OPT
OCEAN POWER TECHNOLOGIES

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List of Acronyms

DOE	U.S. Department of Energy
dB	Decibel
EMF	Electromagnetic Fields
FEA	Finite Element Analysis
FERC	Federal Energy Regulatory Commission
FGBA	Floating Gravity Based Anchor
FMEA	Failure Modes and Effects Analysis
GBA	Gravity Based Anchor
Hz	Hertz
kHz	kiloHertz
km	kilometers
km/h	kilometers/hour
kN	kiloNewtons
LF	Low Frequency
LM	Lockheed Martin
LNG	Liquified Natural Gas
m	meter
MF	Mid-frequency
MHK	Marine Hydrokinetic
MPTO	Modular Power Take-off
NDBC	National Data Buoy Center
NNMREC	Northwest National Marine Renewable Energy Center
nV/m	nanoVolts/meter
nT	nanoTesla
OPT	Ocean Power Technologies
OR	Oregon
PPA	Power Purchase Agreement
PSD	Power Spectral Density
pT	picoTesla
PTO	Power Take-off
RD&D	Research, Demonstration and Development
ROV	Remote Operated Vehicle
S/m	Siemens/meter
SOORC	Southern Oregon Ocean Resources Council
SPL	Sound Pressure Level
TRL	Technology Readiness Level
µPa	microPascal
µT	microTesla
µV	microvolt
µV/m	microvolt/meter

1 EXECUTIVE SUMMARY

Ocean wave power can be a significant source of large-scale, renewable energy for the US electrical grid. The Electrical Power Research Institute conservatively estimated that 20% of all U.S. electricity could be generated by wave energy. Ocean Power Technologies, Inc. (OPT), with funding from private sources and the US Navy, developed the PowerBuoy® to generate renewable energy from the readily available power in ocean waves.

OPT's PowerBuoy converts the energy in ocean waves to electricity using the rise and fall of waves to move the buoy up and down (mechanical stroking) which drives an electric generator. This electricity is then conditioned and transmitted ashore as high-voltage power via underwater cable. OPT's wave power generation system includes sophisticated techniques to automatically tune the system for efficient conversion of random wave energy into green electricity, for disconnecting the system in large waves, and for automatically restoring operation when wave conditions normalize.

As the first utility scale wave power project in the US, the Wave Power Demonstration Project at Reedsport (OR) was planned to consist of 10 PowerBuoys (Phase II)[1], located 2.5 miles off the coast. U.S. Department of Energy (DOE) funding under a prior DOE Grant (DE-FG36-08GO88017) along with funding from PNGC Power, an Oregon-based electric power cooperative, was utilized for the design completion, fabrication, assembly and factory testing of the first PowerBuoy for the Reedsport project.

The design and fabrication of the first PowerBuoy and factory testing of the power take-off subsystem were completed, and the power take-off subsystem was successfully integrated into the spar at the fabricator's facility in Oregon.

The objectives of this follow-on grant were:

- Advance PB150B design from TRL 5/6 to TRL 7/8.
- Deploy a single PB150 and operate autonomously for 2 years.
- Establish O&M costs
- Collect environmental information.
- Establish manufacturing methodologies.

Deployment of the Floating Gravity Based Anchors (FGBA) was attempted in September 2012. However, complications with the controlled descent of the first FGBA were encountered during the deployment attempt, and therefore, the deployment was postponed to allow review of the descent. Further attempts to deploy the remaining two FGBAs were not made. The deployed FGBA was marked with a surface marker that served as an aid to navigation. The timing of the September 2012 deployment was approximately one month after the issue of the FERC license for the ten buoy project (Phase II).

Subsequent compounding issues with recovery of the deployed FGBA, regulatory issues, financing issues, project delays, and the advancement of OPT's Power Take Off (PTO) technology via other DOE supported projects rendering the PTO technology intended for deployment in Oregon obsolete, made this project untenable to continue and hence the full completion and attainment of all its objectives was not achievable. OPT and DOE mutually agreed to terminate the project for these reasons.

[1] The Reedsport Project was planned to consist of the three phases. An autonomous (not grid connected) PowerBuoy in Phase I. Phase II consisted of an additional nine buoys, an Undersea Substation Pod, submarine and terrestrial transmission cables, and shore station which connected the ten buoy project to the Pacific Northwest electric grid. This project is listed in the Federal Energy Regulatory Commission (FERC) docket under Docket P-12713. Phase III of the project was planned to have a capacity of up to 50 MegaWatts (MW).

Project goals and objectives also intended to collect baseline and post-deployment acoustic and Electromagnetic Field (EMF) data and analysis. This objective is 50% complete. Baseline acoustic data was taken at the Reedsport site for one month prior to deployment. The North and South Acoustic Recorders data recorded baseline noises in the 93 – 112 dB re 1 µPa and 95 – 177 dB re 1 µPa, respectively. The median readings were re 1 µPa and 100 dB re 1 µPa. The North recorder served as the control site and was located approximately 5 miles north of the Reedsport Project site, which is in the opposite direction of the Umpqua River mouth. Data taken at the National Marine Renewable Energy Center (Newport, OR) yearlong acoustic survey ranged from 95 – 136 dB re. 1µPa with an average level of 113 dB re. 1µPa. The Reedsport Baseline Acoustic Report is attached as Appendix A.

The Reedsport baseline acoustic testing was performed over thirty days during the calmer summer, which is assumed to be a primary reason for the difference between the month long and annualized data. In addition, the Reedsport acoustic data had to be filtered for frequencies less than 35 Hz due to strumming from the instrument mooring and seabed effects.

An EMF baseline measurement was also performed. Estimates from the Electromagnetic Field Measurements Report (Slater, M., et. al., 2010) indicated that the horizontal and vertical components of the earth's magnetic field at this location are 21.37 and 47.58 microTelsa (µT), with a total magnetic intensity of 52.2 µT. If a uniform flow of 1 meter per second is assumed, a maximum steady state electric field of 52.2 (microVolts per meter) µV/m would be expected. The report also concluded that the following natural conditions are expected at the Reedsport site:

1. The minimum estimated electric fields generated by wave motion are expected to be approximately 6 µV/m, and will be observed at frequencies around 0.3 Hz. The minimum induced magnetic fields due to wave motion should be observed over the same frequency regime with amplitude on the order of 0.02 nT. The minimum levels will occur at the ocean floor.
2. Estimated maximum electric fields generated by wave motion are expected to range to 216 µV/m, and are expected nominally in the 0.04 Hz regime. Maximum induced magnetic fields due to wave motion should be observed over the same frequency regime, with magnitudes up to 0.54 nT or more.
3. Electric fields generated by tidal motion and coastal currents will likely be present the majority of the time. When the currents are absent, so is their contribution to the electric field.
4. Maximum electric fields generated by tidal motion are expected to be 33 µV/m, and the maximum magnetic fields as a result of tidal sources are expected to be .08 nT.3.
5. Coastal currents are expected to generate electric fields up to 22 µV/m, although higher values may be observed, with potential values up to 44 µV/m during extreme current flows. The corresponding estimated magnetic field values for these conditions would be 0.06 nT to 0.12 nT.

Lockheed Martin (LM) participated in the project and performed analysis of different PowerBuoy manufacturing options. This objective was 100% completed. These analyses focused on conceptual float and heave plate designs focusing on improved manufacturability and transportability and included Finite Element Analysis (FEA) for loading and fatigue. The criteria for the designs were to meet the OPT legacy float design stresses for their respective component parts.

A four quadrant concept float design was developed by LM and subjected to FEA. The first iteration of the quadrant design indicated that it could not withstand the hydrostatic buckling loading case.

The second design iteration of the quadrant float utilized a cylindrical inner diameter and roller bearings. The cylindrical inner diameter design required cuts in the OPT legacy spar design to accommodate this revised design. This second float design yielded a 9.8% weight reduction in the float assembly and underwent several revisions and subsequent FEA. The primary focus of these subsequent FEA was to meet the OPT legacy design. The three analyses did not achieve the intended design target. However, there was improvement in the results to suggest that additional concept design work and analysis might achieve the intended fatigue loading target. The results of the redesign also indicated a potential 30% cost reduction in parts for the new concept design as compared to the legacy design. Reductions in component procurement and assembly were also evaluated.

The heave plate design was also optimized based on the LM work; double and single bulkhead heave plate concept designs were developed and evaluated. FEA of the single bulkhead design indicated increased stresses of 20% - 30% over the two bulkhead design. The two bulkhead design stresses were generally consistent with the OPT legacy heave plate stresses. The single bulkhead design achieves a 2,000 lb. weight reduction over the two bulkhead design. Both designs sectioned the two part OPT legacy heave plate to achieve greater transportability, increase the manufacturing vendor base, and for easier heave plate assembly.

The LM study also evaluated application of the commercially available paint coating to the PowerBuoy. The LM analysis generally indicated that the coating failure is largely the result of application procedure failure. This can be attributed to inadequate training of applicators in the use of this particular coating system or that guidelines for the application of the system were not rigorously followed.

There are several lessons learned from the project. The most important ones are related to the challenges of deploying new technologies in the open ocean environment even if they have been utilized in other open ocean industries such as complex logistics, regulatory maturity, qualified supply base and services providers, etc.

The use of the Floating Gravity Based Anchor (FGBA) in a Marine Hydrokinetic (MHK) project was an advancement in deployment technology. A full-scale PowerBuoy had been successfully deployed several months previously with Gravity Based Anchors (GBA). Although reasonable care had been exercised in the design and simulation of the FGBA as an anchoring method, complications were experienced with the descent of the first FGBA whereby a significantly more control of its descent at-sea was required than initially anticipated.

OPT approached DOE, and a mutually agreeable decision to terminate the project was reached. This decision resulted from the compounding effects of a variety of issues as mentioned above that caused an unbearable cost increase including: costs incurred to recover the damaged Auxiliary Subsurface Buoy (ASB) in October 2013, developing an FGBA Recovery Plan and removing the damaged FGBA from the seabed in summer 2014, increased costs due to delays both from weather and deployment issues, and updating the deployment, operating, and decommissioning expenses for the single buoy project. Technical considerations also weighed in on the decision to terminate the project, since significant technical progress was made on the conceptual design of a more efficient PTO, which superseded the design of the Power Take-Off (PTO) in the existing Reedsport buoy.

2 PROJECT BACKGROUND

FERC issued an Original License for the ten-buoy Project on August 13, 2012. Ocean Power Technologies, Inc. (OPT) began construction work at the Reedsport site for the single, autonomous[2] PB150 PowerBuoy in September 2012. Construction activities were performed under permits issued by the Army Corps of Engineers and the Oregon Department of State

[2] Not grid connected

Lands. Construction activities occurred on submerged lands licensed from the Oregon Department of State Lands under a five (5) year Temporary Use Permit.

The award covered the final assembly of the buoy, deployment and an operational period of two years of ocean testing. The buoy final assembly involved assembly of the two float halves onto the spar and attachment of the truss and heave plate to the spar. The grant award also involved baseline acoustic and EMF environmental testing in accordance with the Settlement Agreement.

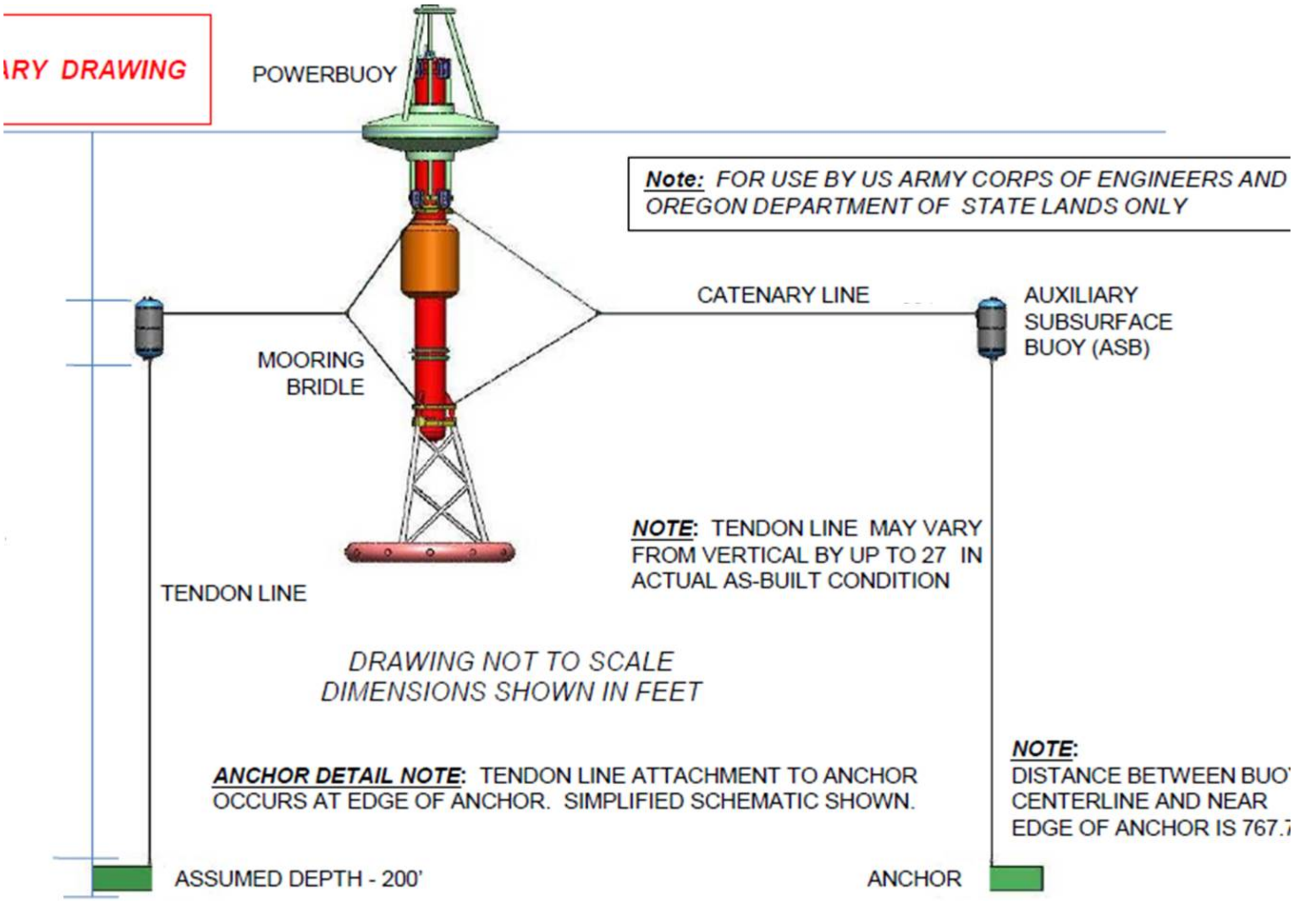
A single PowerBuoy is deployed in two stages. The first stage is the deployment of three (3) Floating Gravity Based Anchor (FGBA) Assemblies. Each FGBA Assembly consists of an Auxiliary Subsurface Buoy (ASB), thirty-three (33) meter length tendon cable connecting the FGBA to an ASB, and one hundred ninety-eight (198) meters of outer mooring line[3]. The three FGBA assemblies are located in a predetermined pattern and orientation consistent with the site wave and seabed characteristics.

The second phase of the deployment consists of positioning the PowerBuoy so that it is at the center of an equilateral triangle with the three FGBAs at the triangle's corners. The PowerBuoy's bridle is connected to the three outer mooring lines. The PowerBuoy, which is in a horizontal orientation when towed to the site, is reoriented into a vertical position by controlled flooding until the correct ballasting is achieved. The final step in the deployment process is to properly adjust the vertically oriented PowerBuoy in its moorings (see Figure 1).

Once the deployment process is completed, the operational check out and commissioning process would be started to confirm the correct operation of the buoy.

[3] The outer mooring line is annotated as Catenary Line in Figure 1.

Figure 1. *Single PowerBuoy Mooring Configuration*



3 COMPARISON OF ACCOMPLISHMENTS TO GOALS & OBJECTIVES

The primary objective of the project was to advance the PB150 design from Technology Readiness Level (TRL) 5/6 to TRL 7/8. To achieve this goal, the following objectives were planned to be demonstrated:

- Advance PB150B design from TRL 5/6 to TRL 7/8.
- Deploy a single PB150B and operate autonomously for 2 years.
- Establish O&M costs
- Collect environmental information.
- Establish manufacturing methodologies.

Other activities were performed by OPT in conjunction with this award in order to ready the buoy for deployment and the two year in-ocean testing period. These activities included:

- Performance modeling – under a prior DOE award, DE-FG36-08GO88017
- Fabrication of PowerBuoy – under prior DOE award, DE-FG36-08GO88017
- FERC Licensing and OSDL; activities to build local stakeholder community awareness – under an OPT internally–funded site development project
- DE-EE0003645 - Development of a larger scale PowerBuoy (PB500) for grid applications with a TRL target of 5/6

Each of these items is described further in the sections below.

3.1 Advance PowerBuoy from TRL 5/6 to TRL 7/8

The objective of the grant was a technology demonstration to advance the technology from a Technology Readiness Level (TRL) 5/6 to 6/7. The definitions of the relevant TRLs are shown in Table 1. Previously, OPT had demonstrated smaller, prototype buoys in less aggressive relevant environments at Kaneohe Bay, Hawaii and also off-the-coast of New Jersey. These demonstrations provided OPT with a significant amount of learning experience on how to deploy, operate, and recover buoys in relatively less energetic ocean environments.

Table 1. *TRL Definitions*

Definitions for reference from DOE G 413.3-4:
TRL 8 Actual system completed and qualified through test and demonstration.
TRL 7 Full-scale, similar (prototypical) system demonstrated in relevant environment.
TRL 6 Engineering/pilot-scale, similar (prototypical) system validation in relevant environment.
TRL 5 Laboratory scale, similar system validation in relevant environment.

These early experiences were built upon with the full scale PB150 deployment in Scotland in April 2012, which occurred after the start date of the original DOE grant. The Scottish deployment utilized standard Gravity Based Anchors (GBA) rather than the Floating Gravity Based Anchors (FGBA) used in the Reedsport Project. OPT successfully deployed the Scottish buoy. However, the operational history of the buoy during this period did not the project objectives.

Since, the Reedsport full-scale buoy deployment and two year ocean test did not occur, the technology advancement to TRL 7/8 was not demonstrated. However, significant technology advancements were achieved outside of the Reedsport project (as described in the prior section), and there were considerable lessons learned during this project that have been beneficial to OPT as well as to the MHK industry as a whole as this industry continues to mature.

While a root cause for the project not achieving its objective was the failure of the FGBA during deployment and the ensuing issues, it should also be noted that this was the first attempt at using an FGBA in this type of application. The floating caisson has been successfully used in aquaculture and was designed with deployment and retrieval in mind. This was a first attempt at utilizing such a GBA to reduce deployment costs, utilize lighter cranes for deployment and recovery, and make decommissioning simpler. While the approach did not succeed in this deployment for reasons summarized previously and discussed in detail later, the approach may be utilized in the future after engineering and operations modifications are implemented based on “Lessons Learned”.

3.2 Deploy PowerBuoy and Operate Autonomously for 2 Years

A two-year ocean test was part of the original grant scope. The intent of this two year test was to validate the reliability and operation of the buoy. Proprietary cost information is provided in Appendix A.

3.3 Establish O&M Targets

Optimistically, the project targeted demonstrating a path towards two cents per kWh O&M which is believed to be the appropriate target for PowerBuoys when produced in high volumes (commercialization) in wave parks.

While estimates, methods and approaches to reducing the O&M costs towards the 2-cents per kWh goal were identified, the lack of directly applicable test data, in particular ocean deployment data, did not allow for such methods and approaches to be validated.

3.4 Collect Environmental Information

The project included collection of baseline and post-deployment acoustic and Electromagnetic Field (EMF) data and data analysis. The collection and analysis were planned to be performed in accordance with the Reedsport Settlement Agreement (July 2010). Baseline acoustic and EMF data were collected. The acoustic data was analyzed and is generally representative of other known data along the Oregon coast.

Considering the buoy deployment did not take place, post-deployment data could not be collected.

3.5 Establish Manufacturing Methodologies

The primary focus of the Lockheed Martin (LM) work was Design for Manufacture (DFM) analysis. LM developed DFM concept designs for the heave plate and float. The heave plate and float OPT legacy designs were the baseline metrics against which improvements were evaluated. Design for Manufacturability and transportability optimization activities were carried out using Finite Element Analysis (FEA) through a collaboration with Lockheed Martin focusing primarily on the Float due to its cost contribution to the overall PowerBuoy cost, and then on the heave plate.

In addition to the DFM work, LM also conducted additional analysis on coating issues with the Reedsport buoy and shock absorber design improvements. Additionally, LM evaluated a spherical roller bearing to replace the brake pads, which has the potential to increase buoy electrical output. Overall, a significant effort was put forth towards reducing manufacturing and assembly costs as well as devising modular designs that could allow for a wider supply base access unconstrained by the need to be close to the deployment sites.

3.6 Work Performed in Conjunction with this Award

In order to accomplish the work under this grant, OPT relied on work performed under the Wave Power Demonstration Project at Reedsport, Oregon (prior DOE Grant DE-FG36-08GO88017). The work performed under the prior grant, and the additional work to support this grant generally included:

- Performance modeling (DOE Grant DE-FG36-08GO88017)
- Fabrication of the PowerBuoy (DOE Grant DE-FG36-08GO88017)
- Development of a larger scale PowerBuoy (PB500) for grid applications with a TRL target of 5/6 (DE-EE0003645)
- FERC Licensing (ten buoy project) and Single Buoy Permitting - OPT–funded under an internal site development project

System performance modeling under DOE Grant DE-FG36-08GO88017 generally involved site power projection modeling which helped determine the buoy's structural requirements, defined brake requirements, determined the Power Take-Off (PTO) force and size requirements as well as specifications for the mooring study.

A detailed buoy design was completed under this prior grant. This design included overall structure optimization utilizing finite Element Analysis (FEA) and other analytical models and tools. The PTO study advised the selection of the mechanical components of the PTO, generator selection, and other components of the PTO system such as the energy storage. This DOE Grant included testing of the full scale PTO in a laboratory environment, which equates to a TRL 5/6.

A number of improvements were identified and preliminary concept designs were developed to include the Modular PTO Technology (MPTO) that was built and tested at OPT's facilities leveraging work under DE-EE0003645. These new approaches made the PB150's PTO two generations behind in PTO development and maturity.

"Fill" Permits from the U.S. Army Corps of Engineers and the Oregon Department of State Lands were required for the buoy to be deployed in the navigable waters of the United States. A Temporary Use Permit was also required from the Oregon Department of State Lands for leasing of the submerged lands of the State of Oregon. The project was 2.5 nautical miles off the coast of Oregon, and Oregon's territorial waters extend to 3 nautical miles.

The Settlement Agreement defined the relevant baseline environmental testing and was negotiated with all relevant stakeholders. These stakeholders included the National Marine Fisheries Service (NMFS), Oregon Department of Fish and Wildlife (ODFW), and U.S. Fish and Wildlife Service (USFWS). As stated in the Settlement Agreement, the Cetacean and Electromagnetic Field (EMF) Studies baseline evaluations were based on the best available information for these types of studies at the time the agreement was signed.

The FERC License Application and activities supporting the License Application filing required extensive stakeholder outreach to build awareness for the single buoy (Phase I) and ten buoy (Phase II) projects. This outreach included community meetings, meetings with local fishing groups, and regulators. The outreach is documented in Volume III of the License Application for the ten buoy project (FERC Docket P-12713 Accession Number 20100201-5045). After the license application was filed, OPT responded to information requests from FERC and completed additional filings with State Agencies for necessary permits and approvals for the ten buoy project. The outreach also included a two-day FERC Scoping meeting for the project in April 2010. OPT has continued to support the single buoy project as noted in the fifty-two various reports and filings for the project on FERC's website. These reports and filings can also be found under Docket P-12713.

4 PROJECT SITE ACTIVITIES

The activities that occurred at the Reedsport Project site can be grouped into four general categories. These categories are: 1) pre-deployment activities, 2) deployment activities, 3) operating, and 4) decommissioning. This section will provide information on these activities.

4.1 Pre-deployment Activities

The PTO was inserted into the Spar under the prior grant (DOE Grant DE-FG36-08GO88017). Pre-deployment activities that were completed under this grant include:

- Rigging and transport of the completed PB150 PowerBuoy Spar assembly from Oregon Iron Works, Vancouver, WA facility to Vigor's Swan Island facility in Portland, OR,
- Offloading of Spar from water transport and staging at Vigor,
- Installation of Buoyancy Collar and ballast hose sections to the exterior of the Spar, and
- Preparation of the FGBAs and the associated components.

Pre-deployment activities also included buoy final assembly and preparation for deployment, which were not completed under the grant.

Also, under this task OPT worked with our subcontractors to develop an alternate method that did not require the use of a dry dock for final assembly. This method involved the use of cradles to secure the spar while the float halves, truss, and heave plate halves were attached to the buoy during its final assembly. The benefit of this method is that the buoy could be assembled without relying on the dry dock, thereby providing maximum scheduling flexibility and eliminating unnecessary dry dock standby costs.

Procedures were developed for deployment of the FGBAs and the PowerBuoy. Equipment from the Pacific Northwest was slightly modified to accommodate the FGBA deployment procedure. The FGBAs were new equipment which OPT and our contractors would use for this deployment. On August 26, 2012, OPT and our subcontractors performed a trial FGBA controlled descent in the sheltered waters of Coos Bay harbor in order to evaluate the FGBA deployment procedure. The harbor waters allowed all aspects of the descent and recovery of the FGBA to be tested prior to deployment at the site. No revisions to the procedure were required as a result of this harbor trial.

The Auxiliary Subsurface Buoys (ASB), mooring lines, and clevis were assembled in preparation for deployment. This involved coiling the outer mooring line onto the ASB for the initial deployment, attaching the ASB to the FGBA with a tendon line, and attaching a surface marker to the ASB. The assembled FGBA, ASB, connected tendon line, and surface marker are referred to as the FGBA Assembly.

In addition to these pre-deployment activities, OPT prepared a Recovery Plan and Spill Prevention Control and Countermeasure (SPCC) Plan which were previously submitted to FERC with the License Application.

4.2 Deployment Activities at the Reedsport Site

Single buoy components installed in 2012 included the outer mooring (catenary) line, which attaches the ASB to the PowerBuoy's mooring bridle as shown in Figure 1. The outer mooring line is coiled and secured on top of the ASB, until such time as the PowerBuoy is installed. The ASB is designed to maintain tension on the outer mooring (catenary) line. The surface marker was attached to the ASB by thirty (30) meters of line.

After the successful FGBA Harbor Trial on August 26, 2012, OPT and our installation subcontractor attempted to install the FGBA mooring system on August 28, 2012, however, a chaffing problem was discovered with the fiber ropes, and the installation attempt was aborted. OPT obtained new ropes, installed rollers at the friction points and was ready for deployment by September 1, 2012. However, the next available weather window did not occur until September 14, 2012.

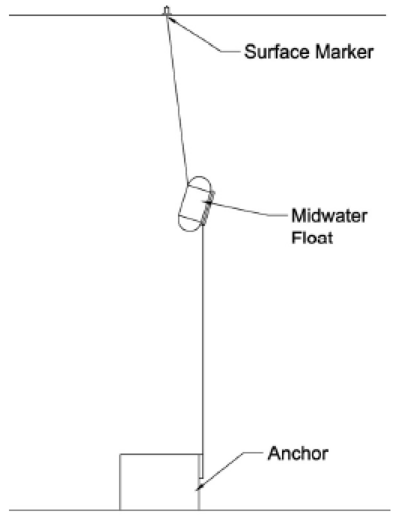
On September 14, 2012, installation of the first Floating Gravity Based Anchor (FGBA) was attempted at the Reedsport Site. OPT's installation subcontractor, Northwest Underwater Corporation (NUC), was in the process of setting the first FGBA at its designated anchoring location at the deployment site. Unfortunately, the system being used to lower the FGBA failed resulting in the FGBA dropping approximately 40 meters to the sea floor. In spite of the complications with the descent, the FGBA was installed on the sea floor (Figure 2) within deployment tolerances[4] and within the Temporary Use Permit Boundaries. The ASB was deployed at an approximate depth of 20 meters. Once deployed, divers removed water and air lines from the FGBA and ASB. The ASB air and water connections were closed and securely capped. The FGBA was allowed to fully flood the interior chamber(s). However, the FGBA deployment incident caused OPT to delay the deployment of the second and third FGBAs in order to reevaluate the installation procedure. The FGBA's descent did not conform with the results of the harbor descent and ascent tests.

On September 17th, a Remote Observation Vehicle (ROV) was used to perform an inspection of the FGBA. It was during this inspection that damage to the ballast piping of the FGBA was observed. This damage was not evident during observations immediately after the FGBA deployment. The most likely cause of this damage was the misplacement of an anchor line from the deployment barge while it was departing from the deployment site. The damaged FGBA could not be utilized as an anchor for the PowerBuoy unless it was repaired and repositioned on the seabed.

[4] Deployment tolerances include vertical orientation of the FGBA and clevis orientation. The clevis is where the ASB tendon line attaches to the FGBA.

On September 20th, a diver survey was conducted of the ASB and outer mooring line, which was securely affixed to the ASB. This inspection did not reveal any post-deployment concerns or issues with the ASB.

Figure 2. *FGBA and Auxiliary Subsurface Float (As Deployed)*[5]



The onset of unfavorable weather conditions also significantly impacted the installation of the moorings. Uncertainty regarding weather conditions during this timeframe caused delays and increased the risks of incurring substantial deployment vessel "standby" costs and adverse conditions.

As a result of the anchor installation issues and the weather delays, OPT was unable to install the FGBA anchoring system within the window specified in the Army Corps of Engineers permit, which was during the Summer period. The next deployment opportunity for the PowerBuoy system would be Summer 2013.

On November 15, 2012, OPT made a planned maintenance visit to the site. The maintenance visit was for the purpose of winterizing the installed components. The inspection team noted that the surface buoy was off station. The FGBA was detectable by a "fish finder," however, the exact location of the ASB in the water column could not be verified. Timely verbal notification of the situation was made to the U.S. Coast Guard. Written notification to the Coast Guard was made on November 30, 2012 by email. Notifications to the Coast Guard were made in accordance with the "Emergency Response and Recovery Plan".

On February 18, 2013, a marker buoy was set near the FGBA to replace the surface marker. On March 16, 2013, OPT performed a ROV inspection of the ASB, which was determined to be located on the sea floor. The results of the ROV inspection were evaluated. No external damage to the ASB was noted during the inspection; however, the inspection noted that the "as found" conditions for the air and water ASB connections were not the same as the divers left them in September 2012. They were found to be in the open condition.

Results of the ROV Survey and conclusions of the failure analysis were shared with the Reedsport Settlement Agreement Parties. The March Underwater Inspection report was filed with FERC on August 30, 2013 after incorporating Settlement Agreement Party comments. The report contains "before" and "after" photos of the valve positions indicating that the

[5] The mooring system was designed for a side attachment of the mooring line to the clevis, which is located at the top of the FGBA. The schematic indicates the as deployed orientation of the FGBA and is correctly deployed in accordance with the mooring system design.

valves were in the correct positions at the conclusion of the ASB deployment. Insufficient information was available to draw an absolute conclusion for the reason(s) the valve positions changed. However, the change in the valve positions allowed air to escape the ASB as water entered the ASB which eventually caused the ASB to sink to the sea floor. The Privileged Filing is listed on the FERC E-Library (Accession Number 20130830-5157). The report's cover letter to the Commission is available to the public under Accession Number 20130830-5156.

With a damaged FGBA and ASB both in need of repair prior to the deployment of the PowerBuoy, it became obvious to OPT that the PowerBuoy system deployment would be further delayed while OPT and our subcontractors determined the best possible methods for repair and redeployment of these key components of the FGBA system. As OPT further investigated the costs and schedule to repair the damage to the ASB and the FGBA, and combined these with the cost and the schedule impact of such deployment delays, now past Summer 2013, OPT determined that the single-PowerBuoy project was no longer financially viable.

OPT was responsible for removing the FGBA and ASB from the seabed in accordance with Oregon State Law.

The removal of the single deployed FGBA assembly was accomplished in three (3) phases. The first phase consisted of removing the ASB, tendon line, and outer mooring line which was still attached to the ASB. This removal was completed in October 2013. A crane barge was used to recover the ASB, outer mooring line, and the attached, sunken surface marker.

The FGBA removal was accomplished in August 2014. OPT evaluated two FGBA removal options. One plan relied on divers and the other plan utilized a heavy lift vessel. The heavy lift vessel plan was approximately 75% more expensive than the diver plan. However, the more expensive plan provided a much higher degree of successful removal than the diver plan. In addition, costs for the heavy lift plan would be incurred in addition to the costs for the diver plan if the latter was unsuccessful. The heavy lift vessel plan was selected based on its higher potential for successful FGBA recovery.

The buoy components, e.g., spar, float, heave plate, and mooring and anchoring components are currently in storage, and scheduled for disposition in accordance with the contract closeout with DOE.

4.3 PowerBuoy Commissioning and Ocean Test

No buoy commissioning activities or two year ocean testing was performed for this project since the buoy was not deployed.

4.4 Site Decommissioning

OPT is in the process of completing the necessary FERC License Surrender steps (Accession Number 20140814-3023). The Commission Order was issued after the Decommissioning Plan was filed with the Commission in July 2014.

5 ENVIRONMENTAL STUDIES

As previously discussed, the single buoy was part of a larger ten buoy project which was planned to occur approximately one year after deployment of the single buoy. In July 2010, OPT filed a Settlement Agreement as part of the License Application for the Reedsport Project. Appendix A of the Settlement Agreement contained six environmental studies which were to be performed on the single buoy (Phase I), ten buoy project (Phase II), or both phases of the project. The two relevant studies for the purposes of this project are the Cetacean Plan (Acoustic Study) and the EMF Plan. Both plans were based on best available information at the time the Settlement Agreement was filed.

5.1 Acoustic Plan

The Acoustic Plan consisted of several parts, which included pre-deployment whale migration monitoring, acoustic test around the single buoy deployment, and array post-deployment whale monitoring. The Plan required one month of acoustic monitoring in the predicted machinery noise range, which is up to 10 kilo-Hertz (kHz). Sampling was to be performed at 22 kHz for five minutes every hour. The Acoustic recorders used were configured with sufficient memory and battery capacity to record continuously for 42 days.

For the baseline testing, recorders were positioned along the same isobaths. One recorder was positioned approximately 730 m from the PowerBuoy centerline (when deployed). The second recorder was placed 5 km away from the proposed buoy centerline. The acoustic recorders were located north of the PowerBuoy location to maximize the distance from vessel traffic near the Umpqua River inlet to the south of the PowerBuoy. The recorders were deployed 7/25/2012 and retrieved on 8/25/2012. Wave data for the period was provided by an OPT supplied Triaxys buoy. Wind data was acquired from applicable National Buoy Data Center buoys located as close as possible to the project site.

The acoustic recorders recorded 24-bit samples at 48,000 samples per second. The total acoustic recording bandwidth was 10 Hz to 24 kHz, which is within the linear frequency range of the hydrophones, and captures sounds at all frequencies that are important to the various marine mammal species that live offshore Oregon. This configuration exceeds the requirement to measure frequencies up to a minimum of 10 kHz. Each hydrophone pair was calibrated in the laboratory before it was shipped, and in the field before it deployment, and in the field immediately after it was retrieved.

Because animals perceive exponential increases in frequency rather than linear increases, analyzing a sound spectrum with passbands that increase exponentially in size gives a more meaningful interpretation of the data. In underwater acoustics, the sound spectrum is commonly split into underwater acoustics, the sound spectrum is commonly split into 1/3-octave-bands, which is one-third of an octave wide; each octave represents a doubling in sound frequency. Automated bulk data analysis of all data was performed to compute ambient sound levels, detect shipping events, and detect transient sound events. The transient events included mammal calls, fish sounds, noise from moorings, and noise from objects touching the hydrophone.

Standard frequency bands used in this study were broadband (10 Hz to 24 kHz), decade-bands, and 1/3-octave-bands. The 1-min averaged, 1 Hz PSD levels were summed over each 1/3-octave-band and decade-band (10–100 Hz, 100–1000 Hz, 1000-10,000 Hz) to obtain 1-min averaged band levels (dB re 1 μPa). To determine the distribution of the recorded ambient noise levels, we computed cumulative probabilities for the 1-min PSDs over the entire recording period. The cumulative probabilities were plotted as percentiles (5%, 25%, 50%, 75%, and 95%); these depicted the proportion of time when PSDs at each frequency exceeded a particular sound level. To determine the distribution of 1/3-octave-band SPLs means, quartiles, and ranges for the 1-min SPLs were calculated.

An automated shipping noise detector was used to identify intervals when short-range vessel noise dominated received sound levels. By identifying these intervals, we could distinguish background noise levels from intermittent periods when sound levels dominated. This analysis also identified a baseline amount of vessel traffic near the project site.

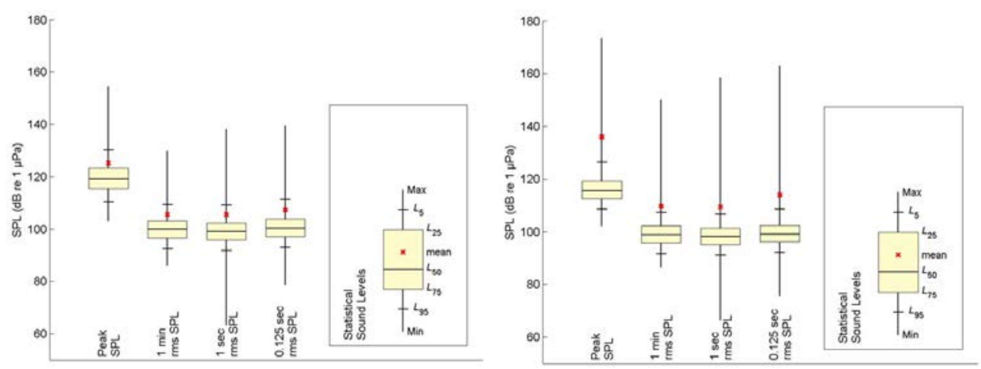
The data of both acoustic recorders showed a significant amount of low-frequency noise (< 35 Hz) for most of the recording period because of mooring movement, mooring line strumming, and water flowing past the mooring in the natural tides and currents. Because these sound levels obscured the true ambient noise readings at frequencies below 35 Hz, a high-pass frequency filter was applied to remove data at frequencies below 35 Hz. The data in the Acoustic Baseline Report (Appendix A) thus encompass frequencies between 35 Hz and 24 kHz. This frequency range covers the range of frequencies most important to the marine mammal species that occur in near shore waters of Oregon, including the dominant frequencies for low-frequency cetaceans such as gray and humpback whales.

Both sets of recorded data were similar and are shown in Table 2. Prominent frequency peaks at 40 Hz were present in most of the data. Above 100 Hz, the noise spectrum is smoother and drops off at a slope of −3 to −1 dB/octave.

Table 2. *Acoustic Recorder Data*

Acoustic Recorder	90th Percentile	Median
South Recorder	95–117 dB re 1 µPa	100 dB re 1 µPa
North Recorder	93–112 dB re 1 µPa	99 dB re 1 µPa

Figure 3. *South Acoustic Recorder Statistical Data Distribution (Left)*
Figure 4. *North Acoustic Recorder Statistical Data Distribution (Right)*



Oregon State University and the NOAA/Pacific Marine Environmental Laboratory's Acoustics Research Group performed baseline acoustic monitoring at the Northwest National Marine Renewable Energy Center (Newport, Oregon) in an area designated for the Mobile Ocean Test Berth site for Wave Energy Conversion devices. Maximum and minimum total sound pressure levels were recorded at 95 – 136 dB re. 1µPa with an average level of 113 dB re. 1µPa. Custom data logging equipment was used to capture frequencies in the 1 Hz to 2 kHz range with fixed landers. The data histogram is shown in the Figure 5. These annual results compare very favorably with the Reedsport baseline acoustic results.

Figure 5. *NNMREC Acoustic Distribution*

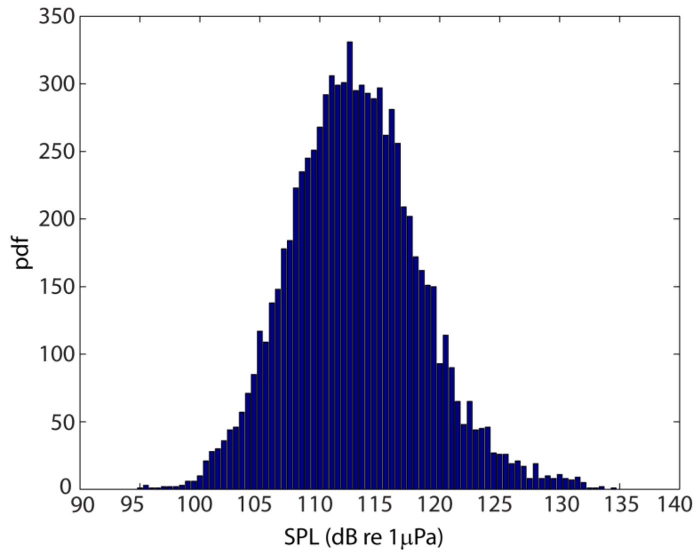
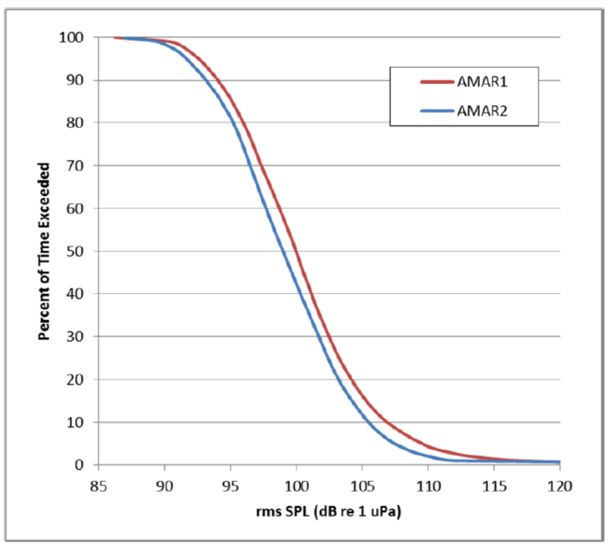


Figure 6 shows a cumulative probability distribution of ambient SPLs from 35 Hz to 24 kHz.

Figure 6. *Reedsport Acoustic Ambient SPL Probability Curve*



Acoustic recorder exceedance percentiles of ambient noise power spectral density levels (1-min average) over the recording period are shown in Figures 7 and 8.

Figure 7. *South Recorder Ambient Noise Power Spectral Density Exceedance Percentiles*

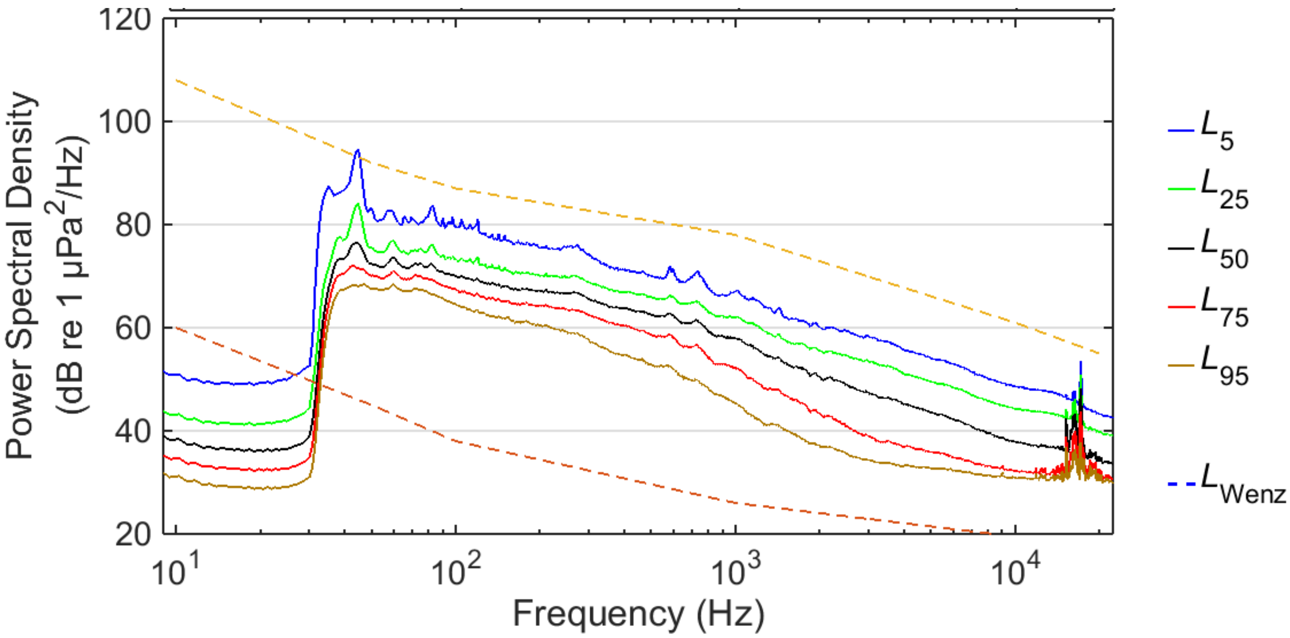
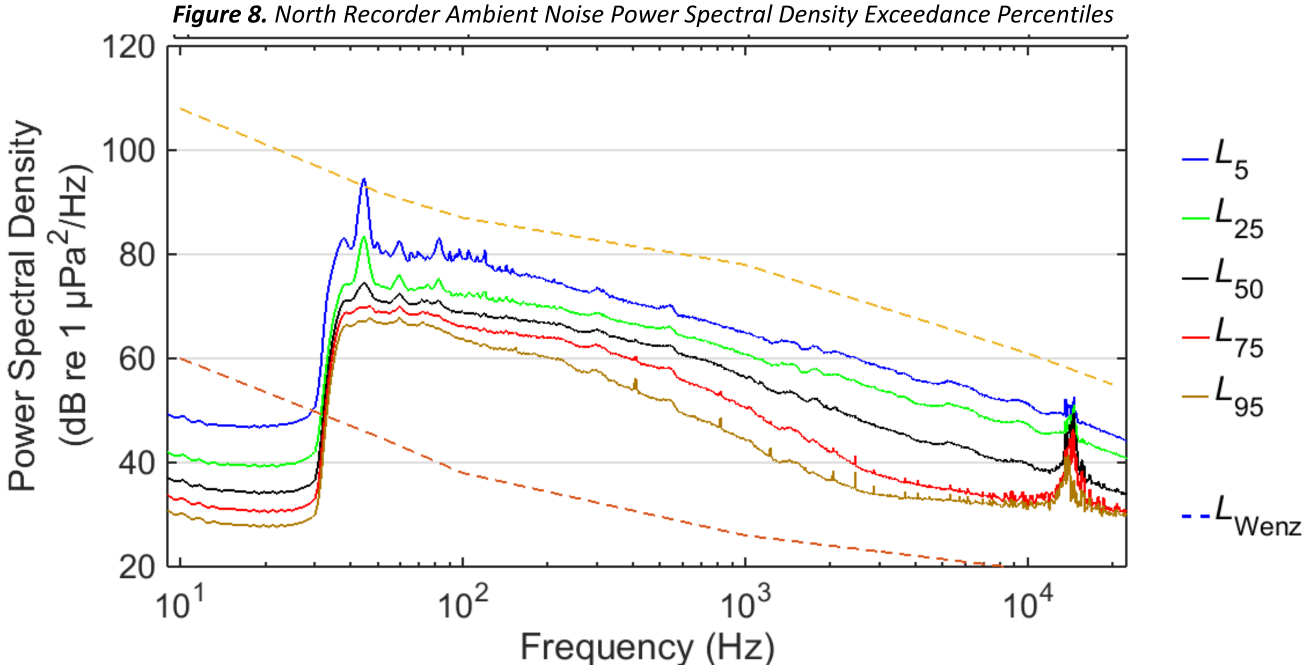


Figure 8. *North Recorder Ambient Noise Power Spectral Density Exceedance Percentiles*



Vessels were detected throughout the recordings on both acoustic recorders; the number of detections was compared between acoustic recorders. Vessel sounds were detected nearly continuously on south recorder with a minimum of 28 vessel detections per day. The north recorder experienced periods in which only a few vessels (< 10 vessels per day) were detected. The Umpqua River inlet, a busy vessel route, is located south of the PowerBuoy and the acoustic recorder locations. Hence, the vessel detection rate is higher nearer this traffic route, which is reflected in the higher number of vessels recorded on the southern recorder.

Linear regressions of the decade-band sound levels against the wind speed and average wave height were performed to determine which factors dominate the measured sound levels. Sound level was uncorrelated with wind speed in all frequency bands. A weak positive correlation between sound level and wave height was noted in the highest frequency bands (> 1 kHz) at both recorders.

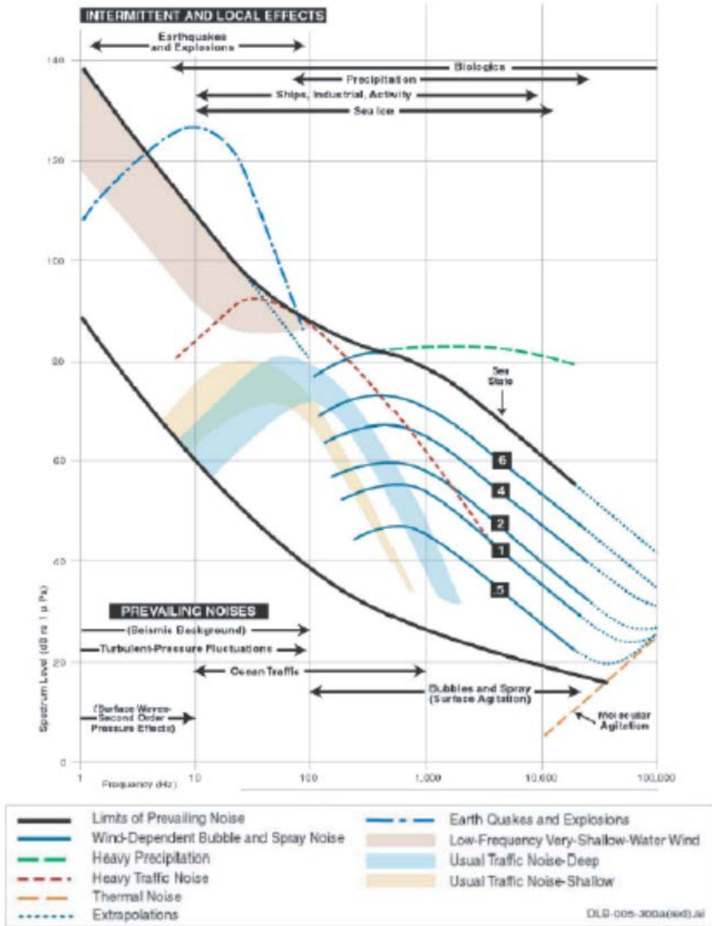
Data were collected on each acoustic recorder over a range of wind speeds—between 0 and 35 km/h. Data from National Oceanic and Atmospheric Administration's buoy Station 46094 indicated that the 2012 yearly median wind speed was 17.6 km/h and the yearly maximum wind speed was 73.8 km/h. Thus, the Phase II acoustic monitoring period captured ambient sound conditions representative of the median wind speed conditions, but not for the most extreme wind speed conditions that could occur.

The data on each acoustic recorder were also collected over a range of wave height conditions—between 0.1 and 1.4 m. The TriAxys data from 24 Jul 2012 to 12 Oct 2012 yielded a median mean-wave-height of 0.8 m, a maximum mean-wave-height of 2.2 m, a median maximum-wave-height of 2.0 m, and a maximum maximum-wave-height of 6.0 m. As with the wind speeds, the acoustic monitoring period captured conditions representative of the median wave height conditions at the project site, but not of the most extreme of possible conditions. The measured data indicate a weak positive correlation between wave height and SPLs for frequencies greater than 1 kHz at northern acoustic recorder and for frequencies greater than 10 kHz at the southern recorder.

The lack of correlation between wind speed or wave height and SPL at frequencies below 1 kHz indicates that meteorological conditions are not dominant factors that contribute to the SPL at those frequencies. Vessel noise is one factor that contributes to the ambient conditions at the project site at those frequencies (Section 2.3). A second factor that is likely contributing to the ambient sound levels on both acoustic recorders is distant surf noise from waves crashing on the shore less than 10 km away; (Wilson et al. 1985) reported that sound levels recorded at 8.5 km from a beach in California were attributable to surf noise at frequencies from 100-700 Hz.

Ambient noise *spectral levels* (sound levels resolved in a range of frequency bands) differ between deep and shallow water environments, and the levels in coastal water, bays and harbors are subject to large variations (Urick, 1975). Oregon's near-shore area, with bottom depths up to approximately 60 m, is classified as a shallow water environment – generally defined as water less than 200 m deep (Richardson et al., 1995). The National Research Council (2003) published a report containing a thorough overview of the various issues to be considered when introducing noise into a marine environment. A chart of adapted Wenz curves based on this National Research Council report is reproduced *Assessment of underwater noise generated by wave energy devices* (Austen, M., et. al, 2009), describing the predicted ambient noise from weather, shipping, and other potential sources of noise, is given in Figure 9.

Figure 9. *Wenz Curves and Sea States*

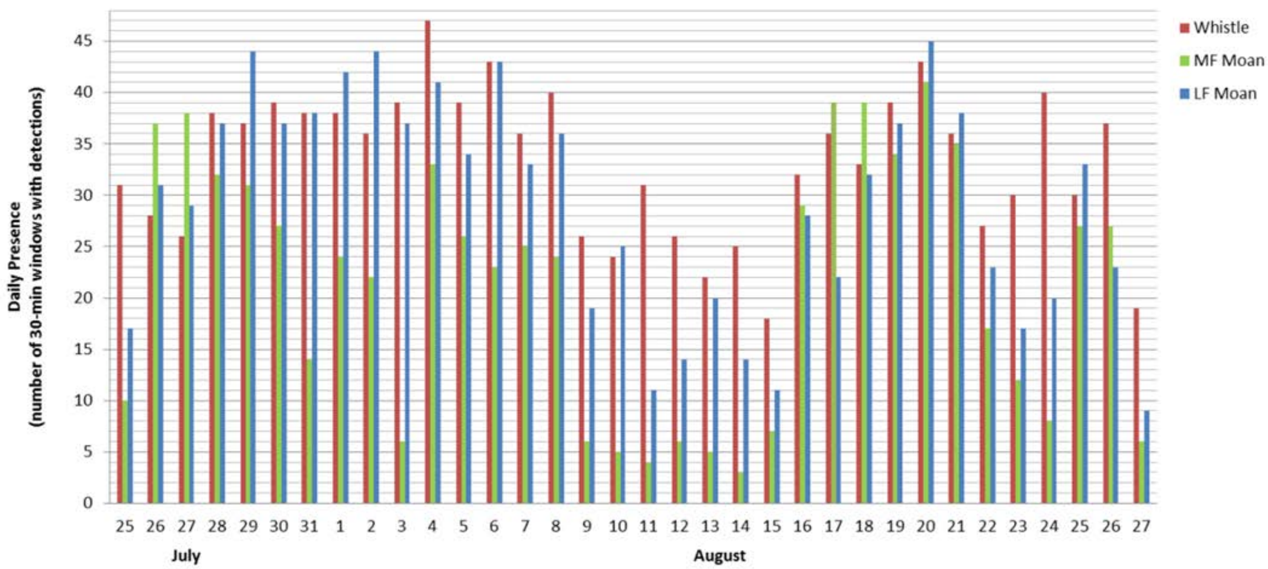


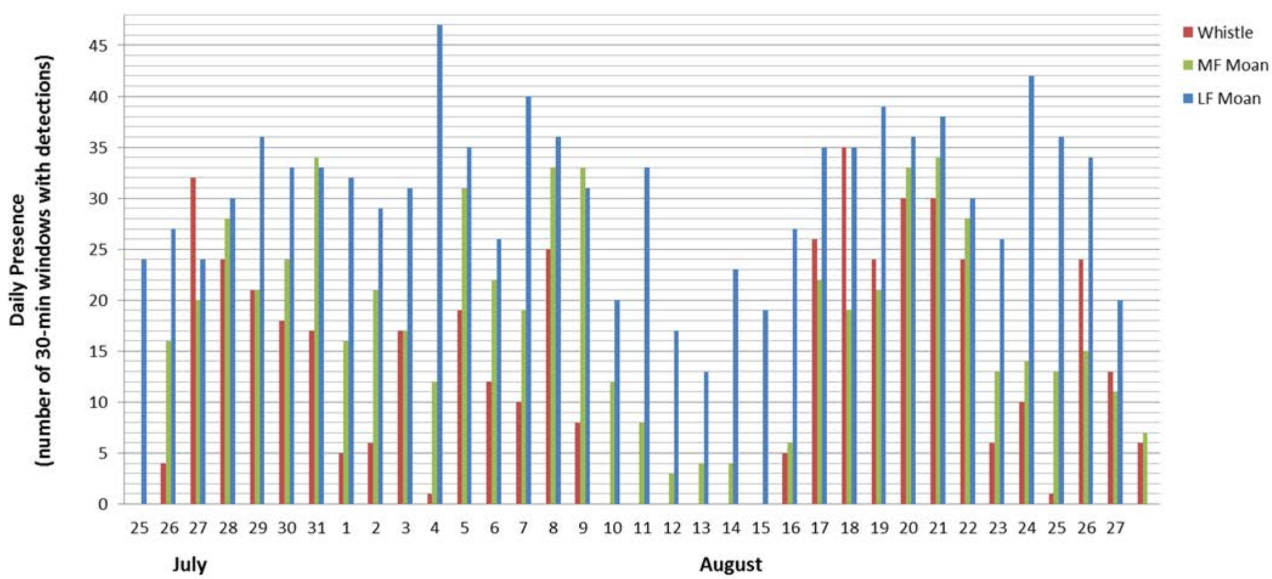
5.1.1 Marine Mammal Vocalization Detections

Marine mammal vocalizations were present throughout the recordings on both acoustic recorders. Figures 10 and 11 are plots of the daily presence of marine mammal vocalizations in 30 minute windows, grouped by frequency. Vocalizations are grouped as whistles, mid-frequency (MF) moans, and low frequency (LF) moans. Sounds consistent with marine mammal whistles occurred more frequently on north recorder compared to the south recorder, which is nearer the mouth of the Umpqua River. A decrease in detections occurred at both recorders during the second week of August; this may be a result of masking since broadband received sound levels on each recorder were also higher during this week compared to the rest of the period.

Figure 10. *South Recorder Vocalization Detections (Top)*

Figure 11. *North Recorder Vocalization Detections (Bottom)*





5.1.2 Estimated PowerBuoy Noise

FERC issued an Environmental Assessment (EA) in December 2012 (Accession Number 20101203-3009) as part of the ten buoy project (Phase II). The following excerpts on PowerBuoy Noise are taken from the EA:

> "*During project operation, underwater noise would originate from waves impacting the float portion of the PowerBuoy. We expect that some noise would also be associated with cycling of the hydraulic cylinders, spinning of the hydraulic motors, and transfer of vibration from the buoys' superstructure into the water, and that noise could also occur as a result of vibration of the mooring cables (Austin et al., 2009). Maintenance divers working underwater around the PowerBuoys deployed in Kaneohe Bay and in New Jersey have not noticed any audible sounds from the PowerBuoys or mooring system, but OPT notes that diver hearing underwater would not likely detect low frequencies.*"

"During operation, the PowerBuoy uses relatively low-intensity wave-to-electrical energy conversion technologies that are expected to produce low-intensity, broadband noise of a repetitive continuous nature, similar in character to noise from ship operations (Austin et al., 2009). Given this design, the source levels generated by the PowerBuoys should be close to ambient ocean noise levels. In addition, noise associated with the power plant machinery would increase in proportion to the ambient background noise associated with surface wave conditions, which would minimize the noticeable effect. We conclude that the potential for PowerBuoy operation to adversely affect cetaceans as a result of underwater noise or vibration would be very low. Acoustic monitoring of the PowerBuoys, together with shore-based and boat-based whale monitoring, would allow any unanticipated effects to be identified, by measuring noise levels in relation to ambient conditions and by evaluating cetacean response."

"In their assessment of underwater noise generated by wave energy devices, Austin et al. (2009) also note that a single point absorber device, such as a PowerBuoy, is not likely to cause a significant noise impact at longer ranges, but a full assessment should consider the additive effect for groups of devices."

FERC's EA referenced the "Assessment of Underwater Noise Generated by Wave Energy Devices" Report (2009). The section in the report contains additional information on point absorbers, the class of Wave Energy Conversion Devices. The FERC EA summarized the information contained in the report, which is excerpted below for convenience.

"Noise associated with the operation of point absorbers would mainly be created by the energy conversion mechanism, which would vary by device design. The mechanisms involved could include turbines, electrical generators, hydraulic or electromechanical energy converters, pumps, valves etc. The noise from these components would likely be continuous and may contain tonal (single or narrow band frequency) features, with most of the sound energy at frequencies less than a few kilohertz (Patricio et al, 2009a). The nature and intensity of this noise should be comparable to that emitted by machinery on board typical vessels (Marine Minerals Management Service, 2007). Any external mechanical noise associated with these devices would arise from vibrating mooring lines and the motion of the device at the surface and would likely be of low level, comparable to underwater sound emissions typically associated with large ocean buoys. A single point absorber device is not likely to cause significant noise impact at longer ranges; a full regulatory assessment, however, would have to consider the additive effect for groups of devices in simultaneous operation since a typical production installation could involve the deployment of tens or hundreds of point absorbers."

5.2 EMF Testing

In addition to Acoustic Testing, the Settlement Agreement also required evaluation of the existing Electro-Magnetic Field (EMF) at the Reedsport site. Testing of the PowerBuoy was to be performed in its energized and de-energized states. Unlike acoustic measurements, near shore *in-situ* EMF measurements of Wave Energy Converers is an evolving field. The Oregon Wave Energy Trust commissioned an Electromagnetic Field Study, attempted to summarize relevant information about the equipment, methodologies, provide initial estimates of baseline EMF fields, and summarized literature on the EMF effects on aquatic animals.

5.2.1 EMF Estimates

Relevant excerpts from the report, Electromagnetic Field Measurements (Slater, M., et. al., 2010), are provided in this section. This provides the reader with a summary of the prior work performed and some theoretical background. EMF arises from many sources in the ocean. These sources emanate EMF at various frequencies based on speed and the various EMF components interact vectorially as shown in Figure 12. The EMF frequencies from potential sources is shown in Table 3.

Figure 12. *EMF Vector Components*

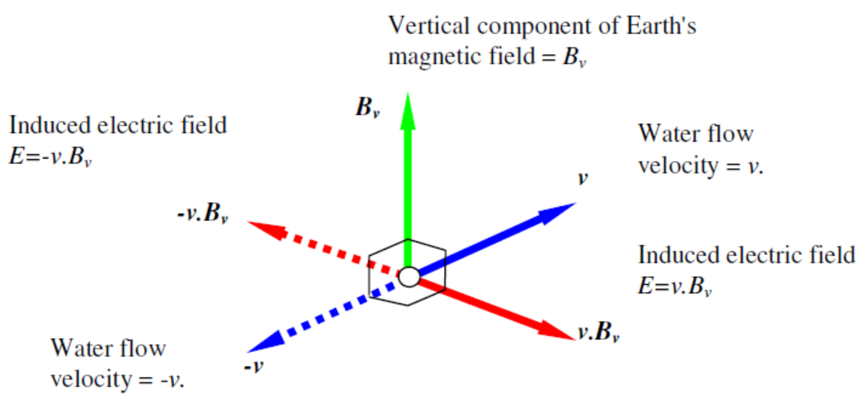


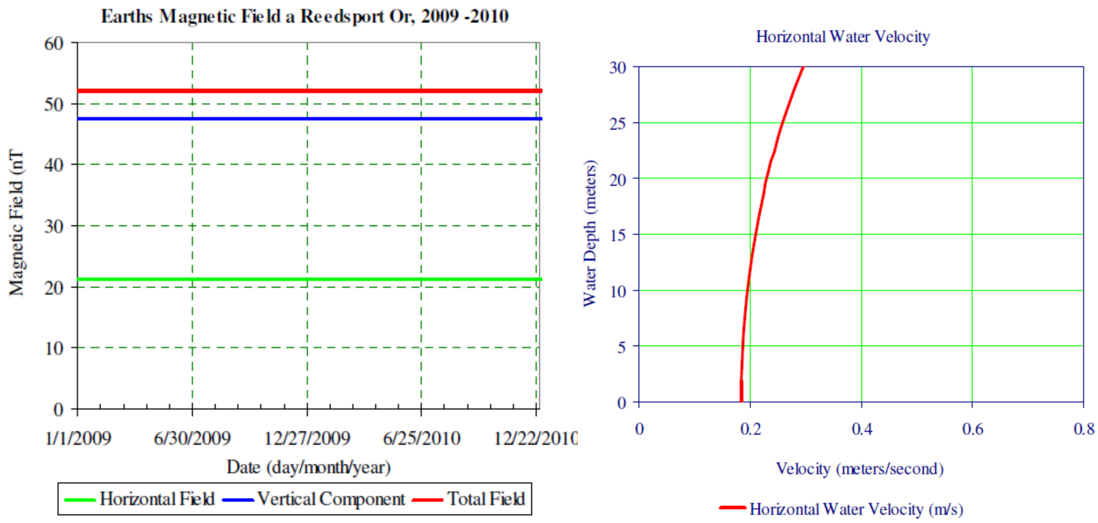
Table 3. *Dominant Sources of Electromagnetic Noise in the Shallow Marine Environment*

Potential Source	**Typical Frequency Range (Hz)**	**Comment**
Internal ocean waves, currents	variable	tidal action, local currents, gyre, and ocean fronts; solitons
Ionosphere and Magnetosphere Pulsations	0.002 – 1 Hz	Driven by solar wind
Bottom Boundary Layer Turbulence	0.01 – 0.1 Hz	turbulence due to local sub-sea geology
Surface Gravity Waves	0.05 – 1 Hz	Wind driven waves and swell
Microseisms	0.1 – 0.3 Hz	Caused by interference of surface gravity wave trains
Rayleigh Waves	0.1 – 1 Hz	Waves on ocean bottom due to seismic activity
Earth-Ionosphere Cavity Resonances	7 – 80 Hz	Schumann Resonances induced by worldwide lightning, including 7.83, 14.3, 20.8, 27.3 and 33.8 Hz**5**
Man-made	30 – 1,000 Hz	Electrical power generating equipment, including sub-harmonics

The induced electric field can be estimated using the conversion factor of .514 V/m/knot/T (Volts per meter per knot per Tesla). The horizontal and vertical components of the earth's magnetic field at the Reedsport location are 21.37 and 47.58 µT , with a total magnetic intensity of 52.2 µT. Thus, with a uniform flow of 1 meter per second in this area, a maximum steady state electric field of 52.2 µV/m would be expected. Figure 13 indicates the Earth's horizontal and vertical magnetic fields calculated at the Reedsport site. Figure 14 indicates the change in water velocity by depth. The changing velocity will affect EMF by depth as indicated in the vector diagram above.

Figure 13. *Reedsport Site Magnetic Field*

Figure 14. *Horizontal Water Velocity as a Function of Depth (30 m depth assumed)*



The resultant dominant electric field would be produced in the horizontal plane, that is, more-or-less parallel to the ocean surface. Data from {NDBC} Station 46229 reported that the dominant direction for waves at this site were from the west (270 degrees), with over one-third of all waves in 2009 arriving from that direction. Wave periods at that same location in 2009 ranged from a maximum of 25 seconds to a minimum of 3.45 seconds. Significant wave heights over this same time ranged from 0.49 meters to 10.77 meters. It should be noted that significant wave height and wave periods do not represent the worst-case conditions, but instead represent a statistical representation of that condition of the highest one-third of waves during the observation period.

Table 4 indicates the maximum induced Electric (E) and Magnetic (B) fields for the 2009 period. Note that the variability of the E field is approximately twenty times the minimum value and sixteen times the minimum for the B field.

Table 4. *Estimated EM Fields at Reedsport Site for Selected Wave Conditions*

Condition	**Wave Height, Hs (meters)**	**Wave Period, Tp (seconds)**	**Maximum Induced E-field (µV/m)**	**Maximum Induced B-field (nT)**
2009 Minimum Wave	0.49	15.38	6.4	0.02
2009 Maximum Wave	10.77	25.00	127	0.32
2009 Mean Wave	2.25	11.01	35	0.09
2007-2009 Maximum Daily Wave	17.37	18.00	216	0.54
Assumptions: Water depth: 56 m Water conductivity: 4 S/m Earth's magnetic field strength 52.2 µT Maximum field magnitude is at sea surface Data source:				

Tidal variations also contribute to the total E and B field. The table below provides an estimate of the impact of tidal variation for a 3 meter wave.

Table 5. *Estimated EM Fields at Reedsport Site for Maximum Tidal Conditions*

Parameter	**Value**	**Units**

Depth	56	m
Wave period	12.42	hours
Maximum wave height (tide)	3.0	m
Maximum horizontal velocity	0.63	m/s
Maximum electric field	33	µV/m
Maximum magnetic field	0.08	nT

Lastly, current velocities also influence these E and B fields. In December 2009, a maximum daily velocity of 43 cm/s (0.43 m/s) was observed on December 16, resulting in an estimated electric field magnitude of approximately 22.4 µV/m, and corresponding magnetic field strength of 0.056 nT. Cursory review of other coastal sites over the same time period indicated that occasional surface velocities can exceed 80 cm/s (0.8 m/s), thus producing a maximum estimated electric field of 42 µV/m, and maximum estimated magnetic field of 0.1 nT.

The Electromagnetic Field Measurements Report (Slater, M., et. al., 2010) concluded that the following natural conditions are expected at the Reedsport site:

1. The minimum estimated electric fields generated by wave motion are expected to be approximately 6 µV/m, and will be observed at frequencies around 0.3 Hz. The minimum induced magnetic fields due to wave motion should be observed over the same frequency regime with amplitude on the order of 0.02 nT. The minimum levels will occur at the ocean floor.
2. Estimated maximum electric fields generated by wave motion are expected to range to 216 µV/m, and are expected nominally in the 0.04 Hz regime. Maximum induced magnetic fields due to wave motion should be observed over the same frequency regime, with magnitudes up to 0.54 nT or more.
3. Electric fields generated by tidal motion and coastal currents will likely be present the majority of the time. When the currents are absent, so is their contribution to the electric field.
4. Maximum electric fields generated by tidal motion are expected to be 33 µV/m, and the maximum magnetic fields as a result of tidal sources are expected to be .08 nT.
5. Coastal currents are expected to generate electric fields up to 22 µV/m, although higher values may be observed, with potential values up to 44 µV/m during extreme current flows. The corresponding estimated magnetic field values for these conditions would be 0.06 nT to 0.12 nT.
6. Man-made sources of EM noise may be observed in measured ambient noise data. It is difficult to estimate the potential range of magnitude from man-made sources on the existing ambient conditions at the site. Man-made sources are expected to exhibit discrete frequencies at 60 Hz and higher order harmonics of 60 Hz.

These conclusions established parameters for instrument sensitivity. The report indicated that this means that the minimum sensitivity for near-shore measurements should be 1 nV/m or better over the regime of 1 Hz or greater, and a sensitivity of 10 to 100 nV/m at lower frequencies to capture the fields generated by ocean waves. Magnetic field instrumentation should be capable of measuring levels of 10 nT to assess the direct measurement of fields associated with the most sensitive of certain known marine species as well as the induced levels due to wave motion—although existing technology should be capable of sensing AC magnetic fields in the pT (pico-Tesla (10^{-12} T)) regime.

For comparison, measured data acquired during the Collaborative Offshore Wind Research Into the Environment (COWRIE) sponsored investigation do not add clarity to the possible levels of background noise in the EMF, primarily due to the selection of sensors employed for the field testing. The electric field probe reported a maximum sensitivity of 420nV/m (10^{-9} V/m), or approximately 10,000 times less sensitive than instruments designed to measure the deep ocean environment. The magnetic field sensor had a maximum sensitivity of 0.5nT (~10^{-9} T), or nearly 100,000 times less sensitive than deep ocean magnetometers.

6 PRODUCTS DEVELOPED AND TECHNOLOGY TRANSFER ACTIVITIES

The project did not result in any technology transfer.

7 COMPUTER MODELING INFORMATION

This information is excerpted from the prior DOE Grant (DOE Grant DE-FG36-08GO88017) for the convenience of the reader.

7.1 Requirement & Specifications

7.1.1 Study to Define Survival MetOcean Conditions

Survival loads for the structure and mooring were based on a defined set of MetOcean conditions for Reedsport, Oregon, namely a 100-year storm (i.e. probability of occurring once in a 100-year period). The 100-year wave height, period, and direction were defined based on a long record of wave observation from NDBC buoys near Reedsport. The study was conducted by Dr. Peter Ruggiero at Oregon State University under subcontract to OPT and concluded that the 100-year return period wave was characterized by a significant wave height of 14.74m and peak wave period of 17.5 seconds. The contractor also estimated the wave climate for Reedsport, a necessary input for power projections and fatigue analysis, based on the same dataset.

The 100-year current, wind, and tidal range were defined based on available local measurements and model outputs. The study was conducted by Marine Innovation & Technology under subcontract to OPT and concluded that the 100-year return period wind speed was 23.4 m/s, the 100-year current velocity at the surface was 3.7 (3.4) knots in ebb (flood) tide, and the sea surface elevation ranged from -2m to 1.65m due to tides on a 100-year return period. Both contractors' reports also included the direction of the 100-year wave, current, and wind, which is required in order to estimate the vector sum of environmental forces on the PowerBuoy and its mooring system.

7.1.2 Site Power Projections

An existing proprietary OPT model called Two Hull Model was developed prior to this project. The model was used to estimate the expected PB150 power output in Reedsport, Oregon. Simulations were performed for a wide range of sea states. At each sea state, the model output included a time series of mechanical power which was time averaged. Power values for different sea states were tabulated to obtain a power matrix. To obtain the annual average power at a site, the power matrix is weighted by each sea state's probability of occurrence and then summed. Both annual and monthly power averages can be obtained in this fashion. The model does not simulate the efficiency of the Power Takeoff in going from mechanical to electrical power. Instead a reasonable efficiency was assumed based on bench test results and values provided by component manufacturers.

7.2 Structural Analysis Methodology

7.2.1 FEA Method

Based on FEA calculations of stress, hot spots are identified and studied. The mesh near the hot spots consists of elements with sizes meeting the requirements of at most $2t$ x $2t$ in critical bending stress directions, but ideally less than t x t. The hot spot stress is derived by linear extrapolation based on the stresses at $0.5t$ and $1.5t$ away from the hot spot. If extrapolation is not possible, the hot spot stress is considered to be 1.12 times the stress at $0.5t$ (2). Hot spot stresses were evaluated in the spar. The stresses radiating from the 1st Principal Stress were approximately half the initial value within 15 mm.

7.2.2 Survivability

Buoy integrity is evaluated using hot spot stresses considered to occur in the high stress regions that will fail first by either yielding or fatigue. Despite higher conservatism than using field stress, hot spot stress is used due to the fact that all the critical locations have high stress caused by stress concentrations and complicated geometry, which leads to unclear definitions of field stresses per FEA results.

Survivability is assessed based on the maximum load seen by the component during a 100 year storm. The von Mises hot spot stresses should be less than the yield strength of the material with a factor of safety of at least 1.11 for certification; however, OPT required a minimum safety factor of 1.5.

7.2.3 Fatigue

While survivability is assessed independently from the loading cycle, fatigue accounts for the loading cycles by calculating the fatigue utilization at each stress fatigue range / cycle count interval.

Stress considered in this calculation is the 1st principal stress. If the stress range is below the endurance limit, the joint will be considered to be free of fatigue. However, if any load cycle induces a stress greater than the endurance limit, a detailed fatigue calculation is assessed. The stress fatigue range used for this fatigue assessment is based on the hydrodynamic loading range per the linear 1st principal stress ratio to applied design or unit loading.

A fatigue calculation by means of total life utilization was also performed. The stress cycle data is based on the buoy region and loading direction/type that is being considered. The respective S-N curve used for the fatigue analyses depends on the joint/component configuration. The second field will note in the parentheses which joint class best describes the buoy joint being considered. The Force Fatigue ranged from 150 kN up to 3,000 kN and was applied over 2,000,000 at the low end and 450 cycles at the high end. The resulting fatigue utilization indicated a Total Life Utilization of 0.15.

The *Fatigue Life Cycle Limit* can be calculated at particular stress ranges that correspond to those in the histogram for the analysis. Based upon the ratio between the *Fatigue Life Cycle Limit* and the expected cycle count, the *Fatigue Utilization* is calculated. Summing the *Fatigue Utilization* over the stress range spectrum yields the *Total Life Utilization*. The component should not experience fatigue failure when the summation (i.e., Total Life Unitization) is less than 1 given that the Design Fatigue Factor (DFF) is set to be 1.

7.2.4 Slam Loading

Survival wave tank tests of the PB150B1 were conducted in 2008 in Newfoundland, Canada and provided the structural loads used in the PB150B2 design. During the wave tank tests, ringing was observed during float slamming onto the free-water surface. The concern is that ringing may accumulate vibration cycles with or without prefect resonance and lead to early fatigue damage. The following calculation considers the added mass effect on a submerged vibrating plate. A modal analysis of the float calculated the first 200 modes of natural frequencies. Of these first 200 modes, none involved the bottom skin of the float. Therefore, this calculation considers the natural frequency of the 200th mode which is 229Hz in air.

The maximum water added mass effect for a panel is up to 1000%. Thus, the natural vibration frequency in water is degraded to 455Hz considered as the most conservative condition. The slam pressure rising and dying time is observed as 0.12 second and 0.45 second with linear profiles, respectively. Therefore, the Duhamel's integral approach to considering tapering pressure induced vibration is taken to calculate the vibration amplification factor with respect to the quasi-static pressure. Given the complication and uncertainty of the damping ratio of the structures, the Duhamel's integral excludes the damping effect and leads to more conservative results, which are shown in the MATHCAD calculation below.

The amplitude of the vibration can then be compared with the stress induced by that vibration. If the stress is within the endurance limit of the structure, there should be no fatigue damage.

The deformation oscillation is ±3.0% of the magnitude of quasi static deformation. Since the maximum stress on the base of the float is less than 200 MPa, the stress range is less than 6 MPa, which is far below the fatigue limit (S-N Curve F – 41.5MPa). Thus, slam force induced vibration does not concern the float integrity.

8 LESSONS LEARNED

8.1 Regulatory Lessons Learned

The project was conceived as the first phase of a three-phase project, potentially leading to a wave energy project of up to fifty MW capacity at the Reedsport site. The first phase of the project was deployment of a single, autonomous (non-grid connected) buoy. Phase II consisted of installation of nine additional buoys, an Undersea Substation Pod, submarine and terrestrial transmission cables and a shore station interconnecting to the Bonneville Power Administration grid. The third phase of the project was potentially to build out the project up to fifty MW total capacity.

Marine Hydrokinetics is an emerging industry, which is evolving within a strong, existing regulatory framework. This particular project was under the jurisdiction of the Federal Energy Regulatory Commission (FERC or Commission). FERC typically deals with established, mature energy related projects, such as transmission lines, gas pipelines, Liquid Natural Gas (LNG) projects, and conventional hydroelectric projects. FERC has developed a robust, well proven set of regulations to ensure that these projects are licensed, built, and operated in an responsible, environmentally sound manner in accordance with sound engineering principles while promoting energy security and protecting public safety. Commission staff in the Washington and local Portland offices provided guidance throughout the license application process. This first FERC wave energy license application acquainted staff to the emerging wave energy technology within the regulatory framework, which had never been done before.

One of the issues facing OPT during this project is that the regulatory process and project schedule varied from the projected timing of the deployment of the first buoy. The schedule variation resulted for a number of reasons. It was anticipated that the Phase II (of the FERC Project) deployment of nine (9) additional buoys would follow a year after the deployment of the single buoy (Phase I of the FERC Project). The single buoy deployment and permitting process was a much simpler process requiring only permits from the Army Corps of Engineers and Oregon Department of State Lands. A number of factors had to converge in order to implement the second phase in the originally planned timeframe. Among these factors was issue of a FERC License, raising additional funds for the second phase build, front end project engineering, order of long lead materials, and agreement for sale of electricity from the Phase II project.

OPT had to file the FERC License Application within the three year Preliminary Permit period or risk losing site priority. One potential approach to avoid losing priority is to file a subsequent Preliminary Permit Application. The subsequent application requires the applicant to demonstrate significant progress on the license application during the prior permit and is issued at the discretion of the Commission. OPT filed the License Application in 2010, coincident with the expiration of the Preliminary Permit. A Settlement Agreement, signed by fourteen Federal and State Agencies and Non-Governmental Organizations, was filed in the summer of 2010. FERC's draft EA was issued in December 2010. The FERC license for the project was issued in August 2012.

As indicated previously, the initial deployment of the first FGBA was September 2012, after the issue of the FERC License. As initially envisioned, the first buoy deployment would have been deployed prior to the FERC License being issued and in compliance with permits from the Army Corps of Engineers and Oregon Department of State Lands. The deployment timing and date of issue of the FERC License added unanticipated complexities to the deployment of the first buoy. It also brought subsequent project operations under a FERC approval process, which was not anticipated to occur in the original scheduling until Phase II of the project.

The issue of the FERC License was important to potential electricity buyers to demonstrate OPT had control of the site, which is a requirement for a Power Purchase Agreement (PPA). At a minimum, the Preliminary Permit and demonstrated progress towards filing of the FERC License application would have been required for the PPA. However, the issue of the FERC License removed one potential condition for raising project funds or executing a PPA. Phase II project funding was anticipated to be potentially contingent upon a number of items including, but not limited to: 1) site control, 2) an executed PPA, 3) buoy deployment and operation, and 4) environmental performance of the buoy. In order to achieve the timing of the closely coupled Phase I and II schedules, the FERC license application timing was critical.

The FERC Licensing process was a much more involved licensing process than the single buoy permit applications. While there was a fixed date for expiration of the Preliminary Permit, there was a broad range of potential dates for issue of the FERC License Application. This broad range was not within the control of FERC or OPT.

Under the FERC Licensing requirements, the project needed to provide a Financial Plan, including decommissioning costs, which was required to be approved by FERC prior to project construction. The minimum period for filing the plan was 90 days. Contract Plans & Specifications for the project were also required to be filed with FERC prior to the deployment of the single buoy, which also had their own consultation requirement and lead times. FERC jurisdiction over the buoy also added additional, unanticipated burdens to the recovery of deployed components.

State regulatory authorities were also gaining experience about wave energy during the licensing and permitting process. OPT conducted numerous meetings with various regulatory and legislative stakeholders. State laws, statutes, and regulations also evolved during the course of the project, primarily in response to the Phase II and potential Phase III (up to 50 MW) projects. There was a clear delineation between a ten buoy project operated under a Settlement Agreement and project which may be as large as 50 to 100 MW.

The lessons learned from this experience are:

1) A comprehensive assessment of the emerging technology demonstration within existing regulatory schemes needs to be performed. This critical assessment needs to reviewed and updated, as needed, upon completion of each phase and prior to the start of the next phase.
2) Timing of the Preliminary Permit filing (for site control) is critical and needs to be carefully coordinated with the project and timing of subsequent project phases, particularly for "first of a kind" demonstrations.

3) The autonomous buoy (Phase I) and ten buoy project (Phase II) should not have been coupled together for regulatory purposes. An acceptable potential alternative would have been to commit to removal of the single buoy from the ocean then redeployment under the FERC License[6].
4) Fund raising, regulatory, and PPA requirements for subsequent project phases are essential to understand at project conception. These should also be part of the ongoing project assessment.
5) A changing regulatory environment requires flexible planning and alternatives to address outcomes which may impact the project or follow on activities to the project.
6) Commitment to an on-going Stakeholder Communications must be part of the project.

8.2 Design and Engineering Lessons Learned

As indicated earlier, OPT planned to substitute FGBAs in this project for the conventional GBAs which had been used in the Scotland deployment of a full scale PB150 earlier in 2010. The buoy deployment was essentially the same process as the Scottish deployment, with the exception of the introduction of the FGBAs.

The experience with the FGBA deployment provides several insights. One positive insight is that technologies demonstrated in other applications have the potential to be utilized in the MHK industry, with the appropriate engineering modifications. The Floating GBA concept had been modified from the aquaculture industry for use in this application. The original application was a floating caisson. The aquaculture application needed to be modified so that the floating caisson could be floated to the site, undergo a controlled descent, and could be raised at the end of the project. An additional benefit of the floating caisson is that it utilizes existing equipment, which is typically present in the Pacific Northwest.

The floating GBA was designed by a third party vendor who also performed validation testing of the design and deployment methods. The results of the testing indicated that the planned FGBA design would meet the requirements of the design specification. The successful trial deployment testing results in the Coos Bay Harbor waters bears out the validity of the design concept. The uncontrolled descent of the FGBA during the actual deployment indicates that additional parameters should have been considered in the design and testing of the FGBA and an overall more conservative design should have been undertaken.

The use of stands compared with a dry dock was also evaluated for the project. The stands provided a much higher degree of manufacturing schedule flexibility compared with the use of a dry dock. The costs associated with the use of the stands and the dry dock were comparable based on the estimated project schedule at the time the comparison was performed. Dry dock availability was a critical path item for the schedule and is required to be schedule well in advance of the buoy manufacture.

The lessons learned from this experience are:

1) Include additional relevant information in the design specification, particularly where this information may impact how to design the component/system or factors which may influence design, construction, or operation of the component/system.
2) Once the component/system meets the initial design specifications and has been successfully simulated, perform additional simulation testing to point of failure for appropriate Risk Register items, e.g., “Low Risk, High Impact” category items. The testing should be run against a comprehensive Failure Modes and Effects Analysis (FMEA). Redesign component/system as appropriate to alleviate the potential source of failure or provide details in Design Test and Acceptance Report on design and operating limits.

[6] This approach assumes that appropriate discussions and regulatory consent(s) would have been obtained prior to the decision to build the buoy.

3) Have a third party perform or validate testing results.
4) Technology transfer externally and internally is critical to success.
5) Manufacturing operations for emerging technology may need to look at alternative approaches to

8.3 Operations Lessons Learned

OPT had demonstrated success with several deployments of smaller buoys in Hawaii. OPT also demonstrated deployment of a full scale PB150 buoy in the North Sea in 2012. The deployment was performed with standard Gravity Based Anchors. Any project is subject to schedule delays. In performing "on-water" work, schedule adherence is a particularly critical factor. It impacts vessel availability, weather windows, and regulatory activities. Once a decision is made to delay a project, planning and execution for the next available opportunity needs to begin shortly after the "no-go" decision is made.

OPT utilized existing marine industry "best practices" and developed a Deployment Study that included weather persistence analysis. The deployment of Marine Hydrokinetic devices can only be performed safely within certain wave heights, current conditions, and wind conditions. One element of preparing for deployment is to develop a monthly statistical analysis of wave conditions at the deployment site. This analysis provides probability based estimates of the percent of time that the correct wave conditions will be present. A critical part of the analysis is the number of consecutive days specific wave conditions exist during a given month.

Planning for deployment requires selection of months where optimum deployment conditions exist. This allows vessels and support equipment to be contracted for the pre-determined deployment timeframe. In addition, planning also needs to take "weather days" into account. These are days when vessels have been mobilized and are waiting in port for the right deployment conditions. These weather conditions may either prevent a planned deployment after vessels are mobilized or cause an "in-progress" deployment to be delayed. The latter can occur when construction occurs in discrete steps, such as setting of anchors prior to deployment of the device.

Weather risk is a necessary component of deploying MHK devices, particularly at full scale. On a commercial scale, weather risk is part of the "cost of doing" business and tends towards generally accepted guidelines when spread over a number of projects. Conversely, weather risk can assume a disproportionate amount of a budget for a single deployment. This is particularly true for Research, Development, & Demonstration (RD&D) initiatives, where cost-sharing for the project may be up to 50% of the total project for a single funding authority. However, weather is a fundamental risk that needs to be accounted for. Cost only increases once vessels are mobilized and committed. Therefore, a "most likely" weather delay forecast needs to be developed and incorporated into the project planning and budgeting cycle.

8.4 Environmental Lessons Learned

Environmental baseline for the project was planned to be conducted under a Settlement Agreement which was signed by all parties in summer 2010. The baseline assessment was intended to be performed in accordance with performance requirements set forth in the Settlement Agreement. The acoustic baseline was to be performed for one month prior to the buoy deployment. The EMF baseline measurements were planned to be performed prior to the buoy deployment.

The buoy deployment schedule delayed the baseline measurements until 2012. During the period of summer 2010 through 2012, new work was being performed and published in the areas of EMF and acoustics. Some of this work was performed at the Northwest National Marine Renewable Energy Center (NNMREC). Reviewers of the work at NNMREC included some of the Reedsport Settlement Agreement Parties. Results from some of the NNMREC work and literature published during that period is believed to have potential to influence study methodologies, length of studies, and study metrics. Seasonal noise "budgets" for the deployment site may provide insight into similarities with seasonal noises at other nearby sites.

The baseline acoustic monitoring which occurred at the Reedsport needed to filter noise <35 Hz due to strumming of the acoustic recorder moorings and flows across the recorders. Once the NNMREC acoustic sampling was publicly available, the two sets of results should have been reviewed so that a determination of the Reedsport baseline noise in the range of 1 - <35 Hz could be assessed and appropriate modifications made to the monitoring plan if required. In addition, modeling of sources of buoy related noise in this range could be performed prior to the deployment if warranted. At a minimum, analysis of one year's worth of data from the NNMREC site could potentially justify an appropriate acoustic monitoring period around the after the deployment of the buoy.

EMF measurement continues to be challenging in the emerging MHK industry. As information grows on the in-situ measurement and familiarity increases on the seasonality of EMF, EMF modeling may take a more prominent role in addressing these concerns. However, these models will need to be developed and subsequently validated for future projects.

The lessons learned from this experience are:

1) Maintain awareness of studies and results from other regional projects and as applicable, participate in relevant discussions on those projects with stakeholders.
2) Continuous engagement with environmental study stakeholders to share research results, such as seasonal noise budgets, and results of literature searches should be ongoing as licensing is in process.

8.5 Local Marine Community

The local fishing community was represented and actively participated in the development of the Settlement Agreement, for the single, autonomous PowerBuoy. The Chair of the Southern Oregon Ocean Resource Coalition (SOORC) made a qualified statement of support for the Phase II project during the FERC Scoping Meeting for the project. He indicated that SOORC was supportive of the planned Phase II so that ocean users could learn about wave energy and its environmental effects. He indicated that SOORC's support did not extend to Phase III.

The local marine community expressed their expectations of the project and its operation[7] and also provided comments where they felt the project or its communications fell short. OPT had several challenges managing the expectations of the fishing community in this regard. Over time, communications with the fishing community and others improved with the appointment of a local representative. A number of communications changes were also put into effect which helped make communications timelier.

One primary issue was the project's location. According to local fishermen, the project was located on "one of the most productive crabbing grounds in Oregon". The impact of locating the project at Reedsport was evaluated as part of the permitting process for the single buoy and the FERC licensing process for the ten buoy project. Public comment periods were held for both processes and OPT was required to address issues brought up during the processes in writing.

The "Fish and Invertebrate" Settlement Agreement study was intended to inform regulators and the fishing community of the impact of the project on resources. However, the Phase II project did not move far enough along so that the baseline

[7] For the purposes of this section, "operation" is considered as the deployment of the FGBA in September 2012 until its removal in August 2012.

studies could begin. This did not allow information to be available to assess the effect of the project on the fishing resources. The "Fish and Invertebrate" Study was planned to commence prior to Phase II of the project. It was assumed that small footprint of the single buoy would have a minimal effect, if any.

The initial ASB evaluation (March 2013) and the pre-decommissioning ROV surveys did note a lot of fish around the ASB. The fish were also noticeably absent when the post-decommissioning ROV survey was performed. The pre- and post-decommissioning videos have been provided to the National Marine Fisheries Service, Oregon Department of Fish and Wildlife, and U.S. Fish and Wildlife Service for their review and evaluation as required under the FERC License Surrender Order.

In addition to the project's location, a number of surface markers went missing during the two year deployment period. Only one of these markers was located during the post-decommissioning survey. It disappeared when the ASB it was attached to, took on water due to suspicious operation of piping valves after deployment. This surface marker was recovered during the ASB recovery operations in October 2013.

The ASB failure root cause analysis determined that OPT's deployment techniques were not the source of the inadvertent valve operation. The valves had been subsequently checked after deployment was complete and were in the proper position(s). The report did not make any conclusions regarding how the change in valve position(s) occurred.

The other two markers are presumed lost since they were not recovered during the post-decommissioning survey of the agreed upon search area. The presence of the surface markers reminds local mariners of the presence of underwater obstructions in addition to the periodic "Local Notices to Mariners".

8.6 Infrastructure

The Oregon Wave Energy Trust commissioned a report titled "*Wave Energy Infrastructure Assessment in Oregon: Understanding the Infrastructure Capabilities for the Responsible Development of Wave Energy*". The report was completed in December 2009. OPT was aware of this report and utilized it for planning purposes for the deployment of the buoy. OPT utilized marine infrastructure from the Pacific Northwest for the deployment of the FGBA. This was the determined to be the least cost option. Local resources were used to perform the monthly site inspections and support the ROV surveys.

While the marine infrastructure of the Pacific Northwest was adequate to meet the OPT's deployment needs, it was not adequate to meet the FGBA recovery needs. OPT consulted with its recovery vendor(s) and determined that the surest way of recovering the FGBA was to resource a recovery vessel from Southern California. This decision was driven by the need to ensure that the recovery was successful on the first attempt. OPT and its vendors developed a primary and backup FGBA recovery plan. The second plan was developed as an option in the event the first one was not successful. Ultimately, it was determined to utilize the heavier marine vessel requirements of the second plan to recover the FGBA.

This decision to use heavier vessel was prudent based on a combination of factors. These factors included: comparative mobilization costs for both barges, weather delays, a risk assessment of the condition of the deployed FGBA, and most importantly, success on the first recovery attempt. While these evaluations are not typically part of the design evaluation (See discussion in Section 9.2), the potential requirement needs to be accounted for in the specific project budget or additional design work performed so that the equipment to be deployed can be deployed in the greatest number of areas with infrastructure local to that region.

8.7 Project Scale

The project scale is not believed to be a factor in the project. As discussed earlier, a full size PB150 and Gravity Based Anchors (GBA) had been successfully deployed in Scotland several months earlier. The two elements which appear to have affected the project were the introduction of the FGBA into a previously tried system. OPT demonstrated that it could successfully deploy a full size buoy and GBAs. The primary reason for a project such as the Reedsport single buoy is to attempt to demonstrate potential cost reduction approaches to achieve a target installed capital cost and levelized Cost of Electricity. The advantages of a full size FGBA over a GBA are significant.

9 CONCLUSIONS

The project's greatest challenges were ones that were not foreseen related to introducing new technologies. Use of the FGBA was intended to reduce installation costs and as a step towards commercialization. The introduction of the FGBA was a new aspect the deployment process. The PowerBuoy technology was successfully deployed using GBAs earlier the same year the Reedsport deployment was attempted. The project could not overcome the FGBA deployment complications and the resulting effects of significant project cost increases, schedule delays, and evolving regulatory requirements.

The FGBA represented a potential cost saving measure over the traditional GBA, which was used in the prior, full scale, successful deployment. The floating caisson was a proven technology in aquaculture that appeared to offer potential cost savings in MHK applications. Once proven, the caisson technology adapted to an FGBA could be readily transferred as part of the project "know how" to decrease capital and installation costs for larger MHK projects. The challenge that OPT faced was successfully deploying this full scale "first of a kind" application. The design and simulation of the FGBA were performed in accordance with standard engineering practice. The test trials in the Coos Bay Harbor were also successful.

Unfortunately, the FGBA descent did not proceed as planned in the open ocean environment at Reedsport although wave conditions were consistent with the design parameters and simulations. In hindsight, an extended Failure Modes and Effects Analysis (FMEA) performed for "off specification" conditions may have identified issues which occurred during the open ocean deployment. Results of the additional analyses could have led to design and operating changes which would mitigate the risks encountered. However, a delicate balance must be stricken between an overly conservative design and the cost of the final solution.

The project also had to contend with scheduling, regulatory, and budgetary issues which were unique to an emerging technology demonstration project of this size. The demonstration operated within the context of a regulatory frame structured around mature technology, i.e., conventional hydroelectric projects. FERC staff consistently provided guidance and assistance to OPT which helped the project move forward in meeting the various regulatory requirements.

Simpler, modular, more efficient, and higher wave energy to electrical output PTO technology had been developed since the Reedsport demonstration began, which made the PB150 PTO technology at the time two generations behind OPT's new State Of the Art technology.

Deployment, operating, and project decommissioning costs were also factored into the decision. As indicated earlier, approximately 80% of the original deployment budget had been expended in the deployment of the first anchor. Much of the cost was driven by weather delays, which amounted to approximately $1 million. Project estimates for the revised deployment, operating, and project decommissioning costs and an "average weather delay" estimate finalized the framing of the deployment decision.

The decision to terminate the project by mutual agreement was the correct decision given the: 1) advancements in the PTO technology since the Reedsport Project started, 2) costs for deployment, operating, and project decommissioning, and 3) the project demonstration would not adequately demonstrate the projected O&M costs with the costs incurred and which may be incurred for preparation and deployment of the buoy in addition to the PB150B2 PTO technology obsolescence that materialized due to advancement in the PTO technology.

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APPENDIX A

REEDSPORT BASELINE ACOUSTIC REPORT

JASCO APPLIED SCIENCES

Noise Characterization Offshore Reedsport, Oregon

Phase II: Baseline Ambient Noise Characterization

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1. Introduction

JASCO Applied Sciences has been contracted by Ocean Power Technologies (OPT) to characterize and assess the underwater noise produced by the OPT PB150 PowerBuoy wave energy conversion device. The three-phase acoustic measurement program was intended to involve a planning phase (Phase I), a Baseline Ambient Noise Characterization (Phase II), and a PowerBuoy Sound Source Characterization (Phase III). Phase III of the acoustic monitoring program has since been put indefinitely on hold. This report completes Phase II and provides a baseline of the existing acoustic noise present at the project site prior to the deployment of any equipment by OPT. A Settlement Agreement between OPT and various stakeholder groups required a minimum of one month of baseline ambient sound characterization, collected using two autonomous recorders with the ability to sample sound levels at 10 m above the seafloor, at frequencies up to 10 kHz, and sampling rates of 22 kHz for five minutes every hour. The Phase II Baseline Ambient Noise Characterization fulfills this requirement.

This Phase II report provides a statistical characterization of the baseline sound conditions, as a function of frequency, under a variety of sea states. This information can be used in Phase III to determine whether marine mammals, specifically cetaceans, will likely detect and avoid sounds from a PowerBuoy wave energy array.

JASCO collected one month of baseline acoustic data at a project site offshore Reedsport, Oregon in August 2012 (Figure 1). The data collection and corresponding analysis here reported were conducted according to the approved protocols described in Appendix A. Wave height data were collected simultaneous with the acoustic measurements using a TriAxys Wave Buoy. This report documents the range, spectral composition, and rate of occurrence of recorded ambient sound levels. Measured sound levels are correlated with recorded wind speeds and wave heights. Statistical analyses are provided for every minute of data using the following sound metrics:

- root-mean-square (rms) sound pressure level (SPL)
- Spectral density
- 1/3-octave-band and decade-band levels

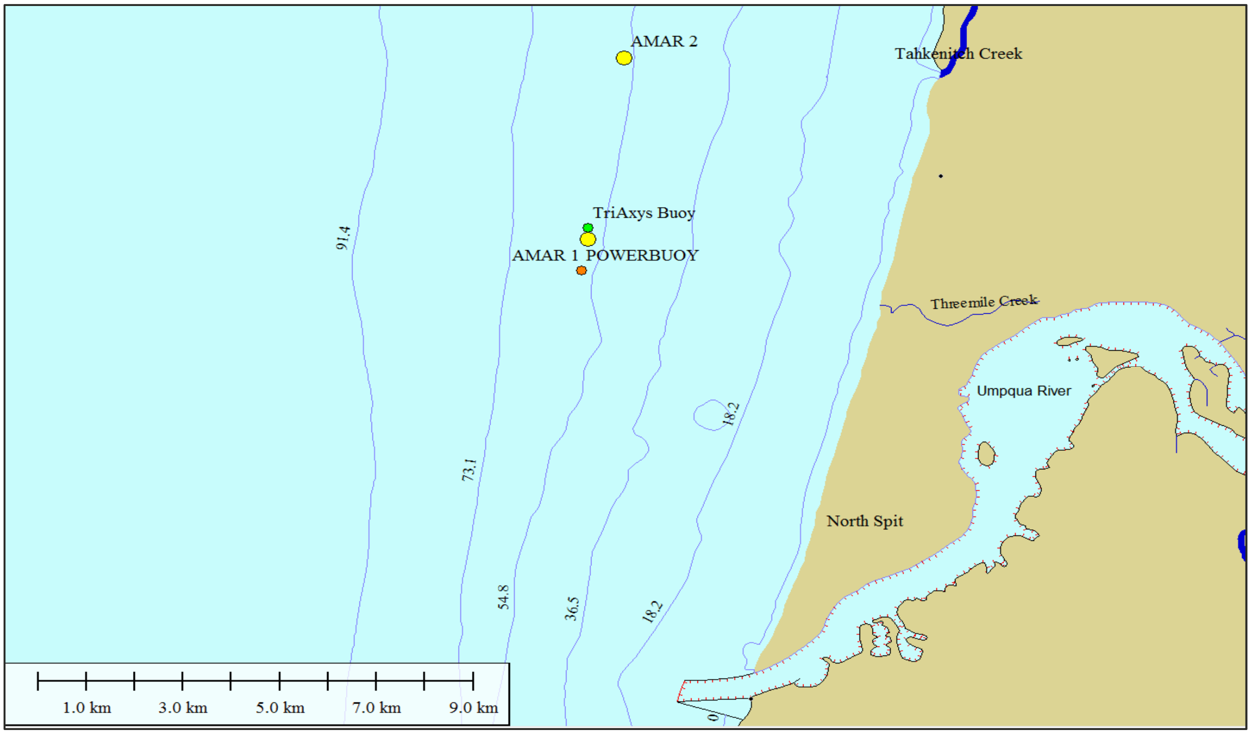

Figure 1. Overview of the study area offshore Reedsport, Oregon, with the AMAR locations (yellow), the planned PowerBuoy location (orange), and the TriAxys Buoy location (green).

Methods

1.1. Data Acquisition

1.1.1. Equipment

Acoustic data were collected with two of JASCO's Autonomous Multichannel Acoustic Recorders (AMARs) configured with sufficient memory and battery capacity to record continuously for 42 days. The AMARs recorded 24-bit samples at 48,000 samples per second. The total acoustic recording bandwidth was 10 Hz to 24 kHz, which is within the linear frequency range of the hydrophones, and captures sounds at all frequencies that are important to the various marine mammal species that live offshore Oregon. This configuration exceeds the requirement to measure frequencies up to a minimum of 10 kHz.

The recording channel had a 24-bit dynamic range with a spectral noise floor of 20 dB re 1 μPa^2/Hz and a ceiling of 171 dB re 1 μPa. Each recorder was fitted with an M8E omnidirectional hydrophone (−165 ± 3 dB re 1 V/μPa sensitivity, GeoSpectrum Technologies Inc.). Each AMAR-hydrophone pair was calibrated in the laboratory before it was shipped, in the field immediately before it was deployed, and in the field immediately after it was retrieved. The calibrations were performed with a GRAS 42AA pistonphone calibrator, which generates a 250 Hz tone at a known sound pressure level. The recorded digital signal yielded an end-to-end recording system gain to convert the digital levels to pressure.

Each AMAR mooring included two floats, a satellite tracking beacon (KILO Subsurface Iridium Mooring Beacon, Xeos Technologies), a tandem acoustic release system (Model 111 Shallow Water Acoustic Releases, InterOcean Systems Inc.), a 200 lb anchor system, and a 240 m ground line (Figure 2). The mooring was designed so that the hydrophone would sit at a depth of 10 m above the seafloor, in compliance with the acoustic monitoring parameters agreed to by the project stakeholders.

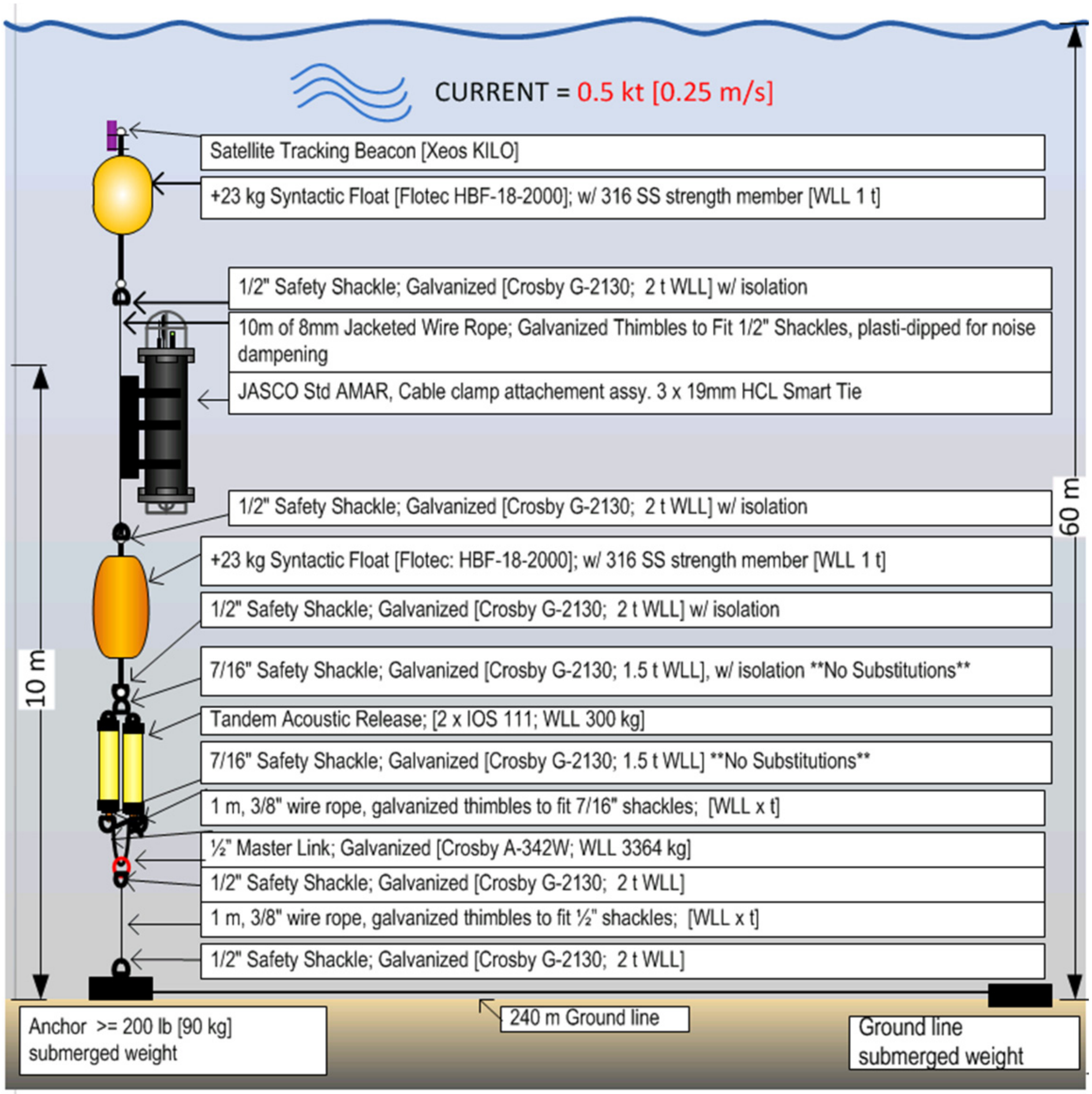

Figure 2. Mooring diagram for the two AMARs.

1.1.2. Deployments

The AMARs were deployed from the M/V *Miss Linda* (Figure 3) on 25 Jul 2012. The deployment locations (Figure 1, Table 1) were recorded with a handheld GPS accurate to 3.3 m (10 ft). The two AMARs were deployed along the same isobath at approximately 730 m and 5000 m north from the centerline of the planned PowerBuoy location. The hydrophones were located 10 m above the sea bottom. One AMAR was placed 5000 m from the PowerBuoy location to avoid noise interference from the PowerBuoy anchor moorings. The AMARs were located north of the PowerBuoy location to maximize the distance from vessel traffic near the Umpqua River inlet to the south of the PowerBuoy. Each mooring was retrieved with a grapple on 27 Aug 2012.

Figure 3. The M/V *Miss Linda* (Coos Bay, OR) from which JASCO deployed the AMARs.

Table 1. Deployment and retrieval information for the AMARs and the TriAxys Wave Buoy off the coast of Reedsport, Oregon and coordinates for the OPT PowerBuoy and the NOAA wind speed Buoy.

Station	Latitude	Longitude	Deployment time UTC	Retrieval time UTC
AMAR 1	43°45′48.5″ N	124°14′12.9 W	00:40 25 Jul 2012	18:01 27 Aug 2012
AMAR 2	43°48′11.2″ N	124°13′50.0 W	01:25 25 Jul 2012	19:53 27 Aug 20120
OPT PowerBuoy	43°45′24.8″ N	124°14′17.7 W		
TriAxys Buoy	43°45′56.9″ N	124°14′14.4 W		
NOAA Buoy 46094	44°37′58.8″ N	124°18′10.8″ W		

1.1.3. Non-Acoustic Data Collection

OPT provided wave height data from measurements collected on a TriAxys Wave Buoy at the project site off Reedsport, Oregon in 2012. Wind data were downloaded from the public server from the National Oceanic and Atmospheric Administration's (NOAA) National Data Buoy Center (http://www.ndbc.noaa.gov/). Data were taken from Station 46094, located approximately 100 km (54 nmi) north of the project site at 44°37′58.8″N, 124°18′10.8″W. Station 46229 was nearer to the project site, but did not provide wind speed data for the deployment period. Although the AMARs were recording until 27 Aug 2012, the wind speed data were only available up to 13 Aug 2012.

1.2. Acoustics Metrics used for Analysis

Underwater sound amplitude is measured in decibels (dB) relative to a fixed reference pressure of p_0 = 1 μPa. Several sound level metrics are commonly used to evaluate how loud noise is and its effects on marine life. This section defines the metrics that were used to characterize the baseline ambient sound levels at the project site.

Ambient noise, the background sound level for a given environment, is composed of sounds both natural and manmade in origin. Wind and waves, rain, marine mammals, volcanic and geologic activity, human activities such as shipping and marine construction are all sources that contribute to ambient noise. Sound signals are typically only detectable if they exceed the ambient noise level at similar frequencies, which is why baseline ambient noise characterization is important when assessing marine mammals' ability to detect an introduced noise source. It is also important to consider the frequency range of the noise relevant to the hearing abilities of marine mammals since the animal will more likely detect and react to sounds at frequencies in which their hearing sensitivity is most acute.

1.2.1. Sound Levels

The zero-to-peak SPL, or peak SPL (dB re 1 μPa), is the maximum instantaneous sound pressure level in a stated frequency band attained by an acoustic pressure signal, $p(t)$:

$$\text{Peak SPL} = 10\log_{10}\left[\frac{\max\left(\left|p^2(t)\right|\right)}{p_0^2}\right] \quad (1)$$

The peak SPL metric is commonly quoted for impulsive sounds, but it does not account for the duration or bandwidth of the noise.

The root-mean-square (rms) SPL (dB re 1 μPa) is the rms pressure level in a stated frequency band over a time window (T, s) containing an acoustic event:

$$\text{rms SPL} = 10\log_{10}\left(\frac{1}{T}\int_T p^2(t)dt \Big/ p_0^2\right) \quad (2)$$

The rms SPL is a measure of the average pressure or of the effective pressure over the stated duration. Because the window length, T, is the divisor, events more spread out in time have a lower rms SPL for the same total acoustic energy density.

Band pressure levels can also be computed for continuous noise by band-pass filtering the pressure data before computing the rms level. In this report the sound pressure levels are presented as both broadband and decade-band levels that are filtered between 10 Hz–100 Hz, 100 Hz–1 kHz, and 1 kHz–10 kHz, and 10 kHz–24 kHz.

1.2.2. Spectral Analysis

The distribution of a sound's power with frequency is described by the sound's spectrum, which shows the fine-scale features of the frequency distribution of a sound. The sound spectrum can be split into a series of adjacent frequency bands, called passbands. Splitting a spectrum into 1 Hz wide bands yields the "power spectral density" (PSD) of the sound. This splitting of the spectrum into passbands of a constant width of 1 Hz, however, does not represent how animals perceive sound.

Because animals perceive exponential increases in frequency rather than linear increases, analyzing a sound spectrum with passbands that increase exponentially in size gives a more meaningful interpretation of the data. In underwater acoustics, the sound spectrum is commonly split into

1/3-octave-bands, which is one-third of an octave wide; each octave represents a doubling in sound frequency. The center frequency of the *i*th 1/3-octave-band, $f_c(i)$, is defined as:

$$f_c(i) = 10^{i/10} \quad , \tag{3}$$

and the low (f_{lo}) and high (f_{hi}) frequency limits of the *i*th 1/3-octave-band are defined as:

$$f_{lo} = 10^{-1/20} f_c(i) \quad \text{and} \quad f_{hi} = 10^{1/20} f_c(i) \tag{4}$$

The 1/3-octave bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced (Figure 4).

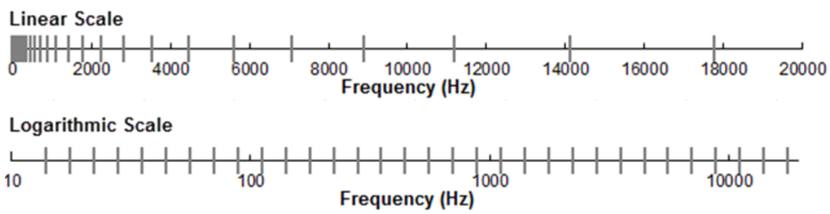

Figure 4. One-third-octave-bands shown on a linear frequency scale and on a logarithmic scale.

The sound pressure level in the *i*th 1/3-octave-band $(L_b^{(i)})$ is computed from the power spectrum $S(f)$ between f_{lo} and f_{hi}:

$$L_b^{(i)} = 10\log_{10}\left(\int_{f_{lo}}^{f_{hi}} S(f)df\right) \tag{5}$$

Summing the sound pressure level of all the 1/3-octave-bands yields the broadband sound pressure level:

$$\text{Broadband SPL} = 10\log_{10}\sum_i 10^{L_b^{(i)}/10} \tag{6}$$

Figure 5 shows an example of how the 1/3-octave-band sound pressure levels compare to the power spectrum of an ambient noise signal. Because the 1/3-octave-bands are the sums of the power spectral densities, the 1/3-octave-band SPL is higher than the power spectrum. This is especially noticeable at higher frequencies where the 1/3-octave-bandwidths increase.

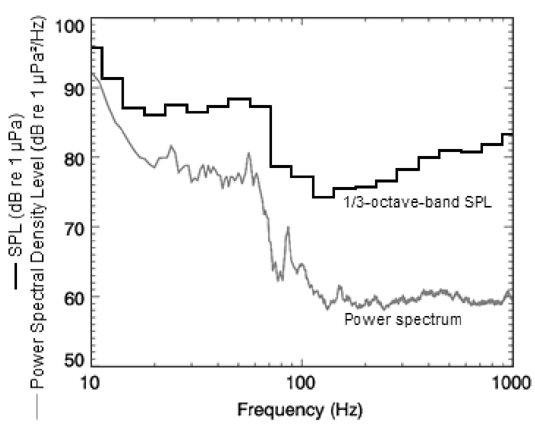

Figure 5. A power spectrum and the corresponding 1/3-octave-band sound pressure levels of example ambient noise shown on a logarithmic frequency scale.

1.3. Ambient Noise Analysis and Vessel Detections

The ambient noise analysis quantitatively describes the underwater soundscape at the planned PowerBuoy location. The raw acoustic data were processed with JASCO's acoustic analysis software to calculate ambient sound levels and to detect noise from vessels. Statistical analysis techniques were applied to the ambient noise data to determine the range and frequency of occurrence of recorded sound.

1.3.1. Automated Data Analysis

Automated bulk data analysis of all data was performed to compute ambient sound levels, detect shipping events, and detect transient sound events. The transient events included mammal calls, fish sounds, noise from moorings, and noise from objects touching the hydrophone. Figure 6 shows a block diagram outlining the processing stages of the bulk-automated processor.

The pressure waveform data recorded on the AMAR were scaled according to the AMAR's mean, calibrated pressure sensitivity and then adjusted for the frequency response of the hydrophone sensor. Each 1-min sound recording was processed using a 1-s sliding analysis window, with 50% overlap, to obtain SPLs and 1/3-octave-band levels versus time. Spectral levels were computed from 1-s long Fast Fourier Transforms (FFTs) shaded with a power-normalized Hamming window. Time-domain pressure waveforms were analyzed to find rms SPLs for the recorded data.

SPL, which is a measure of sound amplitude, can be averaged over time and integrated over different frequency bands. Standard frequency bands used in this study were broadband (10 Hz to 24 kHz), decade-bands, and 1/3-octave-bands. The 1-min averaged, 1 Hz PSD levels were summed over each 1/3-octave-band and decade-band (10–100 Hz, 100–1000 Hz, 1000-10,000 Hz) to obtain 1-min averaged band levels (dB re 1 μPa).

To determine the distribution of the recorded ambient noise levels, we computed cumulative probabilities for the 1-min PSDs over the entire recording period. The cumulative probabilities were plotted as percentiles (5%, 25%, 50%, 75%, and 95%); these depicted the proportion of time when PSDs at each frequency exceeded a particular sound level. To determine the distribution of 1/3-octave-band SPLs, we calculated means, quartiles, and ranges for the 1-min SPLs.

We used an automated shipping noise detector to identify intervals when short-range vessel noise dominated received sound levels. By identifying these intervals, we could distinguish background noise levels from intermittent periods when sound levels were dominated by a single source. This analysis also identified a baseline amount of vessel traffic near the project site.

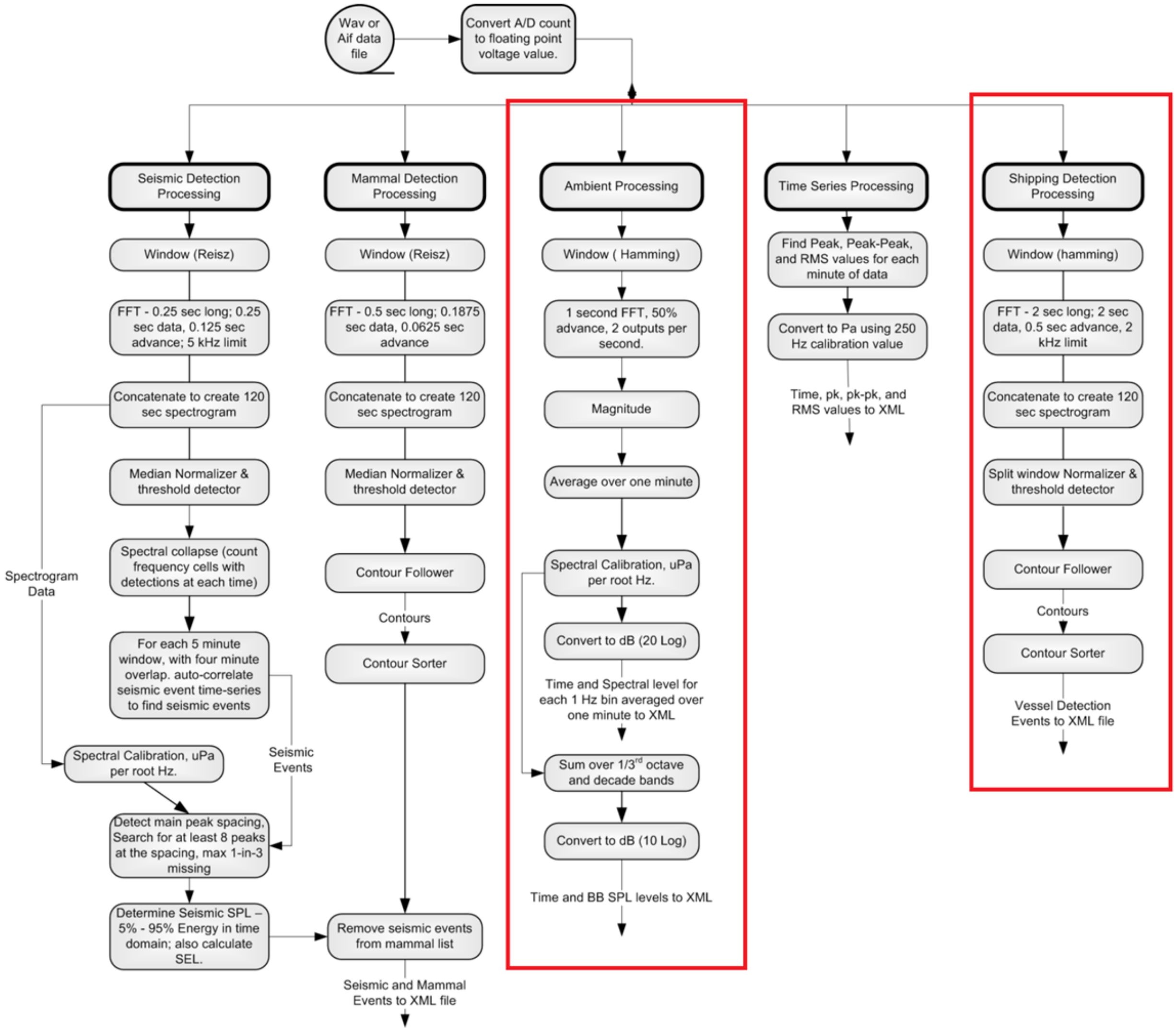

Figure 6. Major stages of JASCO's bulk automated acoustic data processing. Processing steps applied to the data from AMAR 1 and AMAR 2 are delineated in red.

1.4. Post-processing of the ambient data

The data of both AMARs showed a significant amount of low-frequency noise (< 35 Hz) for most of the recording period because of mooring movement, the AMAR mooring line strumming, and water flowing past the mooring in the natural tides and currents. Because these sound levels obscured the true ambient noise readings at frequencies below 35 Hz, we applied a high-pass frequency filter to remove data at frequencies below 35 Hz. The data in this report thus encompass frequencies between 35 Hz and 24 kHz. This frequency range covers the range of frequencies most important to the marine mammal species that occur in near shore waters of Oregon, including the dominant frequencies for low-frequency cetaceans such as gray and humpback whales.

2. Results

2.1. Received Sound Levels

2.1.1. AMAR 1 (South)

Acoustic recordings from AMAR 1 were analyzed to determine power spectral density (PSD) levels and decade-band SPLs for the entire recording period. Figure 7 is a plot of the long-term spectrogram (bottom) and decade-band levels (top) for the data collected from 25 Jul to 27 Aug 2012. The statistical distribution of 1-min sound pressure levels (SPLs) in each decade-band over the monitoring period is shown in Figure 8 (top). The mean 1/3-octave-band SPL is higher than the median SPL, owing to occasional sound level increases from vessel traffic in the area. The distribution of 1-min PSD levels over the monitoring period is shown in Figure 8 (bottom). Prominent frequency peaks at 40 Hz were present in most of the data. Above 100 Hz, the noise spectrum is smoother and drops off at a slope of −3 to −1 dB/octave. Analysis of broadband SPL data at AMAR 1 (red line; Figure 11) showed that 90% of the time sound levels were in the range of 95–117 dB re 1 µPa, with a median level of 100 dB re 1 µPa.

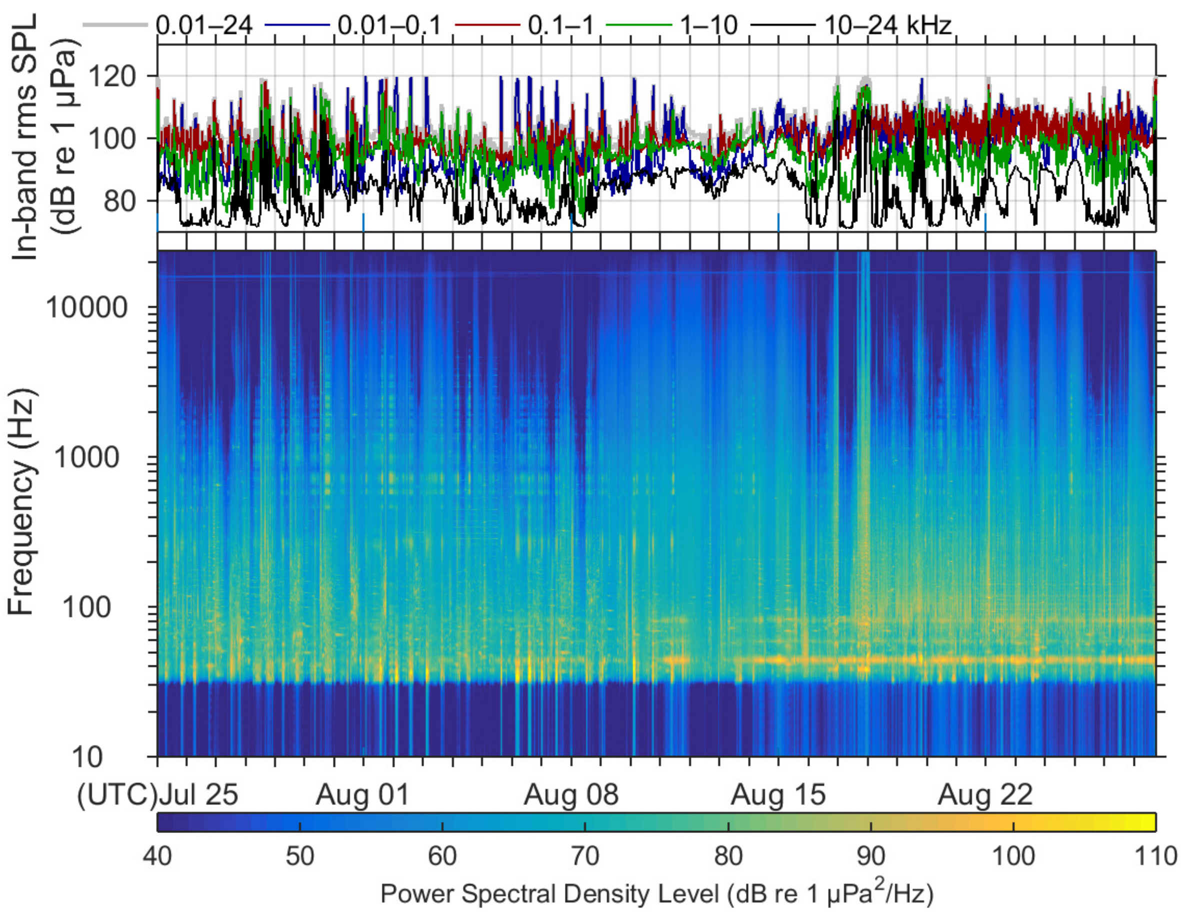

Figure 7. AMAR 1: Top: One-month broadband (35 Hz to 24 kHz) SPL and decade-band SPL (1-min average) from 25 Jul to 27 Aug 2012. Bottom: Ambient noise spectrogram (1-min average) over the same period. Frequency scale is logarithmic. Data were high-pass filtered at 35 Hz.

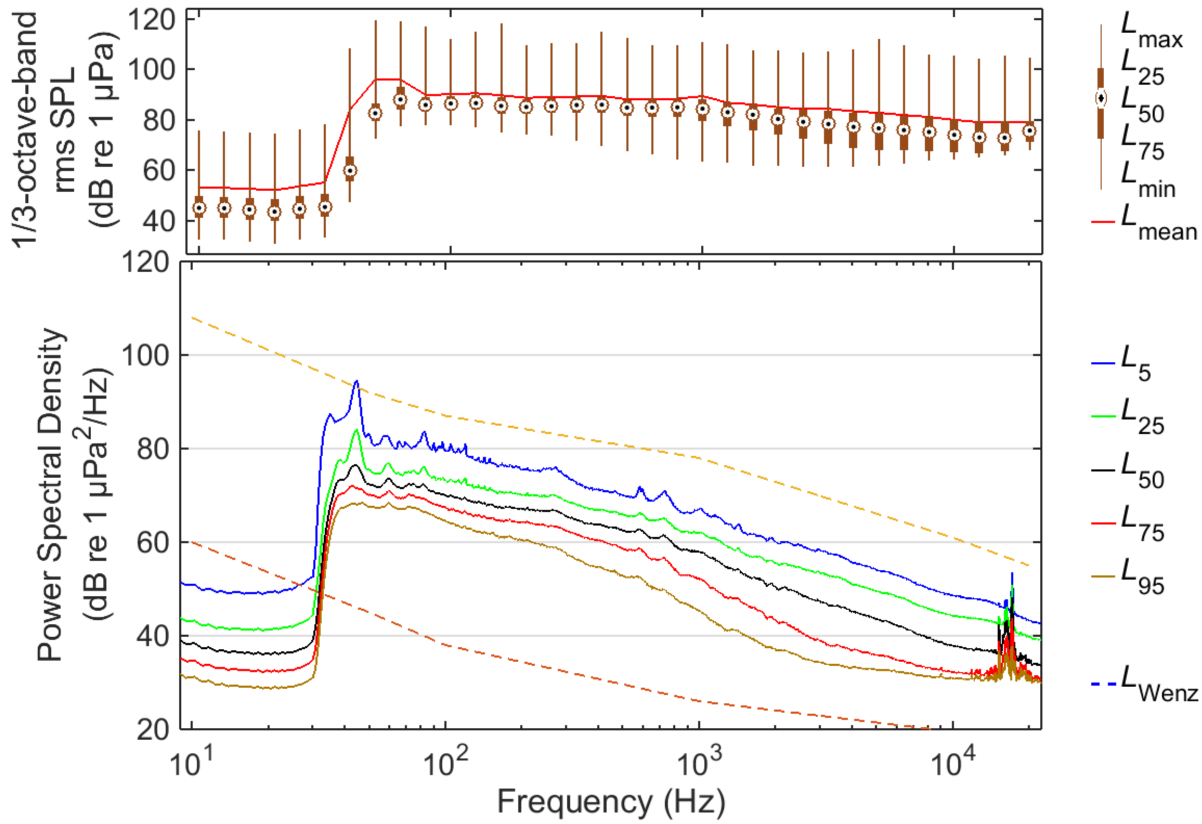

Figure 8. AMAR 1. Statistical distributions of 1/3-octave-band and decade-band SPLs. Top: 1/3-octave-band rms sound pressure levels (1-min) over a 34-day recording period. The boxes indicate the first (25%), second (50%), and third (75%) quartiles. The red line indicates the linear mean. Bottom: Exceedance percentiles of ambient noise power spectral density levels (1-min average) over the recording period. The *N*th percentile corresponds to the sound level that was exceeded by *N*% of the data. Data were high-pass filtered at 35 Hz.

2.1.2. AMAR 2 (North)

Acoustic recordings from AMAR 2 were analyzed to determine power spectral density (PSD) levels and decade-band SPLs for the entire recording period. Figure 9 is a plot of the long-term spectrogram (bottom) and decade-band levels (top) for the data collected from 25 Jul to 27 Aug 2012. The statistical distribution of 1-min sound pressure levels (SPLs) in each decade-band over the monitoring period is shown in Figure 10 (top). The mean 1/3-octave-band SPL is higher than the median SPL, which indicates occasional sound level increases from vessel traffic in the area. The distribution of 1-min PSD levels over the monitoring period is shown in Figure 10 (bottom). Prominent frequency peaks at 40 Hz were present in most of the data. Above 100 Hz the noise spectrum is smoother and drops off at a slope of −3 to −1 dB/octave. Analysis of broadband SPL data at AMAR 2 (blue line; Figure 11) showed that 90% of the time sound levels were in the range of 93–112 dB re 1 μPa, with a median level of 99 dB re 1 μPa.

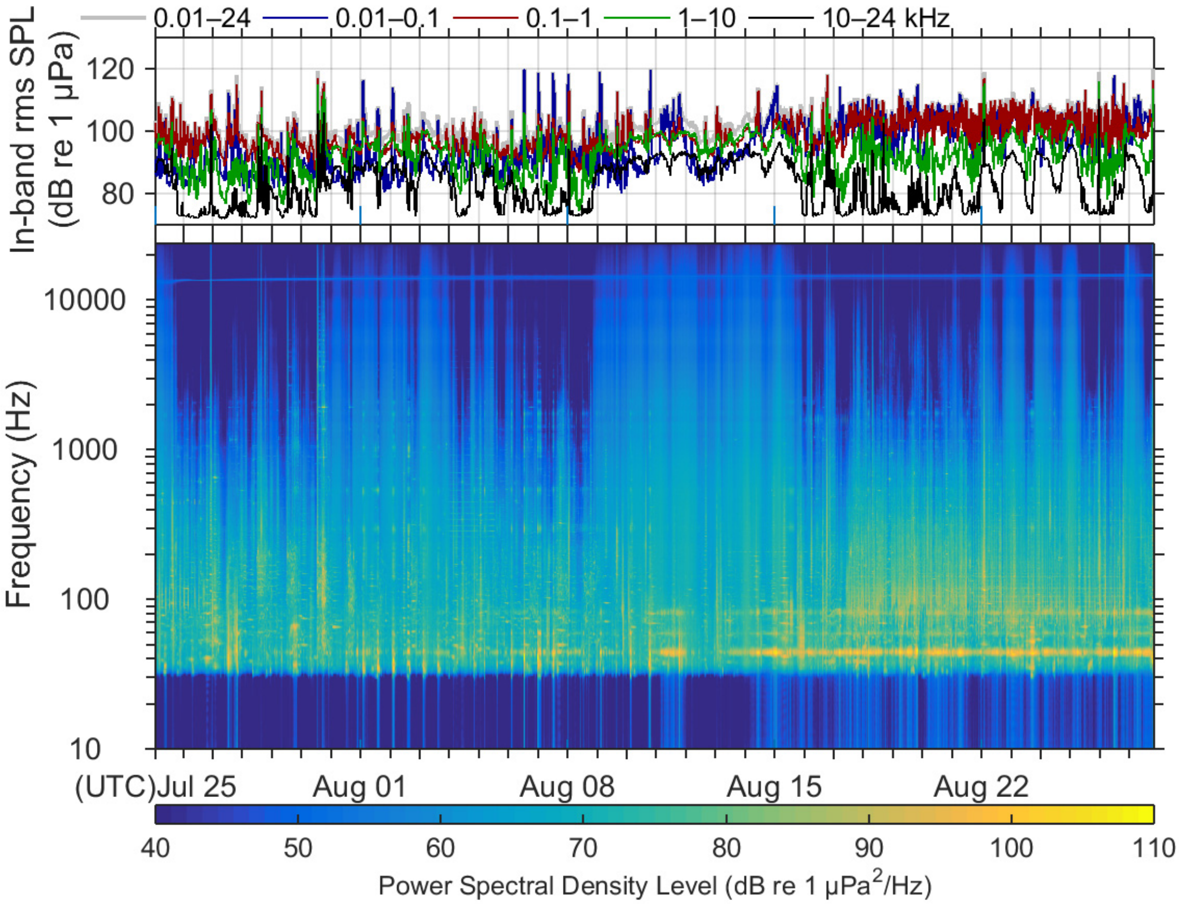

Figure 9.AMAR 2: Top: One month broadband (35 Hz to 24 kHz) SPL and decade-band SPL (1-min average) from 25 Jul to 27 Aug 2012 (UTC). Bottom: Ambient noise spectrogram (1-min average) over the same period. Frequency scale is logarithmic. Data were high-pass filtered at 35 Hz.

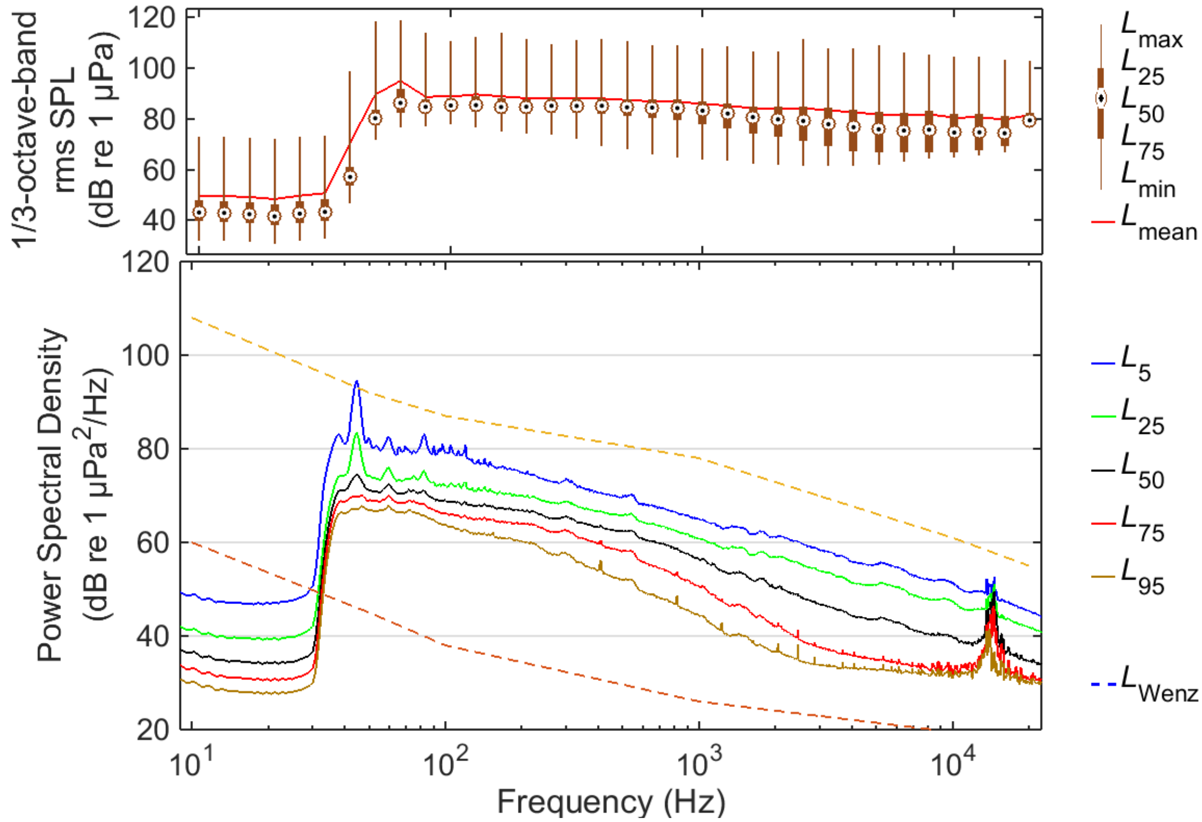

Figure 10. AMAR 2. Statistical distributions of 1/3-octave-band and decade-band SPLs. Top: 1/3-octave-band rms sound pressure levels (1-min) over 34-day recording period. The boxes indicate the first (25%), second (50%), and third (75%) quartiles. The red line indicates the linear mean. Bottom: Exceedance percentiles of ambient noise power spectral density levels (1-min average) over the recording period. The *N*th percentile corresponds to the sound level that was exceeded by *N*% of the data. Data were high-pass filtered at 35 Hz.

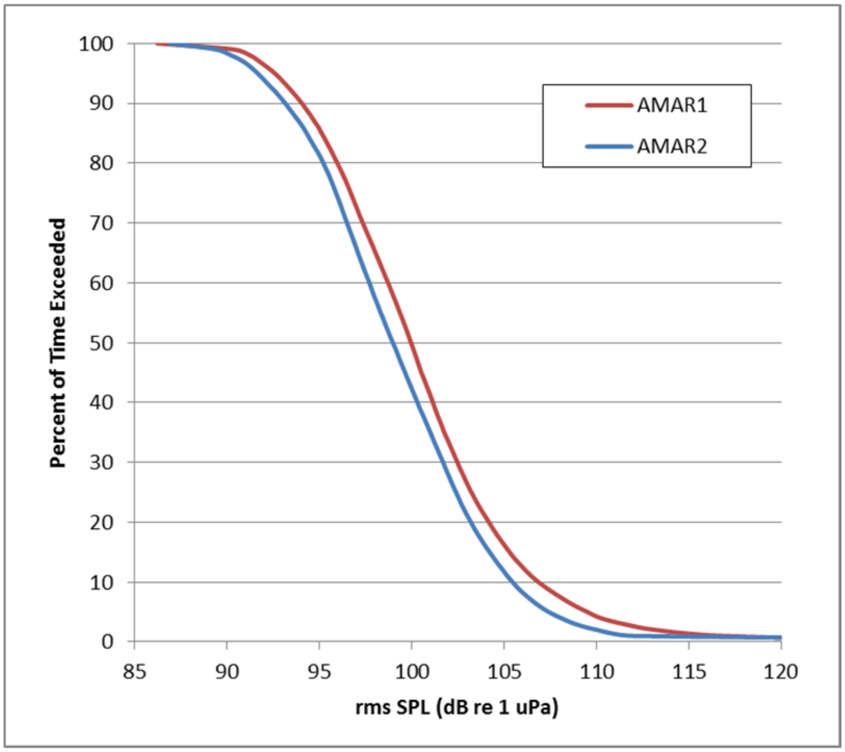

Figure 11. Probability distribution of broadband ambient SPLs (35 Hz to 24 kHz, 1-min average) measured over one month at AMAR 1 (south) and AMAR 2 (north).

2.2. Vessel Detections

Vessels were detected throughout the recordings on both AMARs; the number of detections was compared between AMARs. Vessel sounds were detected nearly continuously on AMAR 1 (Figure 12) with a minimum of 28 vessel detections per day, whereas AMAR 2 (Figure 13) experienced periods in which only a few vessels (< 10 vessels per day) were detected. The Umpqua River inlet, a busy vessel route, is located south of the PowerBuoy and the AMAR locations. Hence, the vessel detection rate is higher nearer this traffic route, on the southern recorder (AMAR 1).

An example vessel detection recorded on AMAR 2 shows a classical acoustic signature from a ship (Figure 14)—the structure has two components. The first component is multiple long duration tonals between 50 and 1000 Hz and the second is the Lloyd mirror interference patterns, which are closer to the vessel's closest point of approach (at around 15:24:25).

Median and 5^{th} percentile SPLs were computed separately for all data containing vessel detections and those in which no vessels were detected. (AMAR 1: Figure 15; AMAR 2: Figure 16). SPLs (median and 5^{th} percentile) for data with vessel detections were higher than data with no vessel detections in all 1/3-octave-bands below 300–400 Hz, which indicates that vessel noise contributes to the ambient conditions at those frequencies.

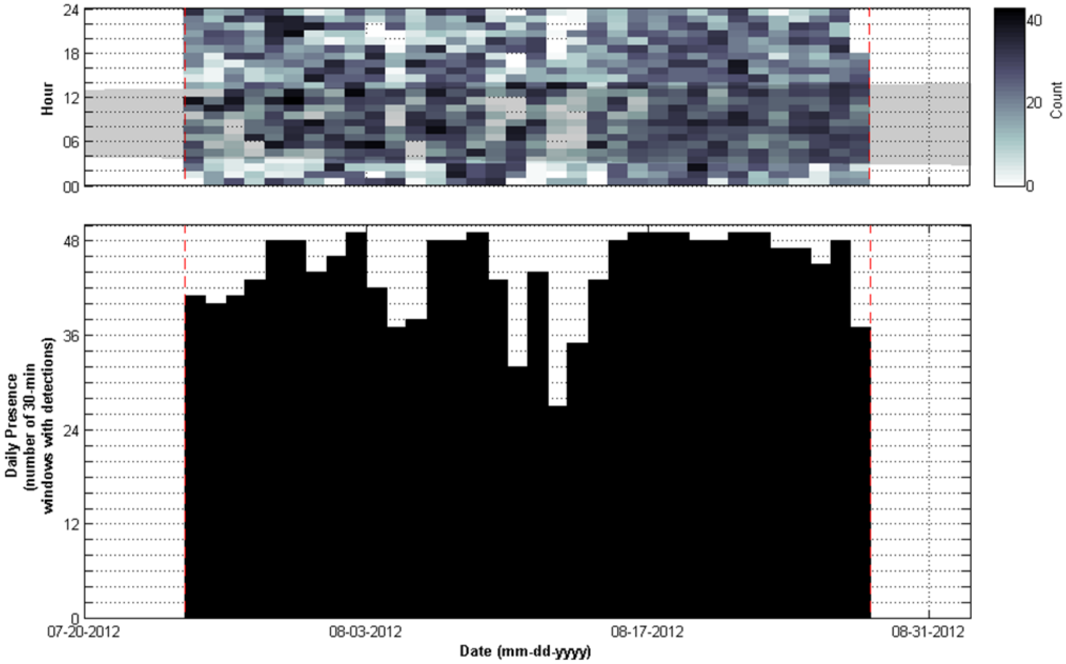

Figure 12. AMAR 1: Top: Distribution of hourly vessel detections per day for the recording period 25 Jul to 27 Aug 2012. Bottom: Daily distribution of vessel detections averaged over 30-min windows from 25 Jul to 27 Aug 2012.

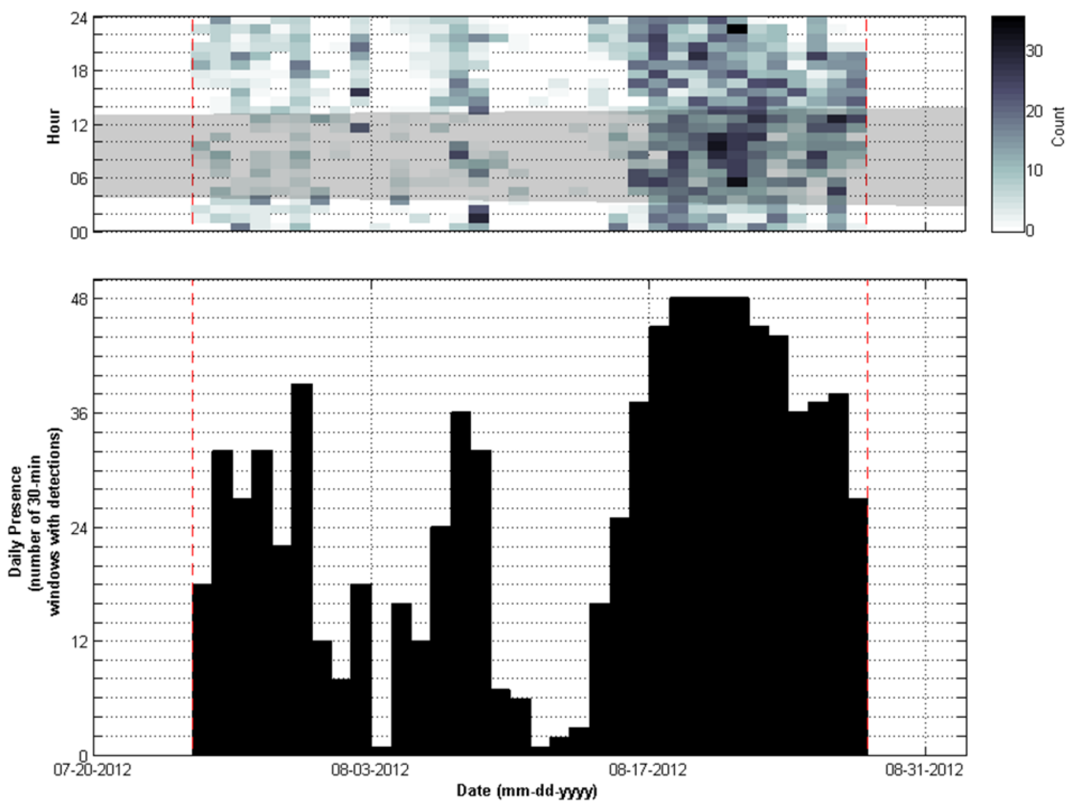

Figure 13. AMAR 2: Top: Distribution of hourly vessel detections per day for the recording period 25 Jul to 27 Aug 2012. Bottom: Daily distribution of vessel detections averaged over 30-min windows from 25 Jul to 27 Aug 2012.

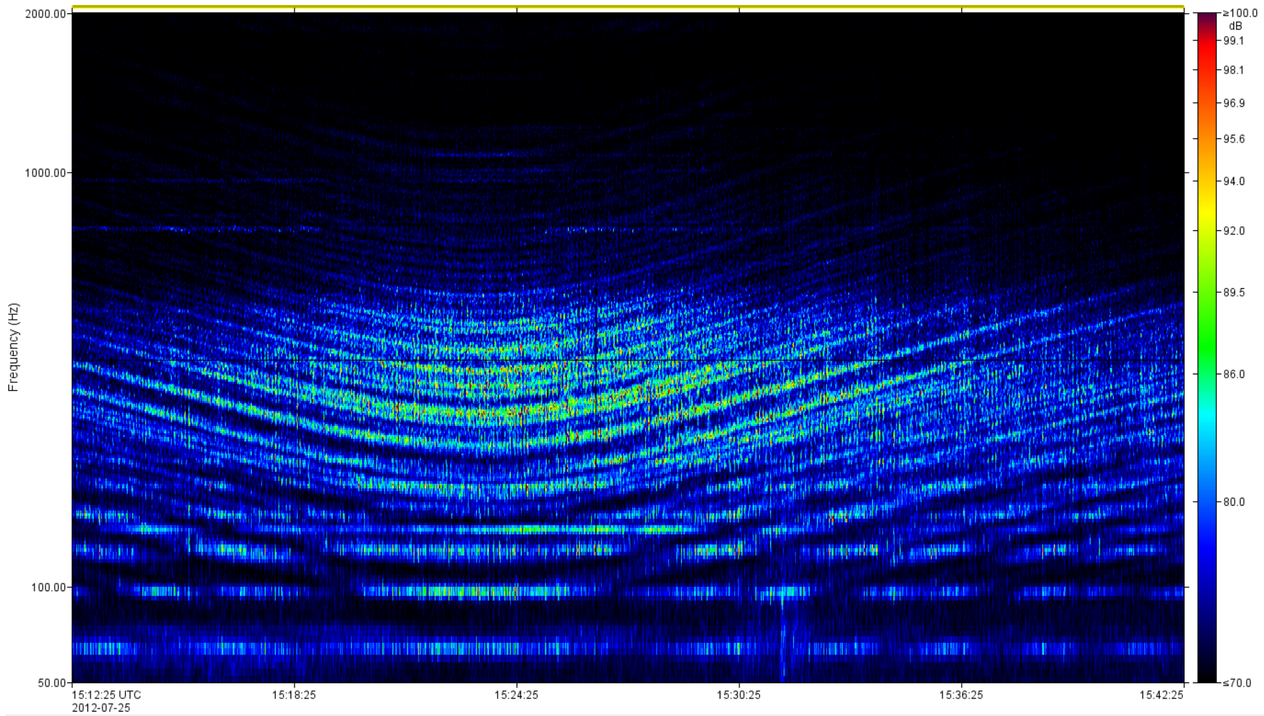

Figure 14. AMAR 2: Vessel detection spectrogram from 25 Jul 2012 for a 30-min time window.

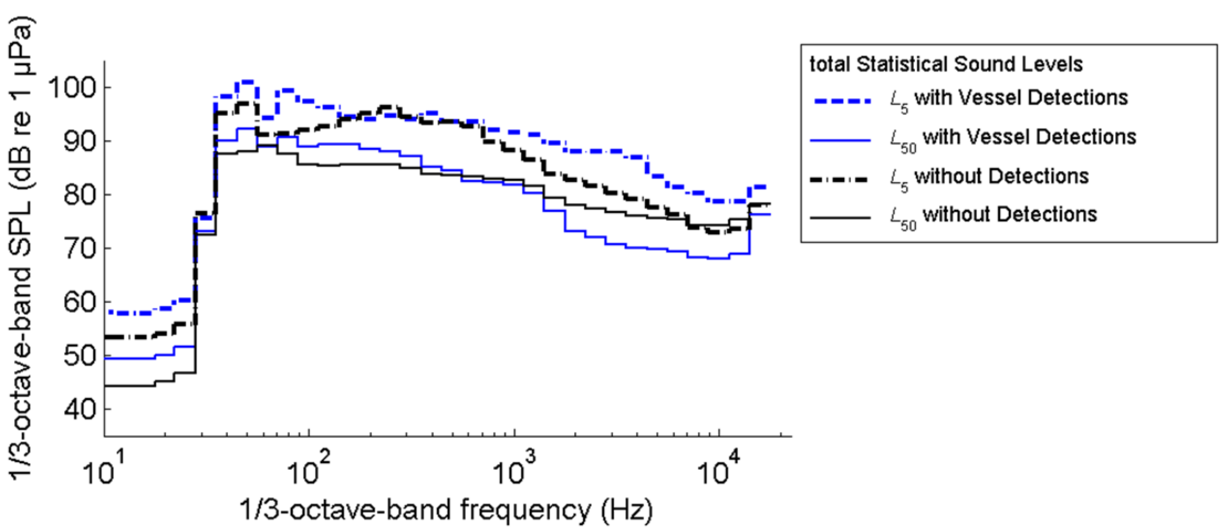

Figure 15. AMAR 1: 1/3-octave-band SPL for periods with and without vessel detections.

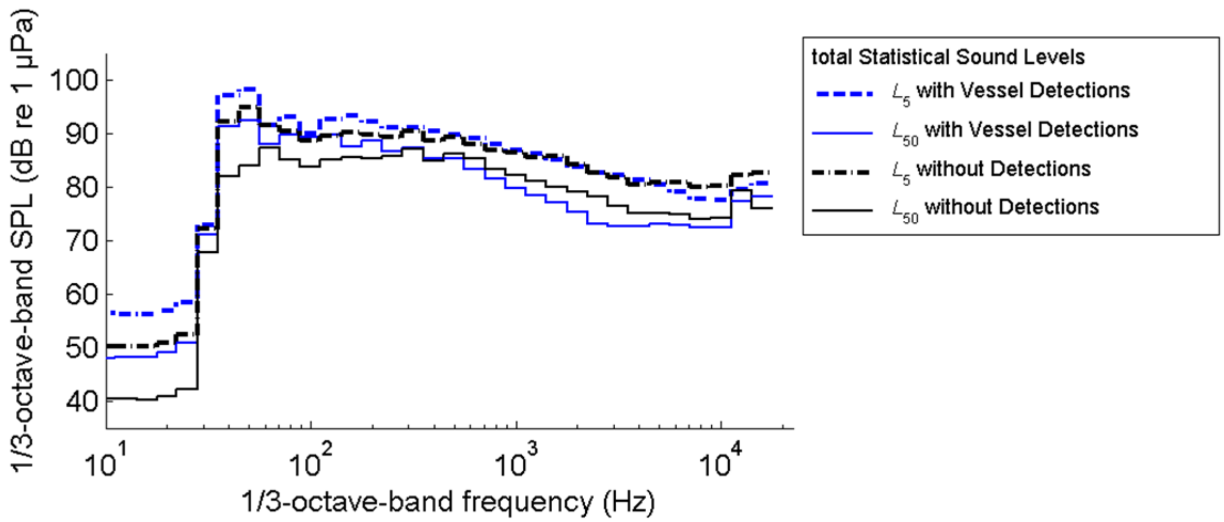

Figure 16. AMAR 2: 1/3-octave-band SPL for periods with and without vessel detections.

2.3. Ambient Noise, and Meteorological and Wave Conditions

Decade-band sound level data were also plotted with wind speed and sea state data (Figure 17). Sea state and wave height data were obtained from the TriAxys Buoy that OPT deployed. The wind speed data was obtained from the NOAA National Data Buoy Center (www.ndbc.noaa.gov). Linear regressions of the decade-band sound levels against the wind speed and average wave height were performed to determine which factors dominate the measured sound levels (Figures 18 and 19 respectively). Sound level was uncorrelated with wind speed in all frequency bands. A weak positive correlation between sound level and wave height was noted in the highest frequency bands (> 1 kHz) at both AMARs (Figures 20 and 21).

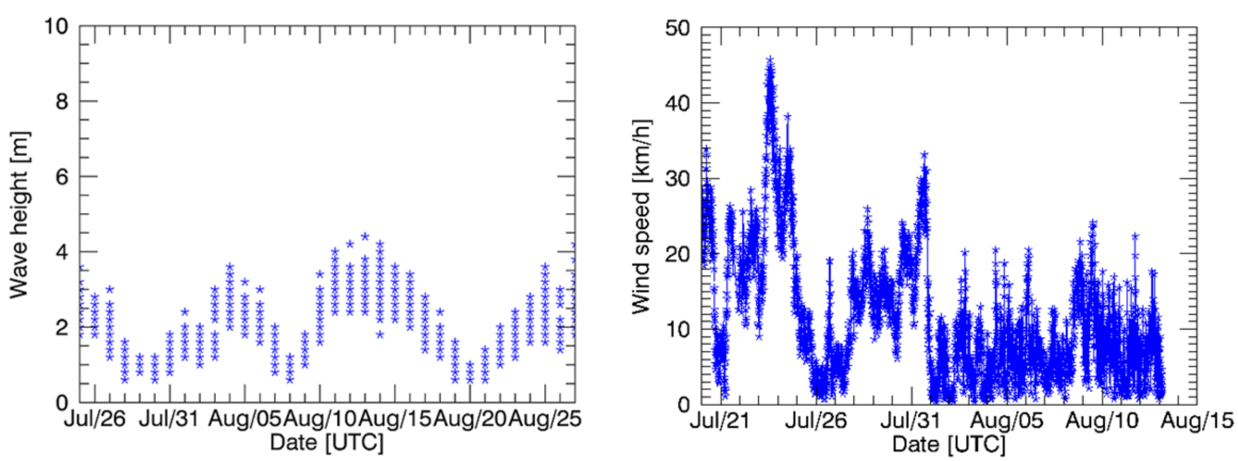

Figure 17. Wind speed (km/hr) and average wave height (m) data from the NOAA webservice and the TriAxys Buoy readings.

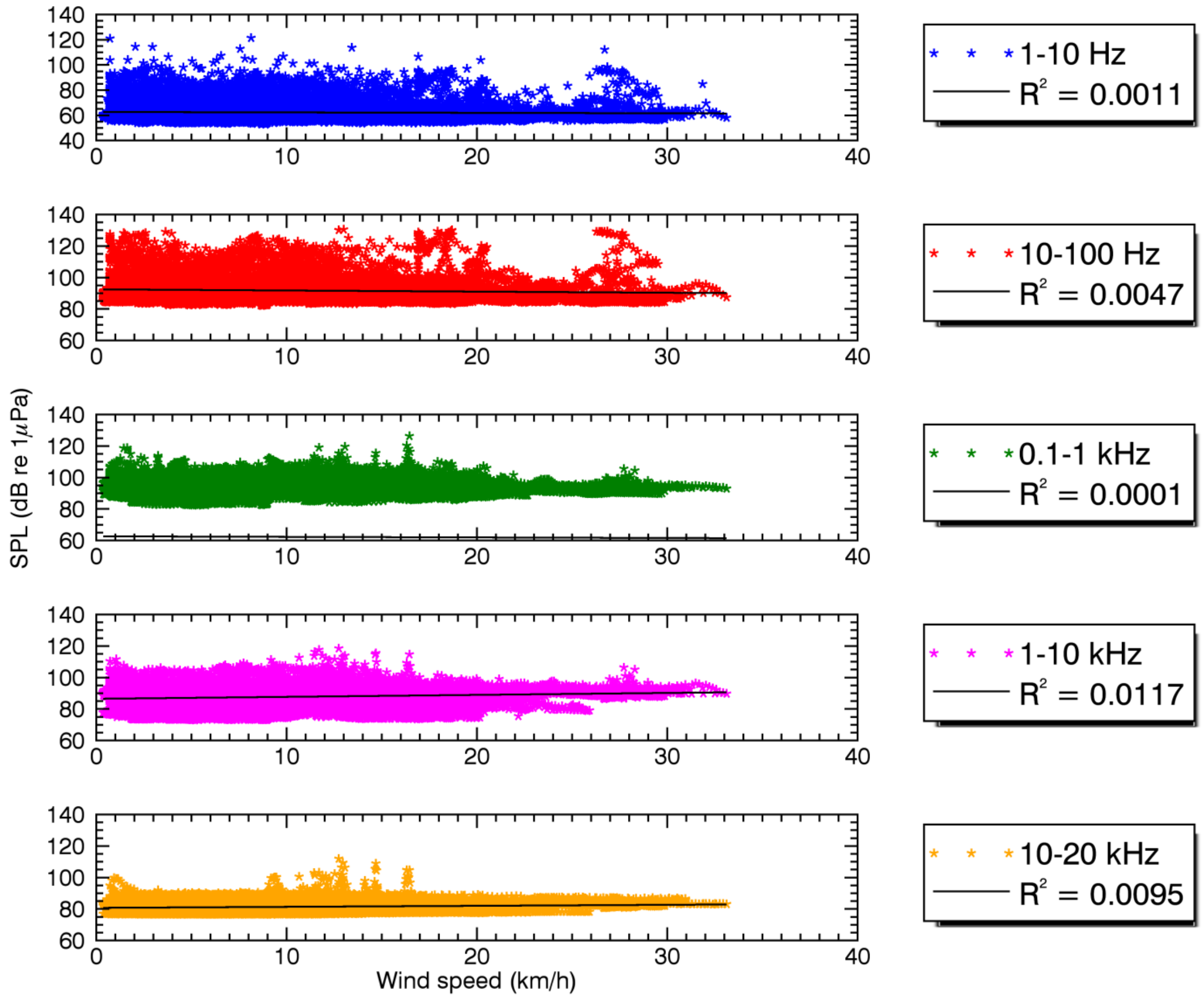

Figure 18. AMAR 1: Linear regression (black line) of 1-min decade-band sound pressure levels (db re 1μPa) compared to wind speed.

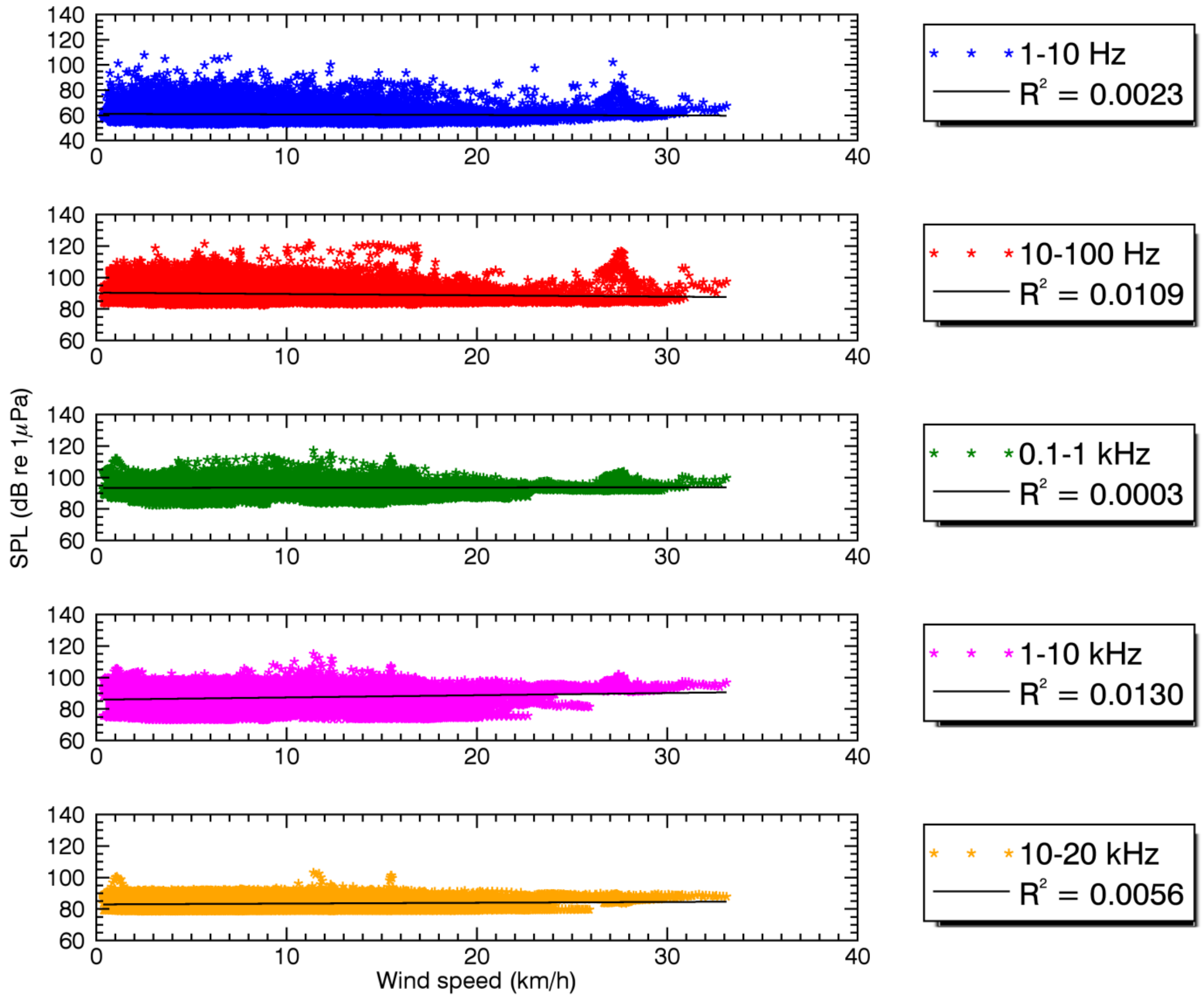

Figure 19. AMAR 2: Linear regression (black line) of 1-min decade-band sound pressure levels (db re 1µPa) compared to wind speed.

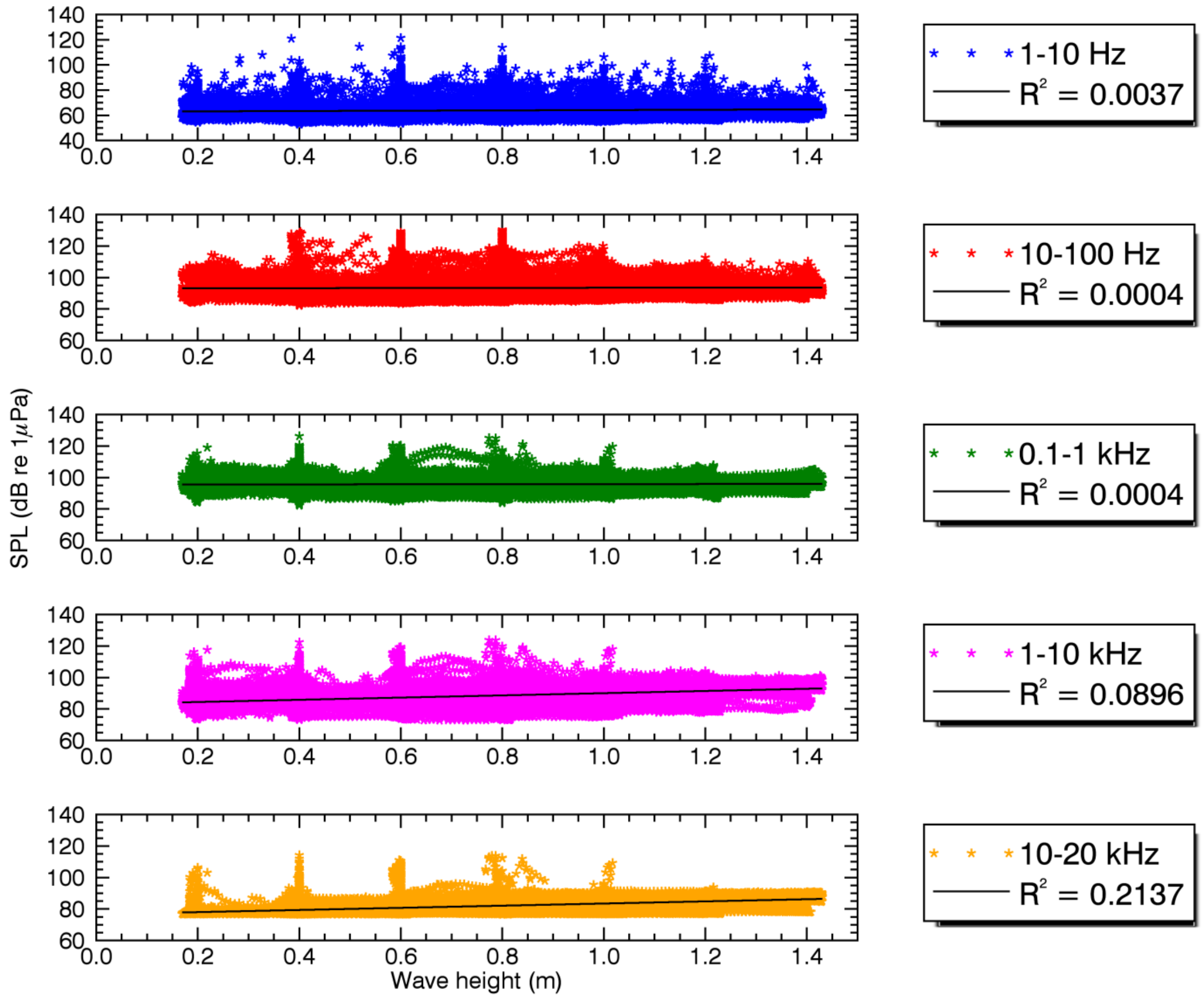

Figure 20. AMAR 1: 1-min decade-band sound pressure levels (db re 1µPa) compared to average wave height (m).

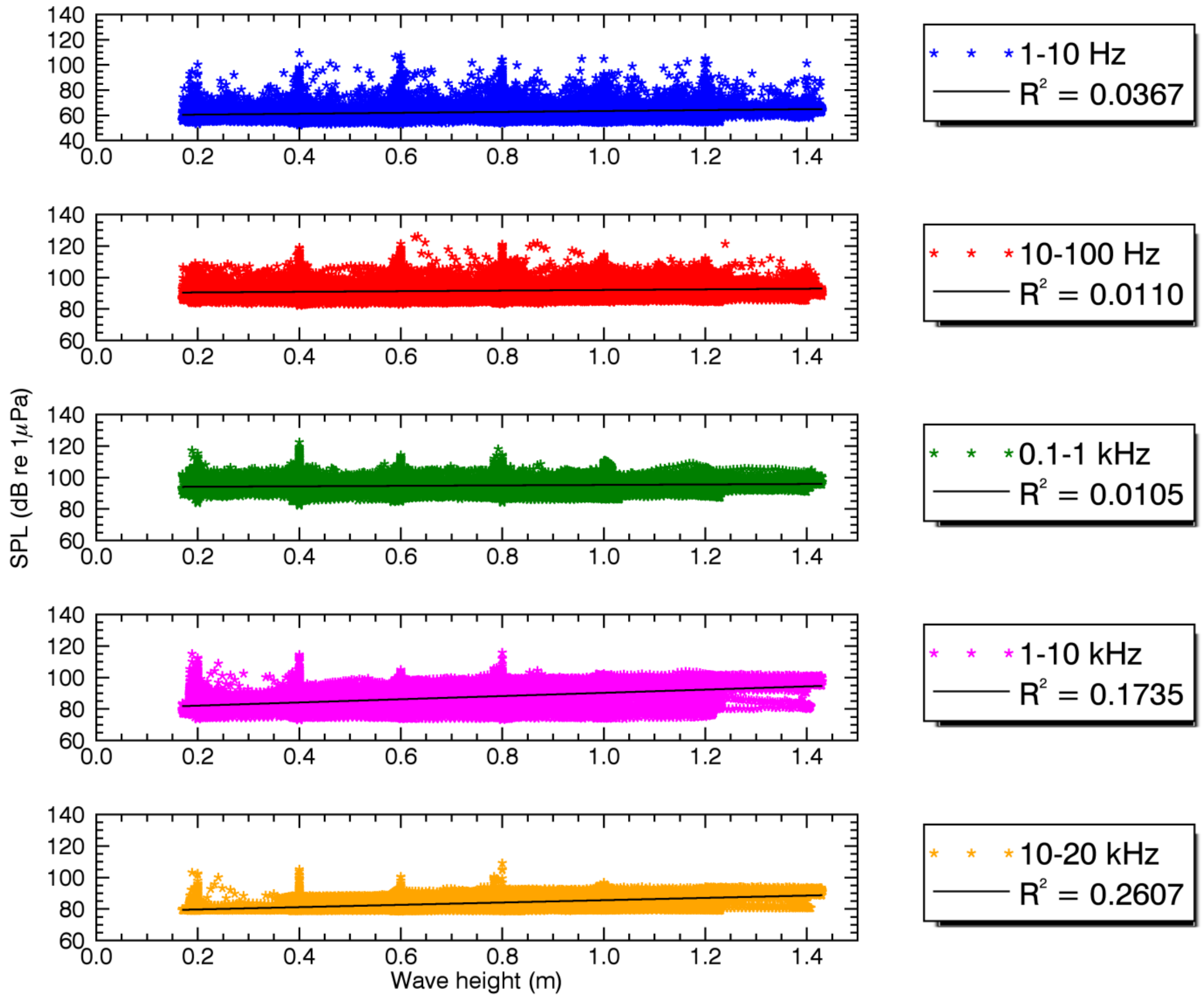

Figure 21. AMAR 2: 1-min decade-band sound pressure levels (db re 1µPa) compared to average wave height (m).

2.4. Marine Mammal Vocalization Detections

Marine mammal vocalizations were present throughout the recordings on both AMARs. Figure 22 and Figure 23 are plots of the daily presence of marine mammal vocalizations, grouped by frequency. Sounds consistent with marine mammal whistles occurred more frequently on AMAR 1 compared to AMAR 2. A decrease in detections occurred at each AMAR during the second week of August; this may be a result of masking since broadband received sound levels on each AMAR were also higher during this week compared to the rest of the period.

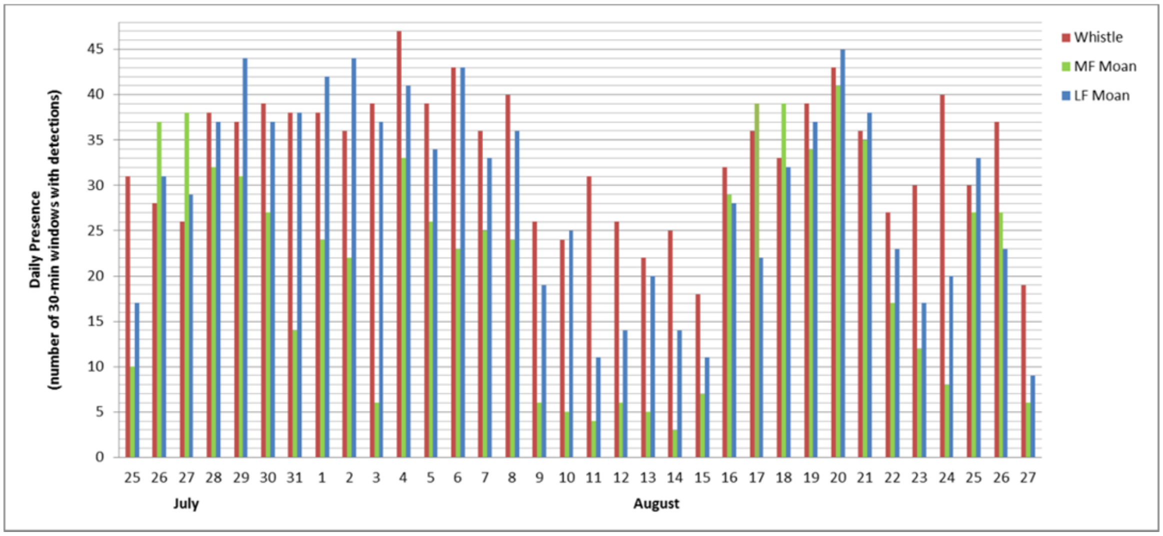

Figure 22 AMAR 1: Daily distribution of marine mammal vocalization detections in 30-min windows from 25 Jul to 27 Aug 2012. Vocalizations are grouped as whistles, mid-frequency (MF) moans, and low-frequency (LF) moans.

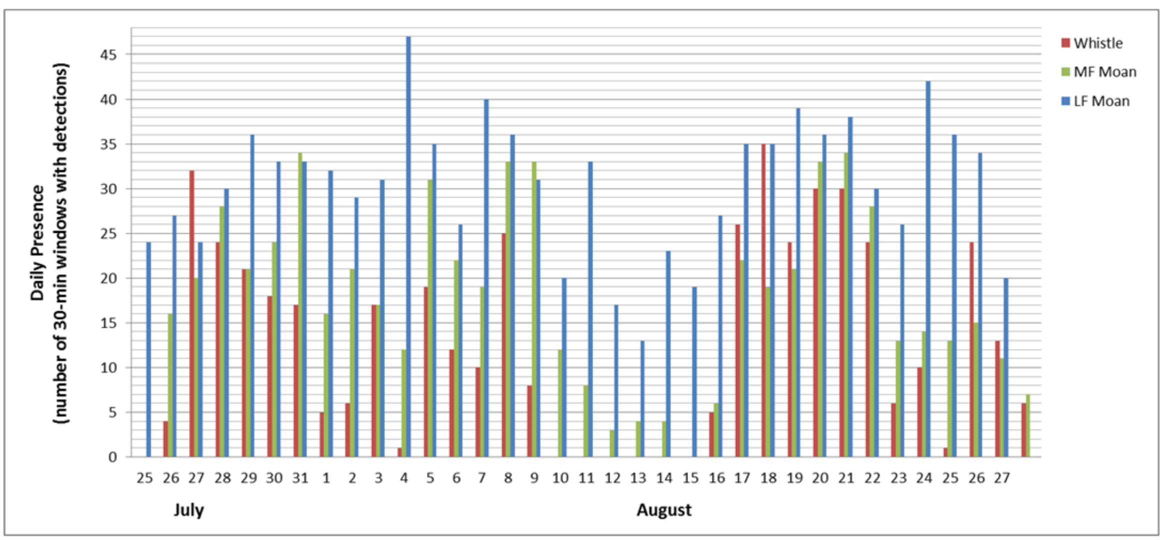

Figure 23 AMAR 2: Daily distribution of marine mammal vocalization detections in 30-min windows from 25 Jul to 27 Aug 2012. Vocalizations are grouped as whistles, mid-frequency (MF) moans, and low-frequency (LF) moans.

3. Discussion

We used an averaging time of 1 minute to compute the rms SPLs for this report. Statistical distributions of broadband rms SPL for the full recording on each AMAR are similar when shorter averaging times are applied (Figure 24 and Figure 25). The 1-minute rms SPLs are assumed to capture the variability of the ambient sound levels. The median broadband, 1-minute rms SPL was 100.0 dB re 1 µPa for AMAR 1 and 99.0 dB re 1 µPa for AMAR 2. The mean broadband, 1-minute rms SPL exceeded the median on both AMARs due to occasional high-sound-level events.

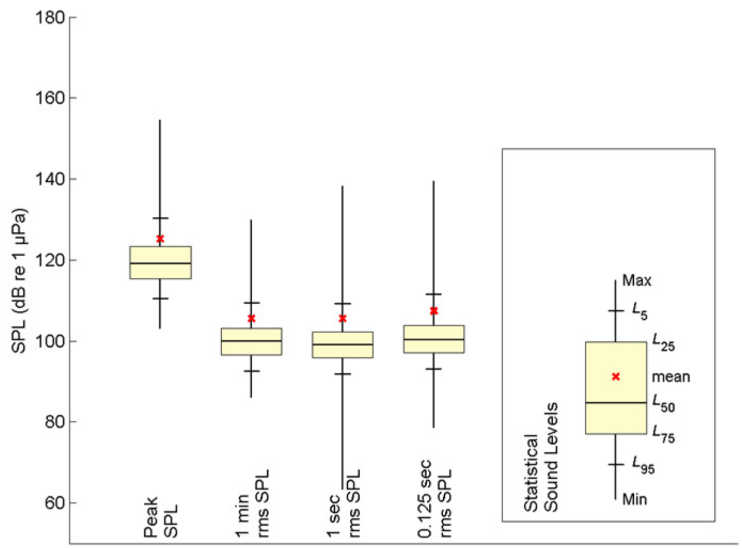

Figure 24 AMAR 1: Statistical distribution of SPLs for all data measured on 25 Jul - 27 Aug 2012.

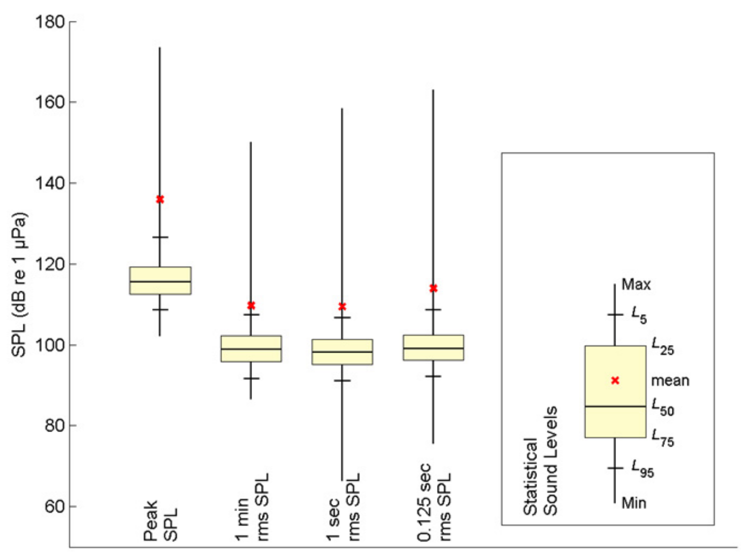

Figure 25 AMAR 2: Statistical distribution of SPLs for all data measured on 25 Jul - 27 Aug 2012.

Wenz (1962) provided a distribution of ambient sound levels as a function of frequency for a range of sea state conditions, commonly referred to as the Wenz curves. The dashed lines in the power spectral density plots in Figures 8 and 10 are the limits of the Wenz curves for low and high sea states. The PSD distributions for each AMAR fall within the limits so are within the expected range for ambient sound levels. The SPLs also decay with increasing frequency at a rate consistent with the rate of decay described by Wenz.

Data were collected on each AMAR over a range of wind speeds—between 0 and 35 km/h. Data from NOAA buoy Station 46094 indicated that the 2012 yearly median wind speed was 17.6 km/h and the yearly maximum wind speed was 73.8 km/h. Thus, the Phase II acoustic monitoring period captured ambient sound conditions representative of the median wind speed conditions, but not for the most extreme wind speed conditions that could occur. It is expected that SPLs should increase with wind speed, particularly at frequencies > 500 Hz, which are frequencies not strongly dominated by vessel noise (Wenz 1962, Wille and Geyer 1984, Richardson et al. 1995) but measured SPLs were not linearly correlated with the recorded wind speeds for the range of wind speeds encountered. This could be because wind speed does not directly measure surface agitation and sea state, the factors that change the ambient SPL, because sea surface conditions do not immediately respond to changes in wind speed. Furthermore, although the best available information was applied, the wind speeds used in the analysis may not truly represent those encountered at the AMAR locations due to the distance between the AMARs and the meteorological buoy from which the wind speed data were obtained. The correlation may be undetected because of a temporal offset between the wind speeds measured at the meteorological buoy and the local onset of surface agitation and sea state at the AMAR locations.

The data on each AMAR were also collected over a range of wave height conditions—between 0.1 and 1.4 m. The TriAxys data from 24 Jul 2012 to 12 Oct 2012 yielded a median mean-wave-height of 0.8 m, a maximum mean-wave-height of 2.2 m, a median maximum-wave-height of 2.0 m, and a maximum maximum-wave-height of 6.0 m. As with the wind speeds, the acoustic monitoring period captured conditions representative of the median wave height conditions at the project site, but not of the most extreme of possible conditions. The measured data indicate a weak positive correlation between wave height and SPLs for frequencies greater than 1 kHz at AMAR 2 and for frequencies greater than 10 kHz at AMAR 1. Because the measurements covered a range of nominal conditions at the project site, the ambient sound conditions at the project site are likely well characterized by the median ambient sound level, independent of the sea state.

The lack of correlation between wind speed or wave height and SPL at frequencies below 1 kHz indicates that meteorological conditions are not dominant factors that contribute to the SPL at those frequencies. Vessel noise is one factor that contributes to the ambient conditions at the project site at those frequencies (Section 2.2). A second factor that is likely contributing to the ambient sound levels on both AMARs is distant surf noise from waves crashing on the shore less than 10 km away; (Wilson et al. 1985) reported that sound levels recorded at 8.5 km from a beach in California were attributable to surf noise at frequencies from 100-700 Hz.

4. Conclusion

Two underwater acoustic recorders were deployed from late July through end of August 2012, both north of the planned location of the OPT PowerBuoy offshore Reedsport, Oregon. The median broadband sound level on AMAR 1, 730 m from the planned PowerBuoy location, was 100 dB re 1 µPa, it was 99 dB re 1 µPa on AMAR 2 located 5000 m to the north. Mean sound levels exceeded median sound levels at all frequencies. 90% of the time, broadband,1-min rms SPLs were between 95–117 dB re 1 µPa on AMAR 1 and 93–112 dB re 1 µPa on AMAR 2. Noise from vessels occurred in the recordings at each location, with nearly continuous vessel detections on AMAR 1 due to its closer proximity to the vessel traffic transiting in and out of the Umpqua River. Even though more vessels were detected on AMAR 1, the median broadband sound levels were very similar at both locations. Sound levels at frequencies below 400 Hz recorded during periods with vessel detections exceeded levels recorded during periods with no vessel detections. Marine mammal vocalizations were detected continuously throughout the recordings. Analysis of wind and wave data at both AMAR locations yielded no correlation between SPL and wind speed and a weak correlation between wave height and received levels above 1 kHz but no correlation at lower frequencies.

Glossary

1/3-octave-band and decade-bands

Acoustic data can be filtered into discrete passbands to analyze the distribution of sound intensity versus frequency. Underwater sounds are typically analyzed in terms of standard 1/3-octave-bands. In 1/3-octave-band analysis, the recorded sound is filtered into a series of adjacent passbands that are each 1/3 of an octave wide, where an octave represents a doubling of frequency. The bandwidth of each 1/3-octave-band is 23.1% of its center frequency. The SPLs computed inside each passband (called 1/3-octave-band levels) give the frequency distribution of the measured sound signal.

The center frequency of the *i*th 1/3-octave-band, $f_c(i)$, is defined according to the following formula:

$$f_c(i) = 10^{i/10} \quad , \tag{7}$$

where i is an integer. The low (f_{lo}) and high (f_{hi}) frequency limits of the *i*th 1/3-octave-band are defined by the following formulae:

$$f_{lo} = 10^{-1/20} f_c(i) \text{ and } f_{hi} = 10^{1/20} f_c(i). \tag{8}$$

Decade-bands are another form of describing underwater sounds, where a decade is a 10-times increase in frequency.

Ambient noise

Ambient noise is the all-encompassing sound at a given place, usually a composite of sound from many sources near and far. Ambient noise can consist of human-generated noise (e.g., shipping vessels, seismic activity) and/or of natural noise (e.g., precipitation, sea ice movement, wave action, and biological activity).

Anthropogenic sound/noise

Anthropogenic sound is sound that originates from human activity (e.g., shipping, construction, geophysical surveys).

Broadband sound level

The broadband level is the total sound pressure level measured over a wide frequency range. If the frequency range is unspecified, it refers to the entire measured frequency range.

Decibel (dB)

Decibels are a logarithmic scale where a factor of ten increase in sound power corresponds to an increase of 10 dB in sound level. One decibel is one-tenth of a bel.

Exceedance level (Ln)

The exceedance level L_n denotes the SPL that was exceeded n-percent of the time during a specified measurement period. For example, the L_{95} level corresponds to the SPL exceeded 95% of the time. Ambient noise measurements are typically reported in terms of exceedance levels.

Isobath

An isobath is an imaginary line that connects locations having the same water depth.

Power spectral density (PSD) and Power spectral density level

Power spectral density (PSD) describes how the power of a signal is distributed with frequency. The PSD level is computed as the dB level of the squared sound pressure amplitude spectrum in 1 Hz bands. The units of PSD levels are dB re 1 μPa^2/Hz. The power spectrum density of acoustic data is generally computed using Fast Fourier Transform (FFT).

Sound pressure level (SPL)

The sound pressure level is a logarithmic measure of the time-mean-square sound pressure relative to a reference value in a specified frequency band. It is a measure of only the pressure component of the sound and does not account for the duration of the sound. Unit: decibel (dB). For sound in water, the reference sound pressure is one micropascal (1 μPa) and the unit for SPL is therefore written as "dB re 1 μPa".

$$L_p = 10\log_{10}\left(p^2 / p_o^2\right) = 20\log_{10}\left(p / p_o\right)$$

where p^2 is the time-mean-square sound pressure and p_o = 1 μPa is the reference sound pressure.

Source level

The SPL that would be measured at 1 meter distance from a point-like source that radiates the same total amount of sound power as the actual source. Source levels are expressed in units of dB re 1 μPa at 1 m.

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Appendix A. Data Analysis Methodology

Data Analysis Methodology and Quality Control

Noise Characterization off Reedsport, Oregon

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1. Introduction

JASCO Applied Sciences has been contracted to provide acoustic services for the characterization and assessment of noise from Ocean Power Technologies' PowerBuoy wave energy conversion device. JASCO will conduct a three-phase acoustic measurement program: a Planning Phase (Phase I); a Baseline Ambient Noise Characterization (Phase II); and a PowerBuoy Sound Source Characterization (Phase III).

This document completes Phase I and describes the data analysis methodologies that will be applied in Phases II and III. The results of this study will inform the consultation process for the expected future deployment of nine additional PowerBuoys. The acoustic program is designed to provide data that will aid in determining whether whales will likely detect and avoid the proposed 1.5 megawatt ten PB150 PowerBuoy wave energy array.

The acoustic data analysis will:

- Provide a statistical characterization of baseline ambient sound conditions, as a function of frequency, under a variety of sea states.
- Provide a statistical characterization of sounds produced by the PowerBuoy, as a function of frequency, under a variety of sea states.
- Determine whether the PowerBuoy generates high-frequency sounds that could interfere with odontocete sonar signals.
- Determine the sounds levels that can be expected at 2 km from the PowerBuoy center line, by frequency and depth.
- Review current information about how whales behave when they encounter noise sources similar to a PowerBuoy and to acoustic pingers.

2. Data Analysis Methodology

2.1. Overview

The data collected during Phase II provides a baseline of the existing acoustic noise present at the project site. For this phase of the work, JASCO collected one month of baseline acoustic data at the project site in August 2012. The one month deployment was performed so that ambient sound conditions could be collected under various sea states. Wave height data were collected simultaneous with the acoustic measurements using a TriAxys wave buoy.

Data were collected at a continuous sampling rate of 48 kHz using two of JASCO's Autonomous Multichannel Acoustic Recorders (AMARs, see Appendix A for specifications). This sample rate was chosen such that sounds between 1 Hz and 24 kHz could be characterized. The two AMARs were deployed along the same isobath at approximately 730 m and 5000 m north from the centerline of the PowerBuoy, at 10 m above the sea bottom. One AMAR was placed 5000 m from the PowerBuoy location to avoid any potential for noise interference from the deployed PowerBuoy anchor moorings. The AMARs were located north of the PowerBuoy location to maximize the distance from vessel traffic near the Umpqua River inlet to the south of the PowerBuoy. JASCO has not yet analyzed these data, but will process the Phase II data automatically on our grid computers, using our acoustic analysis software to rapidly produce ambient statistics from the recordings.

The Phase III objective is to quantify the acoustic signature of the PowerBuoy as a function of sea state, then conduct a literature review to predict how marine mammals will react to the PowerBuoy's presence. Acoustic monitoring will involve four months of continuous recording to capture the temporal variability of operational noise under a variety of sea states that should be comparable to those collected during the baseline characterization. Two AMARs will be deployed along the same isobaths at 200 m and 500 m range from the centerline of the PowerBuoy. JASCO will record on a 30% duty cycle throughout this phase using a 48 kHz sample rate to allow sounds between 1 Hz and 24 kHz to be characterized. JASCO will immediately download all data and begin analysis once the recorders are retrieved, at the end of the four months.

Phase III data analysis will consist of multiple stages. The first stage will quantify the sound levels received at the two recorders using acoustic analysis software. The second stage will be to manually analyze 2 minutes of data from each recorded hour to determine the frequencies that contain the PowerBuoy signature. The third stage will be to estimate the PowerBuoy source level by back-propagating the received sound levels from the recorder position to the instantaneous PowerBuoy location. This back-propagation will be conducted by computing acoustic propagation transmission loss from the recorder to the PowerBuoy location with JASCO's Marine Operations Noise Model (MONM, see Section 2.2.3) and then adding the computed transmission loss to the measured sound levels in 1/3-octave bands that contain the PowerBuoy signature. To estimate the broadband PowerBuoy sound level, the total power will be summed over 1/3-octave bands once per hour.

MONM will be used for forward propagation of the computed source levels to estimate if the received level at the edge of the moorings (240 m from the center) would have exceeded 120 dB re 1 µPa rms. JASCO will notify Ocean Power Technologies (OPT) and the Aquatic Resources and Water Quality Implementation Committee (ARWQC) when this likely occurred. These values will be sent weekly to the selected members of the ARWQC as the analysis progresses.

Once the Phase III data have been processed, JASCO will then conduct a literature review that will focus on:

- the behavior of whales in the presence of acoustic pingers and noise sources similar to a PowerBuoy.
- the SPL above background necessary for cetaceans to detect the PowerBuoy.

The frequency-dependent hearing abilities of different cetacean species will be considered. The review will include the gray whale acoustic deterrent device work conducted for the Oregon Wave Energy Trust (OWET) and US Department of Energy (DOE) by Dr. Bruce Mate of Oregon State University.

2.2. Acoustic Analysis

2.2.1. Ambient Sound Quantification

The aim of the Phase II ambient sound analysis is to document the range, spectral composition, and rate of occurrence of the recorded sound levels. Sound levels will be expressed as a function of time and frequency and plotted as spectrograms (see e.g., Figure 1, lower panel). The spectral density (the sound pressure level in 1 Hz-wide frequency bands) will be calculated using the Fourier transform (Oppenheim and Schafer 1999). The 1 Hz data will also be summed in 1/3-octave bands and decade bands, as shown in the middle panel of Figure 1. The acoustic analysis software will automatically compute these values along with peak, peak-to-peak, and root-mean-square (rms) broadband sound levels for every minute of data. These data will be plotted alongside time-stamped measurements of wind speed and sea state (Figure 1, top panel).

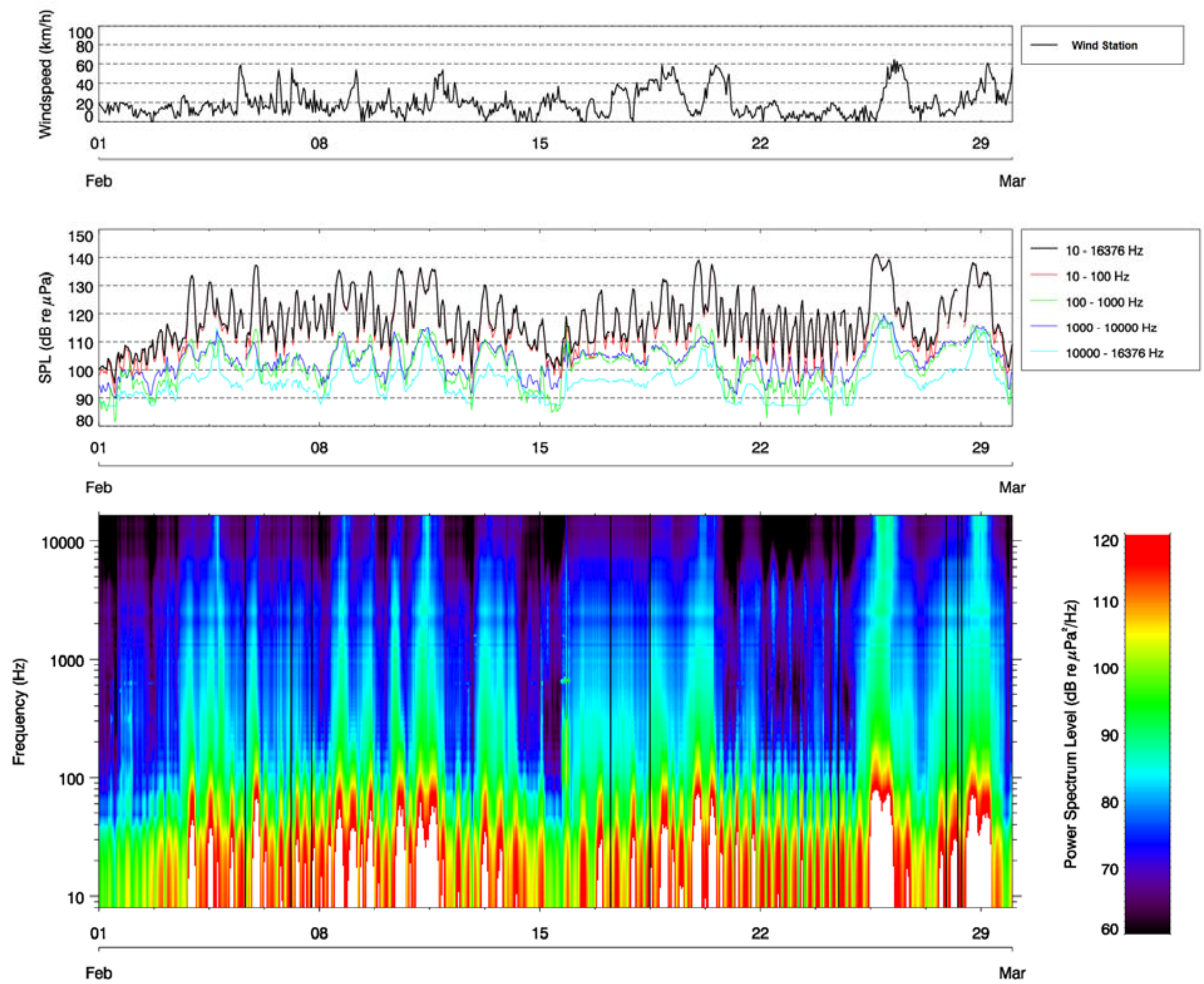

Figure 1. Ambient spectrogram (lower), extracted decade-band sound pressure levels (dB re 1µPa, middle) and wind speed (km/h, top).

Decade-band sound level data will also be plotted with wind speed and sea state data in the format shown in Figure 2. Sea state and wave height data will be obtained from the TriAxys buoy that OPT plans to deploy; wind speed data will be obtained from the NOAA National Data Buoy Center (www.ndbc.noaa.gov). Regressions of the decade-band sound levels against the wind speed and wave height will be performed to determine which factors dominate the measured sound levels.

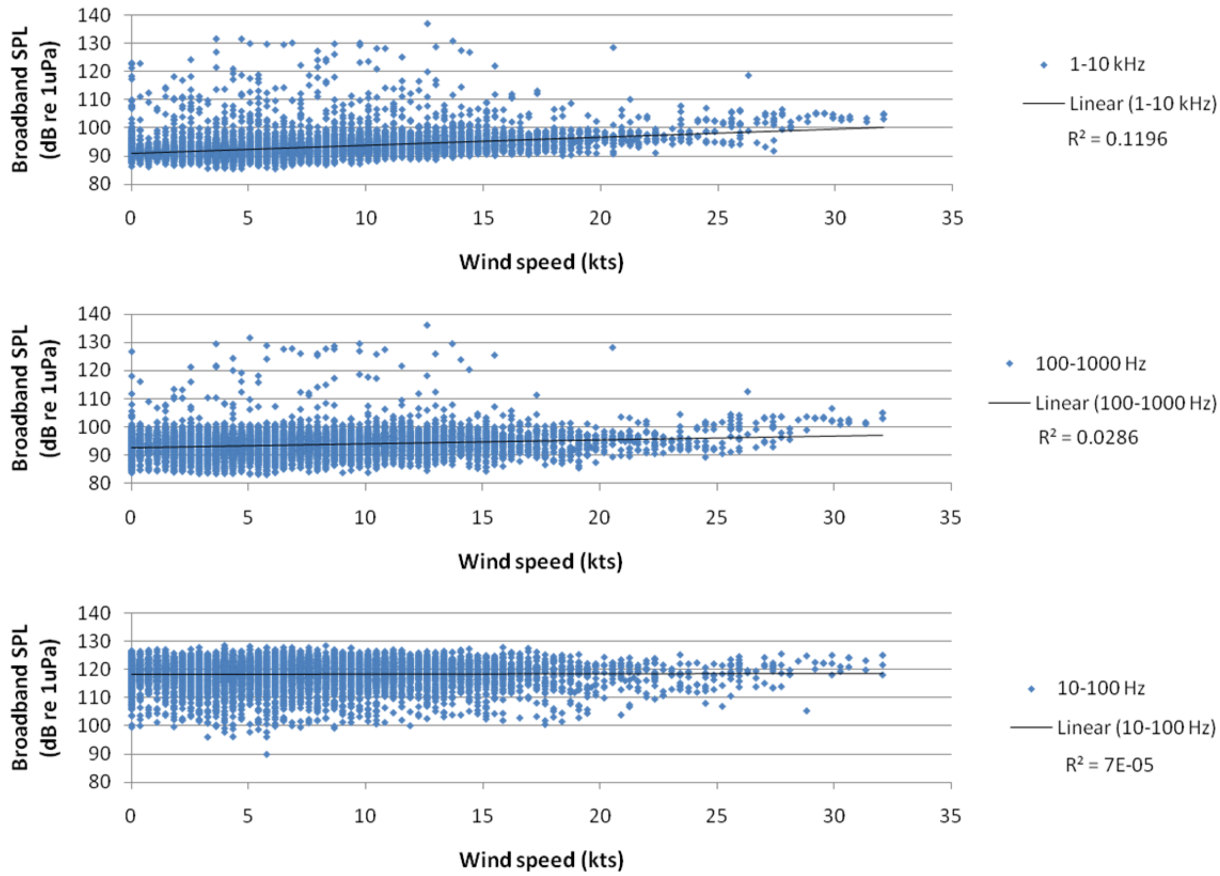

Figure 2. Sample linear regressions of one-minute decade-band sound levels against wind speed. There are no correlations at low frequency (10–100 Hz), and a significant positive correlation at high frequency (1000–10000 Hz).

The range and occurrence of sound levels will also be presented as percentile spectral levels, which are histograms of the spectral density values for the 5th, 25th, 50th, 75th, and 95th percentiles, where the 50th percentile is equal to the median of the spectral distribution and the 95th percentile is the level exceeded by 95% of the data (see e.g., Figure 3). The 95th percentile represents the quietest noise state that is expected to occur; the 5th percentile represents the loudest. The percentile levels will be plotted along with the envelope of the Wenz curves that represent the maximum and minimum expected sound levels in open ocean as shown in Figure 3 Figure 4 shows a spectrogram of a close-range vessel pass. If we detect such events, we will include their spectrograms to show the extent that the sounds deviate from ambient levels.

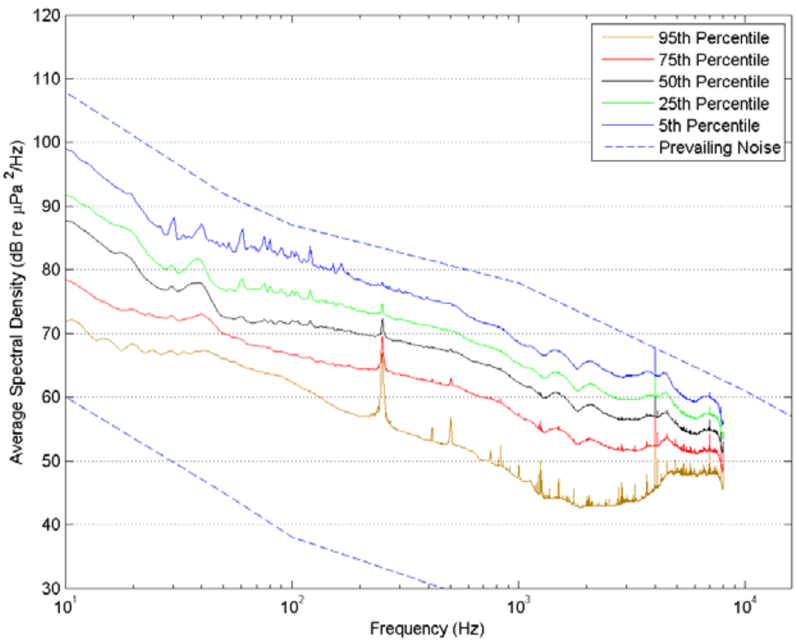

Figure 3 Typical percentile sound distribution plot.

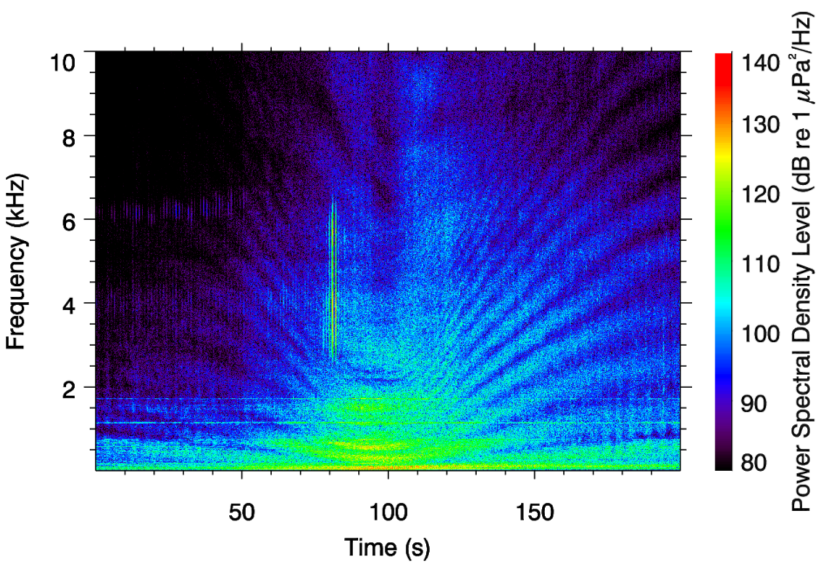

Figure 4. Spectrogram of a close-range vessel pass, 48 kHz, 8192-pt FFT, 87.5% overlap, Hanning window.

2.2.2. PowerBuoy Sound Source Characterization

The acoustic analysis software we use will automatically compute one-minute average broadband SPL, broadband SEL, and 1/3–octave-band SELs of the received sound levels from Phase III. Sections of the data will be presented in spectrograms and band level plots aligned with environmental data as shown in 2.2.1. Power spectral density and 1/3-octave-band levels of the PowerBuoy sound signature will be plotted in a format similar to Figure 5 for a selection of sea state/wind speed conditions.

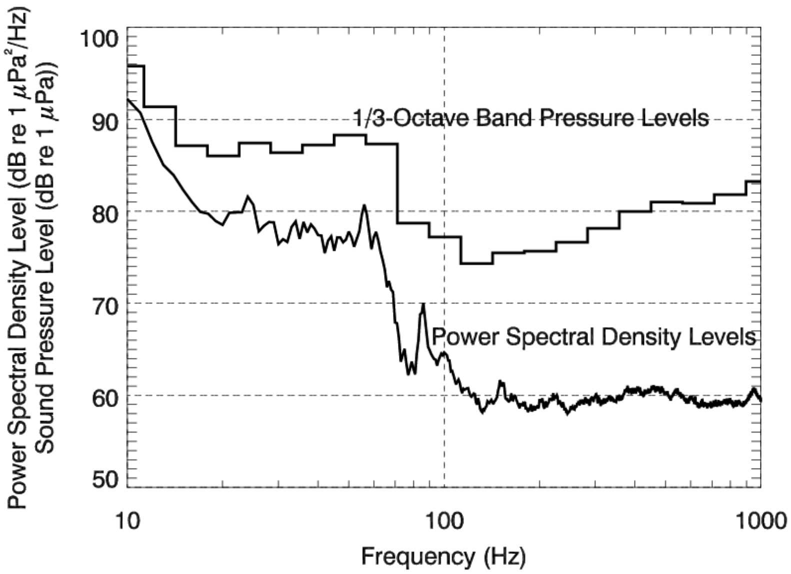

Figure 5. Example power spectral density and 1/3-octave-band levels of recorded noise.

To quickly annotate events in recorded data, JASCO has developed a special-purpose spectrogram and time-series viewer, called SpectroPlotter, for systematic manual analysis. Figure 6 is a sample screen from SpectroPlotter. SpectroPlotter annotations are stored in a systematic manner so information can be extracted as a filter for controlling automatic data analysis. We have also automated the creation of 'summary files' for each deployment day. These files contain a specified amount of data for each hour of the day or each recorded file. Opening a single file for manual analysis of an entire day saves the analysts a significant amount of time and standardizes the analysis protocols.

Phase III data will be processed by performing a manual analysis of 2 minutes of data at the top of each hour to determine the frequencies at which the PowerBuoy is detectable above the ambient noise at each recorder. The average one-minute received level from each 1/3-octave band that is above the noise level will be added to the frequency-dependent transmission loss for the 1/3-octave and the position of the PowerBuoy at that time. All of the 1/3-octave band contributions will be summed to obtain the broadband source level for that time sample. The source levels predicted by both recorders will be compared. If the levels are similar (±1 dB), then we will be confident we measured the PowerBuoy source levels, and not noise.

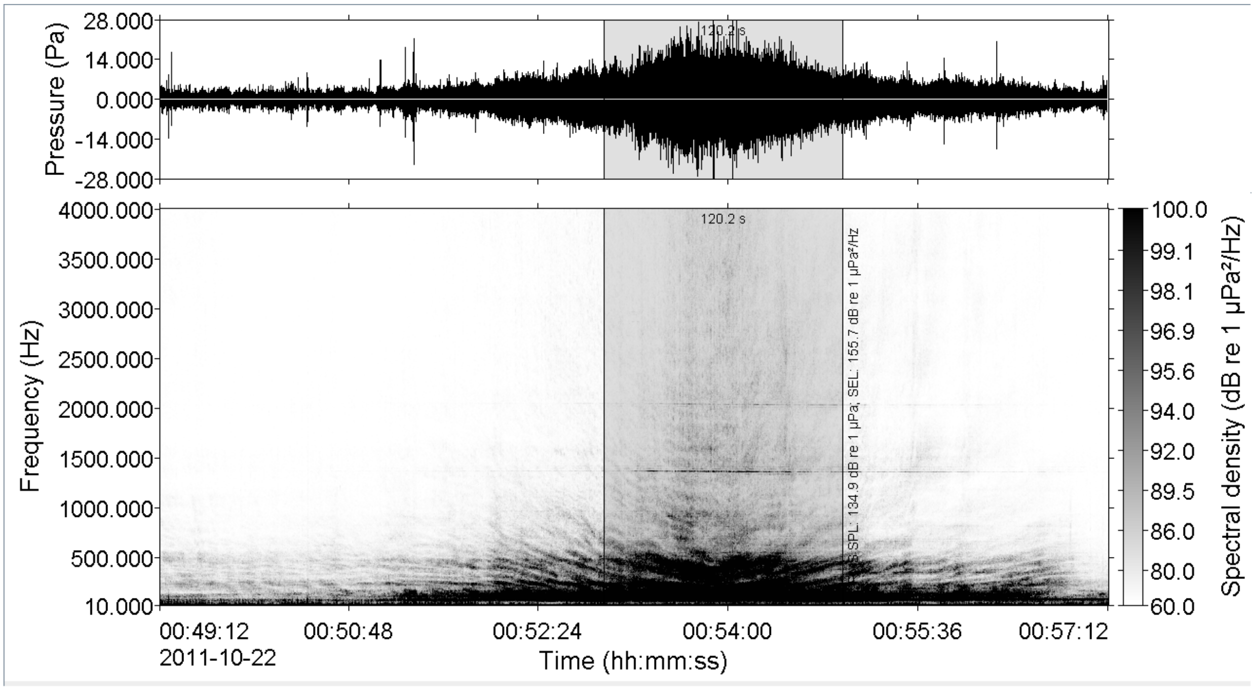

Figure 6. Sample SpectroPlotter window showing an annotation of heaving shipping, with the SPL and SEL of the event.

2.2.3. MONM–Acoustic Propagation Loss Computation Methodology

For Phase III, propagation loss in the environment surrounding the PowerBuoy will be computed with JASCO's Marine Operations Noise Model (MONM). This is a finite difference numerical model that provides a more sophisticated approach to computing sound transmission loss compared to simple standard spreading loss models. The code models the motion of sound pressure waves through an environment of interest, yielding a grid of sound transmission loss values as a function of frequency, depth, and range from a source. MONM has been used to compute transmission loss for several Incidental Harassment Authorizations that NMFS has granted for oil and gas exploration activities in the Alaska Chukchi and Beaufort Seas since 2006 (e.g., Zykov et al. 2013; LGL 2012) and was used in a transmission loss study conducted for Oregon Wave Energy Trust in 2010 (Austin et al. 2009).

MONM computes sound propagation in range-varying acoustic environments through a wide-angled parabolic equation (PE) solution to the acoustic wave equation. The PE code used by MONM is based on a version of the Naval Research Laboratory's Range-dependent Acoustic Model (RAM), which has been modified to account for shear wave losses from elastic seabeds. The PE method has been extensively benchmarked and is widely employed in the underwater acoustics community (Collins 1993). MONM's sound level predictions have been validated against other models and experimental data (Hannay & Racca 2005).

MONM computes acoustic fields in three dimensions by modeling transmission loss along evenly spaced radial traverses covering a 360° swath from the source, an approach commonly referred to as N×2-D. The model fully accounts for depth and/or range dependence of several environmental parameters including bathymetry and sound speed profiles in the water column and the sea floor. It includes compressional and shear wave attenuations in all layers. The acoustic environment is sampled at a fixed range step along radial traverses.

JASCO has extended the PE code from its basic version to account for the additional reflection loss due to partial conversion of incident compressional waves to shear waves at the seabed and sub-bottom interfaces. MONM also contains a module that applies a ray-tracing algorithm to handle high frequency sound propagation (frequencies greater than several kilohertz).

Model input parameters for the project site, including geoacoustic and bathymetric information, are readily available from a previous transmission loss investigation carried out by JASCO for the Oregon Wave Energy Trust. Because of the properties of the environment, the transmission loss is frequency-dependent, which is accounted for in MONM by modeling the transmission loss at each 1/3-octave value. Other frequencies may also be modeled as necessary.

MONM will be used first to correct the recorded sound levels to the PowerBuoy centerline to obtain the PowerBuoy source level and then to estimate the sound levels at the mooring locations and at 2 km. The PowerBuoy source level will be computed once for each hour of recorded data. The source levels computed from the recorder at 200 m and 500 m will be compared to ensure they are equal within ±1 dB at each measurement time to verify that we have measured the source level and not noise. Data that has passed this quality check will then be sorted according to the sea state at the time of the measurement. Once all of the data is computed, the mean and standard deviation of the source level estimates will be found for each sea state; confidence intervals of the mean for each sea state will be computed for 95, 99, and 99.5% confidence levels.

As each data point is computed, the received level at the ends of the PowerBuoy moorings will be predicted. The time, sea state/wave height, and estimated received level for any predicted levels that rise above 120 dB re 1 µPa rms. These values will be sent weekly to OPT and the select members of the ARWQC.

3. Quality Assurance and Quality Control Expectations and Procedures

3.1. Required Data

Wave height and wind speed data are required for this analysis. We expect OPT to provide access to the TriAxys wave data that will be collected at the site. JASCO will obtain wind speed data from the nearest National Oceanic and Atmospheric Administration's National Data Buoy Center station (Station 46094). We will download the appropriate wind data on a daily basis throughout the deployment. Before analysis begins, JASCO will ensure all data is in an acceptable format and contains proper timestamps.

3.2. Calibration of Acoustics Instrumentation

A GRAS 42AC pistonphone calibrator will be used to calibrate the AMARs in the laboratory before shipment and in the field immediately before deployment. The pistonphone generates a precise 250 Hz reference tone at the hydrophone sensor that allows end-to-end system calibration to absolute pressure at the reference frequency. A field calibration will also be performed immediately upon retrieval of the units.

3.3. Manual Analysis

JASCO has developed a special-purpose spectrogram and time-series viewer that allows analysts to quickly annotate events in the data and perform a data quality check. As part of our procedures, we have also automated the creation of "summary files" for each day of a deployment. These files contain a specified amount of data for each hour of the day or each recorded file. Opening a single file for manual analysis of an entire day saves the analysts a significant amount of time and standardizes the analysis protocols. A portion of the ambient data will be manually analyzed to check the validity of the automated results.

3.4. Senior Review

Before release, a senior JASCO acoustician will review all results to ensure they were processed properly and are realistic.

4. References

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Appendix A. AMAR Capability Summary

AMAR: Autonomous Multichannel Acoustic Recorder. Manufactured by JASCO Applied Sciences Ltd. Made in Canada.

Hydrophone Country of Origin: Canada.

Sample Rates: The AMAR supports a variety of sample rates; it will be configured to record at 48 kHz for this study.

Analog Gain: The AMAR provides analog gains of 0 to 42 dB in 6 dB steps.

Analog-to-Digital Converter: The AMAR uses a Texas Instruments ADS1274 24-bit sigma delta analog-to-digital (A/D) converter. This A/D has a built-in anti-aliasing filter which rolls off as shown in Figure A-1. The AMAR implements a single-pole low-pass anti-aliasing filter with corner frequency at 64 kHz to remove high-frequency artefacts from the sigma-delta oversampling clock. The useable frequency range is about 0.49 × sample rate, or 10–62 720 Hz for a sample rate of 128 kHz.

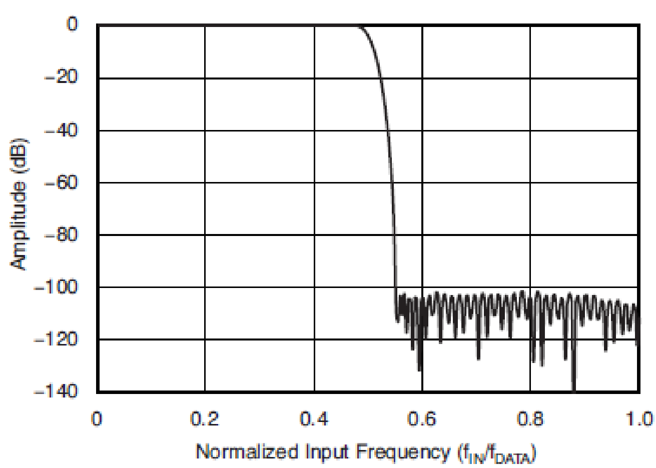

Figure A-1. ADS1274 Anti-Aliasing Filter (http://focus.ti.com/lit/ds/symlink/ads1274.pdf).

AC Coupling: The AMAR is configured for AC coupling of the hydrophone, which results in high-pass filtering of the input signal. Figure A-2 shows the relative attenuation; the −3 dB point is at 16 Hz, with a 25 dB roll off at 1 Hz.

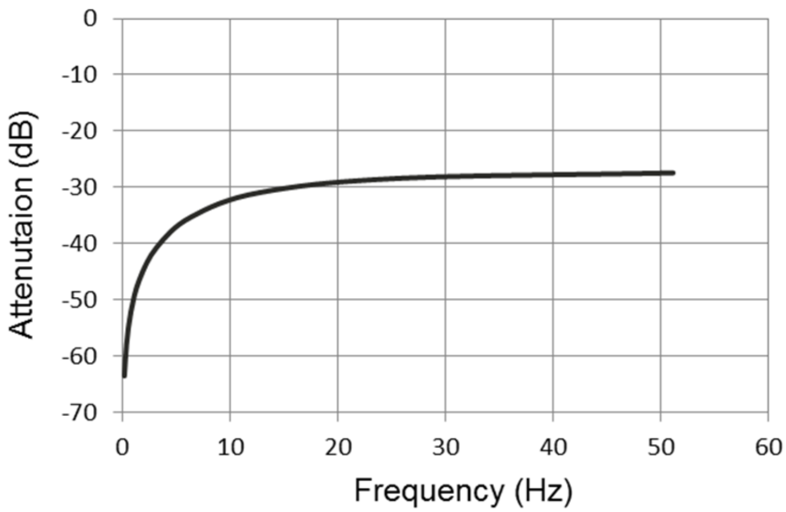

Figure A-2. AC-coupled frequency response of the AMAR.

Hydrophone: GeoSpectrum M8E hydrophones will be used with the AMAR. The M8E ceramic has a nominal sensitivity of −191 dBV/1 µPa, and a 26 dB gain for a total response of -165 dBV/µPa. The response curve for the M8 is shown in Figure A-3. Note that the hydrophone response is down 6 dB at 12 Hz, and 30 dB at 1 Hz. The equivalent electronic noise floor of the hydrophone preamp is approximately 20 dB re 1 µPa^2/Hz.

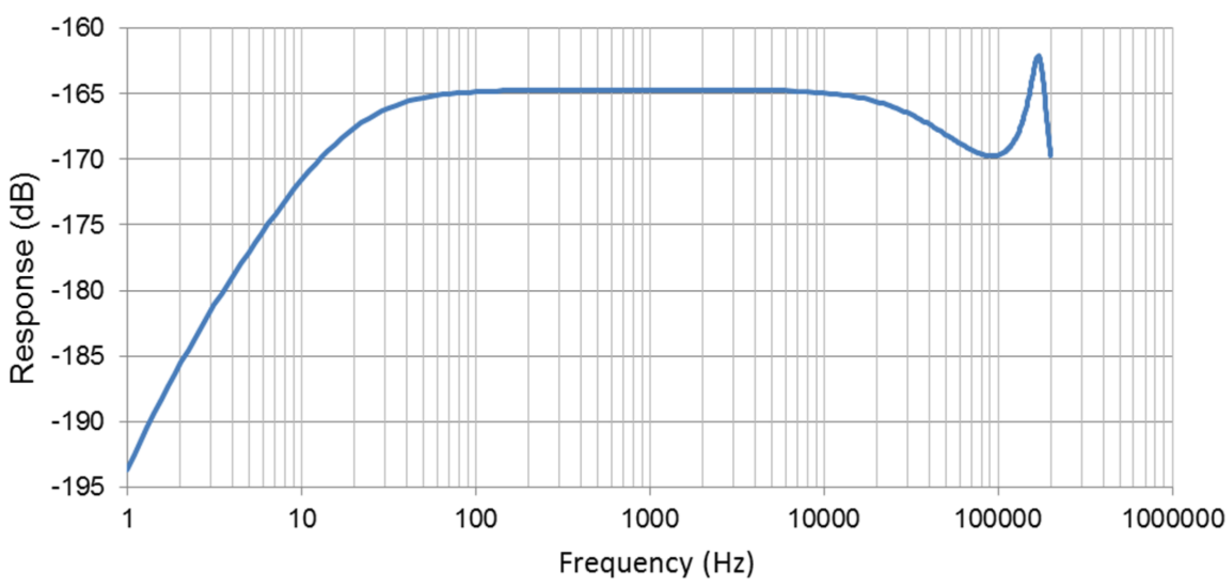

Figure A-3. Frequency response of the M8 hydrophone with 26 dB gain preamp.

Low Frequency Performance: Low-frequency roll off of the AC-coupling and the hydrophone is calibrated and accounted for during analysis. The usable low-frequency limit is 10 Hz or lower.

Noise Floor and Dynamic Range: The noise floor of the AMAR has a nominal level of −147 dB re 1 V/√Hz at 10 kHz and a narrow peak at −112 dB re 1 V/√Hz centered at 1218 Hz. After applying the response of the M8 hydrophone, the spectral noise floor is approximately 23 dB re 1µPa^2 /Hz at 48 kHz and 52 dB re 1µPa^2 /Hz at 1218 Hz at sample rate 128 kHz (Sea State 1 noise at 1 kHz is ~50 dB re 1 µPa^2 /Hz). The dynamic range is 104 dB. The maximum signal that can be accurately measured with zero gain applied and the M8E hydrophone is approximately 171 dB re 1 µPa. The minimum broadband signal is 67 dB re 1 µPa

Data Storage: AMARs store data in a custom memory format on solid-state, non-volatile, flash RAM. Up to 1.792 TB of memory can be installed on each AMAR. The data is striped across the memory to ensure data recovery in the event of defects or errors in the memory hardware. JASCO proposes to configure the AMARs with 256 GB of removable solid-state media, which has enough capacity for about 30 days of storage at 32 kHz sampling. For Phase III, JASCO will configure the AMARs with 512 GB of memory, providing up to 60 days of continuous recording at 32 kHz. For Phase III, JASCO will record at a 33% duty cycle, which will last approximately 150 days (battery limited). Alternative sampling rates and larger storage specifications are possible

Data Download and Parsing: Data is downloaded from the AMAR via FTP. The resulting files are then parsed into a *.wav* format with custom software provided by JASCO.

Environmental Specifications: The AMAR can be operated in −1 to 50 °C water. The standard PVC housing is rated to 400 m depth. An optional aluminum housing is rated to 2500 m depth

Calibration: AMAR calibrations are performed during mobilization with pistonphone calibrator precision noise sources at 250 Hz. The AMARs are also calibrated in the field before and after each deployment to verify system operation.

Time Synchronization: The AMAR has a high-resolution real-time clock that is used to time-stamp the start of all recordings. This clock has a drift of 4 seconds per month. This time stamp is sufficiently accurate to align the acoustic data with the hourly wav and GPS log data so changes in the acoustic sound levels can be correlated with wave height.

Dimensions: Figure A-4 shows the standard AMAR dimensions: 37 in (94 cm) high, 8 in (20 cm) wide, and weighs 47 lbs (21 kg) in air with batteries.

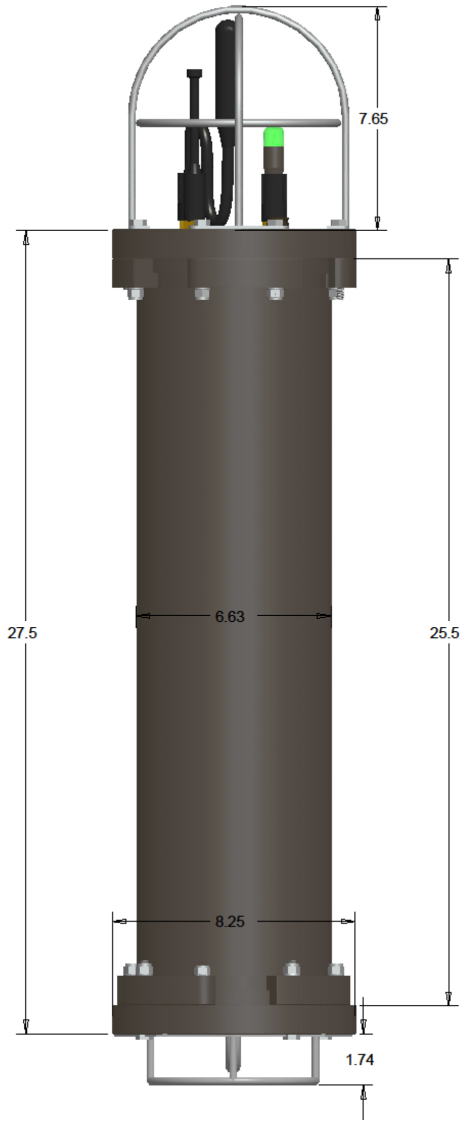

Figure A-4. AMAR dimensions in inches.