs. Fish with gas-filled structures near the ear and/or extensions of the swim bladder respond to fluctuating sound pressure, generating particle motion. The ability to detect sound pressure in addition to particle motion serves to increase hearing sensitivity and broaden the hearing bandwidth. Hence fish with gas filled structures have lower sound pressure thresholds and wider frequency ranges of hearing than do the purely particle motion sensitive species.

Hearing range and sensitivity varies considerably between species. Behavioral audiograms have been published for only a few species of fish (Fay 1988; Ladich and Fay 2013) and there are concerns about the usefulness of many of these.




Note: There is a notable difference in the 2 September (red) and 17th (blue) towed array levels. It's clear that the angle of pile driving produced vastly different results.

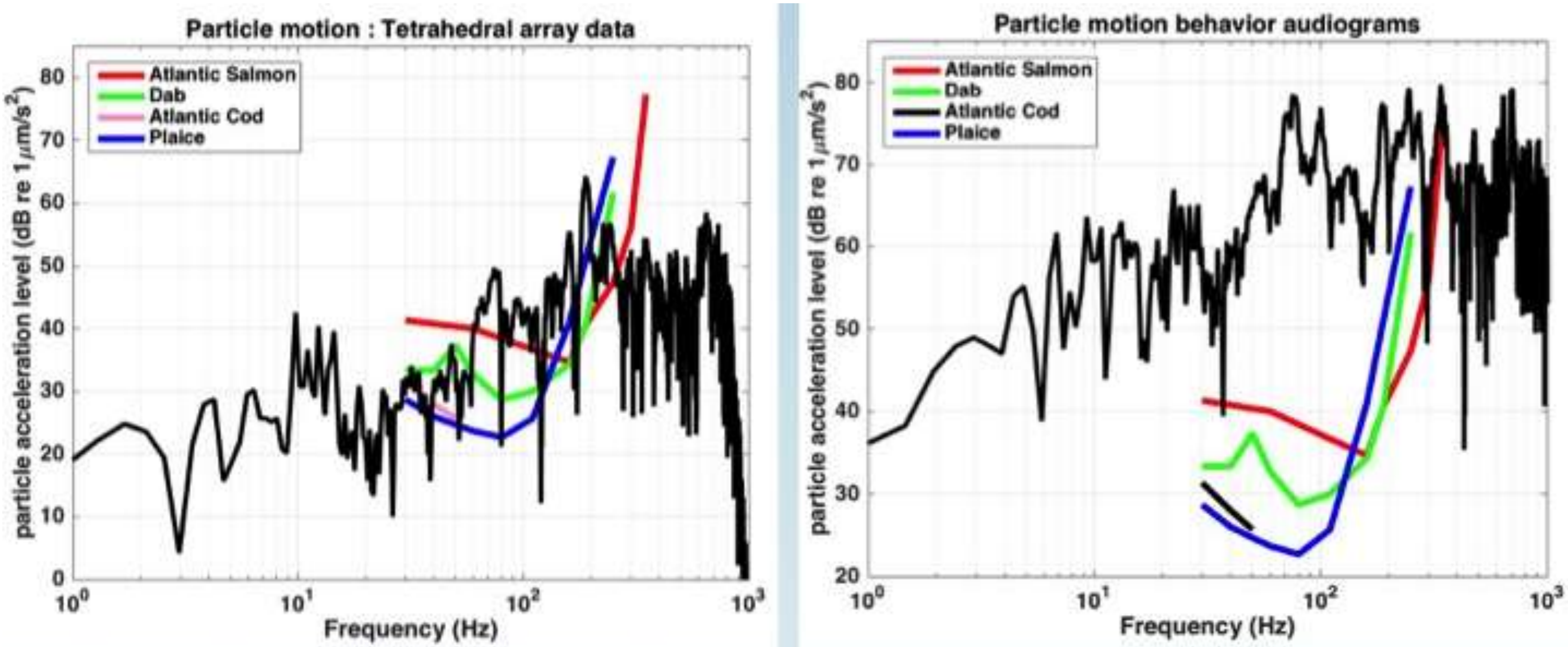
**Figure 51. Initial estimates of the sound pressure level peak-to-peak versus range for the various sensors and dates.**

Acoustic conditions were poorly monitored in many studies and it is difficult to determine from such studies whether the fish were responding to sound pressure or particle motion (Popper and Hawkins 2018). Levels of ambient or background sound can result in the audiograms being masked so that the full hearing sensitivity of the animal cannot be determined. Auditory evoked potentials may not fully reflect the hearing capabilities of animals (Popper et al. 2014).

There are no standards which specify the criteria for mortality, injury and behavioral changes when fish are exposed to sound. The technical report prepared by ANSI-Accredited Standards Committee S3/SC1 (Popper et al. 2014) provides useful sound exposure guidelines for fish and sea turtles. The guidelines for acoustic pressure exposure specify the maximum peak levels as 213 $dB_{peak}$ (fish without gas bubble) and 207 $dB_{peak}$ (other fishes) to avoid mortality and have recoverable injury. The peak sound pressure levels measured in this study at 500 m (1,640.4 ft) are less than the levels that are thought to potentially result in mortality or injury as per this guideline.

**Figure 52** compares particle accelerations calculated from the measurements made during the pile driving with published behavioral audiograms for some species for which there are particle motion hearing data. The behavioral audiograms shown in the figure are from: Atlantic salmon (Hawkins and Johnstone 1978), plaice and dab (Chapman and Sand 1974), and Atlantic cod (Chapman and Hawkins 1973). The left panel shows the frequency distribution of particle acceleration calculated using the tetrahedral array data and the right panel shows the geophone data. Particle accelerations are shown in dB re 1 μm/s2.

Particle acceleration levels in water (left panel in **Figure 52**) are slightly above the behavioral sensitivity for the fishes considered in the frequency range 30 to 300 Hz. Hence fishes may barely 'feel' the particle motion during construction at the 500 m (1,640.4 ft) range. Note that the particle velocity levels measured on the seabed (right panel in **Figure 52**) are well above the behavioral sensitivity for all fishes shown in the figure up to a frequency of approximately 300 Hz. Based on the data, the impact of construction will be more pronounced on fishes whose habitat is close to the seabed compared to fish who spend most of their time in the water away from the seabed.




Note: The acceleration levels are compared with published behavioural audiograms of some fishes. The audiogram data is from: Atlantic salmon (Hawkins and Johnstone 1978), two flat fish plaice and dab (Chapman and Sand 1974), and Atlantic cod (Chapman and Hawkins 1973).

**Figure 52. Spectra of the particle acceleration (black) in the water column estimated using the tetrahedral array (left panel) and measured on the seabed using the geophone (right panel).**

## 4.2 Variable Depth Single Sensor and Seabed Vibration Monitoring

### 4.2.1 Monitoring Approach

Sound level measurements were recorded under a series of varying environmental conditions for 14 separate piles being driven over 5 days. The following monitoring equipment was deployed:

- OceanSonics icListen HF-SB9 (Serial No. 1400)
- icListen HF-X2 (Serial No. 1287) hydrophones
- Reson TC4014 hydrophones (Serial No. 4005034 and 4005035)
- Brüel & Kjær type 8106 hydrophone (Serial No.2575949)
- Tri-axial Vibrock V901 geophone

***Drift measurements*** were taken from a single hydrophone deployed from the side of the survey vessel (R/V McMaster). The survey vessel's engines and other equipment, which might otherwise have caused acoustic interference with the measurements, were turned off and the boat was allowed to drift while measurements were taken.

The hydrophone was attached under a spar-buoy to provide anti-heave while undertaking measurements, thereby reducing the effect of surface waves. The suspended hydrophone was allowed to drift freely from the vessel to minimize flow noise during measurements. The hydrophone would drift up to 10 to 15 m (32.8 to 49.2 ft) from the start position, before it was recovered to the vessel and redeployed. The GPS position was logged at the start of the drift, at the closest point of the hydrophone to the vessel (typically within five m (16.4 ft) of the actual hydrophone position). Measurements of the sound pressure were taken at mid-water depth and at 1 m (3.3 ft) from the seabed.

At intervals starting at approximately 500 m (1,640.4 ft) from the piling and doubling in distance (1 km [0.6 mi], 2 km [1.2 mi], and 4 km [2.5 mi]) sound data were acquired on the computer, together with details of the boat's position and other relevant information. In general, measurements were repeated in each location, taken in succession. For several transects, measurements were taken at two depths: mid-depth and 1 m (3.3 ft) above the seabed. This was done by immediately recovering the hydrophone and changing the connection position of the spar-buoy in order to re-deploy the hydrophone at the second depth. A summary of the measurement details below is shown in **Table 17**. **Figure 53** provides an illustrative map of measurement transects taken from the various wind turbine foundations.

**Table 17. Single hydrophone transect measurements summary.**

| Transect ID | Date | Turbine Foundation | Direction | Ranges | Time (EST) | Water Depth | Hydrophone Depth |
|---|---|---|---|---|---|---|---|
| 1 | 18 Aug 2015 | WTG 2 Stage 1 (1 pile) | Northwest | 450 m – 725 m (1,476.4 ft – 2,378.6 ft) | 15:53 – 16:11 | 20 – 25 m (65.6 – 82 ft) | Mid-depth (10 – 12 m) (32.8 – 39.4 ft) |
| 2 | 03 Sep 2015 | WTG 2 Stage 2 (1 pile) | Northwest | 550 m – 3.1 km (1,804.5 ft – 1.9 mi) | 09:56 – 10:20 | 22 – 29 m (72.2 – 95.1 ft) | Mid-depth (11 – 14 m) (36.1 – 45.9 ft) |
| 3 | 03 Sep 2015 | WTG 2 Stage 2 (1 pile) | Northwest | 550 m – 3.1 km (1,804.5 ft – 1.9 mi) | 09:58 – 10:17 | 22 – 29 m (72.2 – 95.1 ft | 1 m ( 3.3 ft) above seabed |
| 4 | 03 Sep 2015 | WTG 2 Stage 2 (2 piles) | East | 640 m – 20.0 km (2,099.7 ft – 12.4 mi) | 11:14 – 15:11 | 10 – 53 m (32.8 – 173.9 ft) | Mid-depth (5 – 26 m) (16.4 – 85.3 ft) |
| 5 | 03 Sep 2015 | WTG 2 Stage 2 (1 pile) | East | 680 m – 4.1 km (2,231 ft – 2.6 mi) | 11:18 – 11:34 | 10 – 27 m (32.8 – 88.6 ft) | 1 m (3.3 ft) above seabed (9 – 26 m) (29.5 – 85.3 ft) |
| 6 | 18 Sep 2015 | WTG 3 Stage 2 (1 pile) | Southeast | 480 m – 6.4 km (1,574.8 ft – 4 mi) | 14:20 – 15:07 | 25 – 27 m 82 – 88.6 ft) | Mid-depth (12 – 13 m) (39.4 – 42.7 ft) |
| 7 | 19 Sep 2015 | WTG 1 Stage 1 (4 piles) | North | 710 m – 24.0 km (2,329.4 ft – 14.9 mi) | 08:37 – 15:11 | 10 – 40 m (32.8 – 131.2 ft) | Mid-depth (5 – 20 m) (16.4 – 65.6 ft) |

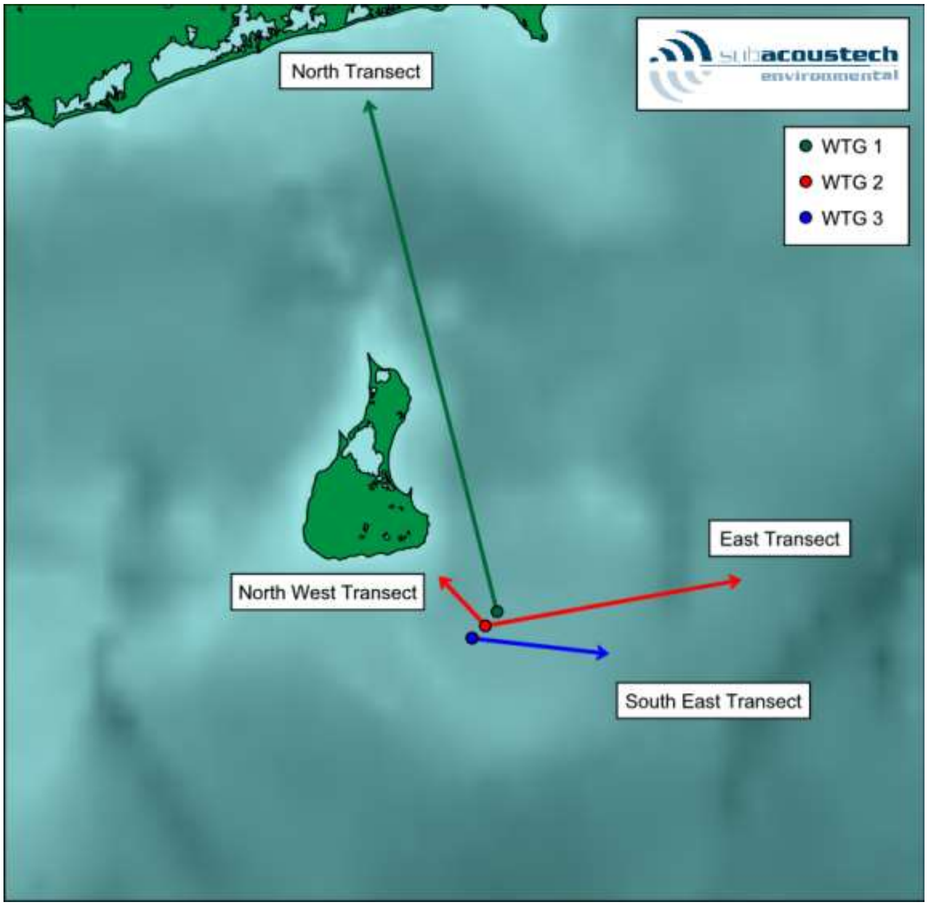



**Figure 53. Orientation of the four transects.**

For **Fixed Monitoring**, an OceanSonics icListen hydrophone was deployed for each measurement day listed in **Table18**. The hydrophone was fixed at mid-depth in the water column between 750 m (2,460.6 ft) and 840 m (2,756 ft) from the location of the piling, except on 19 September 2015 where the hydrophone was fixed at 1 m (3.3 ft) above the seabed at 5.9 km (3.7 mi) north of the piling.

**Table 18. Single hydrophone fixed measurements summary.**

| Date | Turbine Foundation | Direction | Range |
|---|---|---|---|
| 03 Sep 2015 | WTG 2 Stage 2 (4 piles) | Northwest | 750 m (2,460.6 ft) |
| 17 Sep 2015 | WTG 2 Stage 2 (3 piles) | Northwest | 790 m (2,591.9 ft) |
| 18 Sep 2015 | WTG 3 Stage 2 (4 piles) | Southeast | 840 m (2,756 ft) |
| 19 Sep 2015 | WTG 1 Stage 1 (4 piles) | North | 5.9 km (3.7 mi) |

**Seabed Vibration measurements** were conducted on transects following a similar procedure to the underwater noise transect measurements. The geophone assembly was lowered onto the seabed using a second line to maintain orientation and allowed to settle in the sediment. In addition, the geophone was oriented such that the longitudinal axis was in line with the direction of each transect.

Once the geophone was deployed and as each measurement was started, the cable was fed out and allowed to drift with the flow to minimize the effect of additional vibration induced by the current on the cable (cable strum). Each measurement lasted for approximately 30 seconds and once complete, the cable was retrieved to remove any slack and the measurement repeated.

### 4.2.2 Source Level Estimations and Model Results

Estimates of SL were determined from the measured levels of the pile strikes. A simple method for determining the SL is by using the transmission loss to extrapolate back from a measured received level. SL is usually expressed as dB re 1 µPa at 1 m, where 1 µPa is the standard reference pressure used underwater.

In shallow water, estimating SL effectively is not always simple because of the interaction of the propagating sound with the surface and seabed. For the purpose of determining 'first look' source levels based on the measured data presented in this report, the RAMSGeo propagation model was chosen as it is effective at modeling low frequency propagation, allows for variable bathymetry and the incorporation of complex bottom types.

Modeling results for the north transect, which extends 28 km (17.4 mi) from WTG 1 towards the Rhode Island shoreline are shown in **Figures 54** and **55**. Frequency data measured 710 m (2,329.4 ft) from pilings at WTG 1 on 19 September 2015 were used to calculate those losses. In addition, a silt/sand seabed has been assumed based on data from the Block Island Wind Farm and Block Island Transmission System Underwater Acoustic Report (Environmental Report Appendix N-2 by Deepwater Wind).

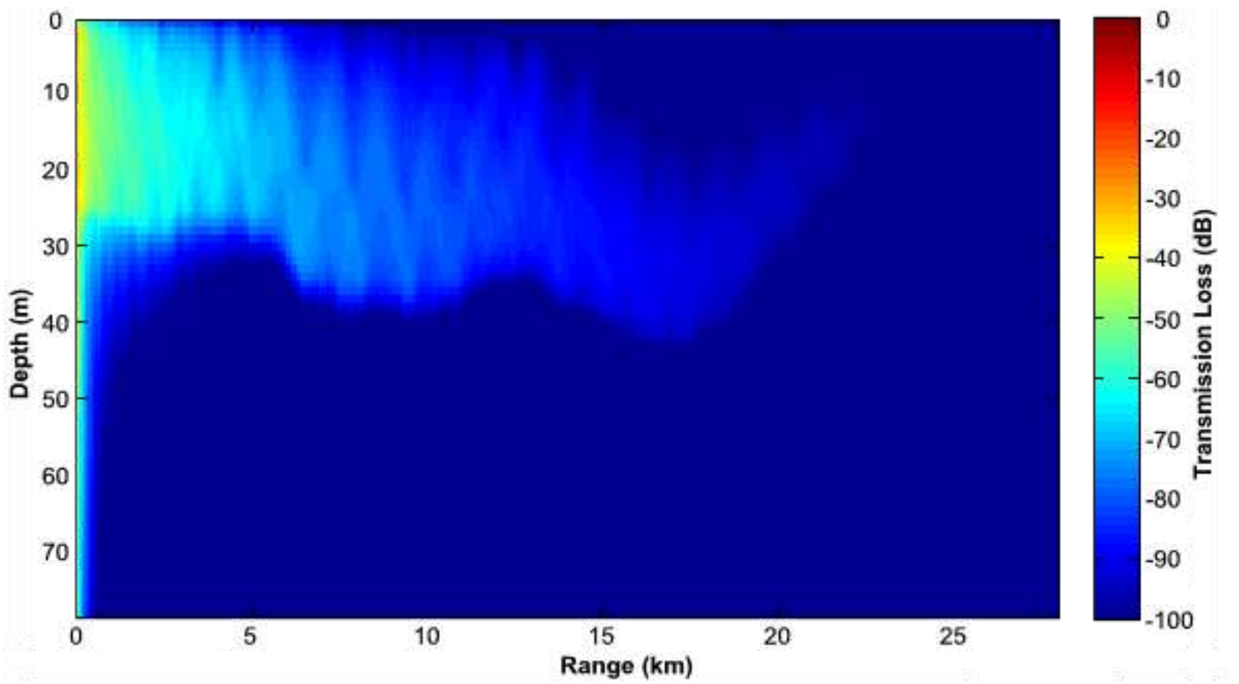



**Figure 54. Plot showing the predicted underwater sound pressure propagation along the north transect.**

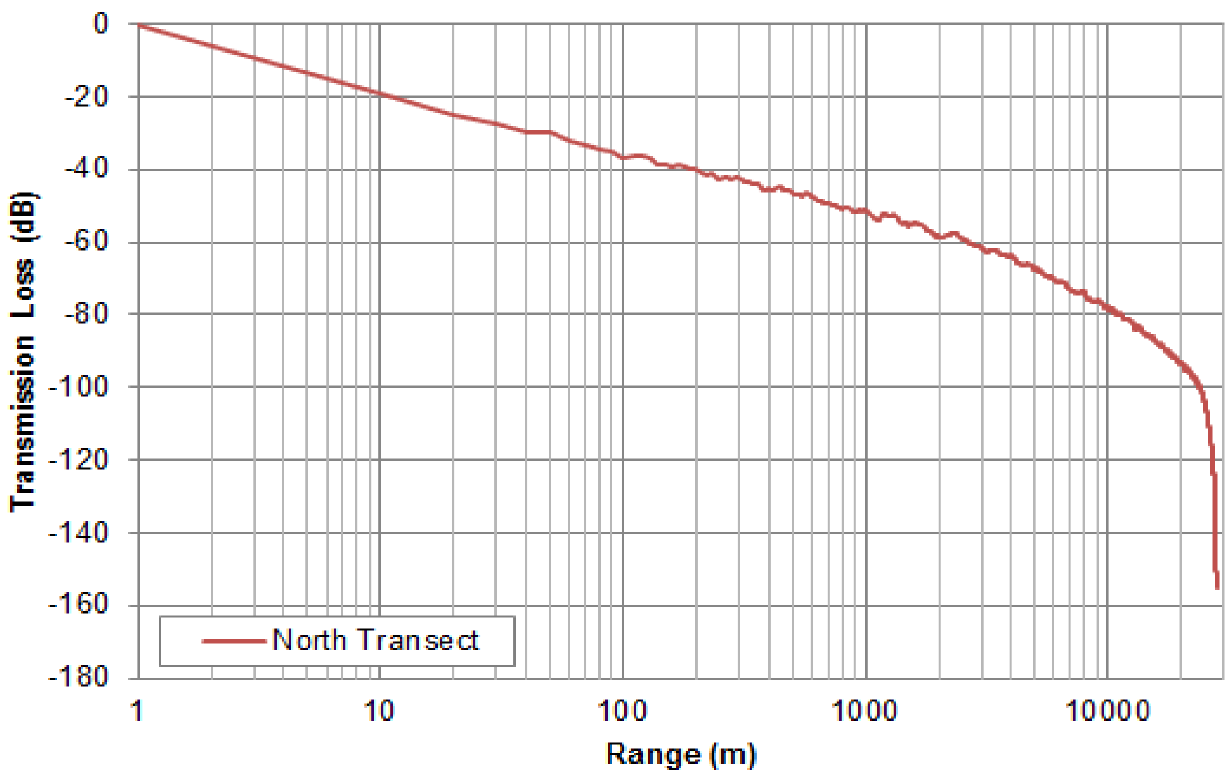



**Figure 55. Level vs. range plot showing the predicted transmission loss along the north transect.**

### 4.2.3 Background Sound Measurement Results

Background noise measurements were undertaken at opportune moments throughout the survey period when no piling activities were ongoing. **Table 19** provides date, location, distance, sea state, and weather condition data for such opportune collections.

**Table 19. Details of location and observed conditions during the background underwater sound measurements.**

| Date | Location | Distance | Sea State (Beaufort scale) | Weather conditions |
|---|---|---|---|---|
| 13 Aug 2015 | Northwest transect | 1.5 – 5.0 km (0.9 – 3.1 mi) Northwest of WTG 2 | 2 | Sunny, clear skies and light winds (2 m/s) |
| 14 Aug 2015 | Southeast transect | 0.8 – 2.9 km (0.5 mi – 1.8 mi) South east of WTG 3 | 3 | Sunny, clear skies and gentle breeze (4 m/s) |
| 23 Aug 2015 | Northwest transect | 1.0 – 1.1 km (0.6 – 0.7 mi) Northwest of WTG 2 | 3 | Sunny, clear skies and gentle breeze (4 m/s) |
| 24 Aug 2015 | North transect | 0.9 - 4.0 km (0.7 mi – 2.5 mi) North of WTG 1 | 3 | Sunny spells, cloud 7/8 coverage, dry, gentle breeze (3.5 m/s) |
| 03 Sep 2015 | East transect | 20.0 - 30.5 km (12.4 – 19 mi) East of WTG 2 | 3 | Dry, sunny, cloud light but clear 1/8, light breeze (3 m/s) |

The maximum, minimum, and mean measured background sound levels are presented in **Table 20**. The mean levels (SPL RMS) range from 107.4 dB re 1 µPa, for measurements taken up to 30 km (18.6 mi) east of the BIWF site, to 118.7 dB re 1 µPa for measurements taken as close as 1 km (0.6 mi) from the work site.

**Table 20. Summary of SPL RMS background sound measurements taken near the Block Island Wind Farm site.**

| Date | Location | Max level (dB re 1 µPa) | Min Level (dB re 1 µPa) | Mean Level (dB re 1 µPa) | Comments |
|---|---|---|---|---|---|
| 13-Aug-15 | Northwest transect | 123.7 | 104.2 | 115.3 | Sound from small vessels and construction barge |
| 14-Aug-15 | Southeast transect | 124.7 | 96.0 | 112.4 | Some sound from construction barge |
| 23-Aug-15 | Northwest transect | 129.7 | 111.1 | 118.7 | Machinery sound from construction barge and passing vessels |
| 24-Aug-15 | North transect | 119.7 | 103.2 | 112.1 | Sound from construction barge and from ferry |
| 03-Sep-15 | East transect | 125.7 | 97.7 | 107.4 | Vessel traffic contributes at 20 km (12.4 mi), very quiet at 30 km (16.6 mi) |

The background sound pressure levels measured near to the BIWF work site were found to be higher due to the presence of construction vessels and also more small recreational vessels than in other locales. The lowest levels were measured at a distance of 30 km (18.6 mi) east of the BIWF site away from vessel traffic and other man-made sound sources. The power spectral density plot presented in **Figure 56** reveals the level across the frequency range is less than that of the measurements from other locations. This was sampled on a different day and, because of the small variation and small sample size, no conclusions should be drawn aside from a general indication of background noise levels in the region. However, the other power spectral density plots show higher levels between 30 and 300 Hz, which are expected to be mostly due to the presence of vessels associated with the BIWF construction operation.

### 4.2.4 SL Estimation Summary Results and Comparisons

A summary of the estimated source levels for each measurement transect is presented in **Table 21**. The estimated peak-to-peak source levels are between 233 and 245 dB re 1 µPa at 1 m (3.3 ft) and are based on the hammer blow energies after ramp up.

**Table 21. Estimates of SL based on fits to the measurement transects from the piling operations.**

| Transect ID | Transect direction | Hydrophone depth | SL |
|---|---|---|---|
| 1 | Northwest | Mid | - |
| 2 | Northwest | Mid | 234 |
| 3 | Northwest | Seabed | 236 |
| 4 | East | Mid | 235 |
| 5 | East | Seabed | 237 |
| 6 | Southeast | Mid | 242 |
| 7 (Pile 1) | North | Mid | 245 |
| 7 (Piles 2–4) | North | Mid | 233 |

Note: The source level for Transect ID 1 (diesel hammer) could not be estimated because of a short piling time and number of ranges sampled.

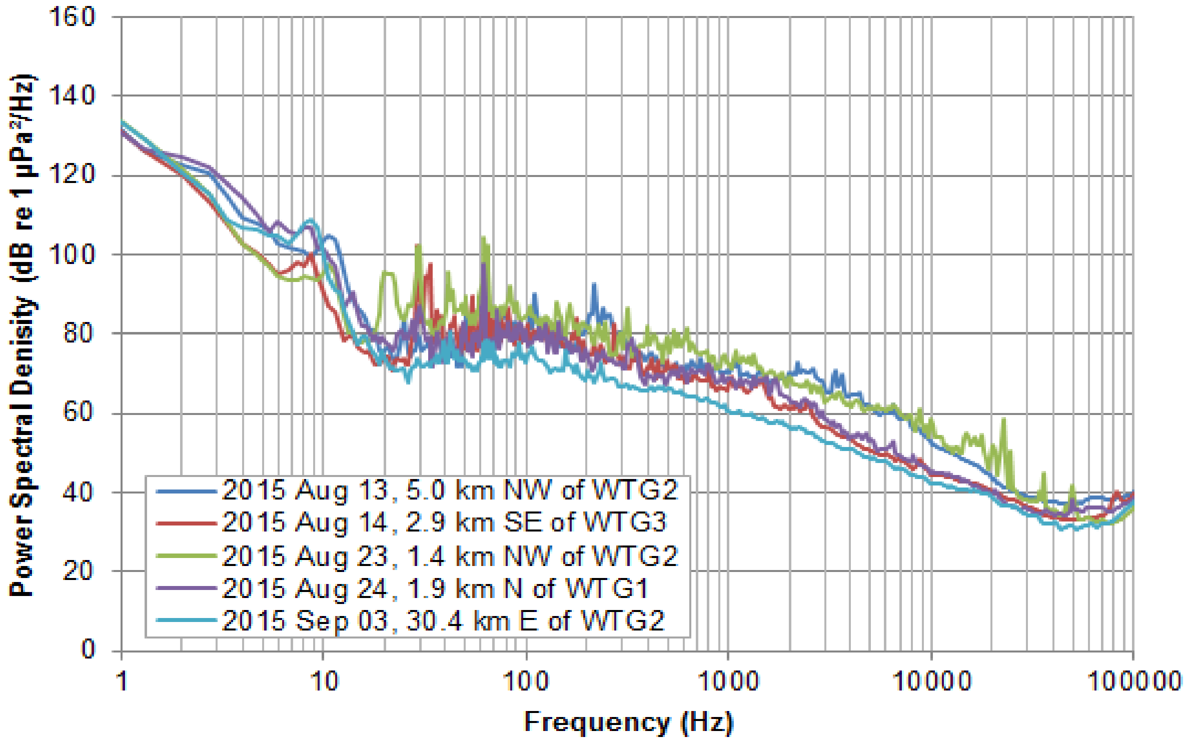



**Figure 56. Power spectral density plots of background sound measurements taken near the Block Island Wind Farm site.**

In general for piling, the hammer blow energies after ramp-up were fairly consistently between 100–200 kJ. The exception was for Transect ID 6, where blow energies were 300 and 500 kJ. The energies used on Transect ID 7 appeared to remain consistent for all piles, despite the increased SL for Pile 1. The reason for this may be associated with the rake angle on that pile relative to the measurements, discussed earlier.

### 4.2.4.1 Comparison with Measured Data from Europe

The sound levels recorded at a range of 750 m (2,460.6 ft) at the BIWF site were compared with measurements at similar projects undertaken by Subacoustech Environmental at European wind farm sites. To calculate the noise level at the exact range of 750 m (2,460.6 ft) to allow a direct comparison with BIWF data, the transmission losses estimated using RAMSGeo have been applied to the measurement at the nearest location to 750 m (2,460.6 ft) at the site. **Table 22** summarizes both the peak-to-peak levels and single strike SEL values for the measurements.

It can be seen that the levels measured at the BIWF (with 1.372 m [4.5 ft] diameter piles) align with the spread of measurements at the European sites. Levels for smaller piles (North Sea, 1.067 m [3.5 ft]) are lower and most levels for the larger piles (East Irish Sea and Moray Firth) are higher. Average 750 m (2,460.6 ft) noise levels at BIWF are calculated 187.1 dB re 1 µPa $SPL_{pk-pk}$ and 189.6 dB re 1 µPa $SPL_{pk-pk}$ for the European wind farms; average SEL is 162.4 dB re 1 µ$Pa^2$s at BIWF and 162.6 dB re 1 µ$Pa^2$s for the European wind farms.

These basic comparisons do not take into account changes in bathymetry, sediment type, or temperature data etc. Although the depth of the water can have a significant effect on sound transmission, the effect will be greatest over long distances and variations in the sound levels at 750 m (2,460.6 ft) or the SL will not be significantly influenced by the above environmental parameters.

**Table 22. Comparison of measured sound levels at a range of 750 m (2,460.6 ft) at the BIWF site (with pile diameters of 1.4 m [4.6 ft) and other measurements undertaken in the EU. Pile diameters given in (parentheses), closest measured range from the pile in [brackets].**

| BIWF Transect ID | Level at 750 m dB $SPL_{pk\text{-}pk}$ | Level at 750 m dB $SEL_{ss}$ |
|---|---|---|
| 2 | 184 | 160 |
| 3 | 185 | 161 |
| 4 | 185 | 161 |
| 5 | 187 | 162 |
| 6 | 191 | 166 |
| 7 (Pile 1) | 195 | 168 |
| 7 (Piles 2-4) | 183 | 159 |

| EU Windfarm site | Level at 750 m (2,460.6 ft) dB $SPL_{pk\text{-}pk}$ | Level at 750 m (2,460.6 ft) dB $SEL_{ss}$ |
|---|---|---|
| **UK east coast** (1.37 m [558 m]) | 182 | 158 |
| **North Sea** (1.829 m [721 m]) | 193 | 165 |
| **North Sea** (1.077 m [675 m]) | 185 | 158 |
| **East Irish Sea** (1.83 m [637 m]) | 191 | 163 |
| **East Irish Sea** (1.83m [500 m]) | 192 | 164 |
| **East Irish Sea** (1.83 m [517 m]) | 192 | 166 |
| **East Irish Sea** (1.83m [510 m]) | 192 | 164 |
| **Moray Firth** (1.83m [728 m]) | 194 | 165 |

#### 4.2.4.2 Comparison with Modeled Data

Underwater sound modeling for impact piling at the Block Island site was carried out by Deepwater Wind using the RAMSGeo acoustic model, as reported in the Block Island Wind Farm and Block Island Transmission System, Environmental Report Appendix N-2 Underwater Acoustic Report (Deepwater Wind 2012). The modeling was carried out in accordance with thresholds defined by the National Marine Fisheries Service over eight equally spaced transects (one every 45°) for two pile hammer energies; 200 kJ and 600 kJ. These thresholds were valid at the time of the assessment, although have since been updated. The ranges to three thresholds were presented:

- 180 dB re 1 µPa (RMS) – Level A harassment threshold, where sound has the potential to injure a marine mammal.
- 160 dB re 1 µPa (RMS) – Level B harassment threshold, where sound has the potential to disturb a marine mammal. This threshold is specifically for impulsive sound sources.
- 120 dB re 1 µPa (RMS) – Level B harassment threshold; as above. This threshold is for a continuous sound source or an intermittent non-pulsed source; this is not specifically relevant to impact piling, however it has been included to aid comparisons to the modeling undertaken by Deepwater Wind.

The measured data along with the RAMSGeo transmission losses are presented alongside the modeled data from Deepwater Wind below. **Table 23** shows the transects measured during piling next to the modeled transects that have the closest orientation match. This table also shows these transects and compares the difference in range between the modeled and measured calculated disturbance thresholds. These results are shown as level versus range plots in **Figures 57** to **60**.

**Table 23. Summary of the measured transects and the modeling parameters from Deepwater Wind that closest correspond.**

| BIWF Measured Transect ID | Approx. measured bearing | Closest modelled bearing | Closest modelled blow energy | Modelled Range to 180 $dB_{RMS}$ | Modelled Range to 160 $dB_{RMS}$ | Modelled Range to 120 $dB_{RMS}$ |
|---|---|---|---|---|---|---|
| 2 (Northwest) | 316° | 315° | 200 kJ | 61 m (200.1 ft) | 3.1 km (1.9 mi) | 5.8 km (3.6 mi) |
| 3 (Northwest) | | | | | | |
| 4 (East) | 80° | 90° | 200 kJ | 60 m (196.9 ft) | 2.7 km (1.7 mi) | 30.6 km (19 mi) |
| 5 (East) | | | | | | |
| 6 (Southeast) | 97° | 90° | 600 kJ | 382 m (1,253.3 ft) | 4.6 km (2.9 mi) | 37.5 km (23.3 mi) |
| 7 (Pile 1) (North) | 346° | 0° | 200 kJ | 61 m (200.1 ft) | 2.8 km (1.7 mi) | 27.4 km (17.03) |
| 7 (Piles 2-4) (North) | | | | | | |

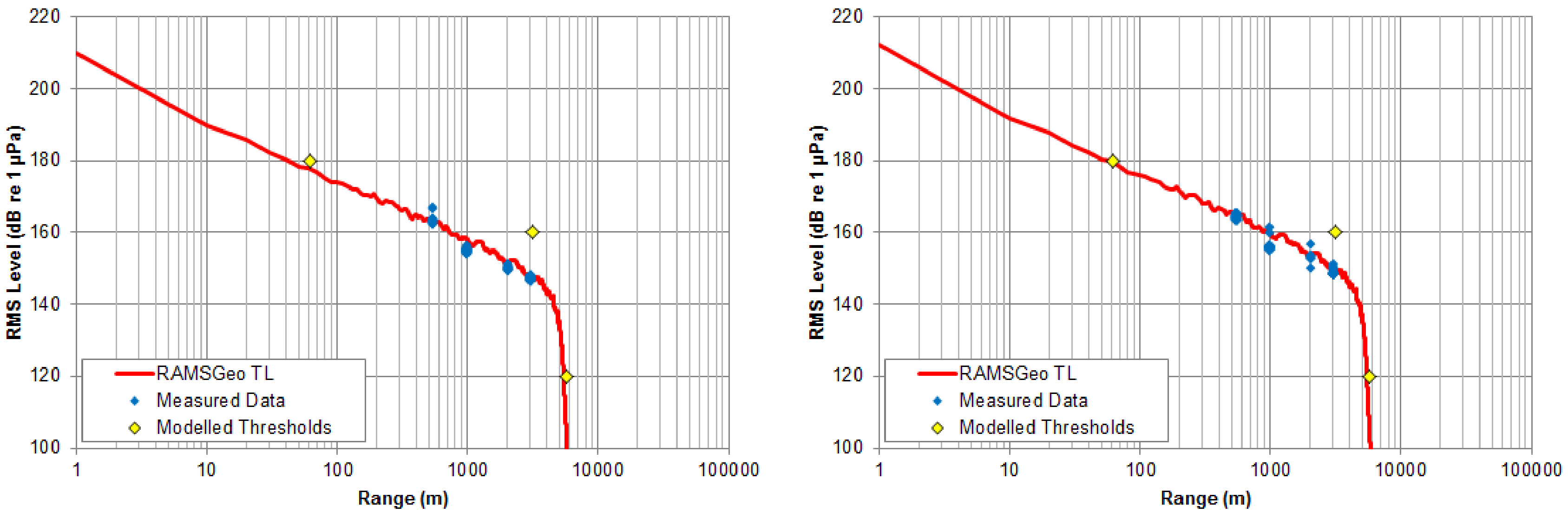



**Figure 57. Comparison between measured data and modeled thresholds for transects 2 (left) and 3 (right) using the modeled data from the 315° transect using a 200 kJ blow energy.**

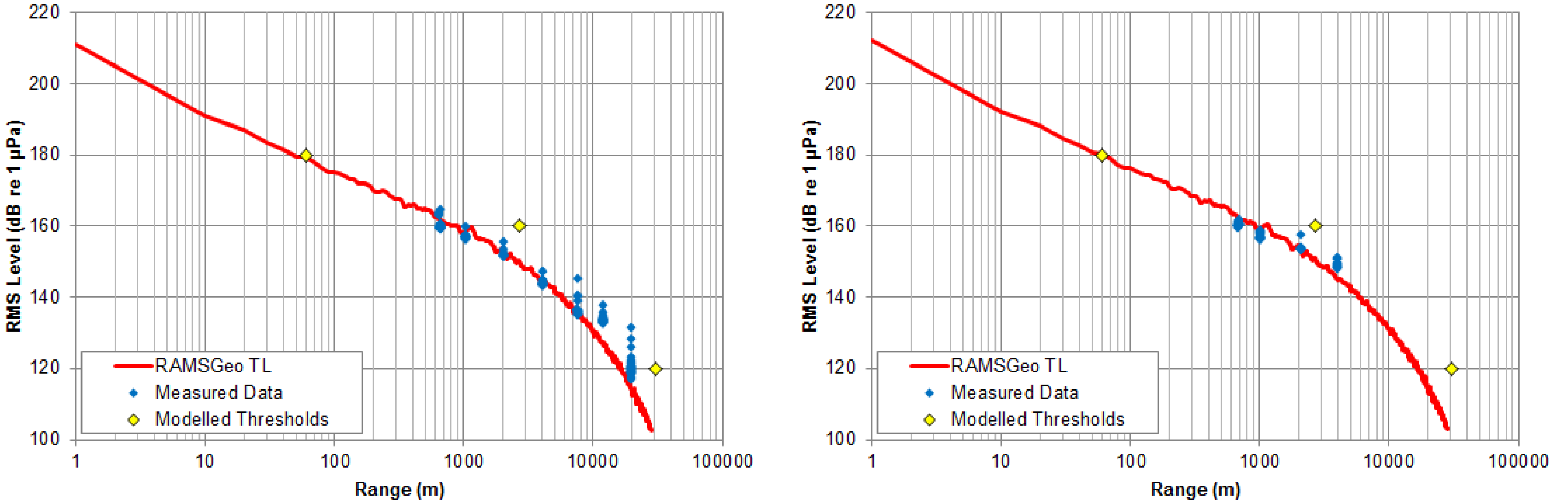



**Figure 58. Comparison between measured data and modeled thresholds for transects 4 (left) and 5 (right) using the modeled data from the 90° transect using a 200 kJ blow energy.**

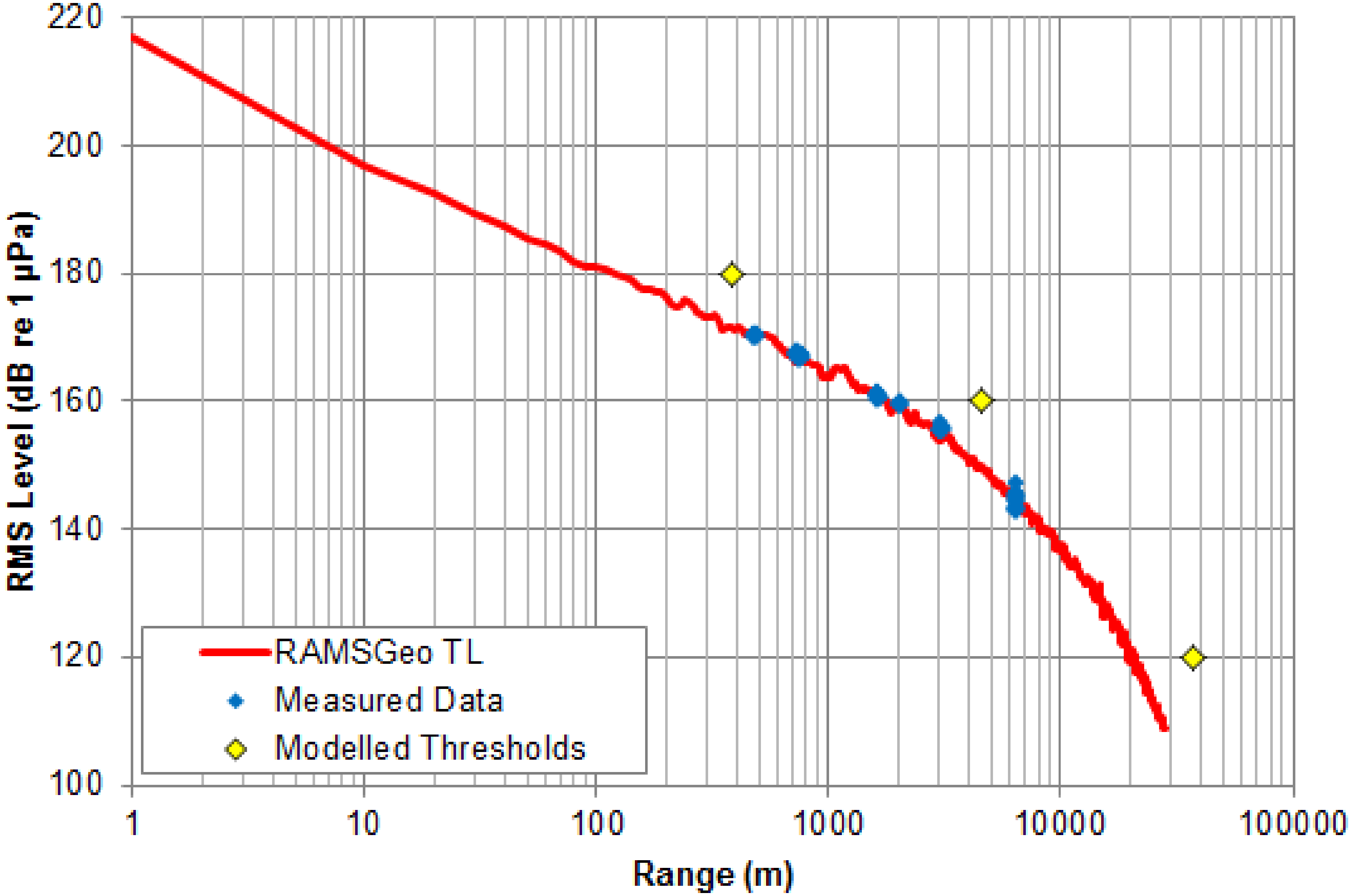



**Figure 59. Comparison between measured data and modeled thresholds for transect 6 using the modeled data from the 90° transect using a 600 kJ blow energy.**

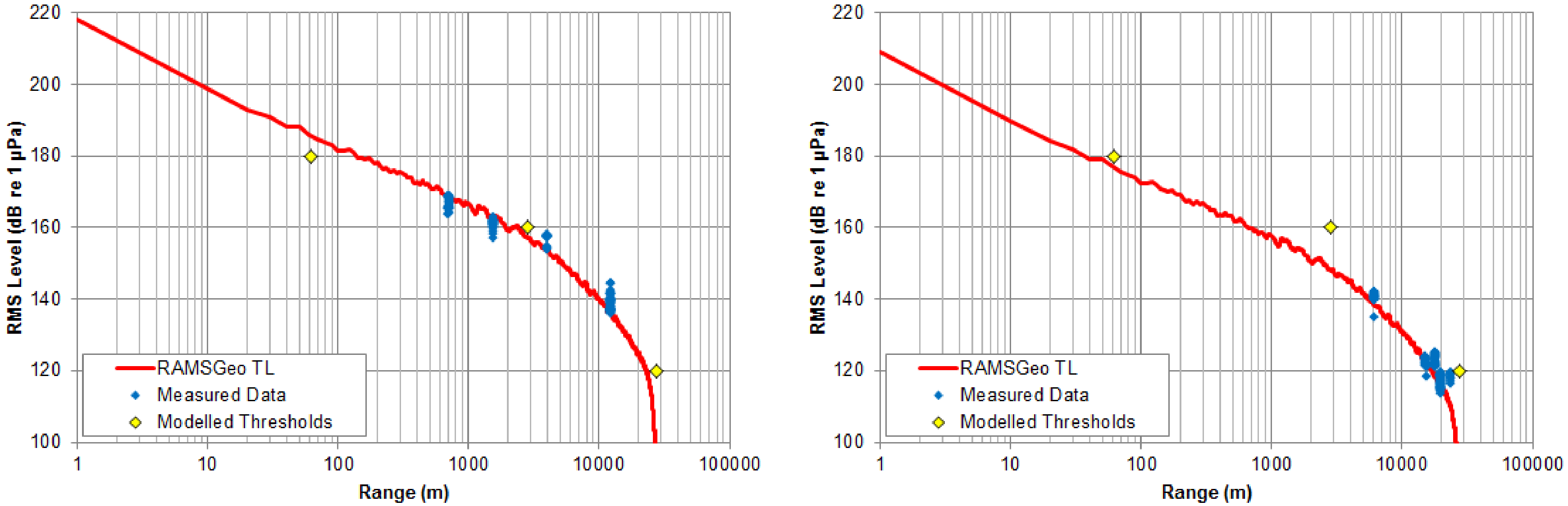



**Figure 60. Comparison between measured data and modeled thresholds for transect 7 (pile 1, left, and piles 2-4, right) using the modeled data from the 0° transect using a 200 kJ blow energy.**

**Table 24** shows the results of the comparison between the ranges calculated from modeling by Deepwater Wind and those measured during pile installation. The modeled ranges were conservative, and tended to overestimate the noise levels produced during piling, and thus most differences in the table are positive. For example, the modeling calculated that 160 $dB_{RMS}$ at Transect ID 2 would be reached 2.4 km (1.5 mi) farther from the pile than was measured, meaning that the piling was less noisy than was predicted.

**Table 24. Summary of the difference in range, between the measured and modeled sound levels for the three disturbance thresholds.**

| BIWF Transect ID | Difference in range between the measured and modelled disturbance threshold levels | | |
|---|---|---|---|
| | 180 $dB_{RMS}$ | 160 $dB_{RMS}$ | 120 $dB_{RMS}$ |
| 2 (Northwest) | + 21 m (68.9 ft) | + 2.4 km (1.5 mi) | + 0.4 km (0.2 mi) |
| 3 (Northwest) | + 11 m (36.1 ft) | + 2.1 km (1.3 mi) | + 0.3 km (0.2 mi) |
| 4 (East) | + 2 m (6.6 ft) | + 1.8 km (1.1 mi) | + 14.2 km ( 8.8 mi) |
| 5 (East) | 0 m | + 1.5 km (0.9 mi) | + 13.8 km (8.6 mi) |
| 6 (Southeast) | + 270 m (885.8 ft) | + 2.8 km (1.7 mi) | + 16.7 km (10.4 mi) |
| 7 (Pile 1) (North) | - 69 m (226.4 ft) | + 0.9 km (0.6 mi) | + 4.5 km (2.8 mi) |
| 7 (Piles 2-4) (North) | + 30 m (98.4 ft) | + 2.1 km (1.3 mi) | + 10.8 km (6.7 mi) |

These results show that the modeling gives an upper estimate of the measured sound, with almost all the measured levels being lower than those predicted by Deepwater Wind using RAMSGeo. In addition, the difference between measured and modeled levels becomes greater with range for most transects.

#### 4.2.4.3 Hammer and SPL Comparison

A comparison of the measured peak-to-peak sound pressure levels, at a range less than 1.2 km (0.8 mi) to piling, for two different hammer types is presented in **Figure 61**. On 3 September 2015, the levels measured for the Bauer-Pileco Inc. Model D280-22 diesel hammer are generally of the same order as the levels measured for the Menck hydraulic hammer and follow the same trend. As compared with the levels measured on 3 September, higher levels were recorded for the diesel hammer on 18 and 19 September 2015 and these are most likely linked to higher blow energies. The blow energies for the diesel hammer were not available for comparison, although specifications for it state that its available blow energy range is much greater than that of the Menck.

The hydraulic hammer used on September 18 and 19 at the higher hammer energies led to the highest overall noise levels relative to distance.

### 4.2.5 Piling Seabed Vibration Measurements

Seabed vibration measurements of impact piling were recorded on 17 September 2015 along transects from the WTG 5 foundation during driving of the first stage piles. All monitored piles were the first segment of each leg. The measurements from these transects are discussed below in the order they were collected.

Measurements of seabed vibration were carried out along a northwest transect from turbine foundation WTG 5. Each measurement transect was sampled twice. Measurements began at approximately 500 m (1,640.4 ft) from the foundation and were then taken at increasing distance in steps of approximately 500 m (1,640.4 ft). The measurements were then repeated on a return transect. The axes were vertical (away from the seabed), longitudinal (toward piling) and transverse (perpendicular to piling).

The first transect measurement was carried out between 12:42 and 13:36 on 17 September 2015. On review of the data, it was found that interference had occurred because of the survey vessel’s engines not being turned off during the measurement. For the second and third transects, measurements were taken once the survey vessel's engines and electronic equipment was turned off.

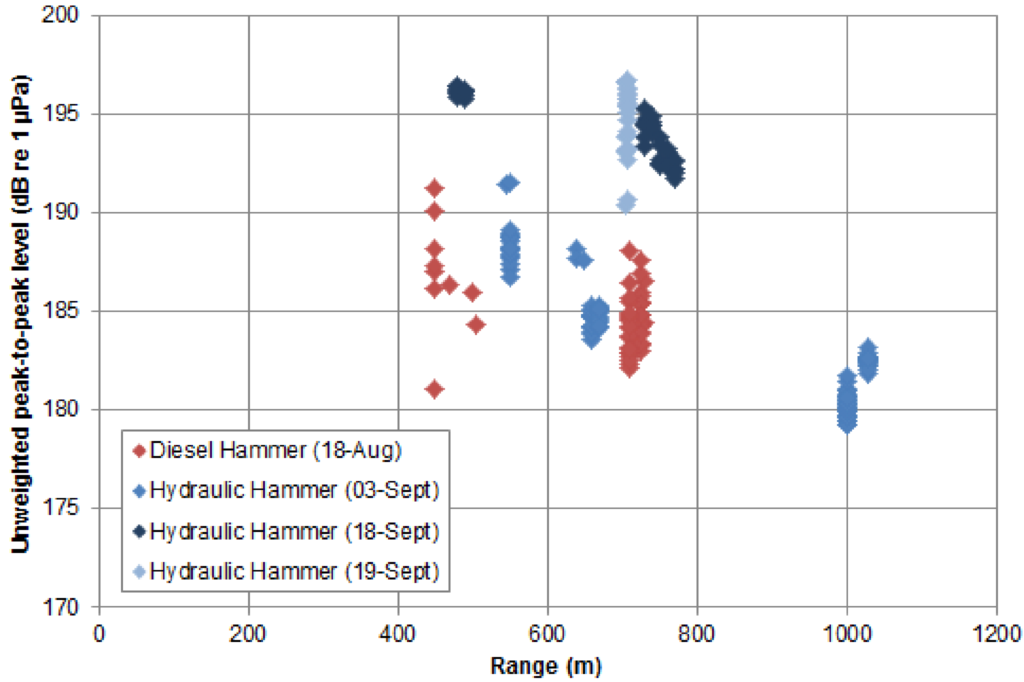



**Figure 61. Comparison of peak-to-peak sound pressure levels between a Diesel Hammer and a Hydraulic hammer.**

Northwest transect vibration measurements taken during installation of pile 2 (first segment) of WTG 5 are presented in **Table 25** in terms of peak particle velocity (PPV) for the three axes. The greatest magnitudes of peak particle velocity are seen to be for the longitudinal axis which was deployed to line up with the transect direction. These data can be seen in graphical form in **Figure 62**.

**Table 25. Measurements of the PPV magnitudes taken along a northwest transect from WTG 5 for the installation of Pile 2.**

| Distance | Approx. Blow Energy (kJ) | Vertical PPV Peak (mm/s) | Longitudinal PPV Peak (mm/s) | Transverse PPV Peak (mm/s) |
|---|---|---|---|---|
| 550 m (1,804.5 ft) | Not available | 0.079 | 0.158 | 0.112 |
| 570 m (1,870.1 ft) | - | 0.100 | 0.177 | 0.112 |
| 590 m (1,935.7 ft) | - | 0.112 | 0.177 | 0.079 |
| 590 m (1,935.7 ft) | - | 0.100 | 0.177 | 0.079 |
| 1,040 m (3,412.1 ft) | - | 0.040 | 0.079 | 0.063 |
| 1,060 m (3,477.7 ft) | - | 0.071 | 0.112 | 0.100 |
| 1,060 m (3,477.7 ft) | - | 0.050 | 0.100 | 0.079 |
| 1,660 m (3,477.7 ft) | - | 0.032 | 0.063 | 0.028 |
| 1,660 m (3,477.7 ft) | - | 0.028 | 0.063 | - |
| 2,150 m (7,053.8 ft) | - | 0.020 | 0.040 | 0.020 |
| 2,150 m (7,053.8 ft) | - | 0.021 | 0.050 | 0.020 |
| 2,500 m (8,202.1 ft) | - | 0.018 | - | - |
| 3,350 m (10,990.8 ft) | - | 0.011 | 0.016 | 0.013 |
| 3,350 m (10,990.8 ft) | - | - | 0.018 | - |

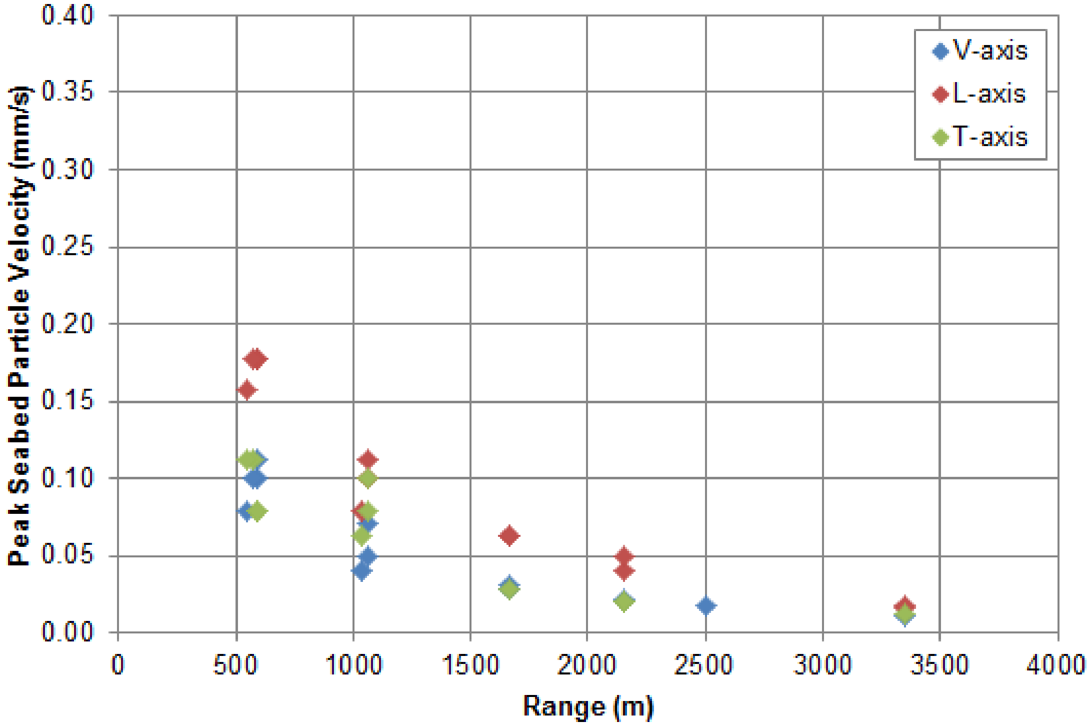



**Figure 62. PPV magnitudes plotted against range for a northwest transect from WTG 5 for the installation of Pile 2.**

Northwest transect vibration measurements taken during the installation of pile 3 (first segment) of WTG 5 are presented in **Table 26** in terms of PPV for the three axes. The greatest magnitudes of PPV are again seen to be for the longitudinal axis 0.354 mm/s at 400 m (1,312.3 ft). Magnitudes of PPV were measured in excess of 0.2 mm/s, at a range of 750 m (2,460.6 ft), greater than the highest magnitude of PPV, measured at a closer range of 570 m (1,870 ft), on the first transect.

**Table 26. Measurements of the PPV magnitudes taken along a northwest transect from WTG 5 for the installation of Pile 3.**

| Distance | Approx. Blow Energy (kJ) | Vertical PPV Peak (mm/s) | Longitudinal PPV Peak (mm/s) | Transverse PPV Peak (mm/s) |
|---|---|---|---|---|
| 400 m (1,312.3 ft) | 65 | 0.177 | 0.354 | 0.177 |
| 420 m ( 1,378 ft) | 70 | 0.188 | 0.281 | 0.186 |
| 710 m (2,329.4 ft) | 230 | 0.112 | 0.171 | 0.133 |
| 750 m (2,460.6 ft) | 70 | 0.071 | 0.126 | 0.092 |
| 750 m (2,460.6 ft) | 80 | 0.079 | 0.149 | 0.112 |
| 750 m (2,460.6 ft) | 235 | 0.119 | 0.199 | 0.112 |
| 750 m (2,460.6 ft) | 235 | 0.106 | 0.199 | 0.100 |
| 750 m (2,460.6 ft) | 235 | 0.100 | 0.211 | 0.094 |
| 780 m (2,559.1 ft) | 250 | 0.094 | 0.223 | 0.112 |
| 780 m (2,550.1 ft) | 230 | 0.106 | 0.164 | 0.089 |
| 1,210 m (3,969.8 ft) | 80 | 0.035 | 0.133 | 0.040 |
| 1,250 m (4,101.1 ft) | 70 | 0.050 | 0.100 | 0.045 |
| 2,050 m (6,725.7 ft) | 240 | - | 0.028 | - |
| 3,050 m (10,006.6 ft) | 240 | 0.014 | 0.021 | 0.019 |

**Figure 63** displays the underwater sound time history for 17 September 2015 and indicates a greater vibration emission in the impact piling of pile 3 compared with pile 2, hence the higher magnitudes of peak particle velocity measured for pile 3.

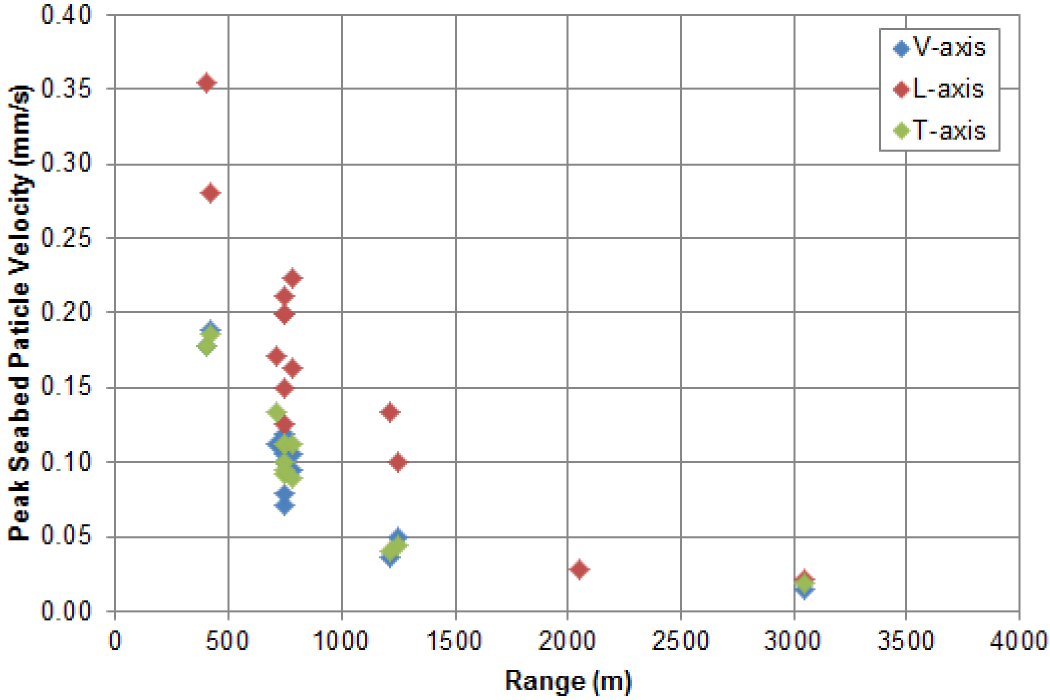



**Figure 63. PPV magnitudes plotted against range for a northwest transect from WTG 5 for the installation of Pile 3.**

### 4.2.6 Single Hydrophone and Seabed Vibration Monitoring Conclusions

Background sound measurements were collected when no piling occurred predominantly in and around the wind farm site. Samples of background sound between 20 Hz and 100 kilohertz were taken up to 30 km (18.6 mi) from the site in quieter waters. The mean RMS SPLs recorded ranged between 107.4 and 118.7 dB re 1 µPa. Higher levels of background sound were found closer to the wind farm site which can be attributed to construction vessels and also to recreational vessel traffic.

As expected, transect measurements of underwater impact piling sound pressure levels were shown to decrease with increasing distance. A comparison of the underwater sound levels measured at mid-depth with those measured at one meter above the seabed showed sound pressure levels of the order of 2 dB higher nearer the seabed.

For each transect, the transmission loss was calculated, using the RAMSGeo propagation model in order to determine the source levels. The estimated peak-to-peak source levels extrapolated from the measured data ranged between 233 and 245 dB re 1 µPa at 1 m (3.3 ft).

The measured data from the fixed monitor captured the variation in the underwater sound level during pile driving operations over the period of a day. These data provided useful information for the analysis of the measured transect data, most notably for the north transect where measurements were taken during the piling of the four piles for the WTG 1 foundation.

Transect measurements of seabed vibration were also undertaken during impact piling operations on WTG 5 using a tri-axial geophone. The measurements were repeated for subsequent piles on a northwest transect. The greatest magnitude of peak particle velocity was measured to be 0.354 mm/s on the longitudinal axis (towards piling) at a range of 400 m (1,312.3 ft) from the piling.

#### 4.2.6.1 Recommendations for future measurements and observations

The following recommendations are offered to guide the design of underwater sound monitoring efforts for future offshore pile driving:

1. At the BIWF, the nearest measurements of pile driving were taken 500 m (1,640.4 ft) away because of safety concerns. It is recommended that measurements be taken at closer ranges if at all possible. In addition, if feasible, accelerometers should be attached to the foundation jackets. Having such data is particularly important because the highest sound pressure and particle motion levels are likely to be within this region, and thus these sound levels are those most likely to have the most significant impact on fishes (and invertebrates). While modeling from data farther from the source appears to be effective, this is not a substitute for testing the model close to the source, and particularly for determining the 3D particle motion levels where models may not work in the shallow water.
2. BIWF measurements were generally confined to one azimuth; more meaningful data would be generated if measurements were recorded simultaneously at different azimuths.
3. At BIWF, sound level measurements were recorded up to 15 km (9.3 mi). For future monitoring, it is recommended that a VLA be placed approximately 50 km (31 mi) away from sound source.
4. Particle velocity was measured on the seabed and close to it (approximately 1 m (3.3 ft) from the bottom). It will be useful if particle velocity measurements can be made mid-water column depth. This could be accomplished by deploy a multi-depth tetrahedral SHRU Array.
5. There is a need to measure particle motion levels at different heights above the seabed to investigate the fall-off.
6. There is also a need to investigate the level of sound pressure at different depths.

Also, the purpose of the RODEO Program is to make direct, real-time measurements of the nature, intensity, and duration of potential stressors during the construction and initial operations of offshore wind facilities. It is well established that the stressors can potentially impact marine life (receptors), and therefore, to get a complete picture, it would be useful to also gather relevant real-time data and conduct analyses for determining potential impacts of the stressors on receptors such as fish, sea turtles, and marine mammals. The impact analyses should focus on the latest guidelines for the key receptor groups and compare ambient underwater sound levels to applicable and relevant guidelines. For example, analysis for fish impacts could reference Popper et al. (2014) while marine mammal analysis might be conducted in terms of recent NOAA reports (NMFS 2016; NOAA 2016).

Relatively little information is currently available on the effects of man-made sounds on aquatic life, and particularly on fishes and invertebrates (Normandeau 2012a, 2012b; Hawkins et al. 2015), and impact analyses would provide data to fill in the knowledge gaps. These analyses would also improve understand of the need and the extent to which underwater sounds from offshore wind farm construction and operation need to be managed and and/or mitigated for.

# 5 Seafloor Disturbance and Recovery Monitoring

The main objective of the seafloor disturbance and recovery monitoring task was to identify seafloor disturbances associated with the BIWF construction activities and monitor seabed recovery over time. Monitoring was also performed to collect field data for evaluation of the spatial extent of seafloor disturbances around each turbine related to construction activities. High-resolution bathymetric data were gathered in the field in parallel with the construction activities and data were analyzed to evaluate seafloor changes.

Three separate surveys were conducted in the area where the construction vessels were positioned (designated as the Work Area) (**Figure 64**). Detailed technical reports from each survey are contained in **Appendix E**. Round 1 was conducted on 11 May and 12 May 2016, and survey data were used to determine seafloor disturbances resulting from Phase 1 construction activities that took place between July and October 2015. A second round of monitoring was conducted from 2 to 5 October 2016 and the focus was to record seafloor disturbances resulting from Phase 2 construction activities that took place between May through August 2016. The last bathymetry survey was conducted on 18 and 19 May 2017, and its purpose was to assess seabed recovery past-construction approximately 18-months post-construction[7]. **Table 27** shows key dates related to the seafloor disturbance and recovery monitoring.

**Table 27. Seafloor disturbance and recovery monitoring survey summary.**

| Construction Phase | Duration of Construction | Major Activities Undertaken | Disturbance and Recovery Monitoring Survey Duration |
|---|---|---|---|
| Phase1 | 26 July–<br>26 October 2015 | • Installation of steel jacket foundations | 11 and 12 May 2016 |
| Phase 2 | 13 May–<br>18 August 2016 | • Wind turbine generators were installed on the foundations | 2 to 5 October 2016 |
| | 3 June –<br>26 June 2016. | • Submarine transmission power cables connecting Block Island and mainland were laid using a jet plowing in the offshore portions and horizontal directional drilling in the near shore area. | |
| Post-Construction | -- | -- | 18 and 19 May 2017 |

[7] The actual survey dates were dictated by availability of research vessel, weather conditions, and sea states.

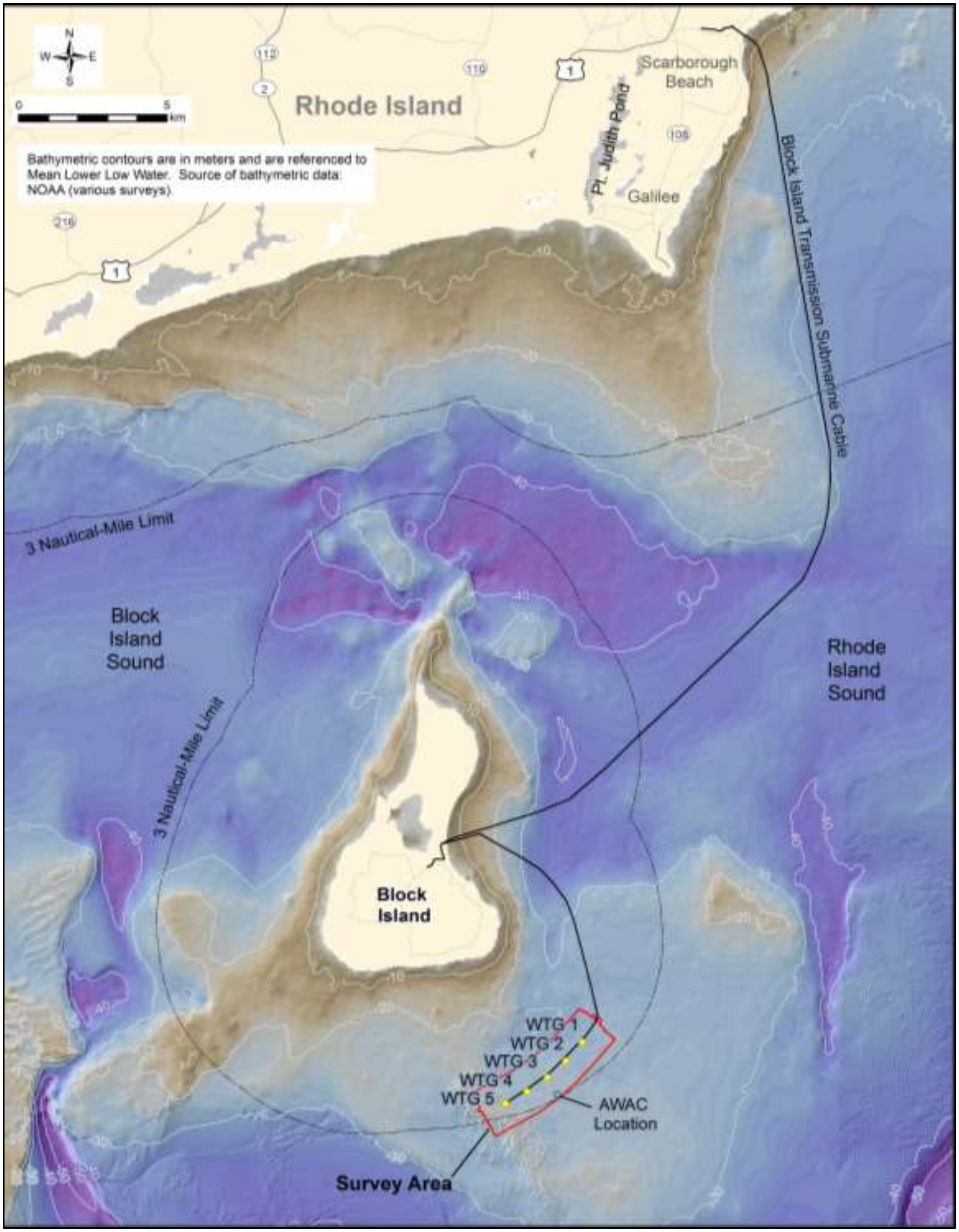



**Figure 64. BIWF seafloor monitoring study area.**

## 5.1 Methods

### 5.1.1 Bathymetry Surveys and Data Processing

The surveys were conducted from a small research vessel using a Reson SeaBat 7125 ultra-high resolution multibeam echosounder. Patch tests and calibration checks were performed at the beginning of each survey. Sound Velocity Profiles were used to correct the bathymetric data for sound refraction or ray bending.

Bathymetric data were edited using the CARIS software. After each survey line was examined and cleaned in CARIS' Swath Editor, the tide corrections were loaded and the lines were merged. The merged dataset was then examined to identify tidal discrepancies, sound velocity errors, motion errors, and data gaps.

All real-time positioning data were converted to World Geodetic System, 1984 (WGS84) (g1150) using an Applanix POS MV positioning system. This real-time positioning was used to process the multibeam survey lines. Horizontal positioning error at the vessel's common reference point is estimated to be less than one meter (during optimal conditions).

All data from the surveys were projected in metric measurement (meters) with the Universal Transverse Mercator (UTM) Zone 19 North coordinate system, using WGS84 geodetic datum. The real-time navigation and position data were used as the geodetic control, receiving differential global navigation satellite system corrections via a G2 subscription to Fugro's OmniStar service. All real-time positioning data were converted to WGS84 (g1150) using an Applanix POS MV positioning system. This real-time positioning was used to process the multibeam survey lines. Horizontal positioning error at the vessel's common reference point is estimated to be less than 1 m (3.3 ft) (during optimal conditions).

Bathymetric data were reduced to mean lower low water based on the National Oceanic and Atmospheric Administration VDatum model[8]. This model provides separation values from the global navigation satellite system ellipsoid down to the chart datum of mean lower low water for the survey area. These values were then applied to the bathymetry using the CARIS HIPS Compute GPS Tide routine.

Once all processing was completed, a digital terrain model (DTM) was generated with CARIS at a 0.5 m (1.6 ft) bin size (**Figure 65**). The ASCII XYZ grid file of easting, northing, and depth values in meters was then output from CARIS for interpretation.

[8] http://vdatum.noaa.gov

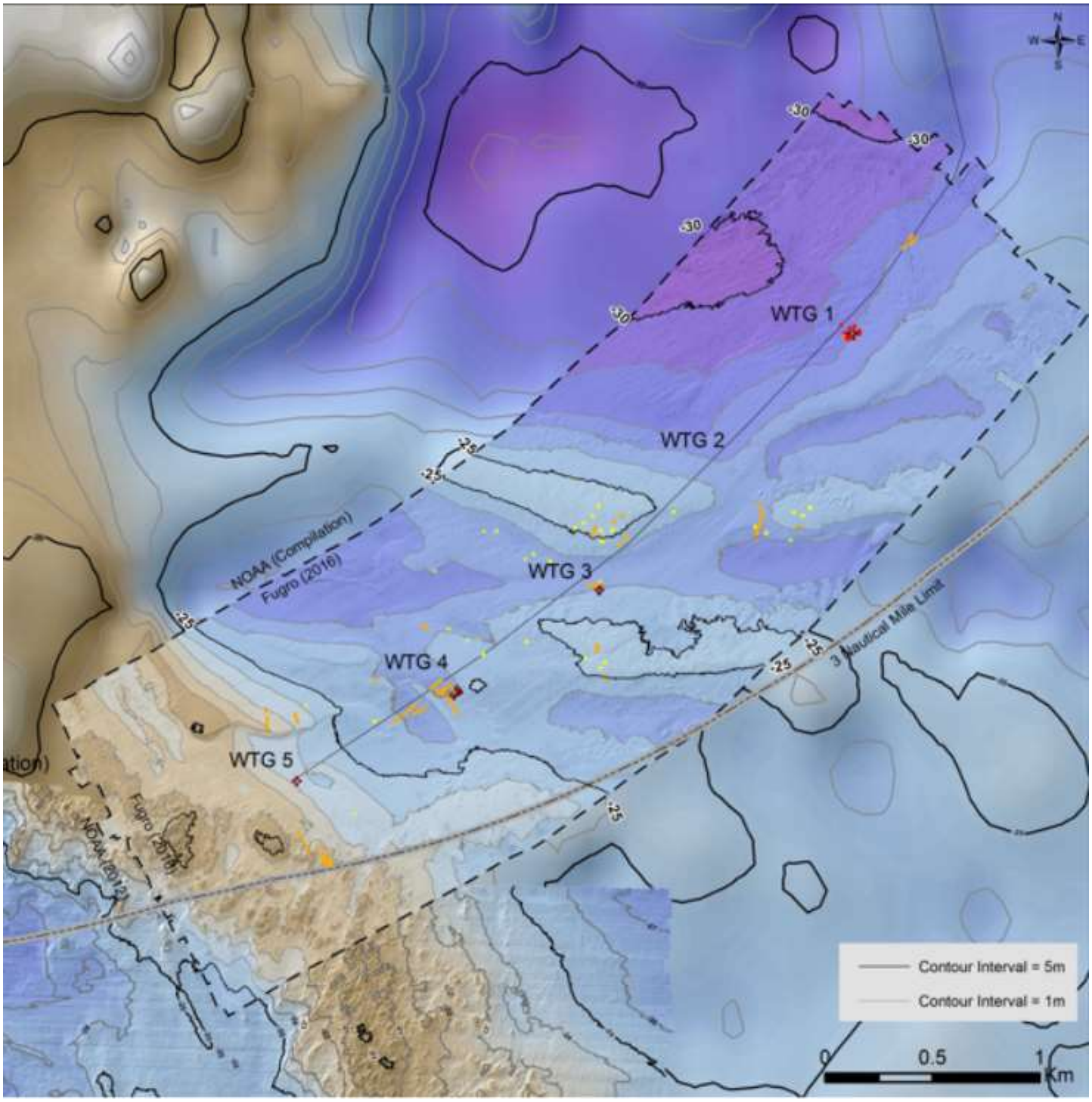



**Figure 65. Bathymetric map from Survey 1.**

### 5.1.2 Data Interpretation

Processed bathymetric data were loaded into a workstation and interpreted using Environmental Systems Research Institute's ArcGIS version 10.4.1 software program. In addition to the DTM, ArcGIS was used to create bathymetric contours and sun-illuminated, hill shaded-relief renderings of the seafloor DTM to enhance seafloor features and aid in visually identifying seafloor disturbances. Initially, a sink-analysis was performed on each survey data set using ArcGIS. The sink-analysis identifies all closed depressions (e.g., spud depression). After the automated screening step was completed, a user reviewed the features and accepted or rejected the feature as being related to construction activities. Also during the review of each feature, the user refined the digitized extent of the feature and calculated the size of each feature (e.g., area, perimeter, and depth). Each digitized feature was associated with the respective construction phase and stored in a GIS database file.

Interpreted seafloor disturbance features (**Figure 66**) are classified based on the following:

- **Spud**: Circular or rectangular depressions arranged in a pattern that match one of the lift boats and are generally located near a WTG. Likely created when a lift boat was on position during installation of the foundation.
- **Circular Depression**: Circular depression not associated with a geometric pattern that would have been created when a lift boat was on position and had all 3 or 4 legs deployed. Circular depression was generally located away from WTG position and may be related to a spud depression or anchor drop.
- **Drag Mark**: Elongated or linear disturbance feature likely created from the dragging of a spud leg or anchor.
- **Scour**: Scour feature that formed around the leg of the jacket foundation or around the concrete mat cable protection.

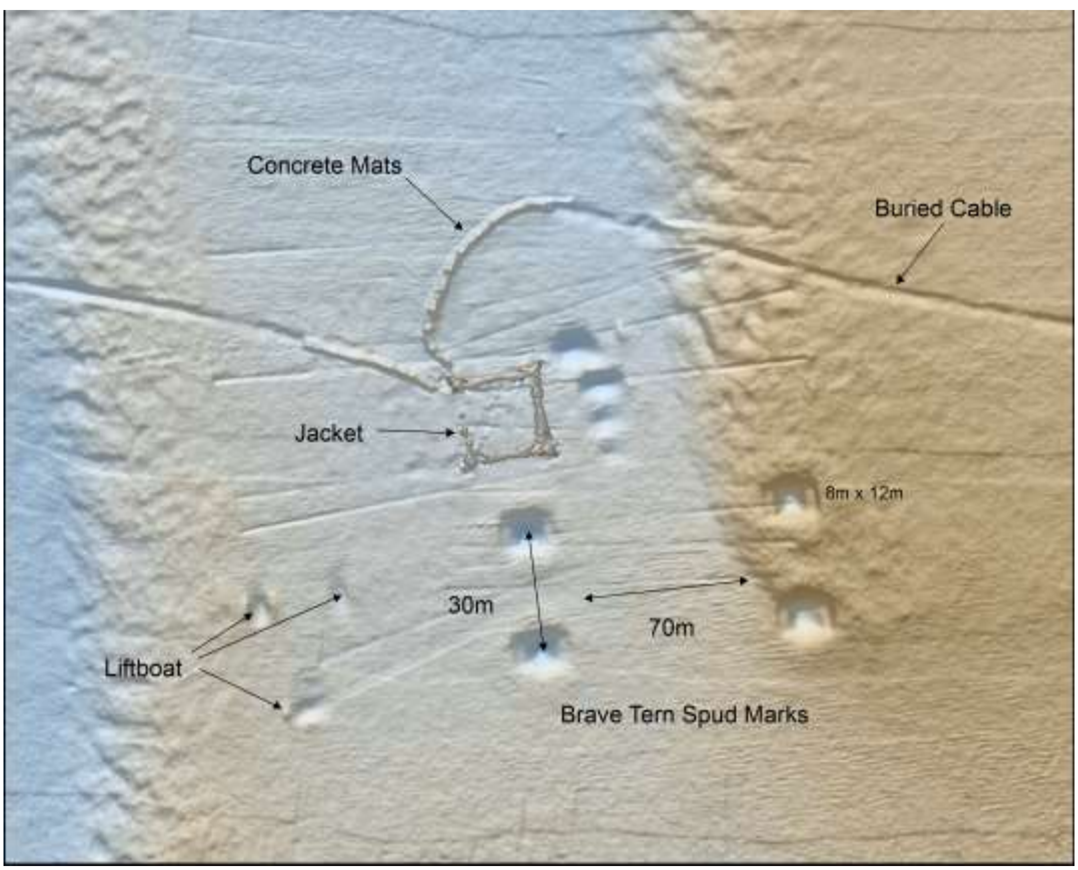



**Figure 66. Examples of seafloor disturbance features at WTG 4 observed in Survey 2 data.**

Features interpreted from each survey were compared to their extents in the previous survey and interpreted to be no change, partially healed, or completely healed. Completely healed features indicate that the feature was no longer discernable in the data.

### 5.1.3 Data Variability and Repeatability

Water depths from an area outside the likely construction impact zone (reference site) were used to establish a baseline degree of variability between the three surveys. Elevation differences between the surveys were obtained by extracting data within the likely impact zone and then subtracting values on a bin node-by-node basis. An average systematic bias of -0.04 (0.1 ft) and 0.02 m (0.07 ft) was observed in the sample set that can likely be attributed to tidal error, subtle boat draft discrepancies, and normal limitations associated with multibeam head calibration.

### 5.1.4 Data Quality

Sea states during the May 2016 survey were calm, resulting in good quality raw data. Minimal data processing was required to generate bathymetric deliverables that were free of motion artifacts and other surface noise. Sea states during the October 2016 were fair to marginal. Quality of the raw data collected during the October 2016 survey was reported to be affected by the marginal sea states and motion artifacts were noted on the outer portions of the bathymetric swath.

Post-acquisition data processing resulted in final deliverables of good quality; however, some motion related artifacts are still observable in the final DTM but the data are deemed adequate for meeting the study’s objectives. Data quality for the raw data collected for the May 2017 survey was affected by some motion in the moonpool at the time of the survey; however, the overall data quality was good and post-acquisition data processing resulted in final deliverables of good quality.

## 5.2 Results and Findings

### 5.2.1 Survey 1

During the first survey 160 seafloor disturbance features were interpreted. These features collectively covered approximately 11,570 square meters ($m^2$) (**Table 28**). Circular depressions comprise the largest number of features; drag marks made up the largest total area of the five different categories of features.

### 5.2.2 Survey 2

During the second survey, 103 new seafloor disturbance features were interpreted. These features collectively comprise an area of approximately 6,876 $m^2$ (**Table 28**). Circular depressions comprised the largest number of features; however, spud impressions comprise the largest total area of the three different categories of features. New seafloor disturbance features that appeared to be associated with the Construction Phase 2 were concentrated around each of the five WTG locations and along the inter-array cable route.

### 5.2.3 Survey 3

Data from Survey 3 indicated that of the 160 disturbance features that were noted during the first survey, 64 features had partially healed and 75 were completely healed (**Table 28**). The completely healed features covered approximately 4,194 $m^2$, which indicated that approximately 36 percent of the disturbed area has completely healed. Sixty of the 75 features that have completely healed were in or adjacent to areas comprised predominantly of fine-grained sand. The other 15 features were in areas comprised of predominantly medium- to coarse-grained sand. The data indicate that disturbance features in areas of predominantly fine-grained sand recovered faster than in areas comprised predominantly of medium- to coarse-grained sand.

**Table 28. Comparison of bathymetry data from Surveys 1, 2 and 3.**

| Interpreted Features | Construction Season Baseline Disturbance | | | | | | Construction Season 1 (2015) Disturbances | | | | | | Construction Season 2 (2016) Disturbances | | | 2015 and 2016 Disturbances Recovery | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Construction Season 1 (2015) Features | | Construction Season 2 (2016) Features | | Construction Seasons 1 and 2 Total | | Recovery Since Baseline at Time of Survey 2 (Oct. 2016) | | | Recovery Since Baseline at Time of Survey 3 (May 2017) | | | Recovery Since Baseline at Time of Survey 3 (May 2017) | | | | |
| | Number of Features | Area ($m^2$) | Number of Features | Area ($m^2$) | Number of Features | Area ($m^2$) | Partially Healed Features | Completely Healed Features | Completely Healed Area ($m^2$) | Partially Healed Features | Completely Healed Features | Completely Healed Area ($m^2$) | Partially Healed Features | Completely Healed Features | Completely Healed Area ($m^2$) | Completely Healed Area ($m^2$) | Percent Disturbed Area Completely Healed |
| Spud | 26 | 1,102 | 37 | 4,152 | 63 | 5,254 | 19 | 0 | 0 (0%) | 8 | 18 | 663 (60%) | 25 | 12 | 830 (20%) | 1,493 | 28% |
| Circular Depressions | 69 | 2,803 | 51 | 1,595 | 120 | 4,398 | 0 | 3 | 58 (2%) | 31 | 38 | 1,454 (52%) | 8 | 43 | 1,298 (81%) | 2,752 | 63% |
| Drag Marks | 44 | 6,414 | 13 | 1,129 | 57 | 7,543 | 1 | 12 | 1,300 (20%) | 25 | 19 | 2,077 (32%) | 1 | 12 | 1,061 (94%) | 3,138 | 42% |
| Total | 160 | 11,570 | 103 | 6,928 | 263 | 18,498 | 20 | 15 | 1,358 (13%) | 64 | 75 | 4,194 (36%) | 34 | 68 | 3,189 (46%) | 7,383 | 40% |

Note: Features were categorized as partially healed if the disturbance feature had lessened in size or depth but still remained discernible. A feature was labelled as completely healed if the feature was no longer discernible in the data set. Scour features were not included in these statistics because they are likely to be present as longs as the structures (e.g., foundations) are present.

Also, of the 103 disturbance features noted from the Survey 2 data, Survey 3 data indicated that 68 features had completely healed, 34 were partially healed, and 1 feature showed signs of recovery. The completely healed features comprised an area of 3,189 $m^2$, which indicated that approximately 46 percent of the disturbed area has completely healed. Fifty-six of the 68 features that have completely healed were in or adjacent to areas comprised of predominantly fine-grained sand. The other 12 features were in areas comprised of predominantly medium- to coarse-grained sand. The data indicate that disturbance features in areas of predominantly fine-grained sand are recovery faster than in areas comprised predominantly of medium- to coarse-grained sand.

Survey 3 data also identified 12 new scour features that had developed around the concrete mats placed to protect the cable at the turbine entry points. Cable sections near the wind turbines were intentionally left unburied until the cables were pulled into the wind turbines. After the cable pulls, concrete mats were placed on the unburied sections of cables for protection. This scour development was only observed on turbines 1 and 2. These disturbance features comprised an area of approximately 844 $m^2$. Scour appears to be notably deeper and wider on the northwestern side of the mats which potentially indicates there was a dominate bottom current flow direction.

Comparison of data from the three surveys identified changes in seafloor bedforms that indicate the seafloor was active during the time between surveys. Ripple fields changed in spatial extent and ripples also changed in orientation and size between Surveys 1 and 2 and then again between Surveys 2 and 3. Ripples were two times taller in Survey 1 and 3 (conducted at the end of winter) than observed in Survey 2 (conducted at the end of summer) where they were approximately 5 to 10 centimeters (cm) (1.8 to 3.9 inches) and 10 to 15 cm (3.9 inches to 5.9 inches) tall, respectively.

Seafloor recovery rates generally correspond to seabed mobility (**Figure 67**). Based on data collected during the three surveys, seafloor mobility within the Project Area was classified into three zones (Zones 1, 2 and 3) and two subzones (Zones 1a and 2a). Seafloor mobility was observed to be the highest within Zone 1, moderate in Zone 2, and low in Zone 3. In general, zones of higher seafloor mobility correlate with higher sediment infill/seafloor disturbance recovery rates.

Prior studies have shown that seafloor disturbances generally recover more rapidly over areas of higher water column energy, shallower bathymetry, smaller particle size, faster current speeds, and/or higher sediment mobility (Sherwood 2011; Smith and McNeilan 2011; and Sumer and Fredsoe 2002). Therefore, seafloor disturbances within Zone 1 are likely to recover faster than those observed in Zones 2 or 3. Of the 143 disturbance features noted to have completely “healed,” 116 were located in or immediately adjacent to Zone 1 (**Table 28**).

**Table 28** compares the interpreted data from the three surveys. A side-by-side comparison of the changes in the seafloor bed that were detected at the five turbines during the three surveys is shown in **Figure 68**.

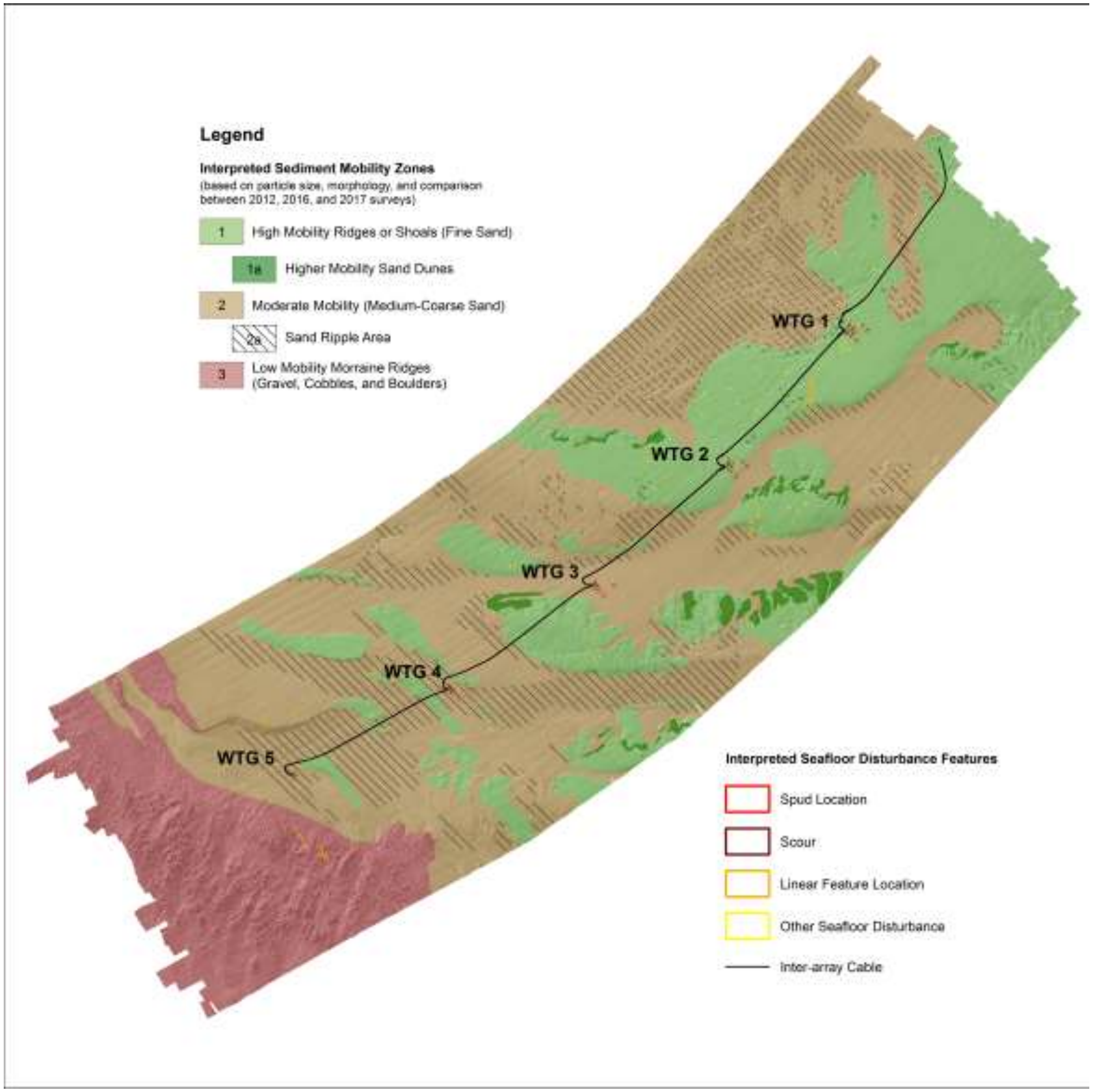



**Figure 67. Interpreted sediment mobility zones.**

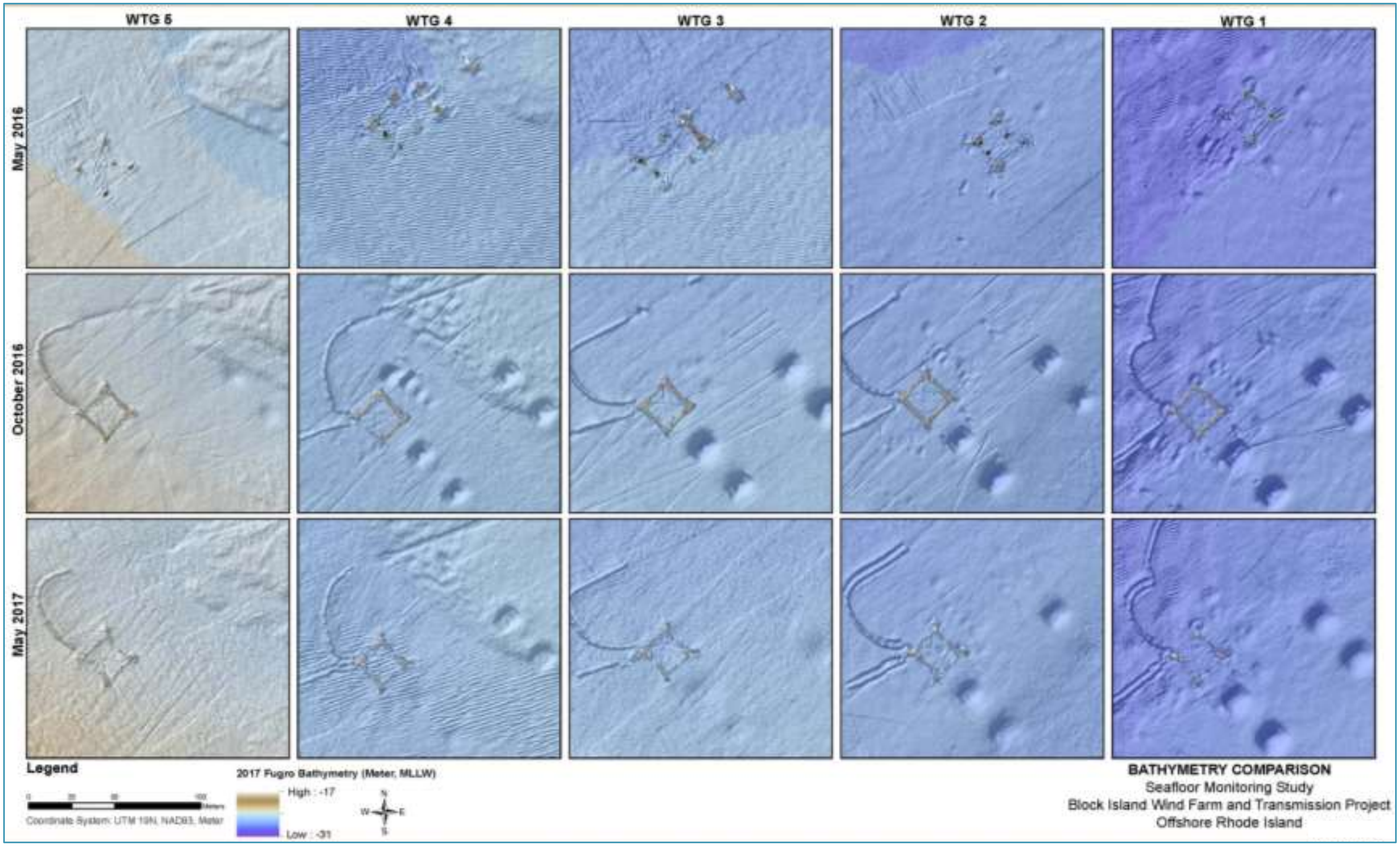



**Figure 68. Side-by-side comparison of the seabed disturbance and recovery monitoring data from the three bathymetry surveys.**

### 5.2.4 Wind Turbine Generator 1

WTG 1 is located in the northeastern-most section of the study area. The surficial sediment around this turbine are characterized by coarse- to medium-grained sand with fine gravel and include patches of rippled sand and gravel. The May 2016 bathymetry surveys showed 21 well-defined seafloor disturbances around this turbine as a result of the Phase 1 construction activities. Over a 12-month period (i.e., through May 2017), 12 of the 21 disturbances appeared to have completely healed and are were not discernable, 5 appeared diminished in depth most likely due to sediment infilling of up to 8 cm (3.2 inches), and the remaining four disturbances did not show any significant change.

The October 2016 bathymetry survey indicated 48 well-defined disturbance features around turbine 1 as a result of the Phase 2 construction activities. Over a seven month period (through May 2017), 33 of the 48 were completely healed and the remaining 15 showed varying levels of recovery because of sediment infilling.

The May 2017 survey showed that several new scour features appear to have formed on the seafloor around this turbine since the completion of the Phase 2 construction activities. These features include disturbances on either side of the concrete mats that were placed on top of the inter-array cable to provide protection to the section of cable that was intentionally not buried. The depth of scour for these features ranges from 5 to 20 cm (2 to 7.9 inches) and extends up to approximately 3 m (9.8 ft) from the concrete mats. Scour development appears to be more extensive in both depth and size on the northwest side of the cable, possibly indicating a dominant flow direction of bottom currents.

### 5.2.5 Wind Turbine Generator 2

WTG 2 is also located in the northeastern-most section of the study area and surficial sediments in this area are similar to those observed around turbine 1. The May 2016 bathymetry surveys showed 10 well-defined seafloor disturbances around this turbine as a result of the Phase 1 construction activities. Over a 12-month period (through May 2017), 4 of the 10 features appeared to have completely healed and were no longer discernable, 2 were reduced in depth because of sediment infilling of up to 3 cm (1.2 inches), 1 appeared to have widened in extent to the northwest by approximately 1.5 m (4.9 ft), and the remaining 3 did not show any change (**Figure 69**).

The October 2016 bathymetry survey indicated 16 well-defined disturbance features around turbine 2 as a result of the Phase 2 construction activities. Over a 7-month period (through May 2017), 7 of the 16 features were completely healed and are no longer discernable, and the remaining 9 experienced some degree of change associated with sediment infilling.

The May 2017 survey showed several new scour features that were formed since the completion of the Phase 2 construction activities. These scour features were observed on either side of the concrete mats that were placed on top of the inter-array cable to provide protection of the section of cable that was intentionally not buried. The depth of scour ranged from 5 to 20 cm (2 to 7.9 inches) and extends up to approximately 3 m (9.8 ft) from the concrete mats. Scour development appeared to be more extensive in both depth and size on the northwest side of cable, possibly indicating a dominant flow direction of bottom currents.

### 5.2.6 Wind Turbine Generator 3

WTG 3 is located in the central section of the study area, in a slightly deeper channelized area of the seafloor where wave ripples were more dominant. The surficial sediment surrounding this turbine is predominantly medium-grained sand with a minor component of fine gravel. The May 2016 bathymetry surveys showed eight well-defined seafloor disturbances around this turbine as a result of the Phase 1 construction activities. Over a 12-month period (through May 2017), four of the eight features remained unchanged.

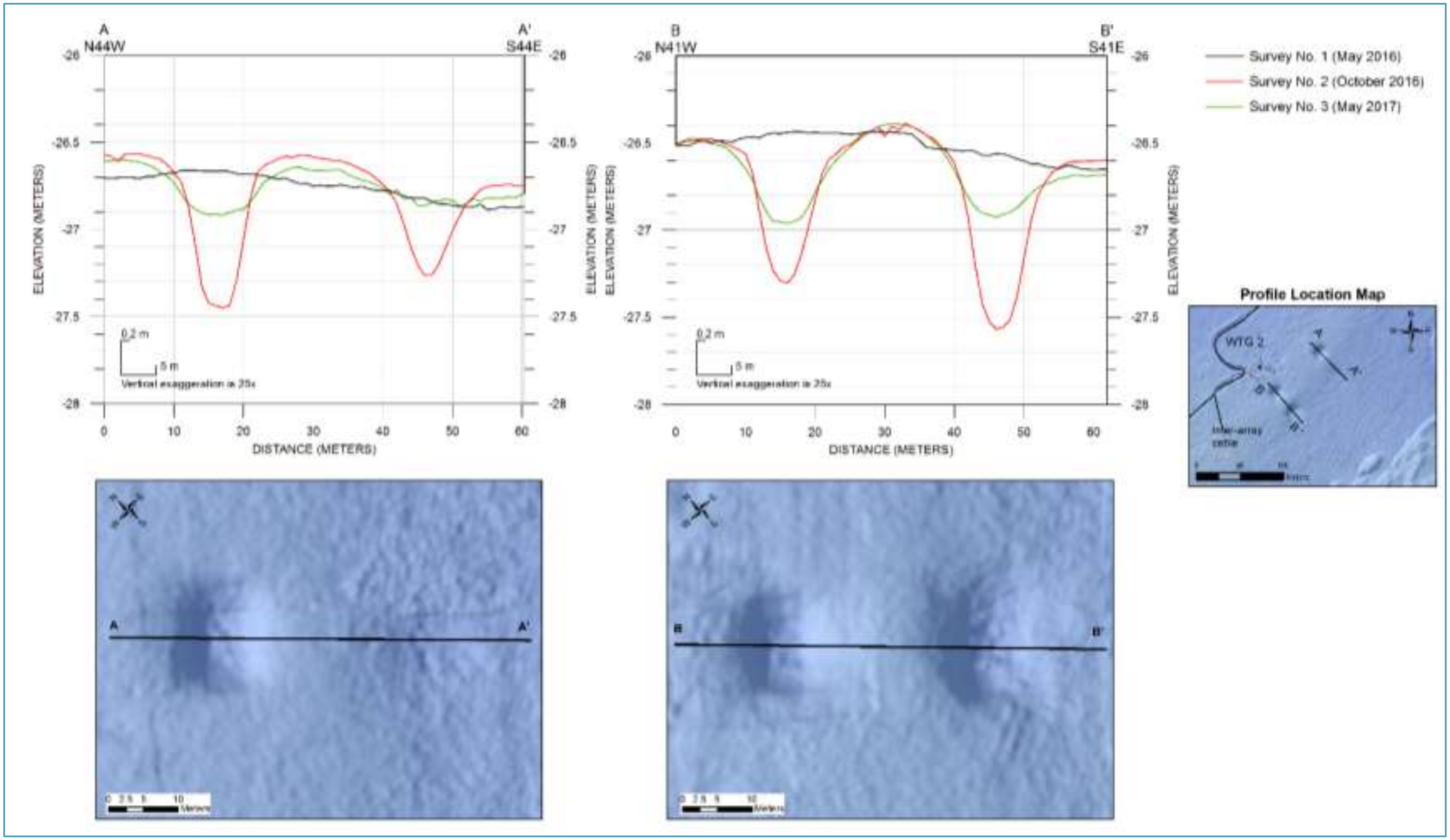



Figure 69. Recovery of spud depressions at WTG 2.

The October 2016 bathymetry survey revealed four spud depressions around WTG 3 as a result of the Phase 2 construction activities. Over a 7-month period (through May 2017), 1 feature was completely healed and the remaining three showed decrease in depth because of sediment infilling of an average of 1 m (3.3 ft). No new seafloor disturbance features were observed on the seafloor around turbine 3 in May 2017.

### 5.2.7 Wind Turbine Generator 4

WTG 4 is located in the southwestern section of the study area and the surficial sediment surrounding this turbine is made up of coarse sand and contains alternating patches (ridges/furrows) of sand and gravel. Wave ripples up to 10 cm (3.9 inches) were also observed on the seafloor. The May 2016 bathymetry surveys showed nine well-defined seafloor disturbances around this turbine as a result of the Phase 1 construction activities. Over a 12-month period (through May 2017), four of the nine features were completely healed and the remaining five showed no measurable change.

The October 2016 bathymetry survey revealed 10 disturbance features around WTG 4 as a result of the Phase 2 construction activities. Over a 7-month period (through May 2017), 6 of the 10 were completely healed, and the remaining 4, which were spud depressions, underwent varying levels of sediment infilling. Of four spud depressions that were still discernable in May 2017, the two located towards the southwest seemed to have filled in with twice as much sediment as compared to the two located to the northwest (**Figure 70**). The differential rate of infilling is probably due to the southwesterly depressions being located in an actively migrating sand ripple field. No new seafloor disturbance features were observed on the seafloor around WTG 4 in May 2017.

### 5.2.8 Wind Turbine Generator 5

WTG 5 is also located in the southwestern section of the study area and the surficial sediment surrounding this turbine is predominantly medium sand. The May 2016 bathymetry surveys showed four well-defined seafloor disturbances around this turbine as a result of the Phase 1 construction activities. Over a 12-month period (through May 2017), none of these features showed significant change. The October 2016 bathymetry survey also showed four disturbance features around WTG 5 as a result of the Phase 2 construction activities. Over a 7-month period (through May 2017), all four features were completely healed. No new seafloor disturbance features were observed on the seafloor around WTG 5 in May 2017.

### 5.2.9 Seafloor Disturbances Elsewhere in the Work Area

The May 2017 survey showed that approximately 45 percent of the disturbances that resulted from Phase 1 construction activities in the Work Area (outside of the immediate vicinity of the turbines) were completely healed and the rest showed varying levels of sediment infilling. Also, approximately 87 percent of the disturbances that from Phase 2 construction activities were completely healed and the rest showed some change as a result of sediment infilling.

### 5.2.10 Surficial Sediment Mobility

Bathymetry survey data indicated variable bedforms in the BIWF Project Work Area. The bedforms varied both in size (dune and ripple scale) and orientation. From May 2016 to May 2017, orientation and location of individual bedforms appeared to have changed. Ripple fields changed in spatial extent and ripples also changed in orientation and size between Surveys 1 and 2 and then again between Surveys 2 and 3. Ripples were two times taller in Survey 1 and 3 (conducted at the end of winter) than observed in Survey 2 (conducted at the end of summer).

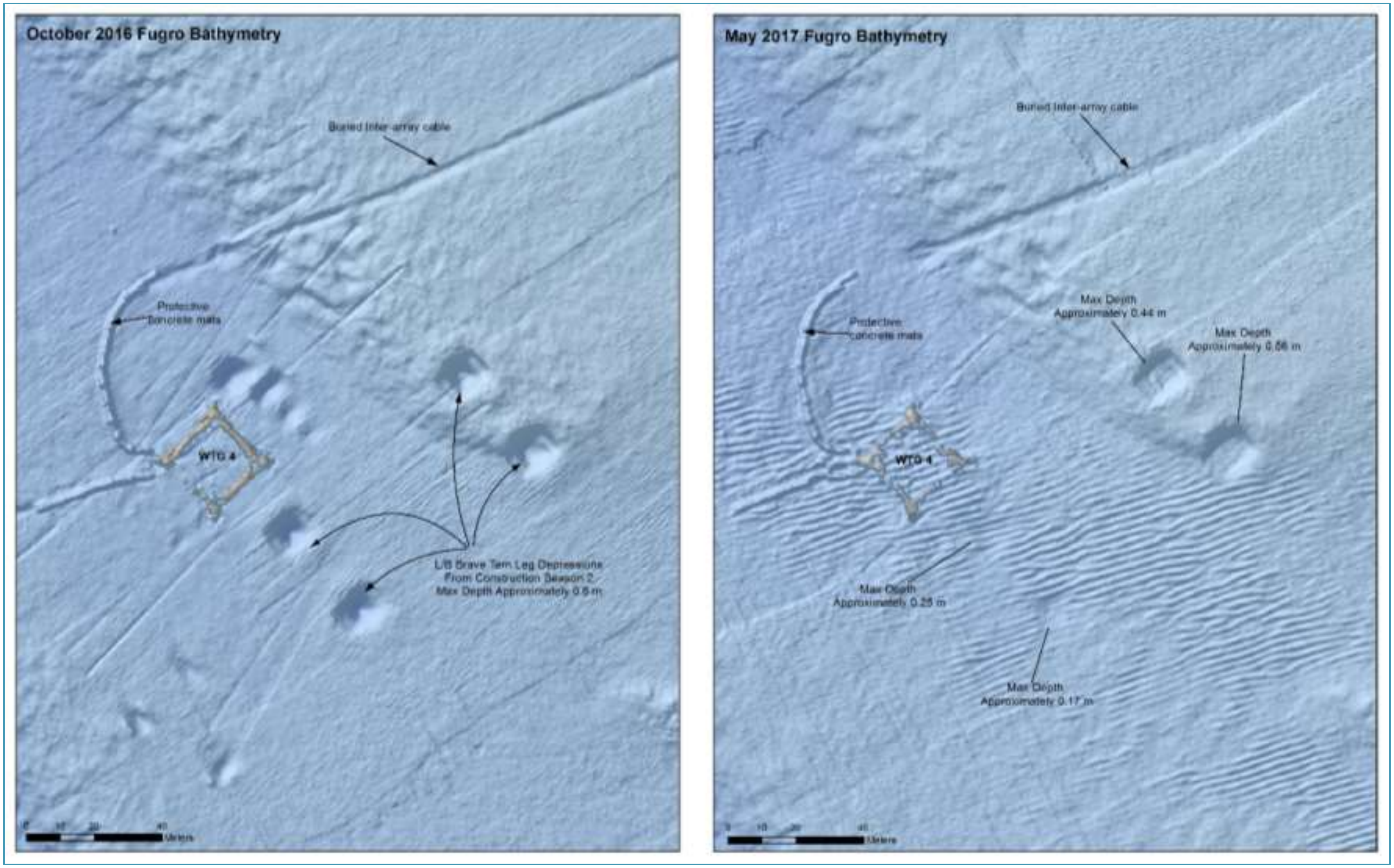



**Figure 70. Variability in seafloor recovery at WTG 4.**

These bedform changes were primarily responsible for the varying levels of disturbance feature sediment infilling that was observed. Changing seasons also seem to have influenced the sediment mobility, which in turn influenced rate of seabed recovery.

### 5.2.11 Overview of Spatial Extent of Disturbance at Wind Turbines

The spatial extent of seafloor disturbance surrounding the WTGs were evaluated. This evaluation provides information that may be used to aid in defining the size of construction corridors where construction equipment is permitted to disturb the seafloor. Currently in the United States, marine archaeological resource assessment surveys of all areas potentially impacted by construction are required prior to conducting activities (e.g., construction, geotechnical exploration, etc.) that will disturb the seafloor. If the surveys and subsequent construction activities could be constrained to corridors in the wind farm, then this could result in a reduction of the amount of area surveyed and ultimately time and costs associated with the surveys.

It should be noted that the BIWF construction activities were not confined to a corridor but were restricted to an area identified (referred to as the Work Area), which was surveyed under this monitoring study. Therefore, seafloor disturbances identified outside the corridors discussed herein do not necessarily indicate that a corridor approach is not feasible. However, developers would need to carefully consider the corridor width required for their equipment.

It appears that the WTG installation vessels (Brave Tern and supporting lift boat [**Figure 71**]) occupied an area within 150 m (1,476.4 ft) around each turbine. Most of the seafloor disturbance occurred within an approximately 300 to 600 m (984.3 to 1,968.5 ft)-wide corridor (**Figure 72**).

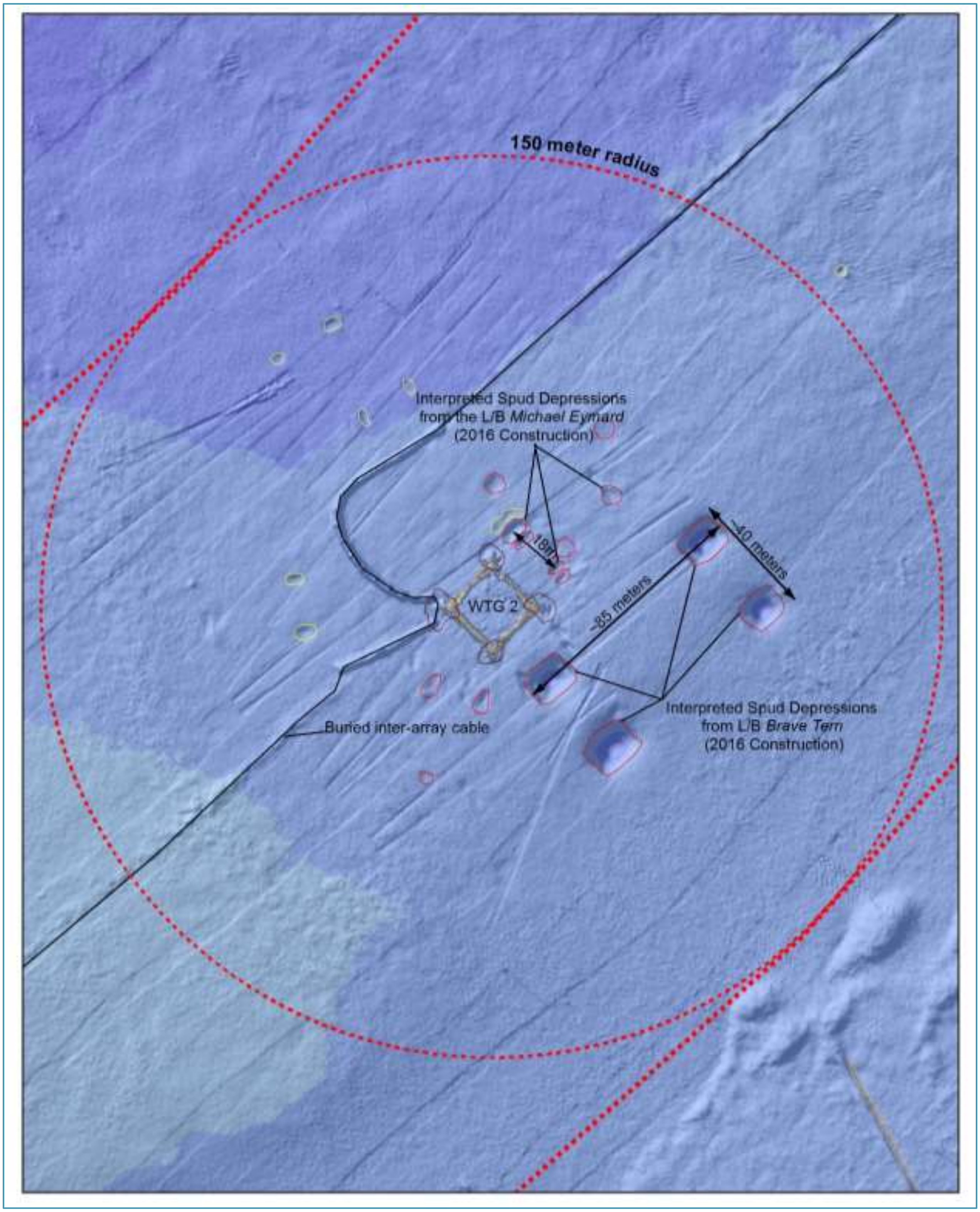



**Figure 71. Installation vessel impact extent at WTG 2.**

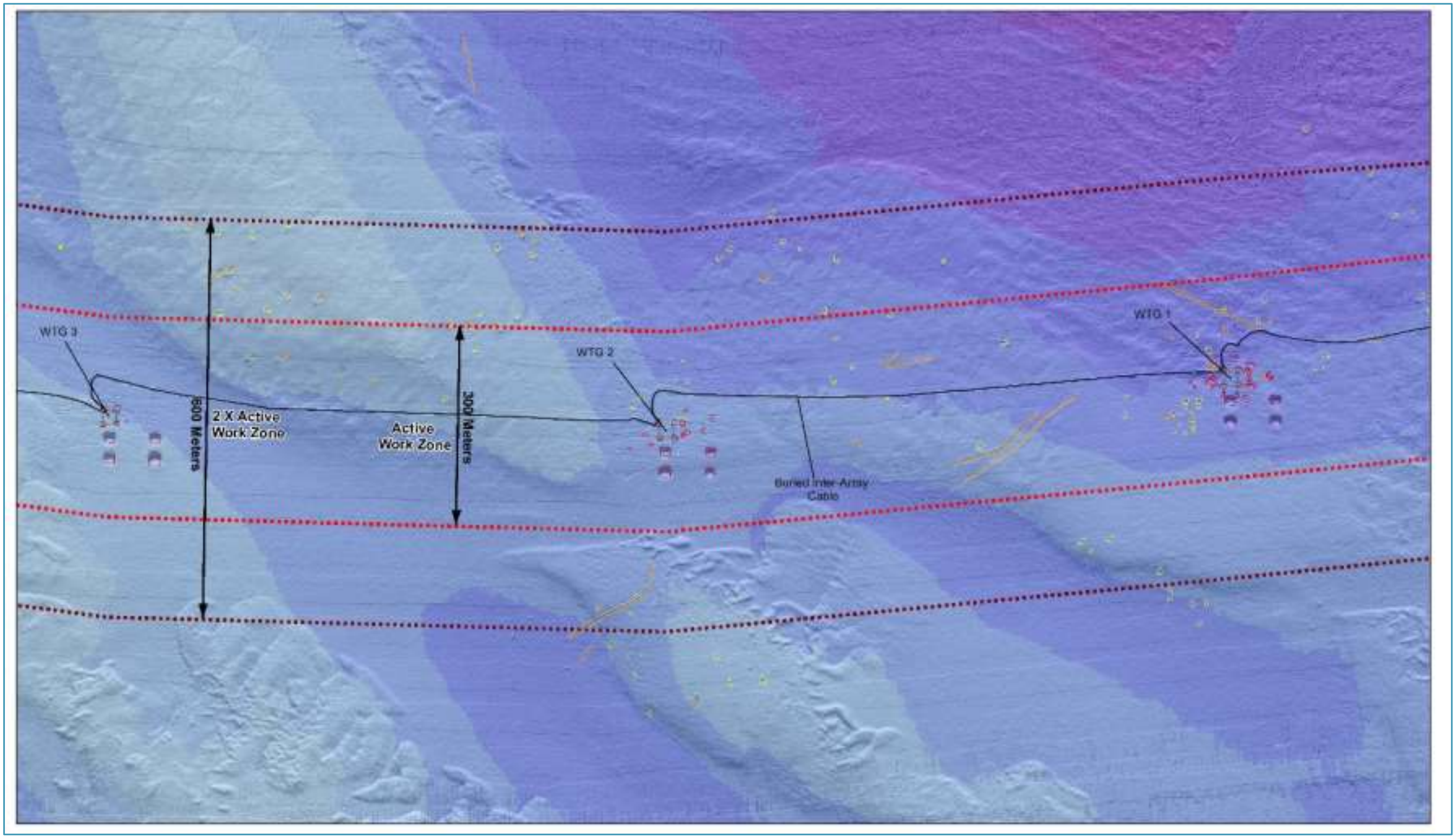



**Figure 72. Seafloor disturbance corridor resulting from construction.**

## 5.3 Wind Turbine Scour Assessment

The primary objective of this task was to develop, implement, and test a methodology for monitoring scour around the WTG foundations using a scour monitor. The results of the scour monitoring will be used to guide design of field studies for monitoring scour conditions at future offshore WTGs. A detailed technical report from the scour assessment is contained in **Appendix F**.

### 5.3.1 Monitoring Approach and Methods

Two scour monitors (**Figure 73**) were installed on the BIWF WTG 3 foundation and changes in seabed levels (scouring patterns) near the foundations were tracked over a 14-month period[9]. The units were serviced every 3 months. An acoustic wave and current profiler (AWAC) was also simultaneously deployed on a seabed frame approximately 500 m (1,640.4 ft) southeast of the turbine (**Figure 73**). The wave, water level and current data collected by the AWAC were used to inform assessment of the factors affecting seabed level changes as measured by the scour monitors. A comprehensive dataset of seabed elevations near the turbine foundation and associated oceanographic data was generated by the study. The data were analyzed to improve understanding of factors that influence scouring rates and patterns.

**Figure 73. Scour monitor in bracketing (left); Seabed frame and AWAC (right).**

**Table 29** and **Figure 74** show the instrument deployment locations and dates. Following the deployment in June 2016, the monitors were serviced in November 2016, March 2017, and October 2017. **Figure 75** is a schematic illustrating the position of the scour monitors on the turbine foundation.

**Table 29. Equipment positions – deployment.**

| Location Name | Latitude (WGS84) | Longitude (WGS84) | UTM Coordinates (NAD83 Zone 19 N) | Deployment Date |
|---|---|---|---|---|
| Seabed Frame | 41° 06’ 34.5” N | 071° 31’ 00.5” W | 288674.5 m E, 4553973.8 m N | 15 June 2016 |
| Anchor Weight | 41° 06 ’36.2” N | 071° 31’ 01.1” W | 288662.0 m E, 4554026.6 m N | 15 June 2016 |
| Scour Monitors (WTG 3) | 41° 06’ 54.0” N | 071° 31’ 15.6” W | 288339.6 m E, 4554585.4 m N | 28 July 2016 |

See the Scour Monitoring Technical Report in **Appendix F** for additional information on the scour monitor and AWAC configuration and techncial specifications.

[9] Scour monitor data were collected for 14 months and 19 days; AWAC data were collected for 16 months and 3 days.

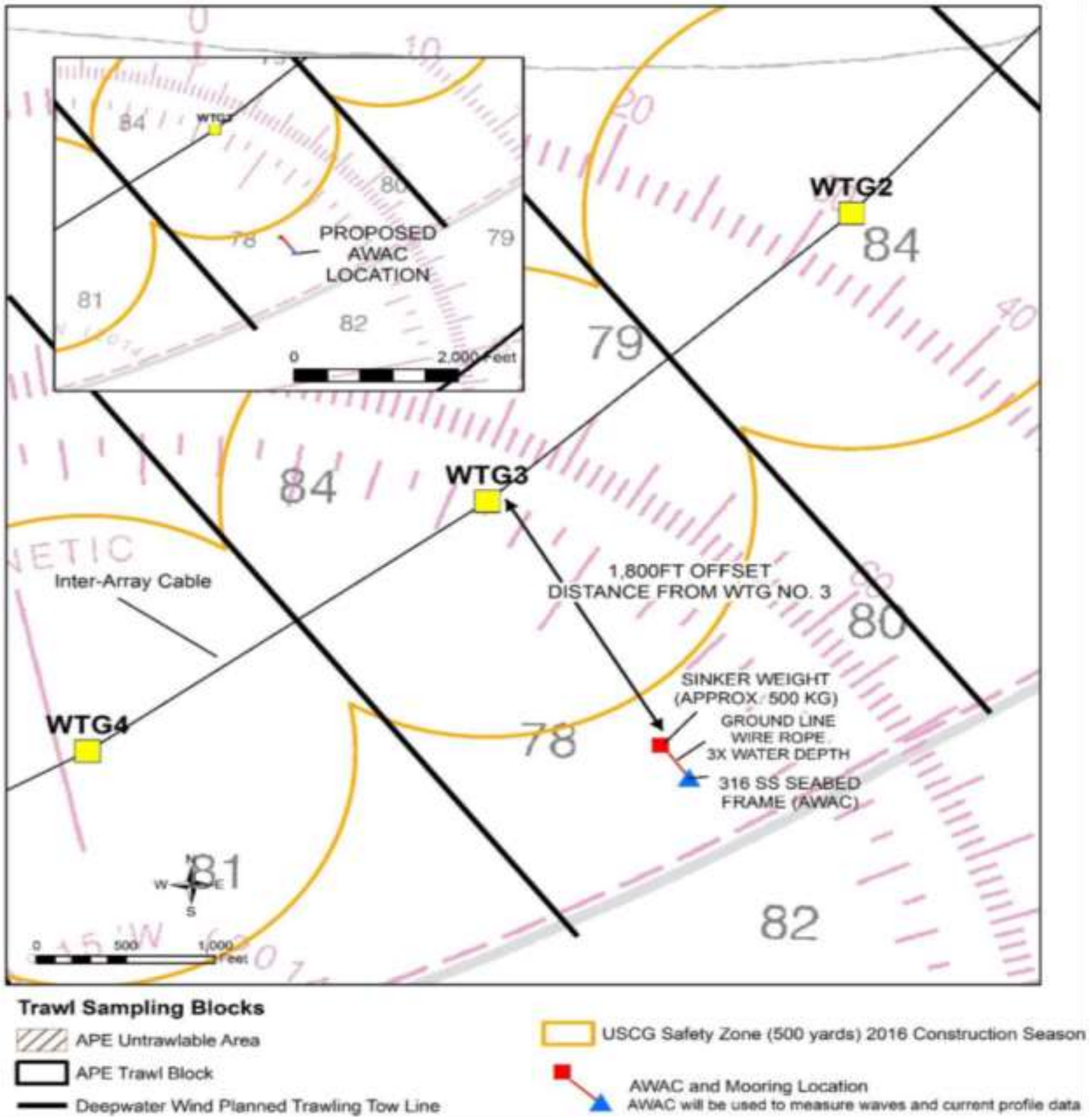



**Figure 74. Location of deployed equipment.**

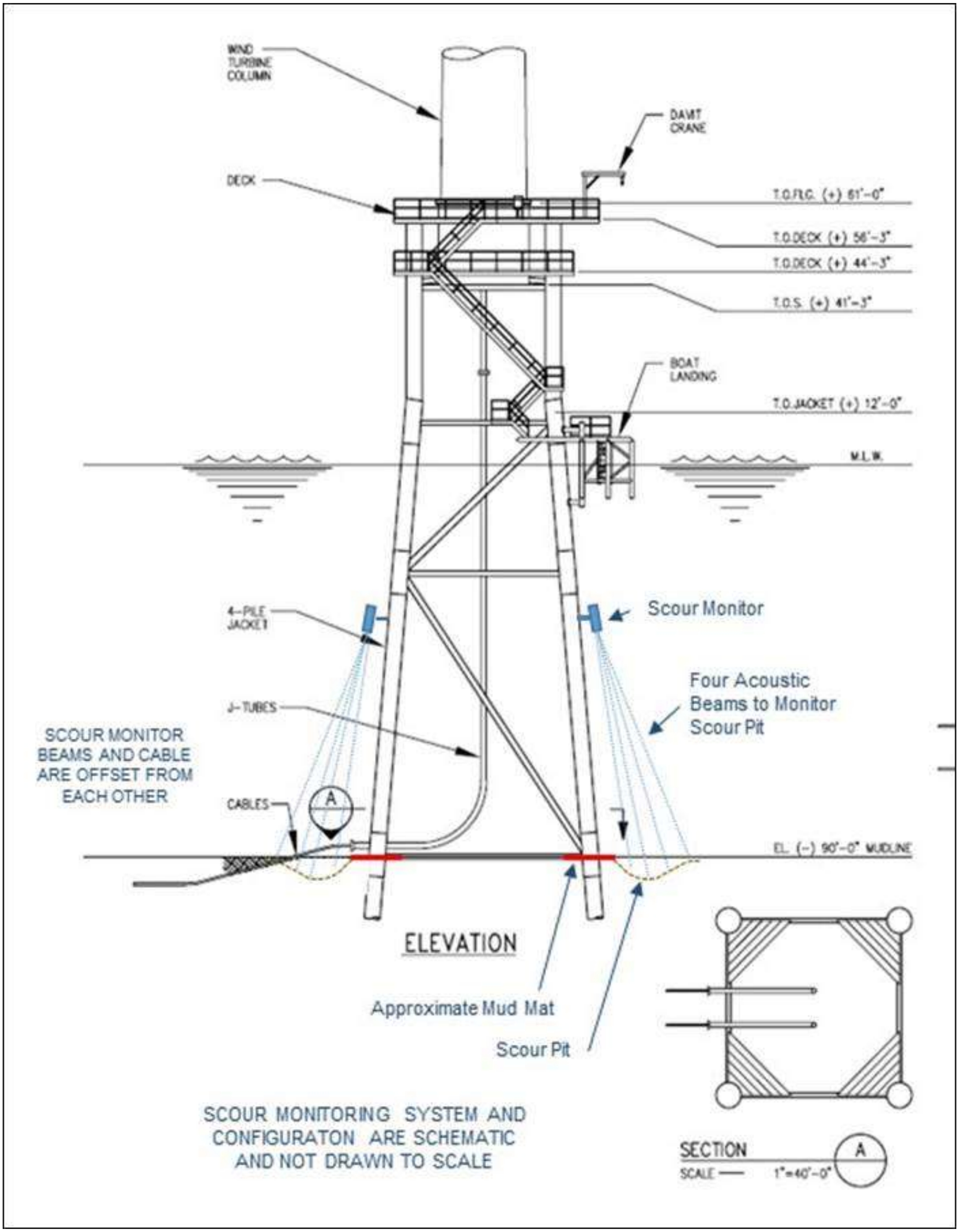



**Figure 75. Positioning of the scour monitors on the turbine foundation.**

### 5.3.2 Monitoring Results

A comprehensive dataset of seabed elevations near the turbine foundation and associated oceanographic data was generated by the study. The data were analyzed to improve understanding of factors that influence scouring rates and patterns.

#### 5.3.2.1 Oceanographic Data Summary

##### 5.3.2.1.1 Water Levels

The Block Island tidal environment is dominated by the open ocean tidal signal, and is therefore characterized by a semidiurnal micro-tidal (less than 2 m [6.6 ft] range) signal. The mean spring range is 1.1 m (3.6 ft) and the mean high water to mean low water interval difference is 6.1 hours; thus, the tide curve is near symmetrical. The autumn and winter months show multiple periods of non-tidal (residual) sea level variations. **Figure 76** presents an extract of the sea level observations and the calculated non-tidal values from a 60-point harmonic analysis of the 16 months of data. The residual values vary by up to ± 0.5 m (1.6 ft) and are thus approximately the same range as the astronomically forced tide. The form of these appear to indicate two potential forcing processes:

- Short to medium term suppression or enhancement of the sea level resulting from atmospheric forcing, either variations in atmospheric pressure or wind enhancement
- 24- to 48-hour oscillations in the residuals that are indicative of a coastally trapped (or Kelvin) wave, however additional data and analysis would be needed to correctly define these.

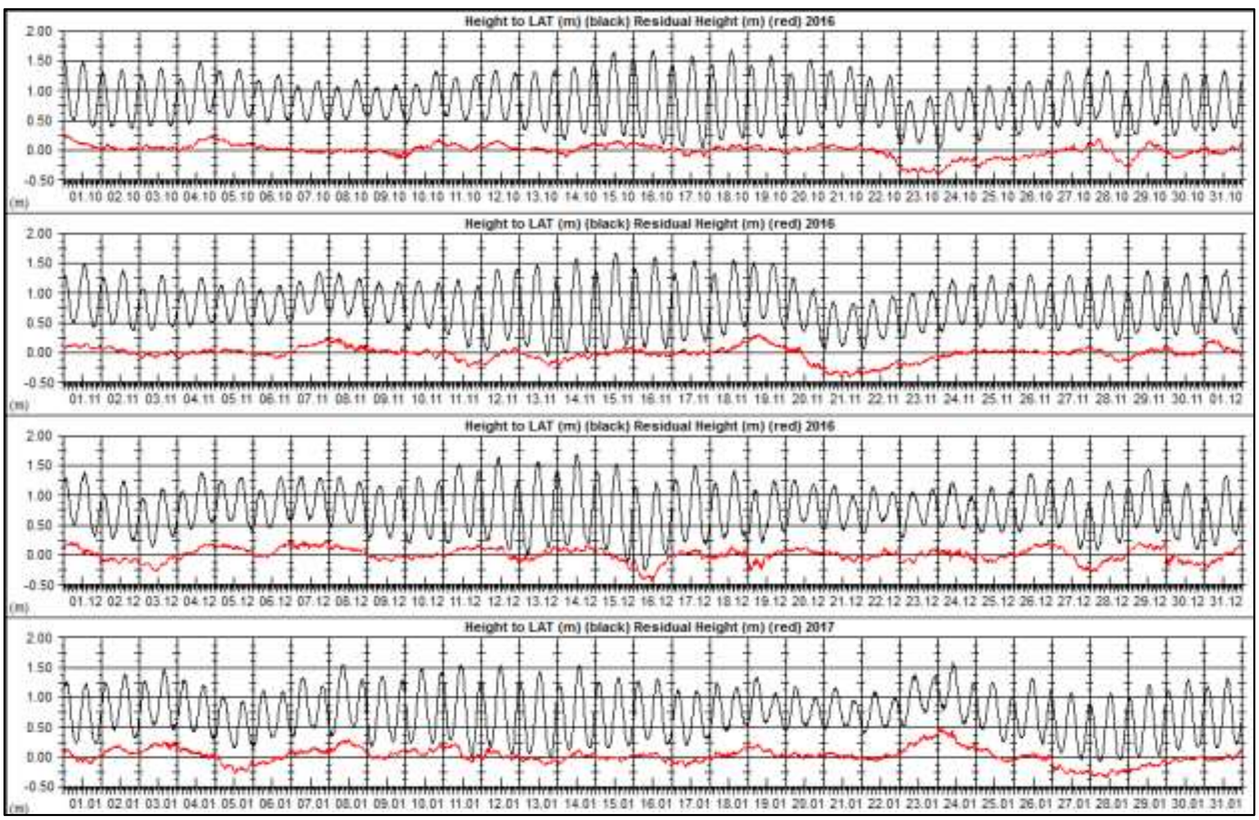



**Figure 76. Winter water level data – height to lowest astronomic tide and residuals.**

### 5.3.2.1.2 Currents

The current data recorded at the study location were orientated along a northeast–southwest axis. The maximum expected depth average tidal current is predicted to be less than 0.4 m/s, based on the results of a 60-point harmonics analysis. The non-tidal component of the flow exceeds the tidal component. **Figure 77** presents the depth average observed current and the non-tidal component, which is of the same magnitude as the observations on multiple occasions. This indicates that atmospheric forcing of the current is dominant in the study area.

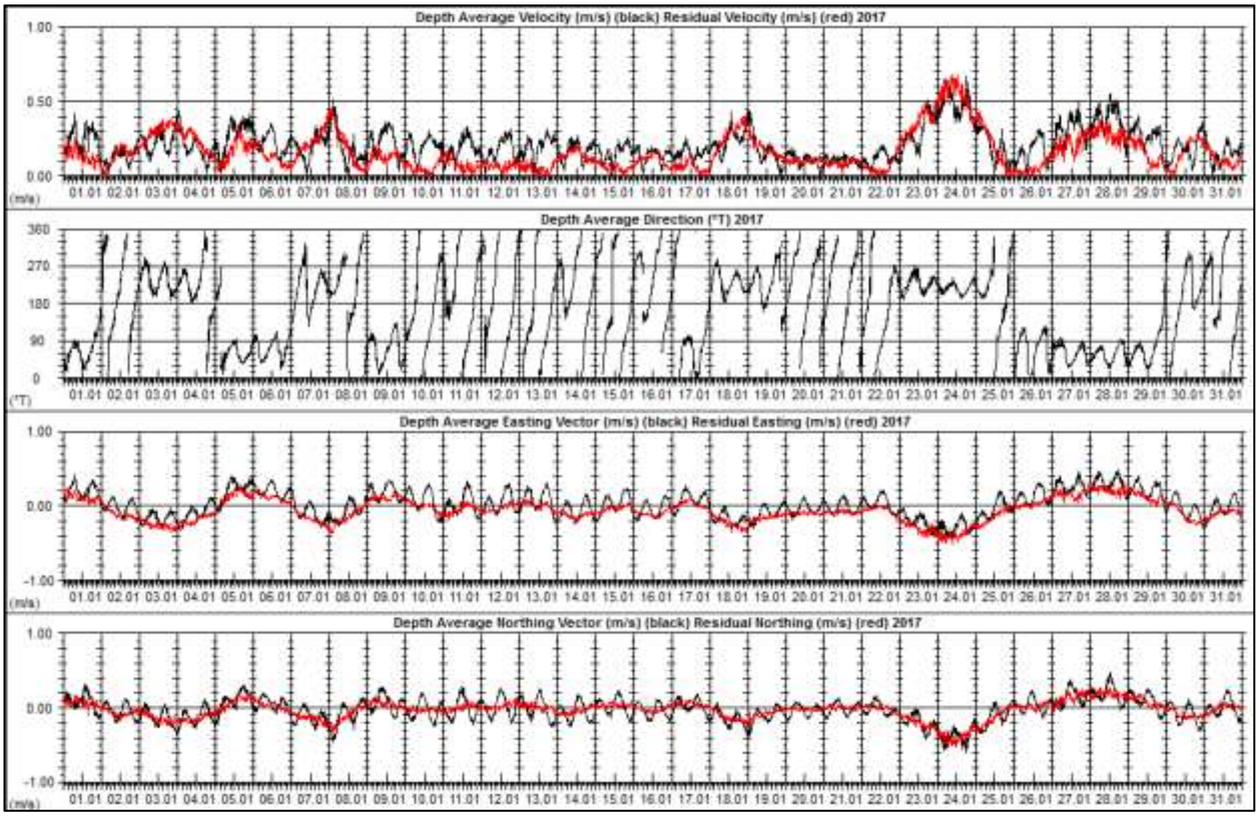



**Figure 77. January 2017 current data – observed and non-tidal components.**

In order to understand the general flow pattern in the study area the data are presented as a progressive vector plot in Figure 78. The data are shown as total water movement past the measurement point, with a label added at 28-day intervals. The summer months show a progressive movement of the water mass to the southwest, which changes to a general motion to the east during the winter months.

### 5.3.2.1.3 Waves

The Block Island Offshore Wind Farm is sheltered by Block Island and the mainland to the north and west, thus the wave climate is dominated by waves coming from the south and east. **Figure 79** presents a hodogram (rose plot) of the significant wave height against the direction for all observations. **Figure 80** presents an example time series of the wave heights, periods and coming directions for March 2017. The wave climate during the measurement campaign was seasonal with wave heights not exceeding 3 m (9.8 ft) for the months of June, July and August, increasing through autumn to spring; the largest wave recorded was observed in March.

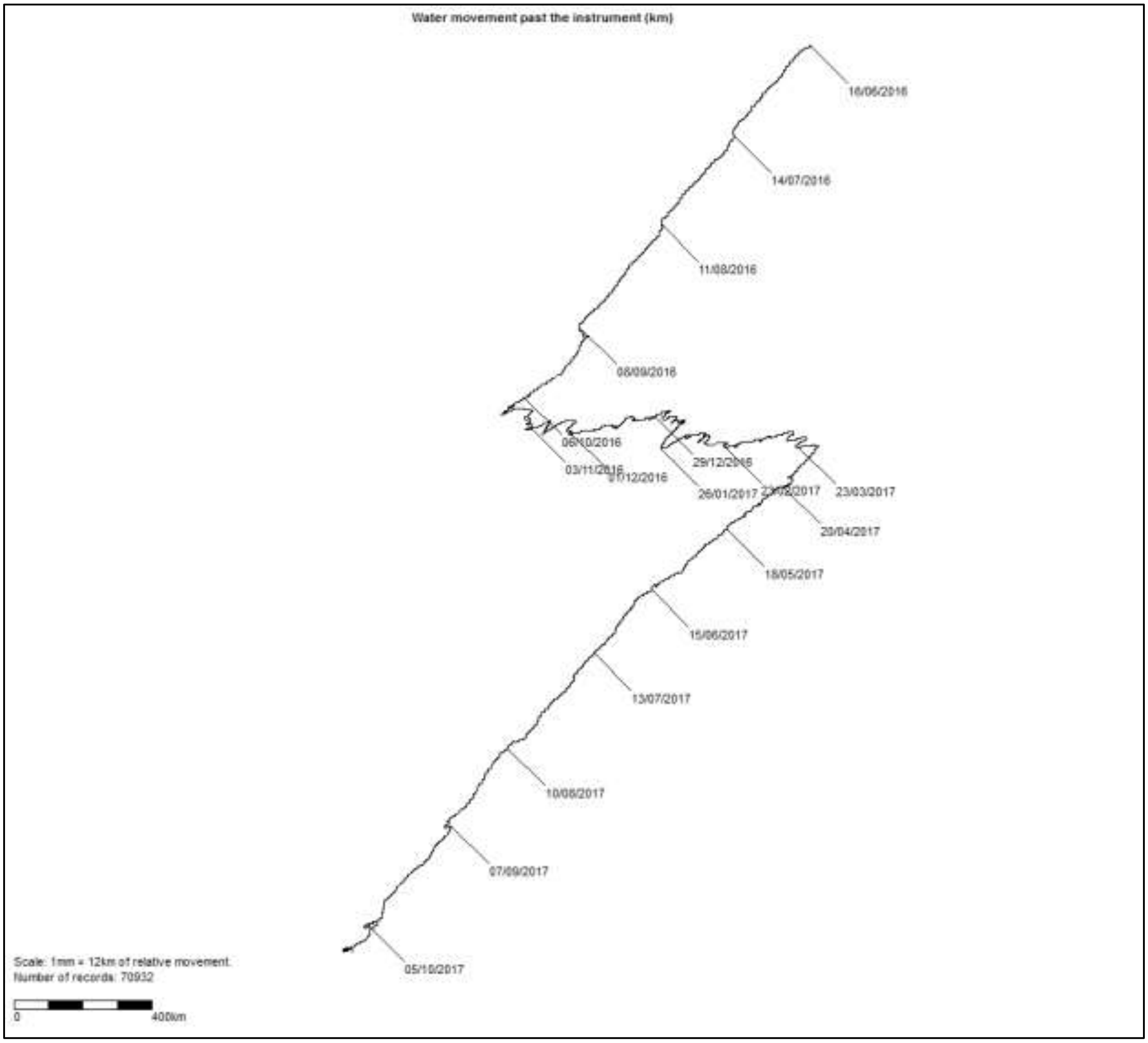



**Figure 78. All current data – progressive vector plot.**

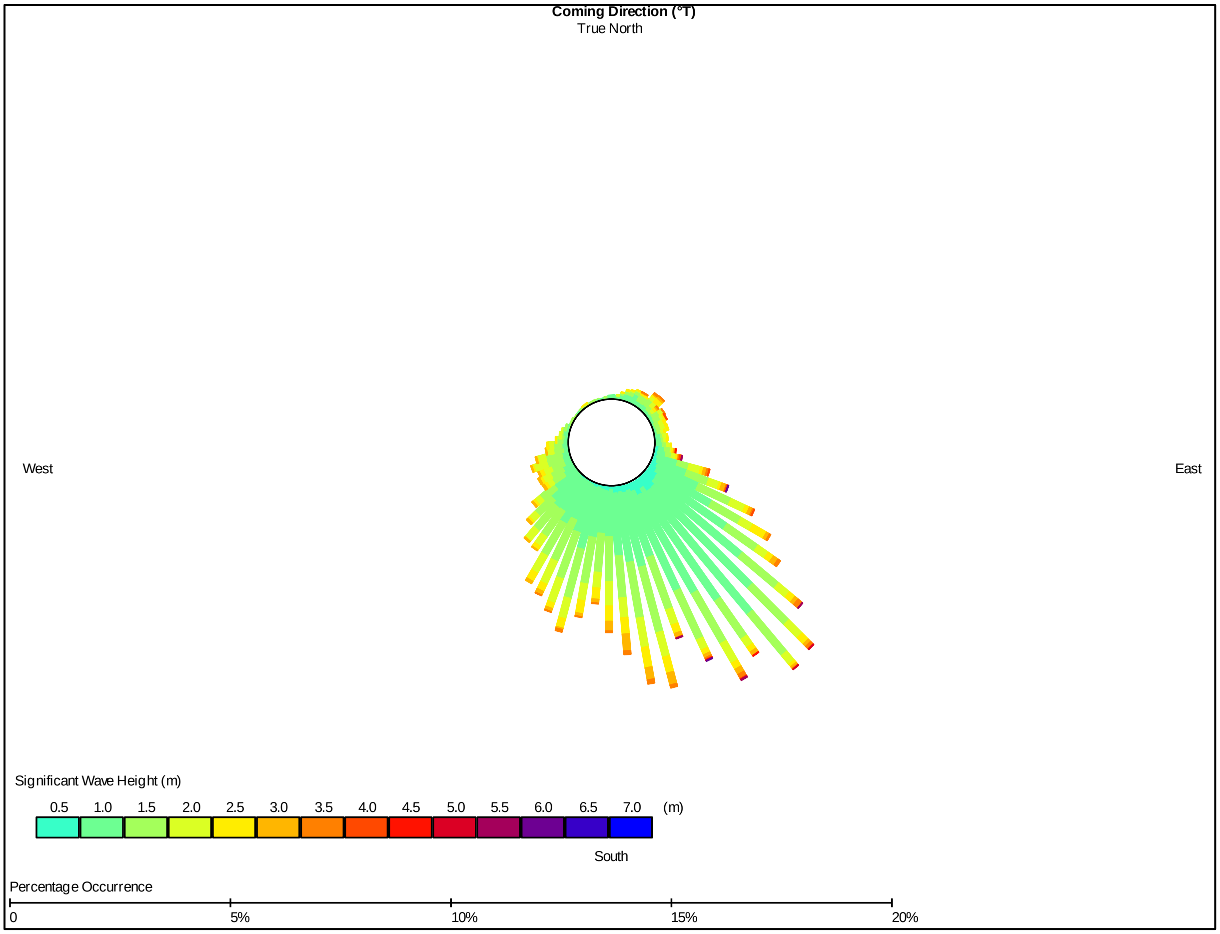



**Figure 79. All wave data – significant wave height versus coming direction hodogram (rose plot).**

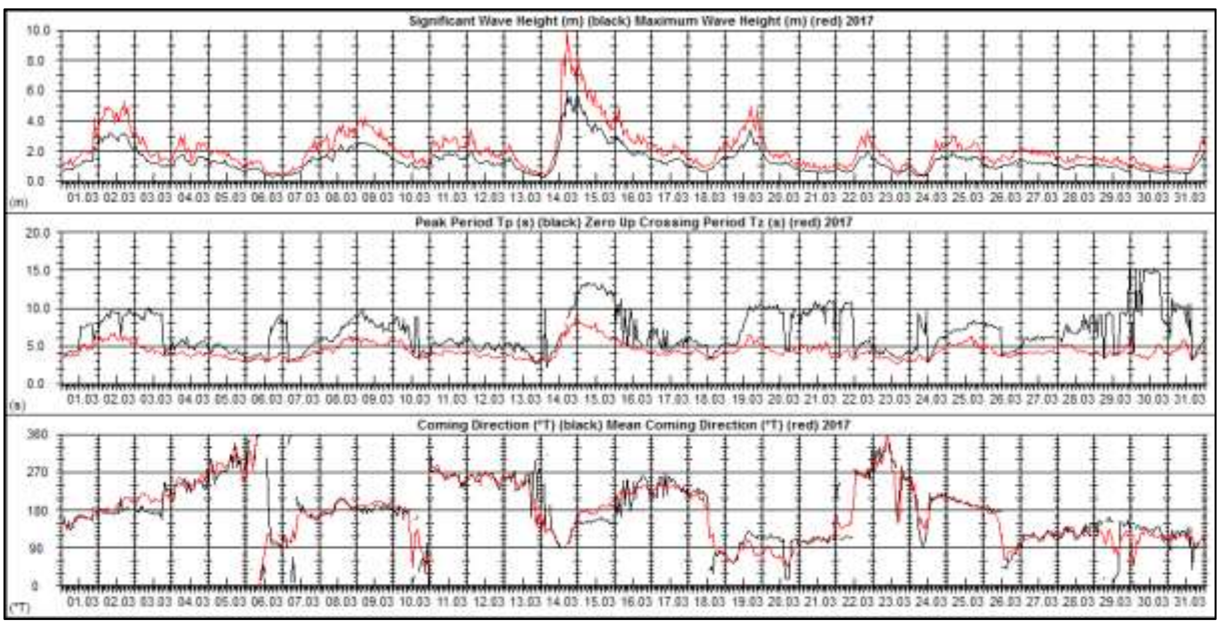



**Figure 80. March 2017 wave data.**

**Table 30** presents a summary of the significant wave heights for each month and the number of storm events observed (a storm event was defined as any period were significant wave height exceeded 3 m (9.8 ft) for this report). The seasonality of the reported events is clear with the highest number recorded in January and through the winter months; however, there is a second smaller peak in September, coincident with the period of anticipated hurricane activity. The duration of storm events observed in September appear to be of longer duration than those in the winter months. However, the duration of the data is insufficient to confirm the statistical significance of this observation.

#### 5.3.2.2 Seabed Data Summary

##### 5.3.2.2.1 Long-term Trends

**Figures 81** to **88** present a temporal summary of seabed level data from beam 1 to 4 for SE and NE scour monitors, respectively. Mean scour depth of each beam per month is shown in **Figure 89** and a summary mean scour profile is presented in **Figure 90**.

Beam 1 is orientated at an angle of 5° and therefore represents measurements taken closest to the turbine. In contrast, beam 4 is orientated at an angle of 20° and represents measurements taken furthest from the turbine. Scour data from the SE leg contained higher levels of interference, which resulted in a loss of the seabed return signal for the 5° beam during the fourth deployment. Thus, summary statistics from the SE leg are unreliable during July, September and October 2017. The NE leg showed little interference and data were thus available for all month on all beams.

Also, the NE monitor seems to show an expected recovery of the seabed at increasing distance from the foundation. Although the minimum level reached over the measurement period are in line. On the other hand, data from the SE monitor is maybe somewhat misleading as it appears the orientation has changed slightly, and the data became corrupted towards the end of the project. It is possible that the data from this instrument show something interesting, in that beam1 data, closest to the foundation and potentially recording the level of the mud mat, show an unexpected trend after April 2017.

**Table 30. Monthly significant wave height statistics.**

| Month | Maximum | | Mean | | Minimum | | Average number of events with significant wave height > 3m, and approximate total duration |
|---|---|---|---|---|---|---|---|
| | (m) | (ft) | (m) | (ft) | (m) | (ft) | |
| January | 4.74 | 15.55 | 1.507 | 4.94 | 0.38 | 1.25 | 4 events 40 hours |
| February | 5.24 | 17.19 | 1.228 | 4.03 | 0.32 | 1.05 | 2 events 24 hours |
| March | 6.04 | 19.81 | 1.407 | 4.61 | 0.32 | 1.05 | 3 events 60 hours |
| April | 3.63 | 11.91 | 1.307 | 4.29 | 0.32 | 1.05 | 2 events 23 hours |
| May | 3.06 | 10.04 | 1.189 | 3.90 | 0.36 | 1.18 | 1 event 1 hour |
| June | 2.3 | 7.54 | 0.999 | 3.28 | 0.36 | 1.18 | 0 events (in 2 months) |
| July | 2.14 | 7.02 | 0.886 | 2.91 | 0.38 | 1.25 | 0 events (in 2 months) |
| August | 2.89 | 9.48 | 0.913 | 2.99 | 0.37 | 1.21 | 0 events (in 2 months) |
| September | 3.5 | 11.48 | 1.396 | 4.58 | 0.4 | 1.31 | 2 events 40 hours (in 2 months) |
| October | 3.28 | 10.76 | 1.254 | 4.11 | 0.31 | 1.02 | 1 event 3 hours (in 2 months) |
| November | 2.94 | 9.64 | 1.209 | 3.97 | 0.39 | 1.28 | 0 events |
| December | 3.44 | 11.28 | 1.385 | 4.54 | 0.32 | 1.05 | 2 events 24 hours |


**Figure 81. SE Beam 1 scour depth.**

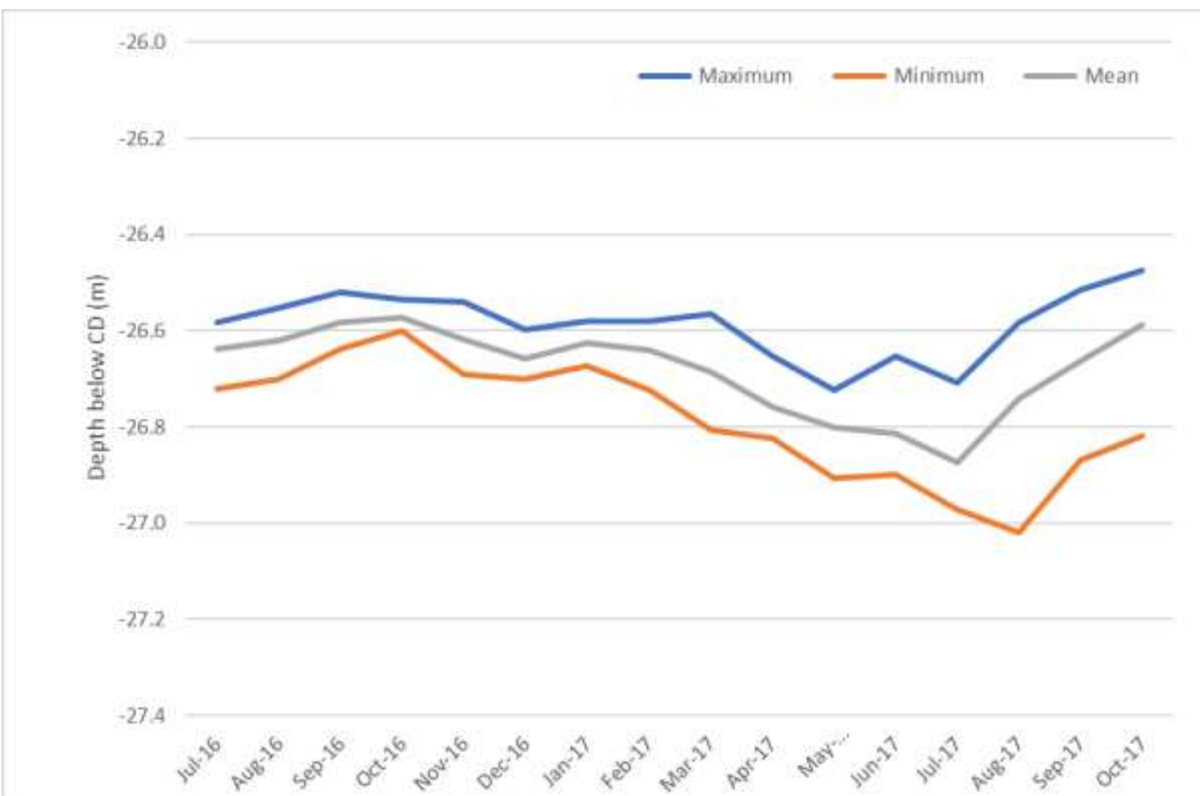



**Figure 82. SE Beam 2 scour depth.**

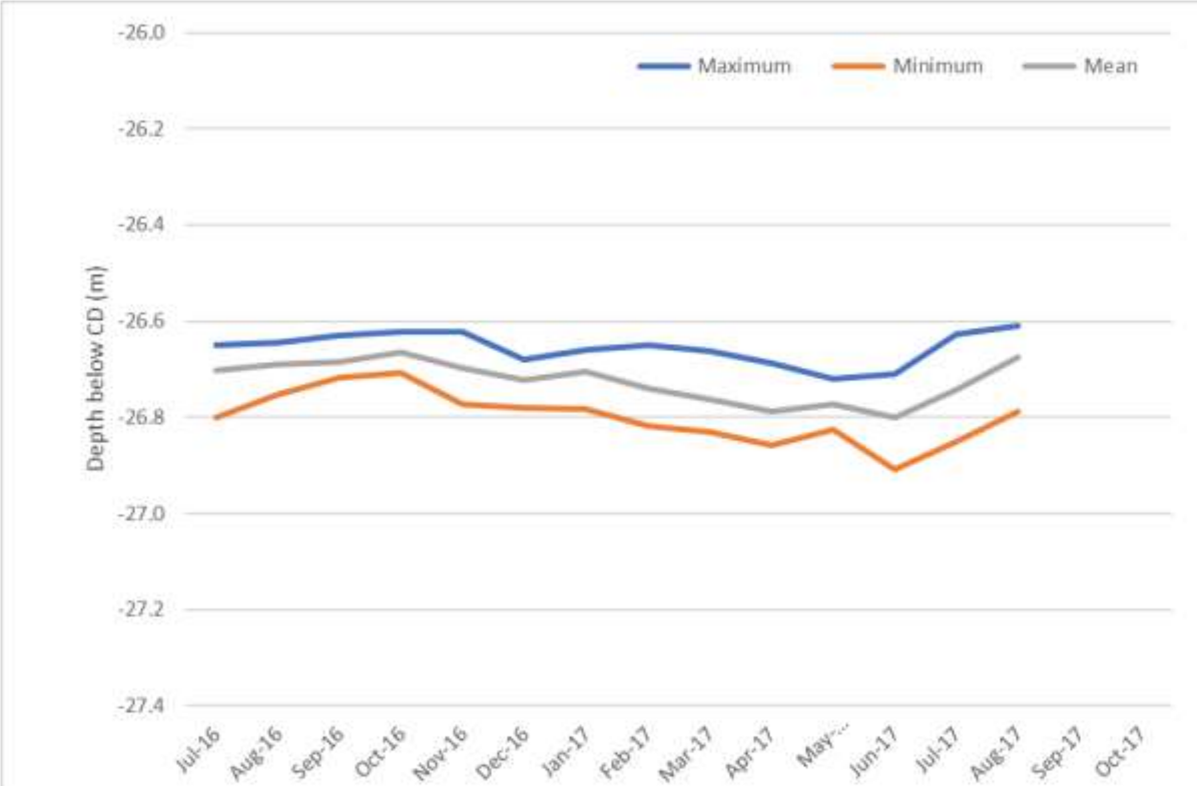



**Figure 83. SE Beam 3 scour depth.**

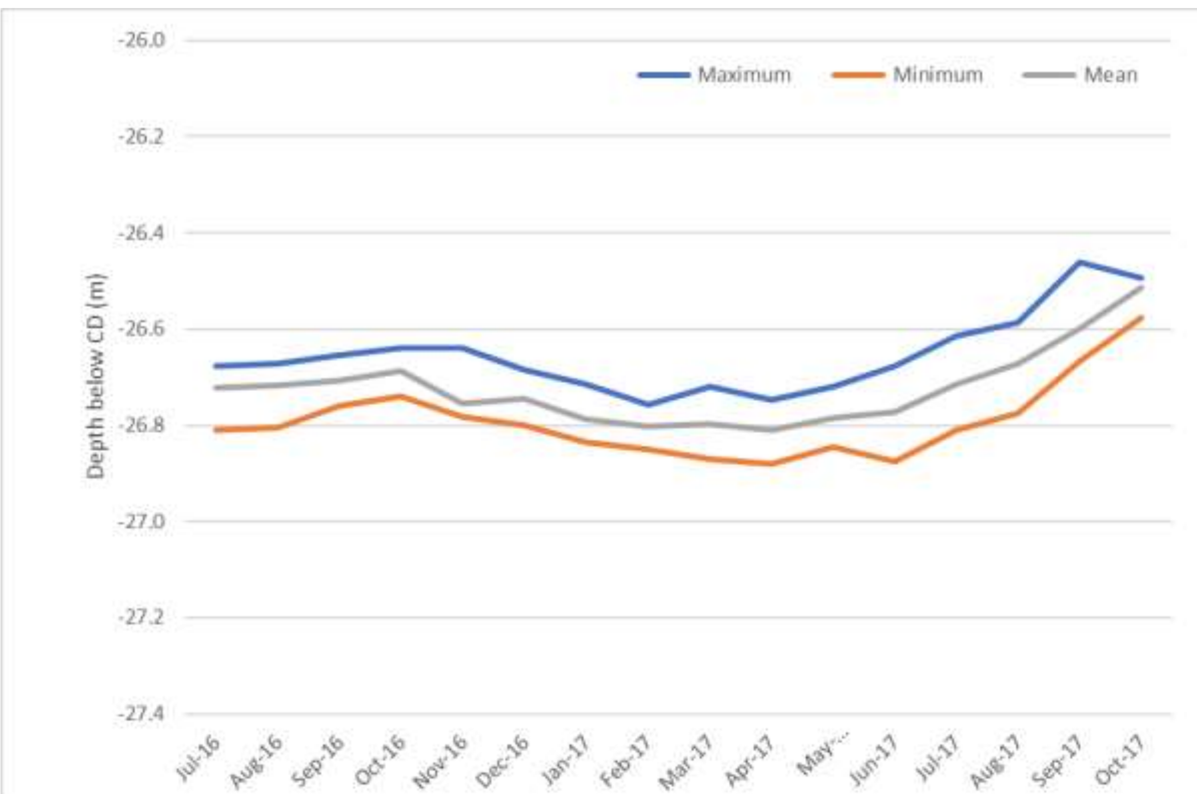



**Figure 84. SE Beam 4 scour depth.**

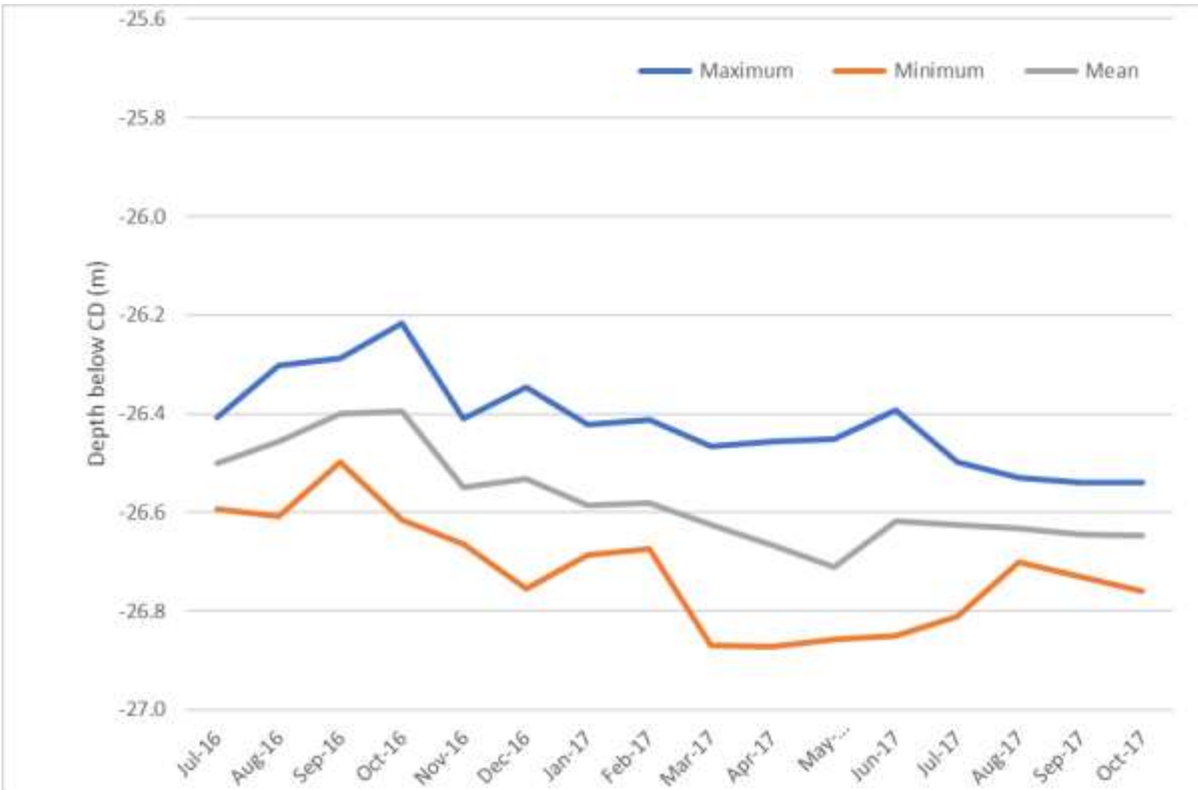



**Figure 85. NE Beam 1 scour depth.**

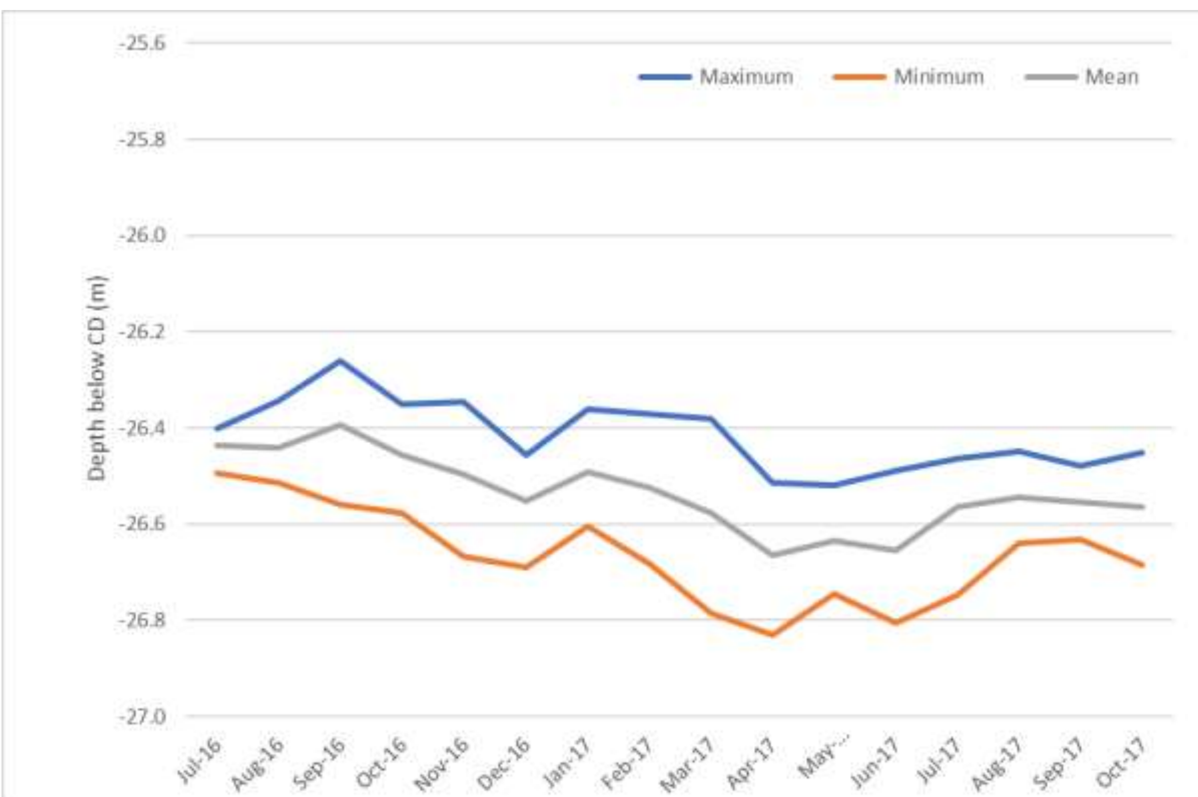



**Figure 86. NE Beam 2 scour depth.**

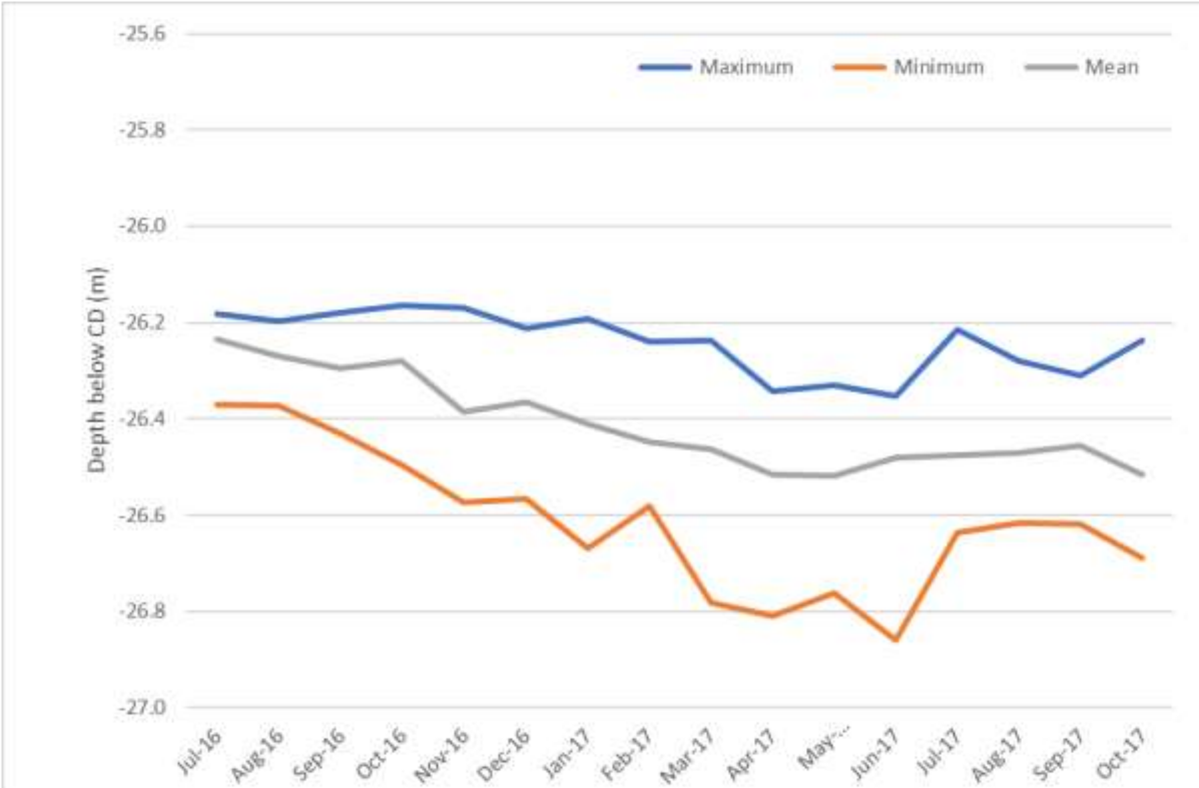



**Figure 87. NE Beam 3 scour depth.**

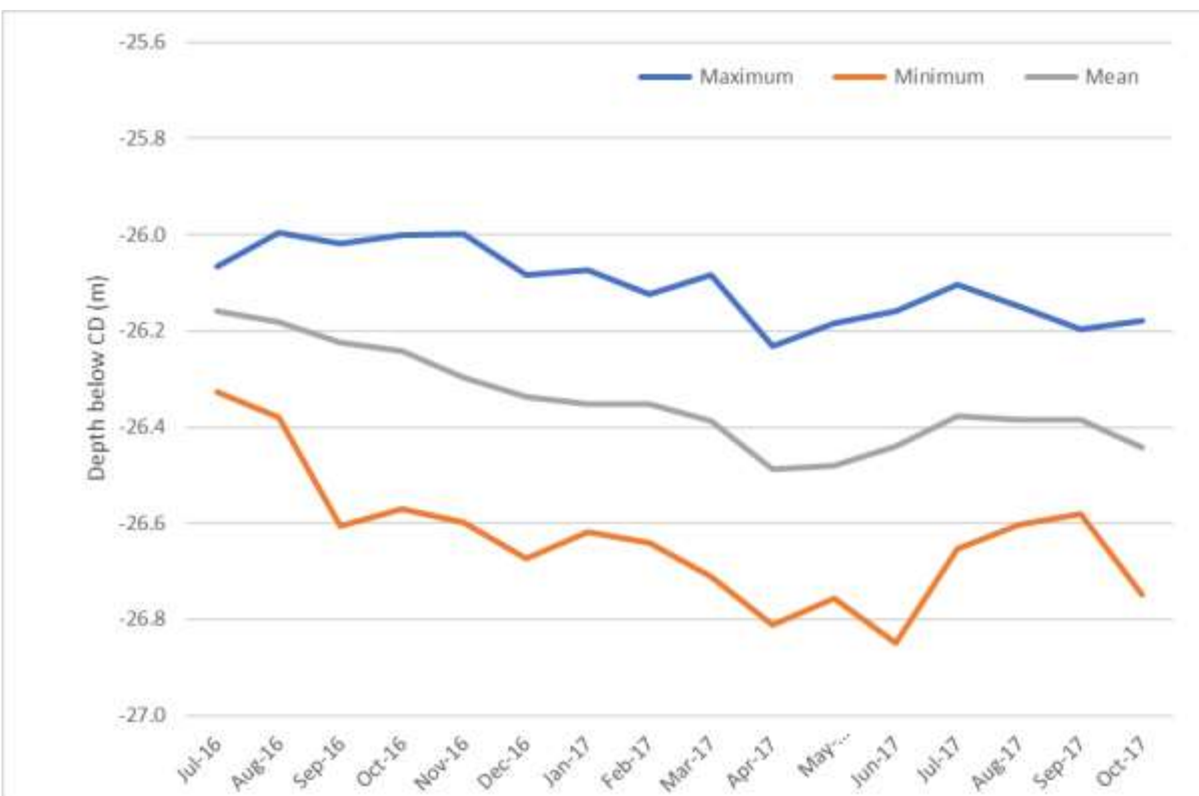



**Figure 88. NE Beam 4 scour depth.**

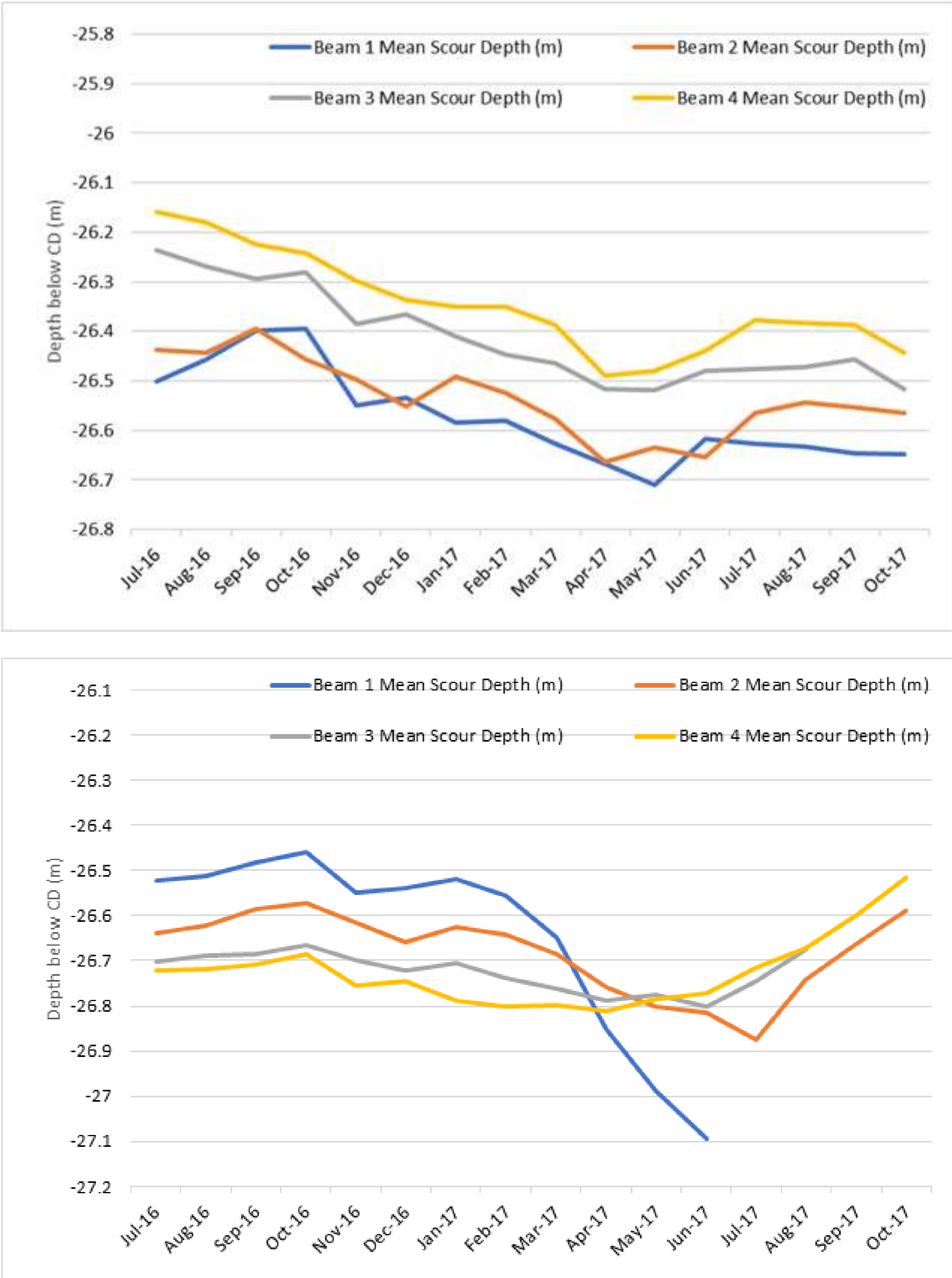



**Figure 89. Mean scour depth of each beam per month.**

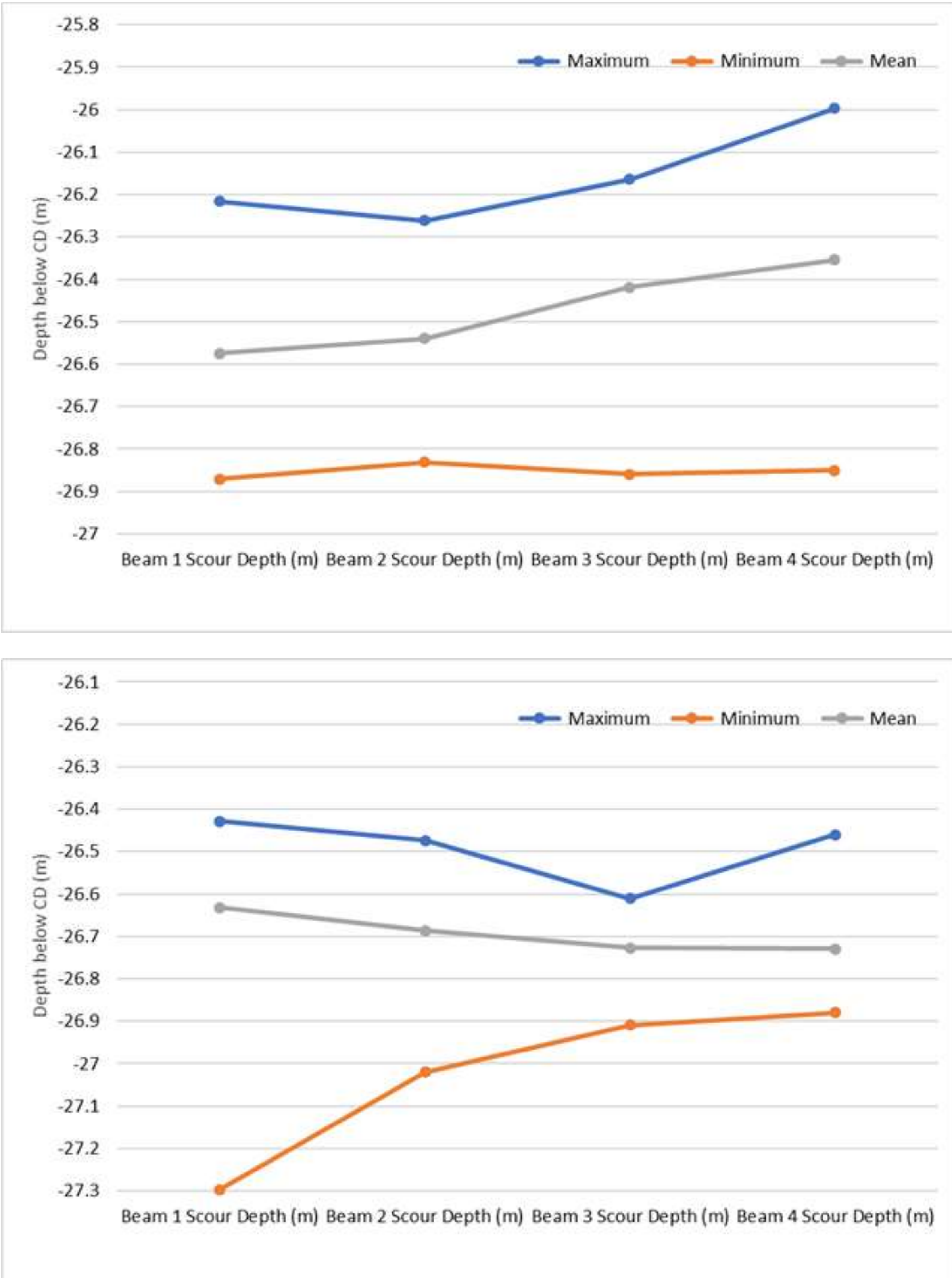



**Figure 90. Summary mean scour profile.**

**Figures 91** to **93** present a temporal summary of oceanographic data from the AWAC. Measurements from both SE and NE units show a slow reduction in the monthly mean seabed level by approximately 0.2 m (0.7 ft) over 14 months. The range of seabed levels (monthly maximum and minimum) exhibit a variation of up to 0.6 m (2 ft) over the month. There appears some correlation between the greatest levels of scour and the highest significant wave heights as measured by the AWAC. It is possible that increased wave action during the winter and early spring lead to reductions in seabed level. Some recovery of the seabed level is seen, particularly on the SE leg. This may be due to increased deposition of sediments following winter conditions close to the foundation. The NE unit shows a small recovery of the mean seabed level (<0.1 m [0.3 ft]) during the summer months, July to September, but does not recover to the levels observed at the start of the study.

#### 5.3.2.2.2 Short-Term Trends

Short term trends show the seabed level responding to changing oceanographic conditions. Bed levels appear to fluctuate by up to 0.2 m (0.7 ft) with tidal conditions. The current flow in the Block Island development responds to increased wave action which significantly alters the flow pattern around the structure leading to a change in the seabed topography at or close to the structure. **Figures 94** and **95** present a comparative time series of scour heights from the northeast sensor compared to the sea level, wave and current data. The scour data presented are based on a 3-hour rolling mean, with Beam 1 closest to the foundation (approximately 5 m (16.4 ft) and Beam 4 furthest from the foundation (approximately 10 m 32.8 ft). The seabed scour level is generally deepest closest to the structure and gets shallower progressively with distance from the foundation.

Variability of approximately 0.2 m (72.2 ft) over 12 to 24 hours is seen in August data (**Figure 94**) and tends to occur in line with the tidal forcing, being most obvious during the period when the net current flow is from the northeast towards the southwest. The presence of an area of sand ripples that are migrating into the area around the foundation during the summer months have been observed in bathymetric surveys conducted at the site (Fugro's Seafloor Disturbance and Recovery Monitoring Program Survey 3, May 2017, Block Island Wind Farm, 2017). Ripples that are approximately 0.1 to 0.2 m (0.4 to 0.7 ft) tall (peak to trough) are inferred to be dynamic and in the area surrounding the monitoring site.

During periods of increased wave activity, the seabed level shows reduced variation, for example between 23 and 25 January 2017 (**Figure 95**). Further work is needed to understand the mechanism for this; however, it is possible that the local seabed morphology changes and the sand ripples that migrate across the site during calm conditions are levelled by the increased seabed disturbance.

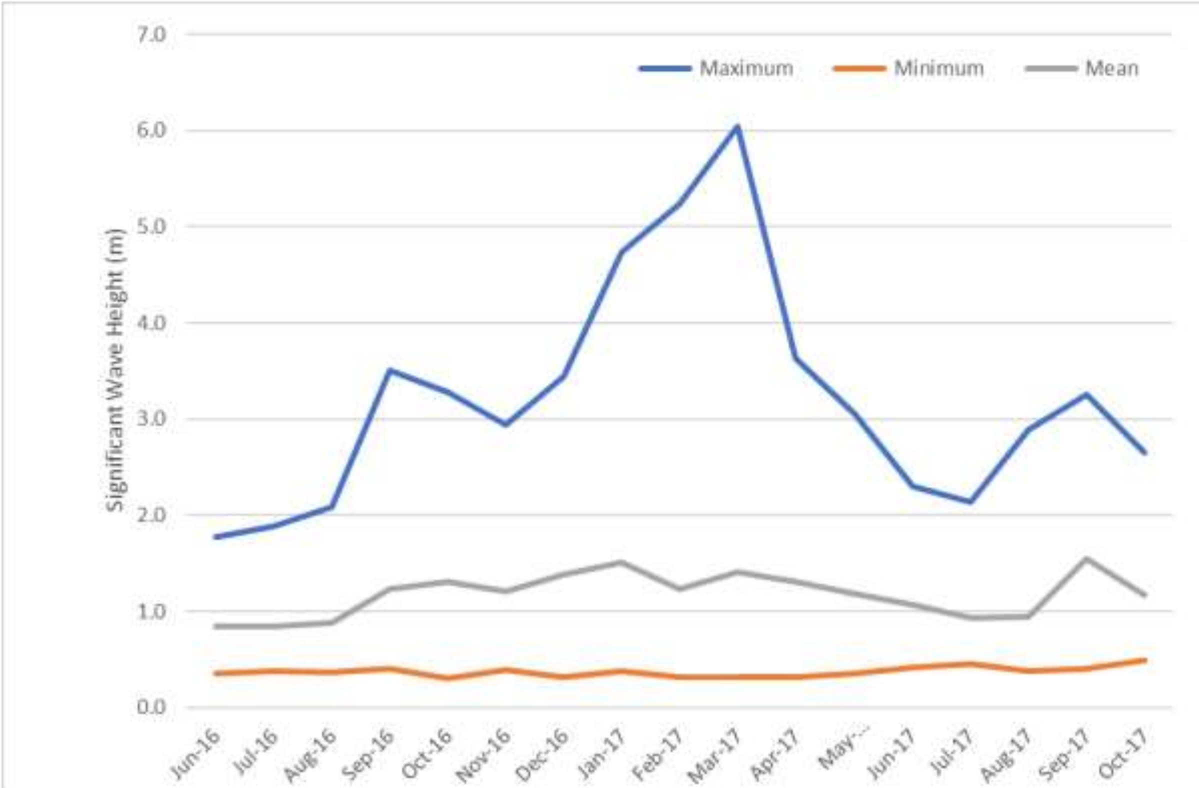



**Figure 91. Significant wave height.**

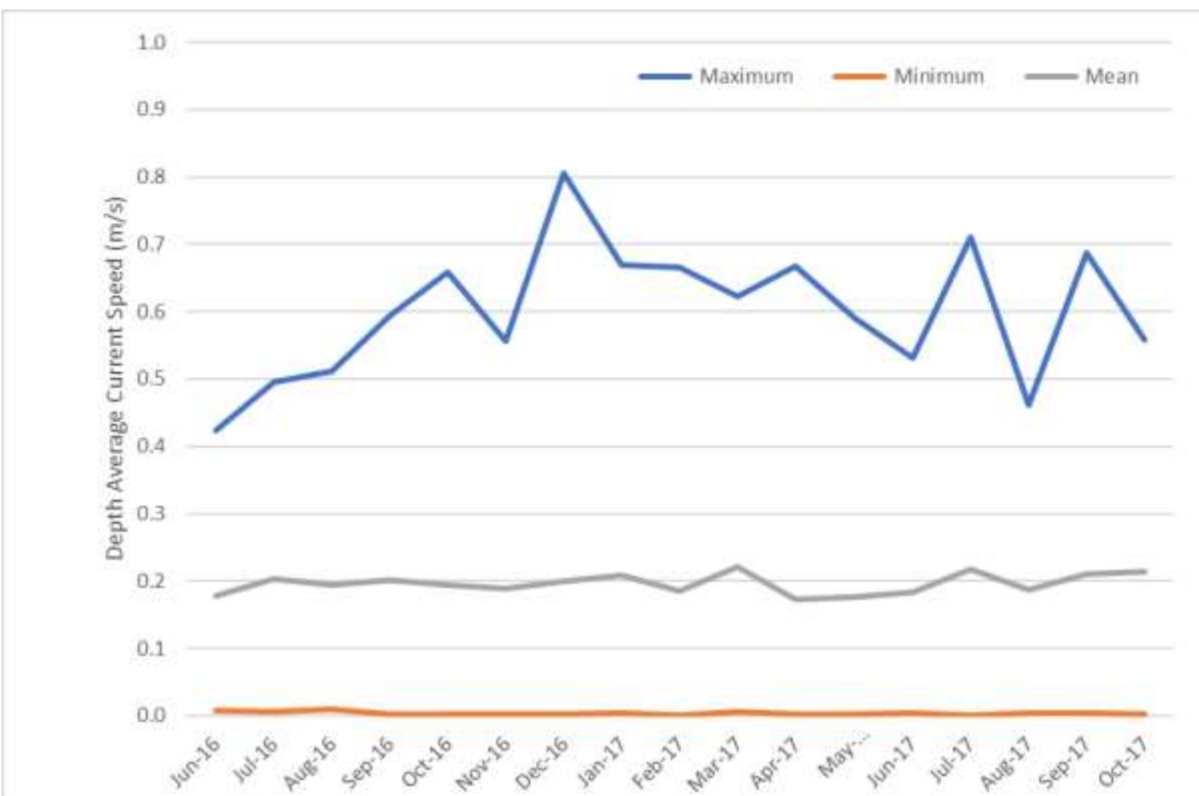



**Figure 92. Depth average velocity.**

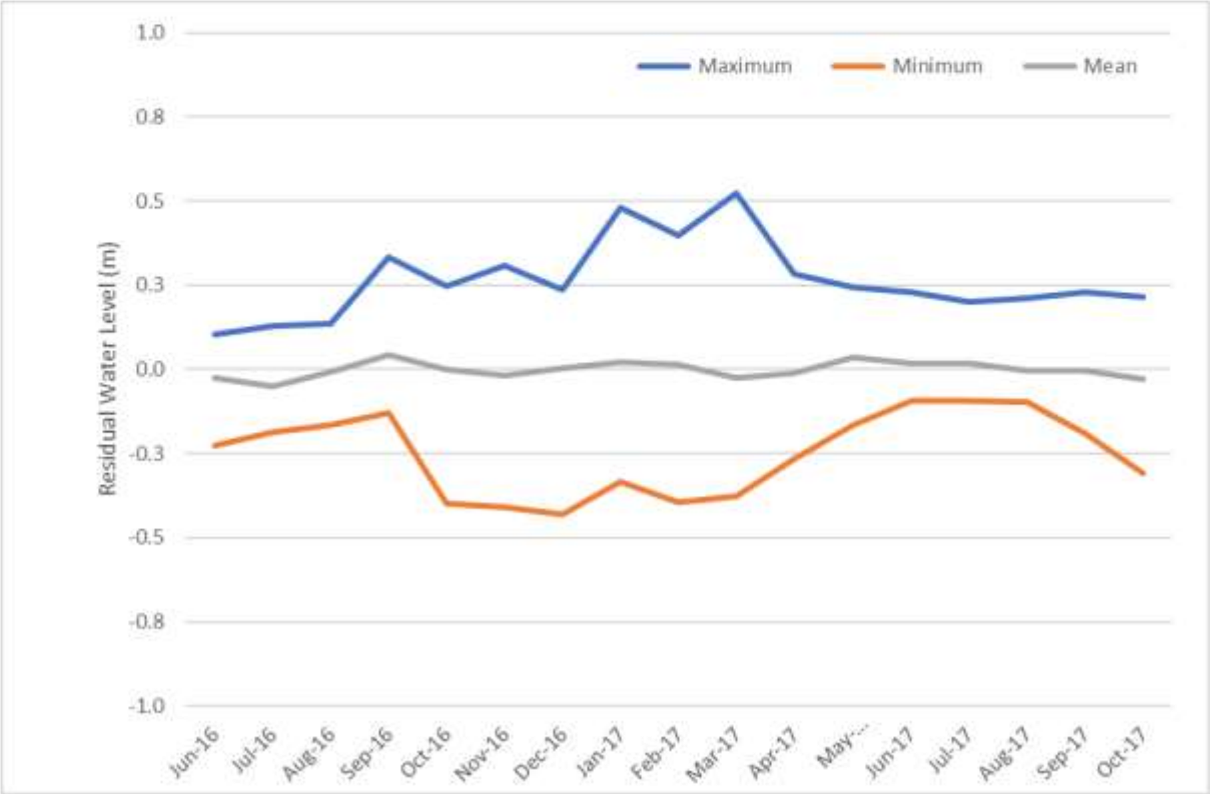



**Figure 93. Residual water level.**

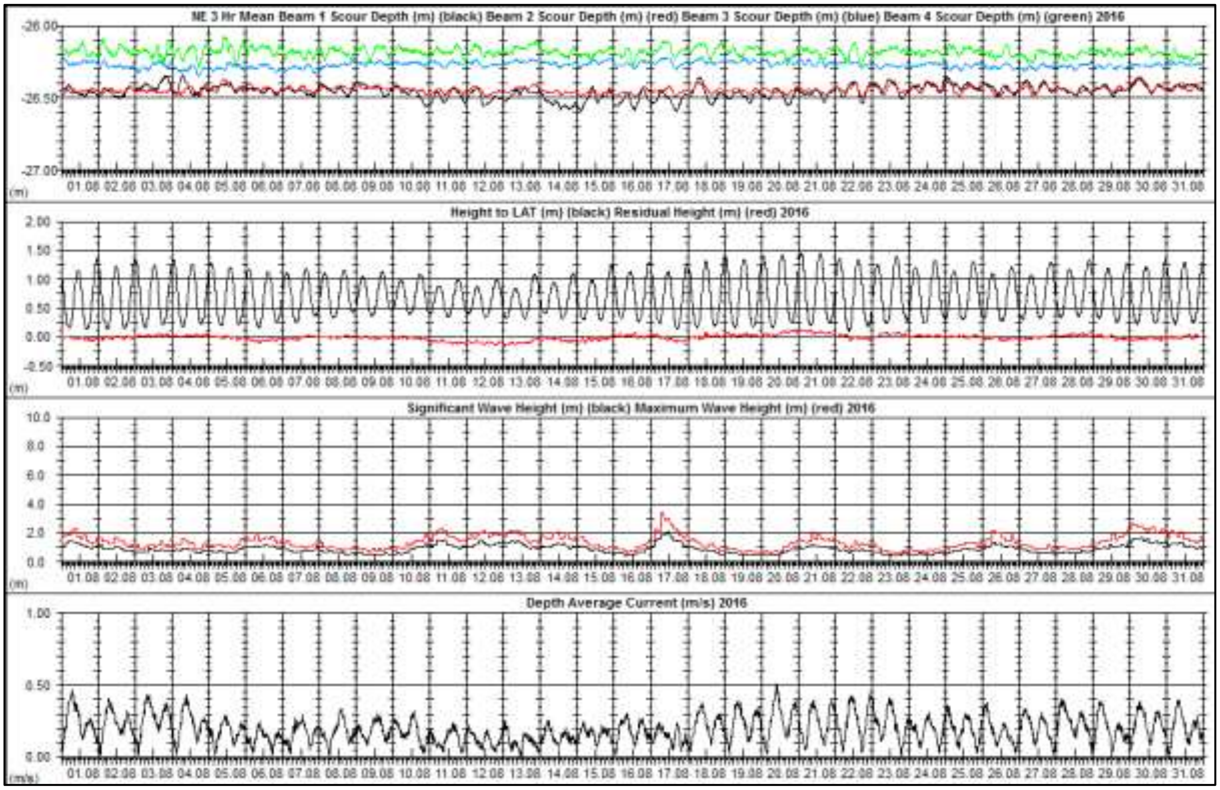



**Figure 94. Comparative time series for August 2016.**

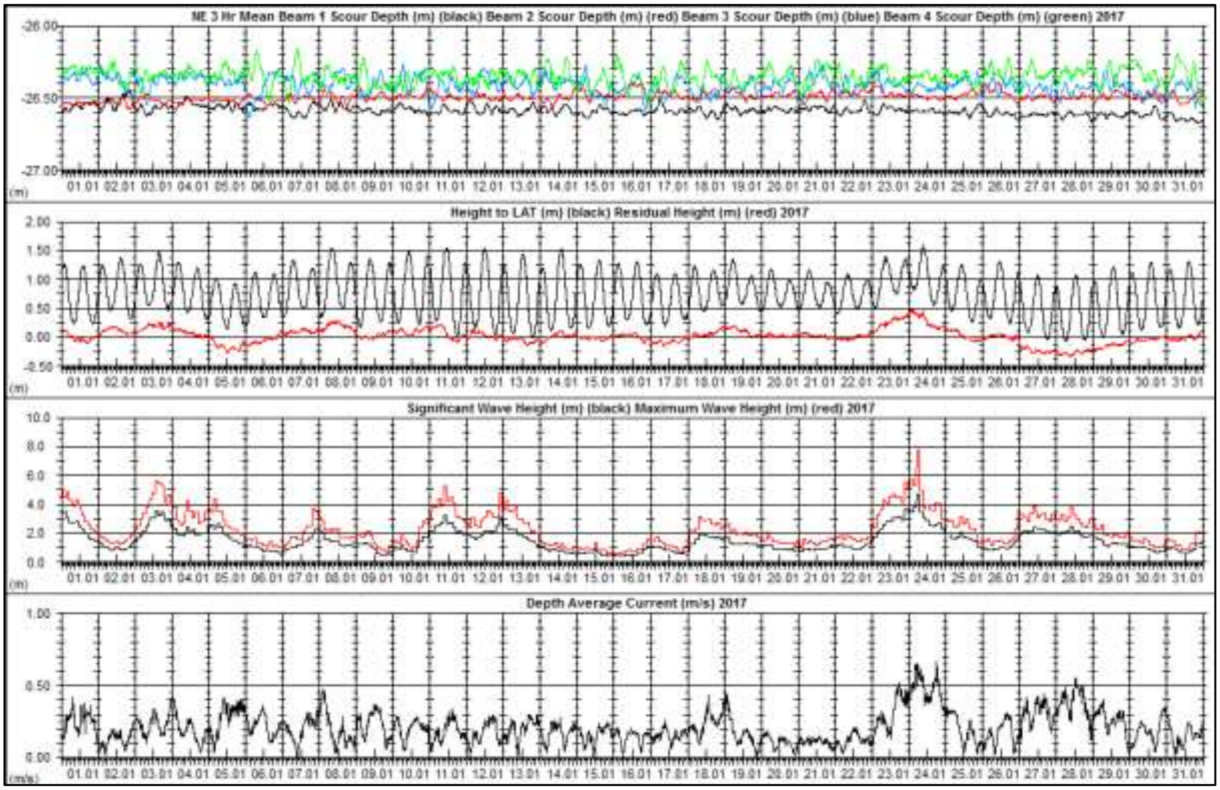



**Figure 95. Comparative time series for January 2017.**

### 5.3.3 Discussion and Conclusions

The general outcomes of the study were as follows:

- The two scour monitors functioned as planned. A near continuous seabed elevation data set was collected over the 14 months and 19 days.
- The seabed mounted AWAC also functioned as planned. A near continuous oceanographic condition (water levels, currents, and waves) dataset was collected over the 16 months and 3 days deployment period.
- The scour monitors returned the following data:
  - Continuous acoustic return data along four beams per instrument
  - Seabed elevations at distance up to 10 m (32.8 ft) rom the foundation
  - Changes in the seabed elevation seen to occur at a variety of periodicities:
    - Less than one day, consistent with the periodicity of the local tidal forcing
    - Over the course of a week to a month, appearing to coincide with perturbations to the tidal current flow resulting from increased wave energy
    - A seasonal signal consistent with increased wave activity in the winter months, and calmer conditions in the summer months.
  - The orientation of the acoustic beams allowed observation of the variation in seabed level with distance from the foundation, and response of the seabed to physical oceanographic forcing.
- Issues encountered with the scour data:
  - Orientation of the scour monitor on the southeast leg meant the data were collected closer to the foundation than planned
  - Corruption of one scour monitor beam on the southeast leg occurred during the final 3 months, probably due to interference from the structure

- Lessons learned:
  - Early interaction with the construction team was vital to allow bracketing to be mounted and orientated correctly.
  - At sites with a strong seasonal thermocline it is essential for long-term variation in the seabed levels to be calculated using a speed of sound derived from a model of (or average of) the conditions between the scour monitor and the seabed. In this case the presence of a strong summer thermocline caused errors in the initial range calculations. Vertical conductivity, temperature, and depth profiles taken in the summer months showed that the thermocline depth was approximately midway between the scour monitor and the seabed. Thus, the average speed of sound between the scour monitor and the seabed AWAC was calculated and used to correct the acoustic ranges.
- Future opportunities:
  - The scour monitors provide a long-term time series of seabed elevations at specific points close to the foundation (in this case up to 10 m (32.8 ft) that can be used to enhance the understanding of the variation in seabed levels.
  - The scour monitors allow measurement of the seabed response in conditions where bathymetric surveys are not feasible.
  - For future sites the scour monitors could be used at a limited selection of foundations in order to support the assumptions about seabed mobility made during design, or if scour occurs under specific circumstances then appropriate preventative intervention can be designed and actioned to maximize the life of the structures.

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# Appendix A: Field Plan

Appendix A is available as a separate digital file.

# Appendix B: Visual Monitoring Data

During the visual monitoring, over 4,500 photographs were taken from Southeast Light House and research vessels. These photographs provide visual examples of the types of activities that occurred during construction. They were provided to BOEM on a DVD and are available upon request.

Selected high-quality photographs, which are illustrative of the construction activities described in this report, are presented in the following photolog.  Key observations recorded during onshore and offshore visual monitoring are summarized in **Sections 2.1** and **2.2**, respectively.  These two sections also include a key for the photographs stored on the DVD that has been provided to BOEM.  **Section 2.3** describes meteorological observations recorded during the visual monitoring.

**Figure B-1. 9/07/2015 Offshore Photo 3929. Placing WTG 5 steel jacket in the water.**

**Figure B-2. 9/07/2015 Offshore Photo 3933. Placing WTG 5 steel jacket in the water.**

**Figure B-3. 9/07/2015 Offshore Photo 3943. Placing WTG 5 steel jacket in the water.**

**Figure B-4. 08/18/2015 Southeast Lighthouse, Block Island – Photo 0154: Weeks Barge 533 placing the diesel hammer on piling at WTG 2. First day of pile driving.**

**Figure B-5. 08/18/2015 Offshore Photo 0111: Weeks Barge 533 piling at WTG2 with diesel hammer (notice smoke).**

**Figure B-6. 08/18/2015 Offshore Photo 0118: Diesel hammer piling at WTG 2.**

**Figure B-7. 08/18/2015 Offshore Photo 0111: Weeks Barge 533 removing diesel hammer from piling at WTG2.**

**Figure B-8. 8/15/2015 Offshore Photo 0014: Two foundations, WTG 2 transition deck, and piles aboard the Cashman barge with support tug Reed Danos. Anchor buoy visible.**


**Figure B-9. 09/17/2015 Offshore Photo 2359: WTG 1 steel jacket arriving onsite after being repaired from being struck by a derrick barge after initial installation.**

**Figure B-10. 8/23/2015 Offshore Photo 0186: Weeks Barge 533 just placed third pile at WTG 3.**

**Figure B-11. 8/26/2015 Offshore Photo 0581: Supply vessel Josephine Miller and Weeks derrick barge 526 at WTG 2. WTG 3 is to the far right with four piles ready to be driven.**


**Figure B-12. 8/29/2015 Offshore Photo 0622: Hydraulic hammer being lifted from Weeks Derrick Barge 533.**

**Figure B-13.8/30/2015 Offshore Photo 0679: Pile driving at WTG 3 with hydraulic hammer.**

**Figure B-14.8/30/2015 Offshore Photo 0692: Pile driving at WTG 3 with hydraulic hammer.**


**Figure B-15.9/02/2015 Offshore Photo 1010: WTG 3 with first set of piles driven by Weeks Derrick Barge 533. Block Island in the background.**

**Figure B-16.9/19/2015 Offshore Photo 2542: Lift Boat Roberts driving the last pile at WTG 1.**

**Figure B-17.9/17/2017 Offshore Photo 2352: Lift Boat Roberts driving the first pile at WTG 5.**

**Figure B-18.11/09/2015 Onshore Southeast Lighthouse Photo 2591: Lift Boat Roberts placing transition deck at WTG 4.**

**Figure B-19. 11/09/2015 Onshore Photo 2661: Lift Boat Robert at dusk next to WTG 4.**

**Figure B-20. 9/20/2015 Offshore Photo 2565: View shed to the south, WTGs 1-5. WTG 1 is in the foreground.**

**Figure B-21. 9/20/2015 Offshore Photo 2579: Weeks Barge 526 next to WTG 5 with second set of piles in place.**

**Figure B-22. 9/20/2015 Offshore Photo 2584 WTG 1 ready for transition deck.**


**Figure B-23.8/25/2015 Offshore Photo 0483: Tug Robert.**

**Figure B-24.9/01/2015 Offshore Photo 0861: University of Rhode Island's Shanna Rose.**


**Figure B-25.8/25/2015 Offshore Photo 0508: Supply vessel Josephine Miller.**


**Figure B-26.8/24/2015 Offshore Photo 0257: Supply Vessel Sorensen Miller.**

**Figure B-27.8/18/2015 Block Island Town Beach – Photo 0036: Tug IONA McAlister.**

**Figure B-28.8/23/2015 Offshore Photo 0178: Subacoustech aboard University of Rhode Island's R/V McMaster.**

**Table B-1. Onshore Photo Log Key and Field Observation Summary**

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 08/18/2015 07:12:54 | f8, 70 mm, first picture of survey, preparing to pile drive | 90 |
| 08/18/2015 07:15:53 | f8, 200 mm appear to be 2 piles sticking up from WTG 2 | 91–96 |
| 08/18/2015 08:09:10 | f8' 70. Pile driving not started. Barge and 3 vessels on site. | 97–99 |
| 08/18/2015 08:10:02 | f8, 200 | 100–102 |
| 08/18/2015 08:26:38 | f8' 70 mm. barge moved next to piling. 3 other vessels onsite. | 103 |
| 08/18/2015 08:27:53 | f8 200 mm | 104 |
| 08/18/2015 08:52:03 | f8, 200 mm hammer not in place yet | 105–106 |
| 08/18/2015 08:53:57 | f8, 70 mm haze creating poor vis. | 107 |
| 08/18/2015 09:48:28 | 3 vessels onsite. | 108–115 |
| 08/18/2015 10:14:43 | 3 vessels onsite. Weeks Barge has re-positioned near piling, appears crane may be hooking to hammer | 118–121 |
| 08/18/2015 10:20:40 | Crane stopped moving. | |
| 08/18/2015 10:30:04 | The crane is picking up the hammer | 124–146 |
| 08/18/2015 10:37:49 | 3 vessels onsite, one appears to be a tug. visibility has improved | |
| 08/18/2015 10:43:15 | Another vessel just arrived, making 4 total onsite. | 178–180 |
| 08/18/2015 10:49:18 | Lifting hammer to top of piling at WTG 2 | 130–146 |
| 08/18/2015 11:12:39 | Hammer is on pile. 3 vessels onsite | 147–154 |
| 08/18/2015 11:27:41 | Crane has moved hammer off the piling | 157 |
| 08/18/2015 11:42:49 | Another vessel on site, 4 total now | 158–159 |
| 08/18/2015 11:55:45 | Vessel passing by site | 160–161 |
| 08/18/2015 12:24:50 | 2 new vessels on site (HDR vessel) | 162–164 |
| 08/18/2015 12:59:04 | Crane movement. 3 vessels on site. Construction communication shows they want to attempt pile driving again. | 165–169 |
| 08/18/2015 13:12:54 | Crane is placing hammer on pile at WTG 2 | 170–177 |
| 08/18/2015 13:22:21 | Removed hammer from pile | 178–204 |
| 08/18/2015 13:34:10 | Lifting hammer off deck | 205–206 |
| 08/18/2015 13:38:26 | Crane is placing the hammer | 207–213 |
| 08/18/2015 14:01:57 | Hammer down , fishing vessel passing by | 214–215 |
| 08/18/2015 14:08:04 | Small vessel on site | 217–216 |
| 08/18/2015 14:39:29 | 4 vessel on site | 218–0219 |
| 08/18/2015 15:09:14 | 5 vessels on site , no activity on barge | 220–221 |
| 08/18/2015 15:29:35 | Crane is placing the hammer | 224–229 |
| 08/18/2015 15:46:35 | First strike heard 3:45 at WTG 2; another at 3:47; VHF radio indicates soft start. | 230–231 |
| 08/18/2015 16:01:39 | 4:01 heard another strike. and another at 4:03 | 233–234 |
| 08/18/2015 16:05:03 | 4:05 heard 5 strikes | |
| 08/18/2015 16:08:08 | 4:07 another round of approximately 5 strikes. | |
| 08/18/2015 16:10:16 | 4:10 constant striking occurring | 235–243 |
| 08/18/2015 16:13:59 | 4:13 pile driving stops | |
| 08/18/2015 16:23:59 | Hammer moved off pile and back on barge | 244–250 |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 08/18/2015 16:52:45 | Radio communication indicate problem with hammer. All 4 piles in foundation with a little progress on one from hammering. | 256–257 |
| 08/18/2015 17:12:22 | Hammer is not hooked to crane. Deepwater has a rope on crane hook now. | 258–261 |
| 08/23/2015 11:21:34 | 4 vessels on site | 262–269 |
| 08/23/2015 11:54:35 | 3 large vessels on site, 3 smaller boats heading toward site, 1 fishing boat going away from site | 270–278 |
| 08/23/2015 12:00:02 | Weeks barge 526, 1 tug and supply vessel in bound toward site | 279–281 |
| 08/23/2015 12:19:00 | 3 vessels on site 1 vessel departing | 282–283 |
| 08/23/2015 12:31:52 | 3 vessels in bound, 3 vessels on site, 1 vessel out bound | 284–289 |
| 08/23/2015 12:52:36 | 7 vessels on site plus McMaster and HDR vessel | 290–294 |
| 08/23/2015 13:06:31 | Boat passing, barge and two boats headed away from platform 2, barge, 3 large boats, McMaster and HDR vessel all onsite. | 295–303 |
| 08/23/2015 13:33:48 | 3 vessels on site along with HDR vessels, 3 vessels headed away | 304–308 |
| 08/23/2015 13:56:18 | 3 vessels on site along with HDR vessels, 3 vessels headed away | 311–314 |
| 08/23/2015 14:27:02 | 2nd barge moving toward the site, on construction site WTG 2 there is a small boat. fishing boat moving toward site 2 | 315–322 |
| 08/23/2015 14:57:52 | 2nd barge is approaching site WTG 2 | 327–337 |
| 08/23/2015 15:29:59 | 2nd crane barge is still approaching the site WTG 2. 3 vessels and barge on site WTG 2. 4 vessels + crane barge 1 on site WTG 3 | 343–346 |
| 08/23/2015 15:55:37 | Pile stabbing at WTG 3 | 347–348 |
| 08/23/2015 16:03:11 | Weeks barge 526 still approaching site WTG 2. 2 vessels + crane barge on site WTG 2. Pile stabbing by Weeks barge 533 on site WTG 3, 4 vessels + crane barge on site WTG 3. | 349–410 |
| 08/23/2015 16:31:10 | 2 vessels + crane barge 2 on WTG 2. 1 vessel and crane barge 1 on WTG 3 3 no activity on either site. | 411–412 |
| 08/24/2015 07:16:48 | Barge near site WTG 2 with crane holding a pile, barge near site WTG 3 but not close enough to jacket. 4 total vessels on sites | 415–419 |
| 08/24/2015 07:43:47 | 6 vessels on site and 1 small boat | 420-424 |
| 08/24/2015 07:55:25 | 2 barges, 7 vessels and 1 small boat on site | 425-430 |
| 08/24/2015 08:11:19 | 2 barges, 5 vessels, and one small boat on site | 431-435 |
| 08/24/2015 08:43:27 | 2 barges, 5 vessels and 1 small boat on site. One small boat passing by | 436-440 |
| 08/24/2015 09:07:52 | Weeks barge 533 appears to be getting close to WTG 3 | 441-443 |
| 08/24/2015 09:30:53 | 2 barges and 3 vessels on site 2 small boats passing | 444-448 |
| 08/24/2015 09:59:33 | 3 vessels and 2 barges on site | 449-451 |
| 08/24/2015 10:28:41 | 2 barges, 4 vessels and 1 small boat on site. 1 small boat passing | 452-454 |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 08/24/2015 11:00:58 | 2 barges, 4 vessels, 2 small boats | 455-460 |
| 08/24/2015 11:32:48 | 2 barges, 4 small boats, 6 vessels on site | 461-463 |
| 08/24/2015 11:59:33 | 2 barges, 7 vessels and 4 little boats barge at left site is beginning to turn | 464-467 |
| 08/24/2015 12:13:30 | Weeks barge 526 at WTG 2 is moving closer to piles and turning | 468-474 |
| 08/24/2015 12:43:54 | 2 barges 4 vessels 3 small boats on site barge is still moving closer to left site | 475-480 |
| 08/24/2015 13:12:13 | 2 barges, 3 vessels, 3 small boats and 1 small passing boat | 481-483 |
| 08/24/2015 13:22:11 | Lifted hammer at WTG 2 | 484-498 |
| 08/24/2015 13:37:14 | Lowering hammer back to deck at WTG 2. | 499-504 |
| 08/24/2015 13:53:28 | Crane no longer holding hammer, 2 barges 6 vessels and 3 small boats on site | 505-507 |
| 08/24/2015 14:00:34 | Crane at WTG 3 swung pile around, not closer to jacket | 508-509 |
| 08/24/2015 14:29:59 | 2 barges, 4 vessels and 3 small boats on site. the crane with the pile is no longer holding the pile directly next to WTG 3 jacket | 510-517 |
| 08/24/2015 14:54:57 | Crane at right site is holding pile close jacket | 518-527 |
| 08/24/2015 15:17:57 | 2 barges, 3 vessels, 1 small boat on site | 527-530 |
| 08/24/2015 15:32:57 | 2 barges 4 vessels and 1 small boat | 531-533 |
| 08/25/2015 07:27:43 | Very foggy, close to zero visibility | 534-539 |
| 08/25/2015 07:59:11 | Can't see anything | 540-541 |
| 08/25/2015 08:33:04 | Still can't see anything | 542-543 |
| 08/25/2015 09:01:01 | Can't see anything | 544-545 |
| 08/25/2015 09:32:09 | Can't see anything but fog is starting to lighten up | 546-547 |
| 08/25/2015 10:08:53 | Still too foggy. can't even see the water | 548-549 |
| 08/25/2015 10:32:14 | Still can't see anything | 550-551 |
| 08/25/2015 10:59:19 | Still can't see the water | 552-553 |
| 08/25/2015 11:30:04 | Still can't see the water | 554-555 |
| 08/25/2015 11:57:31 | WTG 3: Pile is being held up by the crane, 1 barge and 3 vessels on site. Left site: there are 3 vessels and a crane barge no activity | 558-559 |
| 08/25/2015 12:20:06 | Crew boat at barge on left site | 565-566 |
| 08/25/2015 12:59:19 | WTG 2: 3 boats and Weeks barge. WTG 3: crane barge and 3 boats | 571-572 |
| 08/25/2015 13:09:04 | Last pile has been stabbed into the right jacket | 575-576 |
| 08/25/2015 13:32:23 | Right site: no activity on crane barge, 2 boats. left site: no activity on crane barge, 3 boats | 579-580 |
| 08/25/2015 13:58:32 | Nothing has changed from previous | 596-597 |
| 08/25/2015 14:22:46 | Lifted the crane at WTG 2 but some distance from the jacket, incoming service barge from the south side | 598-599 |
| 08/25/2015 14:39:52 | Lifting hammer at WTG 2 | 606-609 |
| 08/25/2015 15:02:59 | Weeks Barge moving closer to WTG 2 | 610-622 |
| 08/25/2015 15:21:50 | Weeks Barge lifting hammer | 623 - 634 |
| 08/25/2015 15:50:56 | Weeks Barge lifting up the hammer. | 635-639 |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 08/25/2015 16:10:58 | After short stop in operation , crane lifting hammer again | 640-651 |
| 08/25/2015 16:23:54 | Crane bringing down the hammer again. | 653-654 |
| 08/25/2015 16:33:08 | Deepwater just sat hammer down on deck and asked if other barge had a welder. | |
| 08/25/2015 16:37:07 | Crane barge on WTG 3 , separated from jacket and approaching site WTG 2 | 656 -659 |
| 08/25/2015 17:10:22 | No new activity. | 679 -682 |
| 08/26/2015 07:53:30 | 2nd crane barge is not on site. The first crane barge is moored close to WTG 2. 2 other service vessel on WTG 2. No activity. 5 vessels + crane barge on site | 683-691 |
| 08/26/2015 08:36:22 | Weeks barge is getting close to WTG 2 | 692 -695 |
| 08/26/2015 09:00:48 | Weeks barge and 3 vessels on site, no visual activity. the service tug disconnected from barge | 696 -701 |
| 08/26/2015 09:32:57 | Crew boat inbound, Weeks barge on site WTG 2. 4 vessels +crane barge on site. no piling activity | 702-713 |
| 08/26/2015 10:00:30 | No visual activity on site. 4 vessels + crane barge on site. | 714 -716 |
| 08/26/2015 10:33:36 | Barge movement on site 2, rotating on the old location only. 2 vessel + crane barge on site 2. No activity on site 3. | 717 -719 |
| 08/26/2015 11:02:11 | 2nd barge still in previous position. Crane activity on barge. No sign of other activities. 2 vessels + crane barge on site. | 720 -725 |
| 08/26/2015 11:38:30 | No visual activity ,2 boats and crane barge on site | 726 -728 |
| 08/26/2015 12:01:18 | No new activity. Discussing whales on VHF. | 729 -732 |
| 08/26/2015 12:31:30 | Crane repositioned. 3 boat + crane barge on site 2. | 733 -742 |
| 08/26/2015 12:37:37 | Service vessel moving in bond of crane barge | 743 - 744 |
| 08/26/2015 12:49:38 | The service vessel is moving out of site 2. | 745 -747 |
| 08/26/2015 13:06:17 | A whale surfaced near WTG 2. | 748 -764 |
| 08/26/2015 13:09:53 | 2 vessels + crane barge on site. No activity | 765 -767 |
| 08/26/2015 13:39:44 | 2 vessels + crane barge on site. Crane relocated. No visual sign of pile driving. | 768 -771 |
| 08/26/2015 13:53:22 | Transferring some equipment using small crane to the service vessel. | 772-775 |
| 08/26/2015 14:01:27 | 3 boat + crane barge on site. | 776 -779 |
| 08/26/2015 14:27:46 | Some equipment has been shipped off the barge by a service boat | 780 -785 |
| 08/26/2015 14:57:08 | Crane movement. A new tug boat inbound to WTG 3. Connected to jacket on WTG 3. No sign of pile driving yet. | 786 -796 |
| 08/26/2015 15:33:25 | Tug boat disconnected from WTG 3 moving toward crane barge. No activity on crane barge. | 797 -799 |
| 08/26/2015 15:38:20 | Tug boat attached to port side of crane barge | 800 -815 |
| 08/26/2015 15:49:55 | 2nd tug boat moving toward the crane barge. The first tug boat is connected to barge. | 816 -833 |
| 08/26/2015 16:08:31 | Weeks barge moving away from WTG 2. No visual pile driving activity. | 834 -836 |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 08/26/2015 16:30:55 | One of the tug boats connected on port side of crane barge. Another one is close the crane hook on the starboard of crane barge. No visual pile driving activity. | 837 -839 |
| 08/28/2015 13:41:12 | The crane barge approaching WTG 3. 3 vessels + crane barge on site. No activity on WTG 2. | 841-850 |
| 08/28/2015 14:10:53 | Barge slowly try to dock on the jacket. 3 vessels moved back from WTG 3 | 851 -852 |
| 08/28/2015 14:44:08 | No new activity on the barge. 3 vessels + crane barge on site | 866 -867 |
| 08/28/2015 15:10:16 | Pick up chatter on radio, about a damaged caliper. Barge requested for hydraulic Jack to fix it. No new activity on site regarding pile driving. | 870 -871 |
| 08/28/2015 15:23:57 | Crane relocation on barge | 872 -880 |
| 08/28/2015 15:35:05 | The crane cable is down. The service boat is back on site. 5 vessels + crane barge on site | 881 -894 |
| 08/28/2015 15:48:47 | Incoming service vessel from north to WTG 3. | 895 -911 |
| 08/28/2015 16:03:19 | Service vessel disconnected from barge. no crane activity at the moment | 912 -913 |
| 08/28/2015 16:19:24 | Service vessel leaved the construction site. | 914 -915 |
| 08/28/2015 16:36:56 | 6 vessels + crane barge on site. No visual pile driving activity. | 916 -920 |
| 08/28/2015 17:02:41 | A chatter on the radio showed they still working on a caliper on barge. Crew is asking for spare steel shaft. | |
| 08/28/2015 17:09:27 | A tug boat connected to the barge, crane movement on barge, no sign of pile driving. | 921 -934 |
| 08/28/2015 17:36:54 | Barge request a mechanic for fixing the cliper. Some crane activity. No sign of pile driving. 3 vessels and crane barge on site 3. 1 service vessel on site 2. | 935 -936 |
| 08/28/2015 17:59:04 | Chatter on radio about fixing the winch. Construction crew calls ends work for the day. | 937-944 |
| 08/29/2015 07:28:43 | No activity on site. 3 vessels (Heather Lynn, HDR, and unknown) + Weeks barge on site. | 945 -947 |
| 08/29/2015 07:47:53 | The project manager vessel and environmental team vessel on site. Crane activity on the barge. | 948 -949 |
| 08/29/2015 08:00:22 | 6 vessels (Supply vessel, Lindsey E, HDR, fishing vessels, Heather Lynne) + Weeks barge at WTG 3. No visual pile driving activity | 950 -951 |
| 08/29/2015 08:16:04 | Chatter on radio: PSO gave them thumbs up for start | 954 |
| 08/29/2015 08:30:25 | 4 vessel + crane barge on site. Chatter on radio as they try to lift the hammer at WTG 3 | 954 -955 |
| 08/29/2015 08:42:19 | They are lifting the hammer | 960 -964 |
| 08/29/2015 08:48:13 | The barge is getting closer to the WTG 3 jacket. | 965 -971 |
| 08/29/2015 09:03:06 | Hammer is half way up. Weeks barge getting closer to the jacket. | 973-974 |
| 08/29/2015 09:08:09 | Positioning hammer over the piles on WTG 3 | 975 -986 |
| 08/29/2015 09:22:19 | Hammer on top of pile | 988 -989 |
| 08/29/2015 09:30:19 | Heard a chatter on radio the hammer is stuck on the pile | 995 |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 08/29/2015 09:38:21 | Hammer on pile. A tug and barge was on site. 5 vessels + Weeks barge on site | 1000 -1001 |
| 08/29/2015 10:04:04 | Chatter on radio indicates hammer stuck on the pile, can not be moved. 14 small vessels are between site 2 and 3. Can not see if they are related to the project | 1008 to 1012 |
| 08/29/2015 10:33:28 | No sign of pile driving. Hammer still on pile, a lot of small boats still around the site. | 1013-1020 |
| 08/29/2015 11:00:58 | Hammer still on the top of pile. Looks like it still jammed. Lots of small boats in the area. No pile driving yet | 1021 -1032 |
| 08/29/2015 11:30:53 | Hammer still on pile, no pile driving. No chatter on the radio | 1033 -1034 |
| 08/29/2015 12:02:42 | Hammer still on the pile. No sign of pile driving. No chatter on the radio | 1035 -1036 |
| 08/29/2015 12:20:48 | Chatter on the radio. They are trying to release the hammer from pile | 1037 -1040 |
| 08/29/2015 12:38:45 | They are trying to release the hammer by moving the crane. | 1041 -1048 |
| 08/29/2015 12:58:26 | Hammer separated from the pile finally. They are checking it for the damage at the moment | 1049 -1055 |
| 08/29/2015 13:06:43 | Picked up chatter on the radio. Deepwater is bringing down the hammer to check hydraulic system. | 1056 -1067 |
| 08/29/2015 13:24:39 | Crane movement on the barge | 1069 -1074 |
| 08/29/2015 13:35:17 | No activity on the site, There was chatter on the radio about damage report. | 1075 -1076 |
| 08/29/2015 13:44:40 | Weeks Barge pivoted on its location. No sign of hammer. Weeks Barge has separated from the jacket. Hammer is on the deck. | 1080 -1087 |
| 08/29/2015 14:02:19 | Chatter on the radio: Switched to auxiliary generator to check the main one on the barge. No activity on the barge, no signs that pile driving will happen. A sailing boat passing in front of the jacket | 1089 -1090 |
| 08/29/2015 14:38:17 | No chatter on the radio, no sign indicating pile driving will happen soon. | 1093 -1094 |
| 08/29/2015 15:04:00 | No sign of activity. Chatter on the radio: group of workers leaving the site based on union rules. | 1095 -1096 |
| 08/29/2015 15:10:01 | Incoming service boat ( Rosemary) to pick up some people from barge (chatter on radio) | 1097 -1105 |
| 08/29/2015 15:26:23 | Chatter on the radio: the night shift will work on new modification for hammer. Service boat "Rosemary" is leaving. | 1106 -1108 |
| 08/29/2015 15:51:34 | All service vessels leaving WTG 3. | 1109-1110 |
| 08/30/2015 08:52:05 | Hammer on piling at WTG 3. | |
| 08/30/2015 09:30:05 | First few strikes made | |
| 08/30/2015 10:10:47 | Cannot hear pile driving | |
| 08/30/2015 09:02:20 | The hammer is set on the pile; they are ready to pile drive. 4 boats on site (Heather Lynn, tow Tugs, fishing charter + Weeks barge) | 1117 -1122 |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 08/30/2015 09:22:37 | The caption acknowledge presence of HDR team near the WTG 3 | |
| 08/30/2015 09:25:23 | They Inform on radio pile driving is on! The offshore vessel had couple hits. | 1123 -1126 |
| 08/30/2015 09:29:06 | They were 10 spaced strokes and their acoustic team on the radio approve the sound level for pile driving | |
| 08/30/2015 09:31:07 | They start to pile drive consistently. Can't hear any noise at SE Lighthouse. | |
| 08/30/2015 09:32:39 | The boat acknowledge they do the pile driving in 1 Hz | 1127 -1145 |
| 08/30/2015 09:38:55 | The pile is 1/3 driven. | 1146-1156 |
| 08/30/2015 09:48:29 | Still driving, hear no noise at lighthouse regarding pile driving! The level of noise and wind direction would not allow me to hear the impacts. | |
| 08/30/2015 09:55:55 | They are still piling driving and it's going forward slowly! Still too much noise can not hear anything. More than half of the pile has been driven. | 1157-1163 |
| 08/30/2015 10:04:14 | Still pile driving. Looks it's slowly going forward. I can see 9 vessel + Weeks barge on site. | 1068-1070 |
| 08/30/2015 10:08:43 | More than two third of pile has been driven , still no piling sound can be heard | 1171-1173 |
| 08/30/2015 10:18:29 | Finally I can hear the strokes in lighthouse location. | 1174 |
| 08/30/2015 10:25:05 | It's the last 10 percent of pile. Still hear the strokes! It's less than 1 hz strokes | 1175-1178 |
| 08/30/2015 10:28:21 | Pile driving complete on south east corner pile. Looks like they are all through. | 1179 -1187 |
| 08/30/2015 10:40:27 | Separating the hammer from the pile | 1188 -1189 |
| 08/30/2015 10:44:26 | Chatter on the radio: Difficulty removing hammer. | 1195 |
| 08/30/2015 10:46:19 | Chatter on radio : Repositioning barge for better angle for putting the hammer on next pile | 1199 -1200 |
| 08/30/2015 10:54:00 | Chatter: They are trying to set the hammer for the next pile, looks like they have an issue. | 1202 -1216 |
| 08/30/2015 10:58:22 | They are lots of small boats between WTGs 2 and 3. Still in progress of releasing the hammer from jacket for next pile driving | 1217 |
| 08/30/2015 11:02:18 | Chatter: Attempting to put the hammer back on barge deck | 1219 -1232 |
| 08/30/2015 11:09:11 | Chatter: Looks like a hose stuck on pile and they are having a problem setting the hammer on deck. | 1234 -1235 |
| 08/30/2015 11:30:08 | Hammer is still on crane hook. Chatter on radio: they still need to bring the hammer on deck for resetting and deal with the hydraulic lines. | 1242 -1243 |
| 08/30/2015 11:32:41 | Try to put the hammer on the barge | 1243 -1248 |
| 08/30/2015 11:58:40 | Still working on hammer. | 1256 -1257 |
| 08/30/2015 12:12:35 | Lifting the hammer again for another try to release the hose from jacket | 1261 -1274 |
| 08/30/2015 12:41:39 | Hammer is back on the deck. chatter : they requested a welder | 1275-1276 |
| 08/30/2015 13:00:59 | VHF Chatter : looks like there are something wrong with the winch , they requested a mechanic | |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 08/30/2015 13:03:35 | They are moving the barge. 4 vessels + crane barge on site | 1277 -1278 |
| 08/30/2015 13:37:37 | They were trying to relocate the barge for doing the second pile | 1279 -1303 |
| 08/30/2015 14:15:52 | Still repositioning the barge. | 1304 -1310 |
| 08/30/2015 14:25:33 | Service vessel Rosemary Miller, approaching the barge. bring some personnel | 1311 -1314 |
| 08/30/2015 14:30:11 | Service vessel Rosemary Miller is moving out of the site | 1315 -1317 |
| 08/30/2015 14:45:33 | They barge still moving toward the new position. | 1318 -1327 |
| 08/30/2015 14:55:51 | They pick the hammer out of the deck. | 1328-1333 |
| 08/30/2015 15:12:55 | They try to put the hammer up but they had wrong angle (chatter), putting the hammer on the barge again | 1334 -1343 |
| 08/30/2015 15:24:41 | Picking the hammer up again | 1344 -1349 |
| 08/30/2015 15:30:19 | They put the hammer back down; they are changing the barge position. | 1350 -1374 |
| 08/30/2015 16:06:28 | Still repositioning the barge, no sign of hammer. | 1375 -1381 |
| 08/30/2015 16:21:12 | They are still reposition the barge. Received update they are resuming work tomorrow morning | 1382 -1383 |
| 08/31/2015 18:44:47 | Started sound meter around 08:45; restarted at 11:56:42 | |
| 09/01/2015 12:24:48 | 4 boats at WTG 3 | 1384-1385 |
| 09/01/2015 12:33:44 | 4 vessels; no driving; restarted meter at 11:56:42; meter started around 8:45 for the day | 1386-1387 |
| 09/01/2015 12:55:43 | 1 vessel, Weeks Barge | 1388-1389 |
| 09/01/2015 13:24:34 | 3 vessels moving north out of area; crane moving | 1390-1391 |
| 09/01/2015 13:41:26 | Moving hammer to pile at WTG 3 | 1392-1393 |
| 09/01/2015 13:54:50 | Setting hammer back down | 1397-1398 |
| 09/01/2015 14:25:14 | 2 vessels and 2 planes pass by | 1399-1400 |
| 09/01/2015 15:10:13 | Crew still working on barge | 1401-1402 |
| 09/01/2015 15:29:03 | Raising the hammer | 1403-1404 |
| 09/01/2015 15:40:37 | Hammer appears to be on the pile at WTG 3 | 1408-1409 |
| 09/01/2015 15:48:04 | One possible blow | 1410-1412 |
| 09/01/2015 15:51:38 | First 3 soft starts occurred at 15:50; next15:52;15:53:30 full impact | 1413-1414 |
| 09/01/2015 15:53:38 | Started | |
| 09/01/2015 15:54:03 | Stopped | |
| 09/01/2015 15:54:58 | Restart | 1415-1420 |
| 09/01/2015 16:21:59 | Continue driving | 1421-1428 |
| 09/01/2015 16:53:55 | Stopped at 16:48:00 | |
| 09/01/2015 16:54:41 | Hammer off pile | 1429-1431 |
| 09/01/2015 17:24:57 | Moving barge; 3 vessels in area | 1432-1433 |
| 09/01/2015 18:02:07 | No activity | 1434-1435 |
| 09/02/2015 08:53:27 | Extremely foggy; started meter at 08:45 | 1436-1437 |
| 09/02/2015 09:16:01 | Still extremely foggy; can barely make out barge | 1438-1445 |
| 09/02/2015 09:45:34 | Visibility just dropped again, I cannot see the barge;9:53 I can no longer see water | 1446-1448 |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 09/02/2015 10:13:31 | Visibility is extremely bad, cannot see water | 1449-1451 |
| 09/02/2015 10:18:55 | Start hammer at WTG 3; 10:21 fog horn started around that time | 1452-1453 |
| 09/02/2015 10:31:24 | Restarted; will need to rely on Tyler for exact start and stop | 1454-1455 |
| 09/02/2015 11:02:18 | Extreme fog and glare cannot see water | 1456-1457 |
| 09/02/2015 11:07:40 | Hammer stopped | 1458-1459 |
| 09/02/2015 11:14:26 | Barge repositioning; fog beginning to lift | 1460-1463 |
| 09/02/2015 11:21:23 | Repositioning barge | 1464-1470 |
| 09/02/2015 12:01:13 | Moving barge around | 1471-1473 |
| 09/02/2015 12:19:54 | Hammer is up at WTG 3 | 1473-1476 |
| 09/02/2015 12:36:29 | Hammer is on pile at WTG 3 | 1477-1478 |
| 09/02/2015 12:46:44 | Barely hear driving, assumed it started at 12:44 | 1479-1480 |
| 09/02/2015 12:55:17 | Barely hearing hammer; 5 vessels present | 1481-1482 |
| 09/02/2015 13:05:59 | Pile still being driven | 1483-1484 |
| 09/02/2015 13:14:20 | Driving deeper | 1485-1486 |
| 09/02/2015 13:36:01 | Continuous driving | 1487-1488 |
| 09/02/2015 13:38:30 | Just stopped | 1489-1490 |
| 09/02/2015 14:19:18 | End of day, moving barge, 2 piles driven today at WTG 3 | 1495-1496 |
| 09/03/2015 08:48:56 | Started meter at 8:47 | |
| 09/03/2015 09:03:48 | Moving crane; appears to be 4 vessels in the area of WTG 2 | 1497-1501 |
| 09/03/2015 09:39:57 | Moving things around on barge | 1502-1503 |
| 09/03/2015 09:45:55 | Lifting the hammer onto pile at WTG 2; 9 vessels in sight | 1504-1505 |
| 09/03/2015 09:54:03 | Hammer is on pile at WTG 2 | 1506-1507 |
| 09/03/2015 10:00:00 | Start at 9:58:40; 6 vessels | 1508-1509 |
| 09/03/2015 10:10:25 | 8 vessels in area while driving | 1510-1511 |
| 09/03/2015 10:30:36 | Pile driving ended around 10:22:00;hammer is off pile | 1512-1513 |
| 09/03/2015 10:57:13 | Placing hammer on next pile at WTG 2; 5 vessels visible | 1514-1517 |
| 09/03/2015 11:09:37 | Visibility dropped, very poor, can barely make out barge | 1518-1519 |
| 09/03/2015 11:14:25 | Visibility dropped, very poor, can barely make out barge; 4 bangs | 1520-1521 |
| 09/03/2015 11:39:35 | Visibility is still poor | 1522-1523 |
| 09/03/2015 12:00:38 | Stopped driving at 11:42; again visibility is extremely poor, no photos taken | |
| 09/03/2015 12:46:26 | Visibility very poor, can barely make out barge, have not heard what's going on | 1524-1525 |
| 09/03/2015 13:02:05 | Visibility very poor, can barely make out barge, have not heard what's going on, can only see 3 vessels | |
| 09/03/2015 13:37:57 | Visibility is getting better; the other tug and barge are crossing in front of the main barge | 1526-1527 |
| 09/03/2015 14:03:57 | Visibility improving; waiting on wildlife boat; about to lift the hammer; 6 vessels | 1528-1529 |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 09/03/2015 14:18:29 | Lowering hammer on pile, visibility is fair | 1530-1531 |
| 09/03/2015 14:37:01 | Hammer on pile | 1532-1533 |
| 09/03/2015 14:43:55 | 14:43:53 start | 1533-1536 |
| 09/03/2015 14:48:26 | Temporarily stopped | |
| 09/03/2015 14:51:25 | Resumed at 14:51:16 | |
| 09/03/2015 15:10:52 | Visibility worsening, faintly hear hammer | 1537-1538 |
| 09/03/2015 15:21:13 | Stopped at15:16:23; barely heard hammering; lots of ambient noise; visibility is very poor, only see 3 vessels | |
| 09/03/2015 15:59:42 | Positioning hammer; visibility is poor | 1539-1540 |
| 09/03/2015 16:36:09 | Moving hammer; visibility is very poor about 3 vessels in sight | 1541-1543 |
| 09/03/2015 16:43:07 | Hammer is going on; fog horn in distance north | |
| 09/03/2015 16:53:18 | Started full at 16:52:10; visibility is very poor | 1544-1545 |
| 09/03/2015 17:11:38 | Continuing; visibility is very poor | 1546-1547 |
| 09/03/2015 17:21:35 | End pile driving at 17:18:09 | 1548-1549 |
| 09/03/2015 17:24:16 | Visibility is very poor; end of day | |
| 09/06/2015 20:00:00 | Night time photos | 3857-3886 |
| 09/07/2015 13:53:43 | WTG 3, there are 3 welders that are welding northeastern most pile in the jacket. At WTG 5, Weeks Barge is placing foundation in water (jacket). | 3980-3986 |
| 09/07/2015 14:15:17 | Continuing same as before; WTG 3 is welding pile onto other pile; WTG 5 straps still on jacket | |
| 09/07/2015 14:31:24 | WTG 3, successfully welded pile to another pile (looks like NE most pile) unaided by crane; on WTG 5 a tug entered area | 3987-3997 |
| 09/07/2015 15:04:52 | WTG 3, welding on unaided pile, barge maybe being pushed to different position; on WTG 5, jacket maybe in proper position, checking now | 3987-4006 |
| 09/07/2015 15:34:17 | WTG 3 appears they are prepping another pile to lift, and continue welding; on WTG 5, lowering crane boom on jacket, appears they are finalizing jacket position. | 4007- 4014 |
| 09/07/2015 20:11:29 | Night time shots. WTG 3, they have 2 piles up, welding on the pile; on WTG 5,barge has released the jacket | 4015-4023 |
| 09/08/2015 07:59:07 | Can only see WTG 3, continued welding on second pile and preparing the third pile (crane over pile barge); extremely hazy/foggy and windy not as much wind as yesterday; fog horn sounding before I got here | 4024-4034 |
| 09/08/2015 08:16:10 | Heavier haze/fog rolled in, will come back later today to check progress | |
| 09/08/2015 11:25:48 | Does not appear to be a second barge, but jacket 5 is in place; visibility cleared up significantly; continued welding and the 3rd pile is hooked up to the crane and being lifted | 4035-4047 |
| 09/08/2015 11:43:53 | Pile being raised is angled/pointed | |
| 09/08/2015 11:52:48 | Pile is being placed into position | 4048-4068 |
| 09/08/2015 17:06:56 | Pile 3 is being worked on welding, still attached to crane; wind has greatly increased from this morning | 4069-4074 |
| 09/08/2015 17:31:29 | Seem to be working somewhat cautiously because of high winds and swell; still welding third pile. | |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 09/08/2015 19:37:41 | Night pictures. Still working on welding 3rd pile; at the moment, it does not appear to be anybody on the pile | 4075-4082 |
| 09/09/2015 07:59:34 | Welding 4th extender pile on, still breezy but not as bad as yesterday | 4089-4094 |
| 09/09/2015 08:21:13 | Appears they are welding piles 3 and 4 | |
| 09/09/2015 08:28:30 | Moving pile barge southeast towards jacket 5 | 4095-4099 |
| 09/09/2015 08:47:43 | Crane is off the pile, still welding pile 3; relocating pile barge northward | 4100-4103 |
| 09/09/2015 09:33:23 | Welding on pile 4 | 4104-4106 |
| 09/09/2015 14:43:04 | Appears that they are inspecting the piles, and very little welding | 4107-4111 |
| | | |
| 11/09/2015 08:24:43 | Start visual survey of installation of transition deck on WTG 4. Deepwater Wind on VHF65. They have transition deck on crane and started positioning. DW said they would not start till 12:00 | |
| 11/09/2015 08:38:31 | LB Roberts next WTG 4 installing the transition deck. 400 mm zoom | 2588-2591 |
| 11/09/2015 08:42:06 | 100 mm zoom. LB Roberts with 3 tugs and crew tender | 2592 |
| 11/09/2015 08:43:11 | LB Roberts at WTG 4 installing transition deck | 2593-2594 |
| 11/09/2015 08:44:16 | WTG 5 - no activity. 400 mm | 2595 |
| 11/09/2015 08:46:06 | WTG 3 - no activity | 2596 |
| 11/09/2015 08:47:49 | WTG 2 with transition deck previously installed. No activity | 2597 |
| 11/09/2015 08:48:40 | WTG 1 with top deck that has been previously installed. | 2598 |
| 11/09/2015 08:54:35 | Slowly lowering transition deck onto piles from steel foundation. | 2599 |
| 11/09/2015 08:58:27 | Radio communication indicate platform is set and within tolerance. They are doing final inspection to prepare for welders | |
| 11/09/2015 09:14:19 | 41deg09.167<br>o71deg33.110 GPS coordinates of observation site | |
| 11/09/2015 09:35:46 | Deepwater lowering boom to unhook from top | 2605 |
| 11/09/2015 09:41:19 | Taken by sign so Change GPS coordinates | 2606-2608 |
| 11/09/2015 09:45:39 | 3 tugs and crew tender still onsite, have not moved | 2608 |
| 11/09/2015 10:06:29 | Crane is de-rigging from top deck. Small fishing boat in background | 2611 |
| 11/09/2015 10:11:37 | Rosemary Miller is the crew tender onsite per VHF communications | |
| 11/09/2015 10:23:37 | Rosemary miller crew tender leaving site. WTG 2 in background | 2612-2613 |
| 11/09/2015 10:34:21 | Crane unhooked from platform at no. 4 | 2614 |
| 11/09/2015 10:40:09 | LBV Roberts starting to jack down, crane is unhooked. They are lowering walkway that welders use to access the transition deck on WTG 4 | 2615 |
| 11/09/2015 11:04:30 | Weeks barge with top deck, leaving moving away from WTG 4, pulled by 2 tugs. 100 mm | 2616 |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 11/09/2015 11:06:03 | 400 mm | 2617 |
| 11/09/2015 11:07:06 | LB Roberts jacked down level with water | 2618 |
| 11/09/2015 11:09:30 | WTG 1 | 2618 |
| 11/09/2015 11:10:31 | WTG 2 | 2619 |
| 11/09/2015 11:11:09 | WTG 3 | 2621 |
| 11/09/2015 11:11:26 | WTG 5 | 2622 |
| 11/09/2015 11:18:18 | Per Bryan Wilson, next transition deck will be installed11/16/2015. Expecting bad weather this week. | |
| 11/09/2015 11:41:18 | Tug pulling remaining 2 top decks to safe harbor in anticipation of weather coming tomorrow | 2623-2625 |
| 11/09/2015 11:44:09 | No activity or VHF communications, they are on lunch break | |
| 11/09/2015 12:56:50 | Crew tender headed towards WTG 4 | 2626-2630 |
| 11/09/2015 12:57:57 | LB Roberts | 2628 |
| 11/09/2015 12:58:50 | LB Roberts and 2 tugs onsite at WTG 4 with Derrick barge in background | |
| 11/09/2015 13:02:48 | Crew tender next to LB Roberts | 2632 |
| 11/09/2015 13:03:31 | 2nd tug onsite at WTG 4 | 2631 |
| 11/09/2015 13:06:27 | Fishing vessel in area of WTG 1 | 2637 |
| 11/09/2015 13:21:18 | Fishing vessel pairing near WTG 1 | 2638 |
| 11/09/2015 13:25:00 | VHF communications - they are preparing for welders by taking supplies out on tender to LV Roberts. Plan to weld tonight and shut down in early morning before bad weather arrives | |
| 11/09/2015 13:34:10 | LB Roberts after Derrick barge has passed. | 2639 |
| 11/09/2015 13:35:26 | 3 tugs. Pulling crane barge that was next to LV Roberts. Headed north away from site towards mainland. | 2640-2642 |
| 11/09/2015 13:37:07 | 2nd tug helping move barge | 2643 |
| 11/09/2015 14:17:36 | DW is anchoring the Derrick barge to the southeast of WTG 1 for the night. | 2644-2646 |
| 11/09/2015 14:25:42 | 1 of the tugs headed to port for the day | 2647-2648 |
| 11/09/2015 14:28:10 | VHF indicates the barge is anchored | |
| 11/09/2015 14:30:47 | VHF -Rosemary tender dispatched to lift boat Roberts to pick up 4 welders | 2649-2650 |
| 11/09/2015 14:54:00 | Rosemary Miller next to LB Roberts, using man cage to lift welders onto Rosemary | 2651-2652 |
| 11/09/2015 14:58:14 | Rosemary leaving lift vessel | |
| 11/09/2015 15:59:08 | LB Roberts | 2660-2661 |
| 11/09/2015 15:59:45 | Barge moored by WTG 1 | 2659 |

**Table B-2. Offshore Photo Log Key and Field Observations Summary**

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 08/18/2015 06:42:01 | Leaving harbor | |
| 08/18/2015 07:14:37 | Arrived on site, Cashman supply barge with foundations and piles on deck, tug Reed Danos | 0011-0014 |
| 08/18/2015 07:21:18 | Tender ship "Rosemary Miller" just departed, we are 750m northwest of platform | 0019 |
| 08/18/2015 07:51:42 | Tug "Robert" and Tug "Elizabeth" | 0016-0017 |
| 08/18/2015 08:20:09 | Weeks Barge 533 gearing up to start pile driving. Cranes are moving! | 0018 |
| 08/18/2015 08:39:06 | Marine Mammal Lookout vessel “Heather Lynn" hanging out 500m south of barge. | 0048-0051 |
| 08/18/2015 09:44:13 | Team removed a balloon floating in water, from Block Island wedding | |
| 08/18/2015 10:18:46 | "Lindsey E" ~25 ft white, down east style boat | 0064-0068 |
| 08/18/2015 10:26:41 | Large crane is picking up the hammer | 0069-0084 |
| 08/18/2015 10:41:51 | Transfer boat "Rosemary Miller" arriving | 0085-0088 |
| 08/18/2015 10:48:23 | Transfer boat "Rosemary Miller" leaving | 0089 |
| 08/18/2015 10:51:33 | Placing hammer to top of first piling, WTG 2 | 0090 |
| 08/18/2015 10:56:55 | Hammer fixed to piling | 0091 |
| 08/18/2015 11:35:54 | Removed hammer from pile and setting it back down on the barge | 100-110 |
| 08/18/2015 13:03:46 | Picking the hammer back up. We think work halted for lunch break. | |
| 08/18/2015 13:24:00 | Rosemary Miller is back | |
| 08/18/2015 13:32:05 | Putting the hammer back down, again. | |
| 08/18/2015 13:42:38 | Hammer attached to top of piling | |
| 08/18/2015 13:59:10 | Picking hammer back up off piling and lowering it back to the deck | |
| 08/18/2015 15:25:50 | Lifting the hammer | 111 |
| 08/18/2015 15:33:00 | Hammer on top of piling at WTG 2. | 112 |
| 08/18/2015 15:45:54 | Heard a few single smacks. "Soft start" to test hammer. | 113-120 |
| 08/18/2015 16:01:08 | Couple big smacks | |
| 08/18/2015 16:04:50 | Started hammering for about 5 seconds | |
| 08/18/2015 16:07:43 | Started hammering again for about 5 seconds. Deepwater testing how much pile moves after being struck. | |
| 08/18/2015 16:09:49 | Hammering again. Can see piston moving and exhaust smoke | 121 |
| 08/18/2015 16:12:37 | Video of pile driving. | 122 |
| 08/18/2015 16:12:00 | Pile driving stopped | |
| 08/18/2015 16:15:06 | Moving hammer back to the deck | |
| 08/18/2015 16:25:27 | The Lindsey E has left. Boats remaining on site are the two tugs and the fishing vessel Heather Lynn. Pictures of URI McMaster. | 124-127 |
| 08/23/2015 11:56:34 | Arrived on site. WTG 3 appears to have 2 of 4 piles stabbed. 2 tugs and a fishing vessel on site. Barge for WTG 2 pile driving inbound. | |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 08/23/2015 12:24:25 | Tug Robert comes out to meet Weeks 526 Derrick barge | 130 - 134 |
| 08/23/2015 12:25:48 | Tugboat Robert | 134-138 |
| 08/23/2015 12:27:28 | Supply vessel Josephine K Miller arrives onsite | 139 - 150 |
| 08/23/2015 12:41:38 | Tug Reed Danos positioning Weeks Barge 526 | 151 -164 |
| 08/23/2015 12:46:31 | Weeks Barge 526 | 165 -173 |
| 08/23/2015 15:24:15 | Weeks Barge 533 lifting a piling at WTG 3 to be stabbed | 182 - 183 |
| 08/23/2015 15:24:53 | Weeks Barge 526 arriving at WTG 2 | 179 -181 |
| 08/23/2015 15:36:02 | WTG 2, stabbing 3 pile | 182-183 |
| 08/23/2015 16:11:13 | WTG 3, pile 3 stabbed | 186 -187 |
| 08/23/2015 16:30:00 | View of onshore observation post at Southeast Lighthouse from vessel | 188-195 |
| 08/24/2015 07:05:19 | Arrived on site. Two barges and two tugs (Todd Danos) on site. Some weather coming thru, dry for now. | |
| 08/24/2015 07:38:21 | Crew tender boat arriving for Weeks Barge 533 (WTG 3) | |
| 08/24/2015 07:49:07 | Another crew tender arriving for Weeks barge 526 | |
| 08/24/2015 07:51:40 | First tender leaving barge 533 | |
| 08/24/2015 08:01:58 | Second tender leaving | |
| 08/24/2015 08:09:20 | White fishing vessel is sitting just off site to the east | |
| 08/24/2015 09:12:31 | Tug with equipment barge moving south west away from site. Barge looks like it holds the pilings | 196-211. blank at 212 |
| 08/24/2015 11:27:12 | Shots of the site. No significant change yet | blanks 242 and 252 |
| 08/24/2015 11:38:40 | Supply Vessel "Sorensen Miller" | 253 - 259 |
| 08/24/2015 12:21:55 | Weeks Barge 526 moving into position | |
| 08/24/2015 13:24:38 | Picking up the hammer off deck of Weeks Barge 526 | 260-282. blank 283 |
| 08/24/2015 13:44:53 | Putting the hammer back down. Shots of the Lindsey E with Deepwater staff | 284-289 |
| 08/24/2015 13:54:56 | Heather Lynn is whale spotter. | |
| 08/24/2015 15:00:10 | Heather-Lynn photo shoot. White fishing vessel with outriggers | 290 - 303 |
| 08/24/2015 15:39:26 | Hammer has been on deck and unhooked from crane for an hour. Marine Mammal Observation and VIP boats have left. Team ended survey | |
| 08/25/2015 07:12:40 | Departing harbor. Fog is strong. Visibility less than 0.3 mi | |
| 08/25/2015 07:36:20 | On site. Positioned 0.25 mi north, fog too strong to see anything | |
| 08/25/2015 07:50:02 | Shots in direction of barge. Too foggy to see, but we can hear engines running | 304-309 |
| 08/25/2015 08:22:16 | WTG 3. Tug and Weeks barge 533 emerge through the fog. | 310 - 318 |
| 08/25/2015 08:30:23 | Fishing vessel and Weeks barge 526 | 319 - 328. 329 is blank |
| 08/25/2015 08:32:45 | R/V McMaster | 330 - 337. 338 is blank |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 08/25/2015 08:33:45 | Tug pushing Weeks Barge 533 into position. | 339 - 342 |
| 08/25/2015 11:15:19 | Series of both sites now that fog has finally lifted. Weeks Barge 533 is moving an anchor. Still no activity on Weeks Barge 526 located at WTG 2. | 345 - 365. 366 is blank |
| 08/25/2015 11:47:03 | Moving Weeks Barge 533 to a better position | |
| 08/25/2015 12:12:47 | Positioning last pile on WTG 3 to be stabbed | 367 -370 |
| 08/25/2015 12:16:30 | Crew boat arriving at WTG 2, barge 526 | 371 - 379. 380 is blank |
| 08/25/2015 13:13:54 | Last pile on WTG 3 has been stabbed and is in place | 381 - 385. 386 is blank |
| 08/25/2015 14:36:12 | Long series of everything on site as we lapped around it clockwise from north | 387 - 503. 504 is blank |
| 08/25/2015 14:38:12 | Weeks Barge 526 lifting the hammer on WTG 2 | 509 - 533 |
| 08/25/2015 14:40:36 | Supply vessel Josephine Miller is moving | 505 - 508 |
| 08/25/2015 14:53:10 | Crew tender arriving | |
| 08/25/2015 15:18:16 | Lindsey E has arrived with the Deepwater Wind executives | |
| 08/25/2015 16:32:38 | Lowering the hammer back on the deck. On VHF radio hear Weeks Barge 526 asking the other barge for a welder | 533-538 |
| 08/25/2015 17:13:47 | Leaving site | |
| 08/26/2015 07:09:07 | Leaving harbor. Sky looks dark to the west | |
| 08/26/2015 07:42:52 | On site in the morning. Josephene Miller (blue fuel vessel), Heather Lynn (white fishing vessel), and Iona McAlister (tug) standing by. Weeks barge 526 has it's boom down and is resting a bit off jacket 2. Weeks barge 533 left from WTG 3 overnight | 539 - 599. 600 is blank |
| 08/29/2015 07:18:11 | Arrived on site. Supply Vessel Josephine Miller (fuel), Tug Robert and crew tender on site. Both cranes on Weeks Barge 533 are up and hammer appears to be hooked up at WTG 3. | 601 - 619. 620 is blank |
| 08/29/2015 08:06:01 | Lindsey E arrived with Brian Wilson (Deepwater Wind Project Manger) and a couple other VIP's | |
| 08/29/2015 08:29:01 | Lifting the hammer. Heather Lynn moved on site | 621 - 643 |
| 08/29/2015 09:22:49 | The hammer is on a piling at WTG 3 | 644 - 649. 650 is blank |
| 08/29/2015 09:29:05 | Fuel tanker passing by | 651 - 656. 657 is blank |
| 08/29/2015 09:59:19 | Rosemary Miller crew tender arrived. Hammer is stuck on piling | |
| 08/29/2015 12:16:36 | Leaving site. Hammer is still stuck and they've been radio silent for two hours | |
| 08/30/2015 09:01:12 | Arrived on site. Hammer is on pile at WTG 3. Tug Stephanie Dan, Tug Robert and the fishing vessel on site. Josephine Miller arriving onsite. | 658 - 663. 664 is blank |
| 08/30/2015 09:07:03 | Lindsey E arrived | 665–668. 669 is blank |
| 08/30/2015 09:08:58 | New tug "Stephanie Dann" one of the two on site | 670–674. 676 is blank |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 08/30/2015 09:17:30 | Supply vessel Josephine Miller appears to have turned around and is heading north away from the site | |
| 08/30/2015 09:26:00 | "Fire in the hole!" Hammering commenced with a few slow smacks at WTG 3 | |
| 08/30/2015 09:28:58 | Hammer firing consistently now for ~30 seconds then slowing down | 675 - 685 |
| 08/30/2015 09:32:57 | Can see the pile is driving in, getting lower than the others | 686 - 689 |
| 08/30/2015 09:40:36 | Hammer is still firing consistently at around 0.5 to 1 Hz | |
| 08/30/2015 09:49:19 | Shots from different angles as we wrap around. Still firing just under 1 Hz and the pile has been driven in about the length of the hammer | 690 - 716 |
| 08/30/2015 09:56:18 | Video to try and capture sound. Can't see much movement but we can hear it through air and water as it echoes off the boat | 728 video |
| 08/30/2015 10:07:57 | Hammer is lower to platform now. Still firing just under 1 Hz. | 730 - 739. 740 is blank |
| 08/30/2015 10:08:42 | 45 second video | 742 |
| 08/30/2015 10:23:02 | Low to deck, about 1/16th length of pile still visible. Hammering slowed to about 0.5 Hz | 743 - 756. 758 is blank |
| 08/30/2015 10:26:05 | Hammering stopped. | |
| 08/30/2015 10:41:05 | Lifting hammer off pile | 759 - 769 |
| 08/30/2015 11:02:28 | Tried swinging the hammer between piles. Now bringing it back to the deck and wrapped a hose or two around another pile | 771 - 790 |
| 08/30/2015 11:13:32 | Hammer back on deck | |
| 08/30/2015 13:33:42 | The tug "Robert" is moving anchors around to get the barge into position | |
| 08/30/2015 14:30:32 | Rosemary Miller crew tender just picked up a few people from the barge and departed for land | |
| 08/30/2015 14:57:59 | Picking the hammer back up | 793 - 806 |
| 08/30/2015 15:12:26 | Hammer back to deck | 807 to 809 |
| 08/30/2015 15:23:00 | Hammer coming back up | 810 - 813 |
| 08/30/2015 15:27:17 | Hammer coming back to the deck. need to readjust anchors | 814 - 816 |
| 08/30/2015 15:48:20 | Leaving site | |
| 09/01/2015 09:10:01 | On site. Tug Elizabeth, Heather Lynn (Observer boat), and a Francis Fleet boat are nearby. the large crane is down and Weeks barge 533 is silent | 817 - 830. 816 and 831 are blank |
| 09/01/2015 10:18:36 | URI research vessel "Shanna Rose" with ocean engineering students | 836 - 879. 880 is blank |
| 09/01/2015 12:54:10 | Crane is lifting | |
| 09/01/2015 13:35:17 | Lifting hammer at WTG 3 | 894 - 910 |
| 09/01/2015 13:46:57 | Heather Lynn | 889–893. |
| 09/01/2015 13:49:18 | Coming back down | |
| 09/01/2015 15:26:21 | Lifting the hammer at WTG 3 | |
| 09/01/2015 15:43:36 | Started audio recording. Notable ambient noise includes: ship's radio (loudest), waves, waves hitting | |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| | hull of our boat, fishing gear on our boat, shutter noise from my camera, engine noise from the barge/crane, and communications between myself and the captain. No other ship noise at the moment. We are drifting about 1 – 1.5 km (0.6 – 0.9 mi) away in between the site and the island. Wind is coming towards us from the southeast | |
| 09/01/2015 15:47:20 | Hammer is on the pile at WTG 3 | 911–914 |
| 09/01/2015 15:50:00 | First three hits | |
| 09/01/2015 15:53:10 | Firing consistently at a little over 0.5 Hz | 915–921 |
| 09/01/2015 15:59:11 | Video | 918 |
| 09/01/2015 16:02:41 | Heather Lynn moved close to us. Can just hear their crew talking and their boat noise, as well as the pile driving echoing off their hull! | |
| 09/01/2015 16:16:10 | Small boat passing by west | |
| 09/01/2015 16:19:09 | Captain received a phone call | |
| 09/01/2015 16:21:21 | Overheard on the radio: Guys from weeks barge seem to think they are to be given one mi outside the anchor pattern from other ships | |
| 09/01/2015 16:23:11 | Hammer seems noticeably louder now. about a quarter length left to go | |
| 09/01/2015 16:24:46 | Background noise from swatting black flies. We've had a ton attacking our ankles all day | |
| 09/01/2015 16:33:28 | Getting lower. noise has changed a little, sounds more like a gong | 919–938 |
| 09/01/2015 16:35:37 | We have shifted so the cabin of the boat is between the site and the noise monitor. I will continue to drift until driving has stopped | |
| 09/01/2015 16:37:48 | Radio noise | |
| 09/01/2015 16:46:01 | The crew tender Sorensen Miller is coming towards us from the other side of the site, loud boat | 937–939 |
| 09/01/2015 16:46:52 | All stop | |
| 09/01/2015 16:53:03 | Lifting the hammer back off the pile at WTG 3 | 940–941 |
| 09/01/2015 17:48:04 | Stopped audio recording. Heading home | |
| 09/02/2015 09:04:52 | Arrived on site. Weeks Barge 533 Crane is up. Tug Robert, Tug Elizabeth, and the Lindsey E on site. Heather Lynn is nearby and the Francis boat and a bunch of small personal craft are fishing to the S/SE of the site | 947–957 |
| 09/02/2015 09:54:30 | Lifting hammer at WTG 3 | 959 - 961 |
| 09/02/2015 10:16:30 | Hammer on pile at WTG 3 | 962 - 964 |
| 09/02/2015 10:22:25 | Fire in the hole. Hammer is firing consistently at around 0.5 Hz | |
| 09/02/2015 10:22:32 | Audio recording started. We are positioned just under one km (0.6 mi) to the E/SE. The wind is from the south and we are drifting slowly north. Ambient noise including: waves, waves on hull, ship noise, foghorn from SE lighthouse, communication between myself and captain, radio noise, camera equipment noise | |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 09/02/2015 10:22:59 | Hammer slowed to under 0.5 Hz | |
| 09/02/2015 10:23:19 | Hammer stopped firing | |
| 09/02/2015 10:24:39 | Firing consistently again at WTG 3 | |
| 09/02/2015 10:25:15 | The Shanna Rose passed right by us, deployed their equipment. And hammer paused again. | |
| 09/02/2015 10:27:38 | Started again. ~0.5 Hz | |
| 09/02/2015 10:34:50 | Video of pile driving. | 964 |
| 09/02/2015 10:36:53 | Smacks are around 67 dB LAeq is 66.8. LApeak is 94.9 | |
| 09/02/2015 10:44:55 | Noise monitor was knocked over a few seconds ago | |
| 09/02/2015 10:47:06 | Heather Lynn passed right next to piling | 965 - 969 |
| 09/02/2015 10:53:27 | Crew tender Rosemary Miller arriving. | 970 - 979 |
| 09/02/2015 11:01:30 | Rosemary Miller coming close to us, loud boat | |
| 09/02/2015 11:07:21 | All stop | |
| 09/02/2015 11:18:49 | Lifting hammer | 980 - 986 |
| 09/02/2015 12:19:13 | Lifting hammer again | |
| 09/02/2015 12:22:34 | Audio recording stopped to change battery and reposition boat. We drifted slowly north, just past turbine 2 | |
| 09/02/2015 12:34:32 | Audio recording started again. positioned slightly farther south than last time | |
| 09/02/2015 12:38:39 | Small personal craft passed about 500 m (1,640.4 ft) by us | |
| 09/02/2015 12:40:12 | Couple starting smacks | |
| 09/02/2015 12:46:02 | Firing consistently but slowly. impacts are a little quieter this time, could be wind which has picked up from the south | 987 - 995 |
| 09/02/2015 12:55:53 | Firing at about 0.5 Hz | |
| 09/02/2015 13:19:44 | Hammer paused for a few seconds then started up again | |
| 09/02/2015 13:37:36 | Monitor fell over | |
| 09/02/2015 13:38:09 | Hammer stopped and removed from pile | 996-1019 |
| 09/03/2015 08:48:35 | | |
| 09/03/2015 08:51:40 | 5 boats in area: Tug Elizabeth, Weeks Barge 533, Tug Robert, URI McMaster, fishing charter boat in the area. | 1025 -1049 |
| 09/03/2015 08:40:00 | Arrival at WTG 2, setting prior to pile driving commencement | 1050-1067 |
| 09/03/2015 09:37:00 | Hammer being lifted to first pile WTG -2 | 1067-1101 |
| 09/03/2015 09:45:00 | Working to seat hammer on pile. | 1102-1123 |
| 09/03/2015 09:47:00 | Hammer aligned | 1124-1133 |
| 09/03/2015 09:50:00 | Green Light received on hammer, hammer penetration | 1134-1140 |
| 09/03/2015 09:52:00 | Fire in the hole @ 0953, First strikes @ 0955, Area shots of vessels on site | 1141-1156 |
| 09/03/2015 10:02:00 | Hammer striking, area shots | 1157-1213 |
| 09/03/2015 10:08:00 | Hammer striking, area Shots | 1214-1332 |
| 09/03/2015 10:21:00 | Hammer striking, area Shots, birds | 1333-1341 |
| 09/03/2015 10:22:00 | Piling Stopped. Area shots. | 1342-1353 |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 09/03/2015 10:24:00 | Piling preparations, Area Shots | 1354-1361 |
| 09/03/2015 10:52:00 | Area Shots; 5 boats in area; Hammer Insertion | 1362-1376 |
| 09/03/2015 10:57:00 | Green Light Received at 1101; Area shots. | 1377-1402 |
| 09/03/2015 11:13:00 | Piling begins, Piling 2nd Pile WTG 2 | 1403-1449 |
| 09/03/2015 11:21:00 | Fog engulfs area | 1450-1463 |
| 09/03/2015 11:32:00 | Vessels in area. Weeks Barge 526 breaks through fog on way to WTG 3 | 1464-1546 |
| 09/03/2015 11:41:00 | Area photos. Fog moves into area. Picture of tug 500 yards from our boat. Barge 500 yards past that and cannot be seen. | 1547-1577 |
| 09/03/2015 12:03:00 | Fog still thick. Construction Crew takes lunch. | 1578-1622 |
| 09/03/2015 12:56:00 | Fog lifting & awaiting clearance | 1623-1653 |
| 09/03/2015 13:03:00 | Barge repositioning. 2 tugs, Weeks 526, Weeks 533, and tug with 526 in area | 1654-1686 |
| 09/03/2015 13:16:00 | Fishing boat pulled up and loitering at safety zone. | 1687-1700 |
| 09/03/2015 13:19:00 | More pictures of visitor fishing | 1700-1708 |
| 09/03/2015 13:26:00 | Lindsey E, PM boat coming in | |
| 09/03/2015 13:30:00 | Lindsey E in to Weeks 533. Wildlife team making rounds to clear area. Expect a clear range at 1415. | |
| 09/03/2015 13:34:00 | 2 Tugs, Hula Dog, and Lindsey E in area. Area scan photos. Weeks 526 in distance moving to location to install jacket on WTG 5. | 1709-1717 |
| 09/03/2015 14:00:00 | Area Shots | 1718-1735 |
| 09/03/2015 14:09:00 | Environmental Boat coming around site | |
| 09/03/2015 14:11:00 | Area shots. Sorreson Miller picking up staff – Hammer off deck | 1736-1756 |
| 09/03/2015 14:33:00 | Weeks 526 coming up to WTG 3. Four boats toward WTG 3 from WTG 2. Scan of boats and hammer being raised. Hammer Mount. | 1757-1808 |
| 09/03/2015 14:36:00 | Green Light | |
| 09/03/2015 14:40:00 | Hammer start | 1809-1847 |
| 09/03/2015 14:45:00 | Hammering | 1848-1861 |
| 09/03/2015 14:47:00 | Stopped to adjust cable. | 1862-1868 |
| 09/03/2015 14:50:00 | Piling begins again. 6 Vessels from L to R. | 1869-1875 |
| 09/03/2015 14:52:00 | Area scans. | 1876-1881 |
| 09/03/2015 15:00:00 | | 1882-1899 |
| 09/03/2015 15:05:00 | Sorreson Miller left area | 1900-1917 |
| 09/03/2015 15:08:00 | Area Photos | 1918-1944 |
| 09/03/2015 15:12:00 | Area Scan Right to Light | 1945-1967 |
| 09/03/2015 15:16:00 | All Stop. Area Scan Right to Left. Sorreson Miller loitering past WTG 3. | 1968-1976 |
| 09/03/2015 15:21:00 | Hammer off Pile. Area scan Right to Left. | 1977-1993 |
| 09/03/2015 15:26:00 | Changing Tug Line to do last pile. | 1994-2007 |
| 09/03/2015 15:45:00 | Adjusting Tug line on Hammer | 2008-2022 |
| 09/03/2015 15:49:00 | Hammer down to swap tug lines (1 to 2 and 2 to 1) | |
| 09/03/2015 16:25:00 | 3 tugs, 2 on Weeks 533 one tug on Weeks 526. Weeks 526 at WTG. | |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 09/03/2015 16:27:00 | Still working on positioning hammer. Hammer coming up. | 2023-2038 |
| 09/03/2015 16:32:00 | Hammer tugs re-rigged and hammer angle looks good. | 2039-2052 |
| 09/03/2015 16:36:00 | Area scan. | 2053-2065 |
| 09/03/2015 16:40:00 | Hammer Insertion. | 2066-2110 |
| 09/03/2015 16:46:00 | Area Scan | 2111-2176 |
| 09/03/2015 16:58:00 | 1 km (0.6 mi) away. | Video 2185 |
| 09/03/2015 17:01:00 | Video of later part of piling and area scan. | Video 2287, Video 2209, 2177-2220 |
| 09/03/2015 17:17:00 | All Stop. | |
| 09/07/2015 10:32:20 | Arriving on site. Sea state a choppy 4. Wind speed 17 mph. WTG 3 has a pile lifted in the air and three tugs nearby. WTG 5 has two transition decks and one steel foundation on the material barge and three tugs and the Lindsey E nearby. The base is hooked up to the crane | |
| 09/07/2015 10:38:05 | WTG 3 from the west | 3893 - 3912 |
| 09/07/2015 10:41:47 | WTG 5 from the north. Sounds like they are trying to lift the base. Two of the tugs are in position right against the leeward side of the barge | 3913 - 3926 |
| 09/07/2015 10:51:28 | Placing the WTG 5 foundation. They lift the base and move the material barge out from under it before dropping the base into the water | 3927 -3941 |
| 09/07/2015 10:54:28 | WTG 2 has 5 guys welding another section of pile on | 3946 - 3957 |
| 09/07/2015 11:06:08 | Lowering the base into the water | 3942–3943 |
| 09/07/2015 11:16:18 | Materials barge holding the top jackets is leaving site for Quonset | 3944 and 3945 |
| 09/07/2015 11:49:39 | Foundation for site 5 is in position. We are heading home | 3958 - 3979 |
| 09/09/2015 09:01:08 | Onsite, Deepwater is welding on fourth pile at WTG 3 | 2247-2250 |
| 09/09/2015 09:08:13 | WTG 5 | 2251-2254 |
| 09/09/2015 09:29:42 | | |
| 09/09/2015 09:35:44 | Tug Elizabeth onsite. | 2255-2257 |
| 09/09/2015 09:36:52 | WTG 2 | 2258-2260 |
| 09/09/2015 09:37:52 | Sorenson Miller | 2261 -2263 |
| 09/09/2015 09:37:52 | Weeks Barge 526 at WTG 2 | 2264- 2281 |
| 09/17/2015 08:10:51 | WTG 5 preparing to hammer | |
| 09/17/2015 08:16:39 | WTG 3 | 2284-2285 |
| 09/17/2015 08:18:25 | Weeks barge 533, Weeks Barge 526 and crew tender by WTG 2 | 2286-2286 |
| 09/17/2015 08:21:54 | Cashman barge with WTG 1 foundation | 2287-2288 |
| 09/17/2015 08:21:59 | Heather Lynne Marine Mammal Observer boat | 2289 |
| 09/17/2015 08:43:53 | Shanna Rose , west of WTG 5 | 2290-2293 |
| 09/17/2015 08:52:48 | Sorenson Miller Crew tender arrives on WTG 5 | 2296 |
| 09/17/2015 09:41:40 | 3 different tugs onsite: Tug Robert, Tug Elizabeth, Tug Stephanie | 2297-2298-2299 |
| 09/17/2015 10:21:32 | URI's McMaster by WTG 5 | 22300-22304 |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 09/17/2015 10:22:16 | Sorensen Miller next to LB Roberts | 2305 |
| 09/17/2015 10:36:46 | WTG 2 | 2306 |
| 09/17/2015 10:46:07 | Picking up hammer at WTG 5 | 2307 |
| 09/17/2015 10:48:50 | Setting hammer back down, not sure why | |
| 09/17/2015 11:19:32 | Close up of hammer on deck | 2317-2318 |
| 09/17/2015 11:37:25 | Picking up hammer again | 2320-2321 |
| 09/17/2015 11:49:24 | Tug Robert next to WTG 5, we think he is spotter to help set hammer on pile | 2326-2327 |
| 09/17/2015 11:59:47 | LB Robert elevating prior to hammering | 2328-2329 |
| 09/17/2015 12:20:38 | Lowering hammer down on pile at WTG 5 | 2338 |
| 09/17/2015 12:31:38 | First strikes | |
| 09/17/2015 12:39:24 | 2 videos of hammer on pile 1 WTG 5 | 2341 and 2344 |
| 09/17/2015 12:52:03 | They stopped hammering, sounds like hammer stuck | 2348 |
| 09/17/2015 12:55:17 | Resumed piling | |
| 09/17/2015 13:22:15 | Still hammering, pile about 1/2 way | 2349 |
| 09/17/2015 13:40:32 | Pile 1 is done | 2350-2353 |
| 09/17/2015 13:48:36 | Setting hammer on deck to inspect | 2355-2356 |
| 09/17/2015 14:09:33 | Hammer on deck after piling 1 | 2357 |
| 09/17/2015 14:13:46 | DW is inspecting pile, hen move on to next pile | |
| 09/17/2015 14:58:24 | Top section for jacket | 2358-2359 |
| 09/17/2015 15:11:17 | Setting hammer on 2nd pile | 2360-2361 |
| 09/17/2015 15:17:18 | First strike on 2nd pile | |
| 09/17/2015 15:23:11 | Video of hammer on 2nd pile | 2363 |
| 09/17/2015 15:42:28 | Hammer on 2nd pile | 2365 |
| 09/17/2015 16:14:09 | Last strike on pile2 | 2366 |
| 09/17/2015 16:31:41 | Setting hammer on 3rd pile | 2370 |
| 09/17/2015 16:39:31 | First strike 3rd pile | 2371 |
| 09/17/2015 16:53:36 | WTG 5 hammering 3rd pile | 2372-2374 |
| 09/17/2015 17:45:04 | Hammering 3rd pile on WTG 5 | 2375-2378 |
| 09/17/2015 17:49:14 | Sorensen Miller vessel headed to WTG 5 | 2379 |
| 09/17/2015 17:55:17 | Finished piling on 3rd pile | 2380-2381 |
| 09/18/2015 08:30:51 | WTG 5, DW drove last pile after we left last night. | 2382 |
| 09/18/2015 08:32:20 | WTG 3 hammer on first pile. this is second set of piles (p2) | 2383 |
| 09/18/2015 08:34:18 | WTG 2 on left and WTG 1, both have 4 piles stabbed. | 2384 |
| 09/18/2015 08:37:11 | First strike | |
| 09/18/2015 08:47:08 | WTG 3 hammering first pile | video |
| 09/18/2015 09:03:35 | WTG 3 hammering first pile | 2386 |
| 09/18/2015 09:23:35 | WTG 5 - getting ready to weld second set of piles | 2388 |
| 09/18/2015 09:25:00 | WTG 3 hammering first pile | 2389 |
| 09/18/2015 09:38:50 | Finished 1st pile | 2390 |
| 09/18/2015 09:50:14 | Several tugs and crane arrives onsite between WTG 3 and WTG 5. We think they are preparing to set jacket 3 | 2391-2397 |
| 09/18/2015 09:58:17 | WTG 5 setting hammer on second pile | 2398 |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 09/18/2015 10:03:46 | Striking on second pile at WTG 3 | |
| 09/18/2015 10:10:45 | WTG 5 hammering 2nd pile | 2399-2404 |
| 09/18/2015 10:27:45 | WTG 1 | 2409-24012 |
| 09/18/2015 10:33:53 | Hammering on WTG 5 | 2413-2024 |
| 09/18/2015 10:37:15 | WTG 4 jackets arriving on barge | 2425-2432 |
| 09/18/2015 10:50:58 | Pile 2 finished driving on WTG 3 | 2433-2434 |
| 09/18/2015 11:19:13 | Sub acoustic research buoy | 2435-2436 |
| 09/18/2015 11:28:14 | Hammer was stuck on pile 2, they finally got it off | 2437 |
| 09/18/2015 11:37:43 | Film crew arrives onsite. Mike's boat | 2444–2446 |
| 09/18/2015 11:42:00 | Positioning WTG 4 jackets | 2447–2448 |
| 09/18/2015 12:20:06 | Jackets onsite for WTG 4 | 2449–2450 |
| 09/18/2015 12:52:05 | Hammer on 3rd pile at WTG 3 | 2451–2454 |
| 09/18/2015 12:53:35 | First strike on 3rd pile WTG 3 | |
| 09/18/2015 13:13:27 | Hammering 3rd pile at WTG 3 , with Lift boat | 2455–2458 |
| 09/18/2015 13:14:17 | McMaster taking measurements during hammering in WTG 3 | 2459–2461 |
| 09/18/2015 13:45:43 | Pile driving 3rd pile on WTG 3. Supply ship at WTG 3 | 2462–2463 |
| 09/18/2015 13:58:26 | Pile 3 completely driven. | 2464 |
| 09/18/2015 14:16:25 | First strike on pile 4 @ WTG 3 | 2465–2466 |
| 09/18/2015 15:16:48 | 4th pile complete on WTG 3 | 2467–2468 |
| 09/18/2015 15:18:37 | Sub acoustic pics | 2469 |
| 09/18/2015 15:39:20 | All 4 piles driven, they will move to next jacket. | 2470–2486 |
| 09/19/2015 08:38:25 | Missed start of piling WTG 1 pile1 | 2487–2490 |
| 09/19/2015 09:00:48 | WTG 1 - Completed first pile and set hammer on deck | 2491–-2494 |
| 09/19/2015 09:05:31 | WTG 2 with 4 piles ready to be driven | 2495 |
| 09/19/2015 09:06:24 | WTG 3 and WTG 4(sitting on barge) | 2496 |
| 09/19/2015 09:11:53 | WTG 1 inspecting hammer | 2497–2498 |
| 09/19/2015 09:16:10 | Hydraulic leak on hammer. will have to go back on pile 1 | |
| 09/19/2015 09:53:36 | Sorensen Miller dropping off hydraulic fluid for hammer at WTG 1 | 2499–2452 |
| 09/19/2015 10:48:50 | Coast guard onsite | 2503–2504 |
| 09/19/2015 10:50:15 | WTG 4 | 2505 |
| 09/19/2015 10:53:04 | WTG 5 installing second set of piles | 2506 |
| 09/19/2015 11:41:08 | WTG 5 2 of the second set of piles in. Transition decks for WTG 3, 4, 5 on Cashman Barge. | 2507–2508 |
| 09/19/2015 11:44:04 | Weeks 533 and Tug Robert at WTG 4. Two of first set of piles installed. Transition deck for WTG 2 | 2509-2510 |
| 09/19/2015 11:45:43 | Research buoy | 2511–-2512 |
| 09/19/2015 12:01:37 | WTG close up of jacket on barge Weeks 533 | 2513–2514 |
| 09/19/2015 12:02:24 | Close up of 3 jackets at WTG 5 | 2515 |
| 09/19/2015 12:13:47 | WTG 1 hammer fixed and placing back on pile 1 to finish | 2516–2517 |
| 09/19/2015 12:23:39 | WTG 3,2,1 | 2518 |
| 09/19/2015 12:24:41 | WTG 2 and 3 | 2519 |
| 09/19/2015 12:30:54 | Piling on WTG 1 first pile | 2520 |

| Date/Timestamp | Observations Notes | Photo Frames ID |
|---|---|---|
| 09/19/2015 12:41:26 | Piling on pile 1 complete | |
| 09/19/2015 12:55:25 | WTG 1 putting hammer on second pile | 2521 |
| 09/19/2015 12:56:40 | Strike did not seem as loud when they finished first pile, may have lowered energy to test hammer repair | |
| 09/19/2015 13:01:05 | WTG 1 hammer start on pile 2 | |
| 09/19/2015 13:38:35 | Pile 2 done WTG 1 | 2522 |
| 09/19/2015 13:49:27 | Placing hammer on 3rd pile WTG 1 | 2525 |
| 09/19/2015 13:57:53 | Pile 3 WTG 1 hammer start | |
| 09/19/2015 14:30:25 | Rosemary Miller just passed our stationary boat extremely close | 2526–2531 |
| 09/19/2015 14:44:17 | 3rd pile complete | 2532–2533 |
| 09/19/2015 14:52:26 | Dunking hammer in water to cool it off | 2534–2539 |
| 09/19/2015 15:11:13 | | 2540–2542 |
| 09/19/2015 15:31:38 | Stephanie Dann Tug by WTG 3 | 2543 |
| 09/19/2015 15:33:32 | Hammer stopped about 1/3 of way through | |
| 09/19/2015 15:35:24 | Hammer started back | |
| 09/19/2015 15:48:50 | 4th pile at WTG 1 | 2544–2549 |
| 09/19/2015 15:53:56 | completed 4th pile WTG 1 | |
| 09/19/2015 16:00:20 | Lifting the hammer and putting back on deck after getting all piles | 2550–2558 |
| 09/20/2015 08:25:08 | Long shots of all WTGs | 2559–2569 |
| 09/20/2015 08:57:53 | We got onsite around 0815 and no hammering occurring. The first pile is about 1/3 of the way down. WTG 4 | 2574–2578 |
| 09/20/2015 08:58:33 | Crew pulled hammer off and lowered crane boom, something wrong with crane | |
| 09/20/2015 09:03:17 | WTG 5 second piles I place, Weeks Barge 526 next to it | 2579–2580 |
| 09/20/2015 09:44:23 | WTG 4 still working on crane | 2581–2583 |
| 09/20/2015 09:46:35 | Area scans | 2584–2587 |

**Table B-3. Meteorological Data Recorded During Visual Monitoring**

| Date/Time | General Weather | Wind Direction | Beaufort | % Cloud Cover | Temperature | Humidity |
|---|---|---|---|---|---|---|
| 08/18/2015 07:17:46 | Hazy | SW | | 20 | 74 | 94 |
| 08/18/2015 08:06:00 | Hazy | SW | | 20 | 74 | 94 |
| 08/18/2015 08:28:37 | Hazy | SW | | 20 | 73 | 94 |
| 08/18/2015 08:57:44 | Hazy | SW | | 15 | 73 | 94 |
| 08/18/2015 09:49:35 | Hazy | SW | | 10 | 77 | 83 |
| 08/18/2015 10:17:36 | Sunny | SSW | | 5 | 80 | 75 |
| 08/18/2015 10:31:27 | Sunny | SW | | 5 | 79 | 68 |
| 08/18/2015 11:14:41 | Sunny | WSW | | 5 | 82 | 62 |
| 08/18/2015 11:34:47 | Sunny | WSW | | 0 | 82 | 62 |
| 08/18/2015 11:44:22 | Sunny | WSW | | 0 | 79 | 79 |
| 08/18/2015 11:56:52 | Sunny | WSW | | 0 | 82 | 62 |
| 08/18/2015 12:25:41 | Sunny | WSW | | 0 | 79 | 62 |
| 08/18/2015 13:03:04 | Hazy | SW | | 0 | 85 | 66 |
| 08/18/2015 13:13:48 | Sunny | SW | | 0 | 84 | 62 |
| 08/18/2015 13:23:39 | Sunny | SW | | 0 | 81 | 62 |
| 08/18/2015 13:51:45 | Hazy | WSW | | 0 | 81 | 74 |
| 08/18/2015 14:21:06 | Sunny | SW | | 0 | 81 | 74 |
| 08/18/2015 15:12:06 | Sunny | SW | | 0 | 79 | 83 |
| 08/18/2015 15:50:39 | Sunny | S | | 0 | 83 | 67 |
| 08/18/2015 16:08:55 | Sunny | NNW | | 0 | 83 | 70 |
| 08/18/2015 16:29:54 | Sunny | S | | 0 | 81 | 66 |
| 08/18/2015 16:55:07 | Sunny | S | | 0 | 81 | 66 |
| 08/18/2015 17:15:25 | Sunny | SSW | | 0 | 81 | 72 |
| 08/23/2015 11:26:40 | Light Rain | NE | 1 | 100 | 76 | 91 |
| 08/23/2015 11:56:55 | Light Rain | NE | 1 | 100 | 77 | 73 |
| 08/23/2015 12:02:42 | Cloudy | NE | 1 | 90 | 77 | 73 |
| 08/23/2015 12:20:19 | Mostly Cloudy | NE | 1 | 60 | 77 | 73 |
| 08/23/2015 12:33:35 | Mostly Cloudy | NE | 1 | 50 | 78 | 90 |
| 08/23/2015 12:54:07 | Sunny | NE | 1 | 20 | 78 | 70 |
| 08/23/2015 13:14:03 | Sunny | NE | 1 | 20 | 80 | 89 |
| 08/23/2015 13:36:27 | Sunny | NE | 1 | 70 | 78 | 73 |
| 08/23/2015 14:00:19 | Cloudy | NE | 1 | 90 | 77 | 83 |
| 08/23/2015 14:30:48 | Sunny | NE | 1 | 30 | 80 | 68 |
| 08/23/2015 14:59:09 | Sunny | NE | 1 | 30 | 80 | 68 |
| 08/23/2015 15:35:53 | Sunny | NE | 1 | 20 | 79 | 78 |
| 08/23/2015 15:38:04 | Sunny | SE | 2 | 50 | 78 | 75 |
| 08/23/2015 16:06:47 | Sunny | NE | 1 | 10 | 77 | 83 |
| 08/23/2015 16:34:21 | Sunny | NE | 1 | 10 | 77 | 84 |
| 08/24/2015 07:18:58 | Light Rain | SE | 2 | 100 | 71 | 93 |
| 08/24/2015 07:47:13 | Light Rain | SE | 2 | 100 | 71 | 93 |
| 08/24/2015 07:58:05 | Cloudy | SE | 2 | 97 | 71 | 93 |
| 08/24/2015 08:12:50 | Cloudy | SE | 2 | 97 | 71 | 93 |
| 08/24/2015 08:47:04 | Cloudy | SE | 2 | 100 | 70 | 97 |

| Date/Time | General Weather | Wind Direction | Beaufort | % Cloud Cover | Temperature | Humidity |
|---|---|---|---|---|---|---|
| 08/24/2015 09:08:43 | Cloudy | SE | 2 | 100 | 70 | 97 |
| 08/24/2015 09:35:54 | Cloudy | SE | 2 | 100 | 72 | 93 |
| 08/24/2015 10:00:38 | Cloudy | SE | 2 | 95 | 72 | 93 |
| 08/24/2015 10:30:49 | Cloudy | SE | 2 | 50 | 73 | 90 |
| 08/24/2015 11:06:38 | Cloudy | SE | 2 | 75 | 76 | 93 |
| 08/24/2015 11:36:16 | Cloudy | SE | 2 | 75 | 74 | 90 |
| 08/24/2015 11:59:54 | Cloudy | SE | 2 | 80 | 76 | 93 |
| 08/24/2015 12:14:29 | Cloudy | SE | 2 | 80 | 75 | 87 |
| 08/24/2015 12:48:35 | Cloudy | SE | 2 | 85 | 76 | 93 |
| 08/24/2015 13:12:48 | Mostly Cloudy | SE | 2 | 60 | 76 | 84 |
| 08/24/2015 13:28:15 | Mostly Cloudy | SE | 2 | 60 | 76 | 84 |
| 08/24/2015 13:48:18 | Mostly Cloudy | SE | 2 | 70 | 77 | 92 |
| 08/24/2015 14:02:45 | Mostly Cloudy | SE | 2 | 60 | 77 | 78 |
| 08/24/2015 14:35:49 | Sunny | SE | 2 | 50 | 77 | 93 |
| 08/24/2015 14:56:42 | Sunny | SE | 2 | 40 | 77 | 78 |
| 08/24/2015 15:20:45 | Sunny | SE | 2 | 40 | 77 | 78 |
| 08/24/2015 15:41:54 | Sunny | SE | 2 | 40 | 77 | 78 |
| 08/25/2015 07:28:07 | Foggy | E | 2 | 100 | 72 | 96 |
| 08/25/2015 08:00:02 | Foggy | E | 2 | 100 | 72 | 96 |
| 08/25/2015 08:33:36 | Foggy | E | 2 | 100 | 73 | 96 |
| 08/25/2015 09:01:40 | Foggy | E | 2 | 100 | 73 | 96 |
| 08/25/2015 09:33:04 | Foggy | E | 2 | 60 | 74 | 93 |
| 08/25/2015 10:10:42 | Foggy | E | 2 | 30 | 74 | 90 |
| 08/25/2015 10:32:49 | Foggy | E | 2 | 40 | 74 | 90 |
| 08/25/2015 10:57:10 | Foggy | E | 2 | 30 | 74 | 90 |
| 08/25/2015 11:30:52 | Foggy | SE | 2 | 10 | 77 | 96 |
| 08/25/2015 12:02:22 | Hazy | SE | 2 | 10 | 79 | 78 |
| 08/25/2015 12:21:43 | Hazy | SE | 2 | 15 | 79 | 78 |
| 08/25/2015 12:50:37 | Hazy | SE | 1 | 25 | 79 | 78 |
| 08/25/2015 13:10:10 | Hazy | SE | 1 | 30 | 79 | 78 |
| 08/25/2015 13:32:45 | Hazy | SE | 1 | 30 | 79 | 766 |
| 08/25/2015 13:59:01 | Hazy | SE | 1 | 15 | 79 | 76 |
| 08/25/2015 14:24:49 | Hazy | SE | 1 | 15 | 81 | 62 |
| 08/25/2015 14:41:21 | Hazy | SE | 1 | 15 | 81 | 62 |
| 08/25/2015 15:04:50 | Hazy | S | 1 | 10 | 82 | 59 |
| 08/25/2015 15:37:44 | Hazy | | | | | |
| 08/25/2015 15:52:38 | Hazy | SSW | 1 | 10 | 81 | 62 |
| 08/25/2015 16:18:53 | Sunny | SSW | 1 | 10 | 81 | 70 |
| 08/26/2015 07:57:24 | Sunny | WNW | 1 | 5 | 72 | 99 |
| 08/26/2015 08:39:11 | Hazy | WNW | 1 | 10 | 72 | 99 |
| 08/26/2015 09:03:58 | Hazy | WNW | 1 | 5 | 72 | 94 |
| 08/26/2015 09:35:59 | Hazy | NW | 1 | 5 | 73 | 88 |
| 08/26/2015 10:04:09 | Sunny | W | 1 | 5 | 73 | 78 |
| 08/26/2015 10:38:17 | Sunny | W | 1 | 5 | 73 | 83 |

| Date/Time | General Weather | Wind Direction | Beaufort | % Cloud Cover | Temperature | Humidity |
|---|---|---|---|---|---|---|
| 08/26/2015 11:05:09 | Sunny | W | 1 | 10 | 75 | 73 |
| 08/26/2015 11:42:20 | Sunny | W | 1 | 10 | 75 | 73 |
| 08/26/2015 12:04:51 | Sunny | W | 1 | 10 | 75 | 69 |
| 08/26/2015 12:34:05 | Sunny | W | 1 | 30 | 75 | 69 |
| 08/26/2015 13:12:03 | Sunny | W | 1 | 25 | 75 | 69 |
| 08/26/2015 13:42:22 | Sunny | W | 1 | 20 | 75 | 69 |
| 08/26/2015 14:03:17 | Sunny | W | 1 | 15 | 77 | 69 |
| 08/26/2015 14:29:54 | Sunny | SW | 1 | 5 | 79 | 58 |
| 08/26/2015 14:59:34 | Sunny | W | 1 | 5 | 79 | 54 |
| 08/26/2015 15:32:16 | Sunny | W | 1 | 0 | 79 | 54 |
| 08/26/2015 16:11:16 | Sunny | W | 1 | 0 | 81 | 42 |
| 08/26/2015 16:35:35 | Sunny | W | 1 | 0 | 79 | 57 |
| 08/28/2015 13:42:48 | Sunny | W | 0 | 5 | 75 | 61 |
| 08/28/2015 14:14:53 | Sunny | WSW | 0 | 5 | 75 | 53 |
| 08/28/2015 14:46:47 | Sunny | WSW | 0 | 0 | 75 | 47 |
| 08/28/2015 15:13:42 | Sunny | SW | 0 | 0 | 75 | 47 |
| 08/28/2015 15:41:06 | Sunny | WSW | 1 | 0 | 75 | 47 |
| 08/28/2015 16:05:01 | Sunny | SSW | 1 | 0 | 75 | 50 |
| 08/28/2015 16:41:56 | Sunny | WSW | 1 | 0 | 75 | 53 |
| 08/28/2015 17:11:21 | Sunny | WSW | 1 | 0 | 75 | 53 |
| 08/28/2015 17:39:47 | Sunny | SW | 1 | 0 | 75 | 53 |
| 08/28/2015 18:00:40 | Sunny | SW | 1 | 0 | 73 | 57 |
| 08/29/2015 07:31:05 | Sunny | NW | 0 | 5 | 64 | 94 |
| 08/29/2015 08:01:58 | Sunny | NW | 0 | 5 | 64 | 94 |
| 08/29/2015 08:31:54 | Sunny |  | 0 | 5 | 73 | 72 |
| 08/29/2015 09:04:45 | Sunny |  | 0 | 0 | 72 | 69 |
| 08/29/2015 09:32:02 | Sunny |  | 0 | 0 | 72 | 69 |
| 08/29/2015 10:06:55 | Sunny |  | 0 | 0 | 72 | 69 |
| 08/29/2015 10:35:29 | Sunny |  | 0 | 0 | 72 | 69 |
| 08/29/2015 11:04:49 | Sunny | SW | 0 | 5 | 72 | 69 |
| 08/29/2015 11:36:29 | Sunny | SW | 0 | 10 | 72 | 69 |
| 08/29/2015 12:04:22 | Sunny | SW | 0 | 10 | 75 | 62 |
| 08/29/2015 12:41:27 | Sunny | SW | 1 | 10 | 77 | 59 |
| 08/29/2015 13:00:33 | Sunny | SW | 1 | 10 | 77 | 59 |
| 08/29/2015 13:19:01 | Sunny | W | 1 | 10 | 79 | 57 |
| 08/29/2015 13:37:10 | Sunny | W | 1 | 15 | 79 | 57 |
| 08/29/2015 14:40:47 | Sunny | SW | 1 | 10 | 79 | 51 |
| 08/29/2015 15:05:28 | Sunny | SW | 1 | 10 | 79 | 54 |
| 08/29/2015 15:30:45 | Sunny | SW | 1 | 15 | 77 | 54 |
| 08/29/2015 15:52:54 | Sunny | SSW | 1 | 25 | 77 | 61 |
| 08/30/2015 09:03:41 | Hazy | WSW | 1 | 0 | 73 | 88 |
| 08/30/2015 09:54:39 | Hazy | W | 1 | 0 | 75 | 78 |
| 08/30/2015 10:28:00 | Hazy | WSW | 1 | 0 | 79 | 69 |
| 08/30/2015 10:49:15 | Hazy | WSW | 1 | 0 | 79 | 69 |

| Date/Time | General Weather | Wind Direction | Beaufort | % Cloud Cover | Temperature | Humidity |
|---|---|---|---|---|---|---|
| 08/30/2015 11:14:59 | Hazy | W | 1 | 0 | 77 | 69 |
| 08/30/2015 11:34:17 | Hazy | SW | 1 | 0 | 79 | 69 |
| 08/30/2015 12:07:35 | Hazy | SW | 1 | 0 | 79 | 69 |
| 08/30/2015 12:43:08 | Hazy | WSW | 2 | 0 | 82 | 69 |
| 08/30/2015 13:10:17 | Hazy | WSW | 3 | 5 | 81 | 74 |
| 08/30/2015 13:39:59 | Hazy | WSW | 4 | 5 | 79 | 74 |
| 08/30/2015 14:20:36 | Hazy | SW | 3 | 15 | 79 | 74 |
| 08/30/2015 14:57:24 | Hazy | SW | 3 | 40 | 79 | 74 |
| 08/30/2015 15:37:03 | Hazy | WSW | 3 | 55 | 79 | 70 |
| 08/30/2015 16:08:48 | Hazy | SW | 3 | 45 | 79 | 74 |
| 08/30/2015 16:19:53 | Hazy | SW | 2 | 45 | 77 | 74 |
| 09/01/2015 13:34:34 | Sunny | E | 2 | 0 | 77 | 65 |
| 09/01/2015 13:58:50 | Sunny | E | 2 | 0 | 77 | 69 |
| 09/01/2015 14:30:56 | Sunny | SE | 2 | 0 | 79 | 65 |
| 09/01/2015 15:11:49 | Sunny | SE | 2 | 0 | 79 | 65 |
| 09/01/2015 15:29:40 | Sunny | SE | 2 | 0 | 79 | 61 |
| 09/01/2015 15:41:24 | Sunny | SE | 2 | 0 | 79 | 65 |
| 09/01/2015 16:01:01 | Sunny | S | 2 | 0 | 77 | 65 |
| 09/01/2015 16:24:08 | Sunny | S | 2 | 0 | 77 | 69 |
| 09/01/2015 16:56:07 | Sunny | S | 2 | 0 | 77 | 69 |
| 09/01/2015 17:26:11 | Sunny | SE | 2 | 0 | 77 | 69 |
| 09/01/2015 18:02:59 | Sunny | SE | 2 | 0 | 77 | 69 |
| 09/02/2015 08:55:13 | Foggy | SW | 2 | | 73 | 94 |
| 09/02/2015 09:13:00 | Foggy | SW | 2 | | 73 | 94 |
| 09/02/2015 09:46:56 | Foggy | SW | 2 | | 75 | 83 |
| 09/02/2015 10:15:27 | Foggy | SW | 2 | | 73 | 83 |
| 09/02/2015 10:20:05 | Foggy | SW | 2 | | 73 | 83 |
| 09/02/2015 10:42:47 | Foggy | SW | 2 | | 73 | 94 |
| 09/02/2015 11:09:20 | Foggy | SW | 2 | | 77 | 78 |
| 09/02/2015 11:17:51 | Foggy | SW | 2 | | 77 | 83 |
| 09/02/2015 11:23:25 | Light fog | SW | 2 | | 77 | 78 |
| 09/02/2015 11:59:38 | Very little fog | SW | 2 | 0 | 79 | 69 |
| 09/02/2015 12:20:53 | Hazy | SW | 3 | 0 | 79 | 74 |
| 09/02/2015 12:37:06 | Haze | SW | 3 | 0 | 79 | 74 |
| 09/02/2015 12:47:50 | Sunny | SW | 3 | | 79 | 74 |
| 09/02/2015 12:56:31 | Sunny | SW | 3 | 0 | 79 | 74 |
| 09/02/2015 13:05:23 | Sunny | SW | 3 | 0 | 79 | 74 |
| 09/02/2015 13:15:07 | Sunny | sw | 3 | 0 | 79 | 74 |
| 09/02/2015 13:37:54 | Sunny | SW | 3 | 0 | 79 | 74 |
| 09/02/2015 14:20:44 | Sunny | SW | 3 | 0 | 81 | 74 |
| 09/03/2015 08:49:21 | Hazy/Foggy | SW | 2 | | 73 | 94 |
| 09/03/2015 09:06:08 | Hazy/Foggy | SW | 2 | | 75 | 89 |
| 09/03/2015 09:38:14 | Hazy/Foggy | SW | 2 | 50 | 75 | 89 |
| 09/03/2015 09:46:38 | Hazy/Foggy | SW | 2 | 75 | 75 | 89 |

| Date/Time | General Weather | Wind Direction | Beaufort | % Cloud Cover | Temperature | Humidity |
|---|---|---|---|---|---|---|
| 09/03/2015 10:03:18 | Hazy/Foggy | SW | 2 | 75 | 77 | 83 |
| 09/03/2015 10:11:42 | Hazy/Foggy | SW | 2 | 75 | 77 | 83 |
| 09/03/2015 10:33:59 | Hazy/Foggy | W | 2 | 75 | 77 | 83 |
| 09/03/2015 11:00:13 | Hazy/Foggy | W | 2 | 75 | 77 | 83 |
| 09/03/2015 11:10:30 | Hazy/Foggy | SW | 2 | | 79 | 78 |
| 09/03/2015 11:15:26 | Hazy/Foggy | SW | 2 | | 79 | 78 |
| 09/03/2015 11:41:11 | Hazy/Foggy | SW | 2 | | 79 | 78 |
| 09/03/2015 12:02:21 | Hazy/Foggy | SW | 2 | | 79 | 78 |
| 09/03/2015 12:44:05 | Hazy/Foggy | SW | 2 | | 81 | 74 |
| 09/03/2015 13:02:57 | Hazy/Foggy | SW | 2 | | 81 | 70 |
| 09/03/2015 13:39:14 | Hazy/Foggy | SW | 2 | 0 | 82 | 70 |
| 09/03/2015 14:06:04 | Hazy/Foggy | SW | 2 | 15 | 82 | 70 |
| 09/03/2015 14:19:16 | Hazy/Foggy | SW | 2 | 10 | 82 | 70 |
| 09/03/2015 14:37:36 | Hazy/Foggy | SW | 2 | 10 | 82 | 70 |
| 09/03/2015 14:49:43 | Hazy/Foggy | SW | 2 | 10 | 82 | 70 |
| 09/03/2015 15:09:39 | Hazy/Foggy | SSW | 2 | | 81 | 79 |
| 09/03/2015 15:22:59 | Hazy/Foggy | SSW | 2 | | 81 | 74 |
| 09/03/2015 16:03:52 | Hazy/Foggy | SSW | 2 | 10 | 81 | 79 |
| 09/03/2015 16:34:08 | Hazy/Foggy | SSW | 2 | | 79 | 83 |
| 09/03/2015 16:43:46 | Hazy/Foggy | SW | 2 | | 79 | 83 |
| 09/03/2015 16:54:36 | Hazy/Foggy | SW | 2 | | 79 | 83 |
| 09/03/2015 17:12:22 | Hazy/Foggy | SW | 2 | | 79 | 83 |
| 09/03/2015 17:22:22 | Hazy/Foggy | SW | 2 | | 79 | 83 |
| 09/07/2015 13:58:05 | Sunny | SW | 5 | 0 | 77 | 74 |
| 09/07/2015 14:18:34 | Sunny | SW | 4 | 0 | 77 | 74 |
| 09/07/2015 14:35:45 | Sunny | SW | 4 | 0 | 77 | 74 |
| 09/07/2015 15:12:11 | Sunny | SW | 5 | 0 | 77 | 74 |
| 09/07/2015 15:33:08 | Sunny | SW | 5 | 0 | 75 | 83 |
| 09/07/2015 20:22:29 | Night | SW | 5 | 0 | 72 | 94 |
| 09/08/2015 08:03:43 | Hazy/Foggy | WSW | 3 | 0 | 72 | 94 |
| 09/08/2015 08:15:06 | Hazy/Foggy | WSW | 3 | 0 | 72 | 94 |
| 09/08/2015 11:39:33 | Sunny | W | 3 | 0 | 81 | 74 |
| 09/08/2015 11:53:50 | Sunny | W | 3 | 0 | 81 | 74 |
| 09/08/2015 17:05:49 | Sunny | SW | 4 | 75 | 77 | 83 |
| 09/08/2015 17:33:10 | Sunny | SW | 4 | 85 | 77 | 84 |
| 09/08/2015 19:37:36 | Sunny | SW | 3 | 10 | 73 | 94 |
| 09/08/2015 19:54:39 | clear | SW | 3 | 5 | 73 | 94 |
| 09/08/2015 20:28:39 | clear | SW | 4 | 5 | 73 | 94 |
| 09/09/2015 08:01:45 | Sunny | WSW | 3 | 50 | 73 | 94 |
| 09/09/2015 08:21:43 | Sunny | WSW | 3 | 60 | 73 | 94 |
| 09/09/2015 08:30:05 | Sunny | WSW | 4 | 20 | 73 | 94 |
| 09/09/2015 08:50:12 | Sunny | WSW | 4 | 20 | 75 | 94 |
| 09/09/2015 09:19:49 | Sunny | S | 4 | 20 | | |
| 09/09/2015 09:33:46 | Sunny | SW | 4 | 30 | 75 | 94 |

| Date/Time | General Weather | Wind Direction | Beaufort | % Cloud Cover | Temperature | Humidity |
|---|---|---|---|---|---|---|
| 09/17/2015 08:12:25 | Sunny | S | 2 | 40 | 60 | |
| 09/17/2015 08:12:25 | Sunny | S | 2 | 40 | 60 | |
| 09/17/2015 11:20:54 | Sunny | SW | 2 | 40 | 74 | |
| 09/17/2015 17:00:40 | Sunny | SW | 2 | 40 | 76 | |
| 09/18/2015 08:35:27 | Sunny | S | 1 | 20 | 60 | |
| 09/18/2015 10:12:02 | Sunny | S | 2 | 20 | 69 | 92 |
| 09/18/2015 11:22:16 | | S | 2 | 20 | 76 | 74 |
| 09/18/2015 12:21:54 | Sunny | S | 2 | 20 | 76 | 66 |
| 09/19/2015 08:48:24 | Sunny | | 1 | 15 | 63 | 96 |
| 09/19/2015 09:54:29 | Cloudy | | 1 | 50 | 69 | 96 |
| 09/19/2015 10:53:58 | Cloudy | N | 1 | 50 | 73 | 84 |
| 09/19/2015 11:46:02 | Sunny | WSW | 1 | 40 | 76 | 68 |
| 09/19/2015 14:01:58 | Sunny | SE | | 20 | 76 | 68 |
| 09/19/2015 16:02:44 | Sunny | S | 2 | 15 | 76 | 63 |
| 09/20/2015 08:27:36 | Cloudy | NW | 3 | 80 | 71 | 86 |
| 09/20/2015 08:57:37 | | | | | | |
| 09/20/2015 09:20:21 | Cloudy | NW | 3 | 90 | 69 | 70 |

# Appendix C: Airborne Noise Monitoring Data

Appendix C is available as a separate digital file.

# Appendix D: Underwater Sound Monitoring Data (Near and Far-Field)

Appendix D is available as a separate digital file.

# Appendix E: Seafloor Disturbance and Recovery Monitoring Data

Appendix E is available as a separate digital file.

# Appendix F: Scour Monitoring Data

Appendix F is available as a separate digital file.

**Department of the Interior (DOI)**

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

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