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NORTHWEST NATIONAL MARINE RENEWABLE ENERGY CENTER
WAVE ENERGY RESEARCH, TESTING AND DEMONSTRATION CENTER
FINAL TECHNICAL REPORT

Recipient: OREGON STATE UNIVERSITY
350 Batcheller Hall, Corvallis, OR 97331

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Principle Investigator: Dr. Bob Paasch, bob.paasch@oregonstate.edu, (541)737-7019
Report Submitted by: Brenda Langley, brenda.langley@oregonstate.edu, (541)737-6138

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Working Partners: Oregon State University, Dr. Belinda Batten, NNMREC Director belinda.batten@oregonstate.edu , (541)737-9492
University of Washington, Dr. Brian Polagye, NNMREC Co-Director, bpolagye@u.washington.edu, (206) 543-7544

Cost-Share Partners: Oregon State University, Jim Lundy (541)737 5235
Oregon Wave Energy Trust, Jason Busch (503)481-5949

DOE Project Team: DOE HQ Program Manager – Jose Zayas
DOE Field Contract Officer – Pamela Brodie
DOE Field Contract Specialist – Laura Merrick
DOE Field Contract Officer – Tim Ramsey
DOE/CNJV Project Monitor – Erik Mauer

Submitting Officer: BABatten
Belinda Batten, NNMREC Director

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Disclaimer: “Any findings, opinions, and conclusions or recommendations expressed in this report are those of the author(s) and do not necessarily reflect the views of the Department of Energy”

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List of Acronyms

ADCP – Acoustic Doppler Current Profiler
AWAC – Acoustic Wave and Current
CDP – Congressionally Directed Project
DOE – US Department of Energy
MOTB – Mobile Ocean Test Berth
NDBC – National Data Buoy Center
NETS – North Energy Test Site
NOAA – National Oceanic and Atmospheric Administration
NOMAD – Navy Oceanographic Meteorological Automatic Device
NNMREC – Northwest National Marine Renewable Energy Center
OSU – Oregon State University
PMEC – Pacific Marine Energy Center
SETS – South Energy Test Site
UW – University of Washington
WEC – Wave Energy Converter

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1 Executive Summary

The purpose of this project was to build upon the research, development and testing experience of the Northwest National Marine Renewable Energy Center (NNMREC) to establish a non-grid connected open-ocean testing facility for wave energy converters (WECs) off the coast of Newport, Oregon. The test facility would serve as the first facility of its kind in the continental US with a fully energetic wave resource where WEC technologies could be proven for west coast US markets.

The test facility would provide the opportunity for self-contained WEC testing or WEC testing connected via an umbilical cable to a mobile ocean test berth (MOTB). The MOTB would act as a "grid surrogate" measuring energy produced by the WEC and the environmental conditions under which the energy was produced.

In order to realize this vision, the ocean site would need to be identified through outreach to community stakeholders, and then regulatory and permitting processes would be undertaken. Part of those processes would require environmental baseline studies and site analysis, including benthic, acoustic and wave resource characterization. The MOTB and its myriad systems would need to be designed and constructed.

The first WEC test at the facility with the MOTB was completed within this project with the WET-NZ device in summer 2012. In summer 2013, the MOTB was deployed with load cells on its mooring lines to characterize forces on mooring systems in a variety of sea states. Throughout both testing seasons, studies were done to analyze environmental effects during testing operations. Test protocols and best management practices for open ocean operations were developed.

As a result of this project, the non-grid connected fully energetic WEC test facility is operational, and the MOTB system developed provides a portable concept for WEC testing. The permitting process used provides a model for other wave energy projects, especially those in the Pacific Northwest that have similar environmental considerations.

While the non-grid connected testing facility provides an option for WEC developers to prove their technology in a fully-energetic wave environment, the absence of grid connection is somewhat of a limitation. To prove that their technology is commercially viable, developers seek a multi-year grid connected testing option. To address this need, NNMREC is developing a companion grid connected test facility in Newport, Oregon, where small arrays of WECs can be tested as well.

2 Introduction

In 2009, the Northwest National Marine Renewable Energy Center (NNMREC), a partnership between Oregon State University (OSU) and the University of Washington (UW), was established through a competitively awarded project from the US Department of Energy (DOE) to support the development of marine energy technology through closing gaps in understanding of the technology, environmental effects, and socio-economic impacts of this new sector. With the goal of understanding and advancing the potential energy contribution from wave energy converters

(WECs), NNMREC developed a foundation from which to expand testing capabilities in the Pacific Northwest.

In 2009 and 2010, NNMREC was awarded funding through DOE for two Congressionally Directed Projects (CDPs); the results of those projects are discussed in this report. The core of the work in the CDPs was to build out NNMREC's non-grid connected open ocean test facility for WEC testing. This facility is known as the Pacific Marine Energy Center North Energy Test Site (PMEC-NETS). The project was structured around activities required to make NETS operational such as environmental and physical site characterization, regulatory and permitting activities. Once NETS was established, the project included a WEC deployment. This project accelerated research and development of the OSU mobile ocean test berth (MOTB), the Ocean Sentinel. In addition to Ocean Sentinel design and construction, the project focused on OSU research to fill knowledge gaps in the areas of wave characterization at the open ocean test site, marine biofouling and acoustics of WECs. In addition, this project advanced educational outreach and engagement activities associated with marine renewable energy and NNMREC.

Personnel support for testing operations was also included in the project. Personnel supported on the grant included NNMREC's: Ocean Test Facilities Manager, Test Engineer, Environmental Compliance Engineer, Project Manager, Director, Operational Manager, and all temporary personnel required for open-ocean WEC testing. At the time that the CDP was contracted, NNMREC leadership envisioned that WEC testing fees would cover personnel costs once the facility was operational. However, it appears that WEC developers do not have adequate funding to support WEC testing and are reliant upon 3rd party funding. Consequently, there has been only one WEC test at the site, partially supported through DOE funding to the developer, and partially funded through this project. Since that time, research into mooring systems and additional environmental studies have been done at NETS.

3 Background

In 2009, there were no full-scale open ocean WEC test facilities in the continental US. To fill the gap, NNMREC faculty at OSU developed the concept of a MOTB where developers could connect their WECs to a "grid surrogate" via an umbilical cable and characterize the performance of their WEC in the vigorous ocean climate off the coast of Newport, Oregon. To realize this vision for WEC testing, an ocean site needed to be identified, permitting and regulatory processes needed to be completed, and personnel needed to be hired. The tasks contributing to that vision were funded under this project.

When this project began, NNMREC had recently been created through a competitively awarded project from the DOE to support the development of marine energy technology through closing gaps in understanding of the technology, environmental effects, and socio-economic impacts of this new sector. The NNMREC team was composed of experts at OSU and UW in technical, environmental and social aspects of marine energy, and included a team at OSU that developed a scaled WEC prototype that they tested in September 2009 off the coast of Newport Oregon. One of NNMREC's project objectives was to develop integrated testing facilities. At OSU, NNMREC could bring to bear a Large Wave Flume and Directional Wave Basin that were ideal for scaled WEC testing, both of individual devices and of small arrays. With an eye toward ocean testing, NNMREC personnel had been active in community outreach and engagement to identify a site that would be suitable for WEC testing. Through the CDP, personnel were hired, the ocean site was characterized and developed, permits and licenses for testing were obtained, environmental effects were studied, and the first open ocean WEC test in a full-scale wave environment in the continental US was performed.

Specific tasks within this project included:

1. Accelerated development of facilities to serve as an integrated, standardized test Center for U.S. and international developers of wave and tidal energy;
2. Development of an Educational Outreach and Engagement Plan, with initial implementation of the plan;
3. Wave climate characterization of resource experienced by the WEC under test;
4. Research on marine biofouling resistant materials to evaluate the performance of various novel surfaces and coatings towards fouling in marine environments;
5. Characterization of marine acoustics to understand the noise levels that will be generated by WEC devices off the Oregon Coast
6. Hiring a part-time MOTB Program Manager for development and implementation of the commercial aspects of the Ocean Sentinel
7. Development of operational protocols for the Ocean Sentinel.
8. Continued stakeholder outreach contributing to Ocean Sentinel operations;
9. Characterization of environmental effects of Ocean Sentinel/WEC deployments in the open ocean.

The work and outcomes within these tasks will be discussed in the subsequent sections.

4 Results and Discussion

4.1 Task 1.0 Advancing Ocean Test Berth & Demonstration Site

In 2005, OSU began engaging the local ocean community of Newport, OR, to propose a wave energy testing facility in a cable-to-shore configuration. At that time, concerns were expressed regarding the invasiveness of the cable-to-shore (which off Oregon needs to be buried and horizontal drilled) before successful demonstration of wave energy testing and before the industry benefits and needs were better understood. Therefore, in 2006, OSU proposed the concept of a floating MOTB as a temporary, reduced-impact wave energy testing facility. In 2007, OSU was awarded $3M of funding from the Oregon Legislature toward the design and construction of the MOTB. With the establishment of NNMREC in September 2008, OSU sent the MOTB concept out for bid. In 2009, SAIC was selected as the contracting company, and the pre-design began in January 2010. Nine months later, a pre-design for a 500 kW floating MOTB was completed. Unfortunately, due to the size and flexibility characteristics of the power cable from the floating MOTB to the WEC under test, challenges remained to find a solution for stability and survivability issues. After review of the challenges associated with the design, installation, and costs of the MOTB at the 500 kW scale, NNMREC determined it was prudent to reconsider the MOTB scale and design process. Thus, NNMREC assembled a group of outside experts to review the alternatives (and components of the alternatives) and provide expert feedback to consider in planning the path forward. NNMREC was recommended to pursue a phased test facility process toward a cable-to-shore based test berth, with Phase 1 as follows:

PHASE 1 - Now completed and branded as PMEC-NETS (North Energy Test Site):
Phase 1a: Developed Permitted Open Ocean Test Site
Phase 1b: Developed Testing Protocols for Open Ocean Testing
Phase 1c: Built 30 kW Power Analysis and Data Acquisition (PADA) system for operation from on vessels, and a 100kW stand-alone MOTB (which became the "Ocean Sentinel")

For the stand-alone MOTB, Ocean Sentinel, for WEC ocean testing, NNMREC completed a detailed "Specifications and Requirements" document for sending out as a "Request for Quote", and two strong approaches were investigated for this process: 1) collaborating with custom buoy manufacturers for the system integration, 2) working with EMEC and the developers of their scaled wave energy testing buoy for their nursery site. In an effort to increase collaboration opportunities with EMEC, NNMREC first investigated working with a developer of EMEC's scaled wave energy testing buoy for their nursery site. Through these investigations it was found that the developer was not able to provide the information requested, and unable to move forward with the project.

NNMREC then continued with approach (1) above - collaborating with custom buoy manufacturers for the system integration. Having investigated several potential buoy designs, NNMREC determined that the 6m Navy Oceanographic Meteorological Automatic Device (NOMAD) buoy was the best match for the Ocean Sentinel application. The west coast supplier of these buoys, who also provides the NOAA NDBC buoys, is AXYS Technologies Inc., located in Sidney, British Columbia, Canada. Thus, NNMREC contracted with AXYS Technologies to provide the 6m NOMAD hull, and NNMREC researchers worked through the design and development processes for the systems integration to enable WEC testing. The systems that needed to be integrated into the Ocean Sentinel for WEC testing included the switch gear, converter, load banks and telemetry system, as well as the mounting structures for the umbilical cable. For the umbilical cable, a specifications and bid request process was completed and the contract was awarded to 3U Technologies headquartered in Conroe, Texas. Two umbilical cable systems were procured, namely a lower power cable (20 kW) for testing lower power (scaled) devices, and a full capacity cable (100 kW). The lower power cable was used in the 2012 testing of the WET-NZ device. The initial Ocean Sentinel mooring design was developed by AXYS Technologies and then reviewed by Sound and Sea Technologies, who also designed the mooring system for the WET-NZ WEC.

The Ocean Sentinel is a stand-alone instrumentation buoy using the 6m NOMAD hull, with the wave energy equipment and instrumentation installed. A concept diagram of the Ocean

Sentinel instrumentation buoy testing a WEC is shown in Figure 1, where the 2012 deployment is shown in Figure 2 and the Ocean Sentinel is shown in Figure 3.

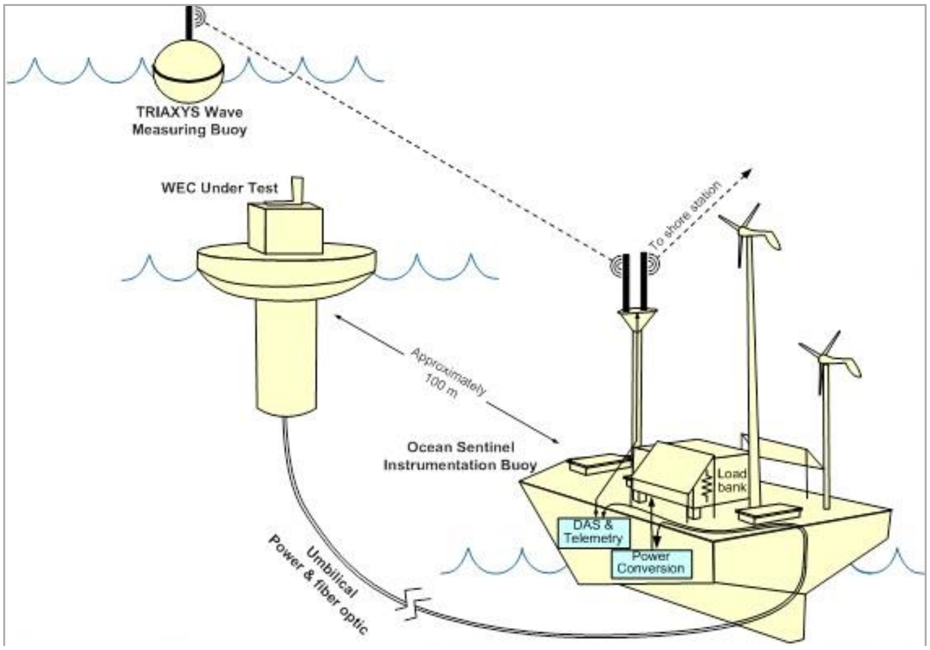

Figure 1 WEC Testing with Ocean Sentinel Instrumentation Buoy.

Figure 2 2012 Deployment of Ocean Sentinel

Figure 3 Ocean Sentinel Instrumentation Buoy on Station.

WECs under test are moored approximately 125 meters from the Ocean Sentinel, connected by the power and communication umbilical cable. Power generated by the WEC is controlled by the switch gear and power conversion equipment located on board the instrumentation buoy (1st hull compartment of 4) and dissipated in the onboard load bank. Data is transmitted from the WEC under test to the instrumentation buoy via the umbilical cable. Wave data recorded by wave measurement buoys is also transmitted to the Ocean Sentinel, via wireless telemetry.

The primary functions of the Ocean Sentinel instrumentation buoy are as follows:

- Provide stand-alone electrical loading and power conversion for the WEC under test.
- Measure and record WEC power output.
- Collect and store data transmitted from both the WEC under test and a wave measurement buoy moored nearby.
- Transmit collected data to a shore station via a wireless telemetry system.
- Conduct environmental monitoring.

The Ocean Sentinel power conversion and load bank system provides a stand-alone load for the WEC under test. This system provides generator control for WECs in early stages of development that do not include onboard generator power conversion. A switchgear enclosure that includes the contactors along with an electrical disconnect, current and voltage sensors, and fuses is installed below deck in the forward compartment of the Ocean Sentinel, together with the power converter. Two 50 kW, air-cooled load banks are installed above deck. This system is controlled by a National Instruments CompactRIO based data acquisition system developed by NNMREC, which is also used to record WEC power and measured wave data.

Because NNMREC anticipates testing WECs with different power outputs and generator configurations, the Ocean Sentinel loading system has been designed for a high degree of flexibility and is reconfigurable via terminations in the switchgear enclosure. The air cooled load banks can be reconnected for different voltage and power levels, and can be controlled by either contactor switching, converter control, or a combination of the two. WECs with output current to 125 A continuous can be accommodated, for a power capability of 100 kW at 460 V or 50 kW at 230 V.

An onboard power system developed by AXYS Technologies can supply up to 400W of 24 Vdc and 120 Vac power to the instrumentation and power conversion equipment installed on the Ocean Sentinel, and to the WEC via the umbilical. Primary power is provided by 40x sealed lead acid batteries (2000 Amp-hours at 24V), which are maintained through the use of a 1 kW wind generator, 2x 210 W solar panels and a 3.2 kW standby diesel generator. The solar and wind generation are designed to provide the primary battery support required during normal operations, and sufficient battery storage is included for typical periods when this generation is not adequate (based on Newport, Oregon summer characteristics). The generator can be relied upon to provide backup power if required, and is designed for 3-month minimum deployment periods without the need for refueling, though the system is designed to allow refueling at sea. The Ocean Sentinel power system is controlled and monitored by a Watchman 500 data acquisition and control system.

Two independent cellular telemetry systems are used between the Ocean Sentinel and shore, one for the Watchman 500 that controls and monitors the power system, and the other for the CompactRIO system that provides control and data acquisition for WEC testing.

Appendix A contains further information for the 2012 and 2013 deployments including recovery processes.

Deliverables

- Hired NNMREC Test Engineer to assist with management of the research and development of the wave energy ocean test berth system.
- Assessed deployment, performance and operation of NNMREC's first full scale MOTB, the Ocean Sentinel (described in section 4.1).
- Comprehensive technical details on the Ocean Sentinel are provided in associated paper: A. von Jouanne, T. Lettenmaier, E. Amon, T. Brekken, R. Phillips, "A Novel Ocean Sentinel Instrumentation Buoy for Wave Energy Testing", Marine Technology Society (MTS) Journal, January/February 2013

4.2 Task 2.0 NNMREC Educational Outreach and Engagement

Through our partners at Oregon Sea Grant, a Marine Renewable Energy Education Outreach and Engagement Plan was developed. It outlines educational needs, target audiences, and the methods and outcomes for informing and engaging the public about marine renewables. Additionally, on-going PI engagement was reported quarterly.

Deliverables

The following documents have been uploaded to the EERE site:

- Marine Renewable Energy Education Outreach and Engagement Plan
- Oregon's Non-Consumptive Recreational Ocean User Community – Understanding an ocean stakeholder
- Science and Knowledge Informing Policy and People: The Human Dimensions of Wave Energy Generation in Oregon
- On-going quarterly reporting

4.3 Task 3.0 Wave Measurements

This task included measurements of the wave and current climate experience during open-ocean tests at the PMEC-NETS site in 2012 and 2013.

The 2012 deployment involved testing of the WET-NZ WEC with the Ocean Sentinel. As discussed in section 4.1, during this test from August through October 2012, a TRIAXYS Wave and Currents measurement buoy by AXYS Technologies was deployed for the measurement of the waves and currents at the testing site experienced by the device under test. The TRIAXYS is a surface wave measurement buoy that includes a downward pointing Acoustic Doppler Current Profiler (ADCP) for measuring ocean currents. Data was recorded in continuous 20-minute intervals during the test, with statistical data sent to shore in real-time via cellular telemetry and time-series data stored onboard. Recorded data includes time-series wave height and directional wave spectra, in addition to directional ocean current measurements binned by depth.

In 2013, the Ocean Sentinel was deployed from July through October at PMEC-NETS to perform a mooring characterization study as discussed in section 4.1, comparing actual mooring performance, measured with inline load cells, with that predicted by mooring simulations performed during the Ocean Sentinel design process. To capture the wave climate that the Ocean Sentinel experienced, two wave and current measurement devices were deployed for redundancy. These included a TRIAXYS buoy, deployed with the data acquisition configuration detailed above, and a bottom-mounted Nortek Acoustic Wave and Current (AWAC) profiler. The AWAC is an ADCP, which was mounted on a trawl-resistant bottom mount (TRBM) from Mooring Systems Incorporated. The AWAC is deployed on the sea floor pointing upward to measure directional wave spectra and currents binned by depth every hour. Current speed and direction are measured along a vertical transect from near-bottom to the near-surface. The AWAC stores data on-board and was retrieved upon instrument retrieval at the end of the deployment.

Data collected during the 2012 and 2013 deployments are presented in the following papers (available on our website):

- T. Lettenmaier, A. von Jouanne, E. Amon, S. Moran, A. Gardiner, “Testing the WET-NZ Wave Energy Converter using the Ocean Sentinel Instrumentation Buoy”, Marine Technology Society (MTS) Journal, July/August 2013.
- A.von Jouanne, T. Lettenmaier, E. Amon, S. Moran, “Wave energy testing using the Ocean Sentinel Instrumentation Buoy”, 6th Global Marine Renewable Energy Conference: Marine Energy Technology Symposium, 2013.
- J. Baker, S.C. Yim, E. Amon, S. Moran, T. Lettenmaier, A. von Jouanne, “Mooring Analysis of a NOMAD buoy through experimental and numerical testing”, OMAE Conference, 2014.
- J. Baker, S.C. Yim, E. Amon, T. Lettenmaier, A. von Jouanne, “Numerical and Experimental Analysis of the Ocean Sentinel Instrumentation Buoy Mooring System to Enable Improved Modeling and Design”, GMREC-METS, 2014.
- Garcia-Medina, G., Özkan-Haller, H.T., Ruggiero, P., Wave Energy Resource Characterization in Oregon and Southwest Washington, *Renewable Energy,* 64, 203-214.

Deliverables:

The following documents have been uploaded to the EERE site:

- B. Cahill, “Wave Measurement and Analysis at the Pacific Marine Energy Center North Energy Test Site (PMEC NETS)” 2014.
- J. L. Baker, “Mooring Analysis of the Ocean Sentinel through Field Observation and Numerical Simulation” M.S Thesis, Oregon State University, November 2013.

4.4 Task 4.0 Marine Biofouling Resistant Materials

Following a comprehensive literature search on testing methodology of biofouling prevention coatings, including accelerated testing procedures, the most important literature being summarized in the Biofouling Prevention Coatings Test Facility document (see Appendix), our work focused on developing a testing platform suitable to examine the accelerated aging rate of degradation of Cu/biocide based biofouling prevention coatings. Because the aging mechanism of these coatings is complex, including both copper ion and synthetic organic biocide leaching from the paint matrix, as well as rate of hydrolysis of the polymeric matrix (for self-ablating coatings), the best methodology determined requires a) increased temperature (to increase the transport rate of the organic biocide through the coating matrix and increase rate of coating ablation by hydrolysis), and b) decreased pH (to increase the rate of Cu(II) ion leaching from the coating). Naturally, due to the increased chemical and environmental load resulting from these requirements, it was preferable to operate the testing as a closed loop, rather than in open flow mode. For the purpose of accelerated testing suitable water tanks, pumps, heaters and ancillary control equipment was acquired and used to build the test platform. Characterization was carried out by optical microscopy and spectroscopic analysis. It was also determined that optimally, the characterization suite would include an FT-IR or Raman microscope/spectrometer (FT-IR = Fourier Transform InfraRed Spectroscopy) to measure local concentrations of remaining biocide within the polymer matrix, and a hyperspectral Visible light microscope, to measure changes in Cu concentration. Both these pieces of equipment are prohibitively expensive to acquire on the budget available, and other instrumentation available at the OSU campus was employed. Testing of representative materials was carried out in the lab, and comparison with samples exposed to the environment demonstrated an acceleration factor of ca. 24x for some of the testing conditions employed.

Samples of coatings not envisioned for testing in this context, such as superslick coatings, were also exposed to the environment at the request of WEC developers. Observations show that these coatings do rapidly become colonized, but that with sufficient water shear, these organisms can be detached. No clear methodology to evaluate the performance of these coatings as a function of aging has been determined by the end of the project period of performance.

Publications:

- A. von Jouanne, T. Lettenmaier, E. Amon, S. Moran, M. Bunn, A. Yokochi, "Wave Energy Testing Using the Ocean Sentinel Instrumentation Buoy Including Testing of Materials and Technologies for Bio-Fouling Resistant Surfaces", Ocean Energy Special Issue of the Shore and Beach Journal, 2013.
- Bamaga, O.A.; Yokochi, A.; Zabara, B.; Babaqi, A.S. "Hybrid FO/RO desalination system: Preliminary assessment of osmotic energy recovery and designs of new FO membrane module configurations" Desalination 2011, 268, 163-169.
- O.A. Bamaga, A. Yokochi, E.G. Beaudry "Application of forward osmosis in pretreatment of seawater for small reverse osmosis desalination units" Desalination Water Treatment 2009, 5, 183–191.
- M. Bunn, A. Yokochi, A. von Jouanne, Electrochemical Antifouling Technology for Replacement of Heavy Metal and Organic Biocides in Marine Hydrokinetic Energy Generation, SusTech 2014, July 2014.
- von Jouanne, T. Brekken, E. Amon, M. Bunn, A. Yokochi, "Wave Energy Research, Development and Testing Including Testing of Materials and Technologies for Bio-Fouling and Corrosion Prevention", OTC 2014, Houston, TX, May 8th, 2014.
- von Jouanne, J. Baker, S.C. Yim, E. Amon, S. Moran, T. Letternaier, M. Bunn and A. Yokochi. (2014) "Wave Energy Research, Development and Testing Including Testing of Materials and Technology for Bio-Fouling and Corrosion Prevention," Offshore Technology Conference, Houston, TX, USA, May 5-8, 2014, in press.

Additional publications are in preparation:

- J. Pommerenck, A. von Jouanne, A. Yokochi "Electric Fields Induced by Power Transport in Seawater", paper in preparation for submission to the IEEE Transactions in Ocean Engineering
- M Bunn, M Delaney, A. Yokochi, "Potential and current requirements for electrochemical bio-fouling prevention on marine environment surfaces", in preparation for submission Biofouling
- M Bunn, A. Yokochi, "An electrochemical reaction engineering model for the electrochemical biofouling prevention of marine surfaces", in preparation for submission to Journal of the AIChE.
- M Bunn, A. Yokochi, "Initial evaluation of the operational lifetime of electrochemical biofouling prevention coatings in marine environments by accelerated aging", in preparation for submission to International Journal of Marine Energy.

4.5 Task 5.0 Acoustic Characterization Study

This task initiated research in support of two broader, longer range research initiatives. Additional funds will be sought for the completion of the research in both subtasks.

4.5.1 Task 5.1 Acoustic Background

This task focused on obtaining continuous and adaptive long-term passive measurements of ambient sound levels across a broad frequency range within a shallow water site (50m) on the central Oregon coast near the Port of Newport and during the first wave energy test at PMEC-NETS off the coast of Newport, Oregon. The publications noted in the deliverables section (and available on the NNMREC website) provide a full account of the deliverable completion.

Deliverables:

- S. Henkel, J. Haxel, A. Schultz, A. Hofford, "2012 Annual Operations & Operations & Monitoring Report: North Energy Test Site".
- J. Haxel, R. Dziak, H. Matsumoto, "Observations of shallow water marine ambient sound: The low frequency underwater soundscape of the central Oregon coast". Journal of the Acoustical Society of America. 133:2586-2596. Initial acoustic measurements of ambient marine sounds, 2013.

4.5.2 Task 5.2 Acoustic Deterrence

This task initiated the research and actions required to obtain a Marine Mammal Protection Act (MMPA) Research Permit allowing the intentional harassment of gray whales. Two studies were conducted to determine whether a low-powered sound source could be effective at deterring gray whales from areas that may prove harmful to them. With increased interest in the development of marine renewal energy along the Oregon coast the concern that such development may pose a collision or entanglement risk for gray whales. A successful acoustic deterrent could act as a mitigation tool to prevent harm to whales from such risks.

In the initial study, an acoustic device was moored on the seafloor in the pathway of migrating gray whales off Yaquina Head on the central Oregon coast. Shore-based observers tracked whales with a theodolite (surveyor's tool) to accurately locate whales as they passed the headland. Individual locations of different whales/whale groups as well as track lines of the same whale/whale groups were obtained and compared between times with the acoustic device was transmitting and when it was off. Observations were conducted on 51 days between January 1 and April 15, 2012. A total of 143 individual whale locations were collected for a total of 243 whales, as well as 57 track lines for a total of 142 whales. Inclement weather and equipment problems resulted in very small sample sizes, especially during experimental periods, when the device was transmitting. Because of this, the results of this study were inconclusive. Therefore, another season of field testing was conducted the following year from January to mid-April 2013 with a theodolite (surveyor's tool) to accurately locate whales as they passed the headland. Individual locations as well as track lines of whales/whale groups were obtained and compared between times when the acoustic device was transmitting and times when it was off. As in the 2012 study, an acoustic device was moored on the seafloor in the pathway of migrating gray whales off Yaquina Head on the central Oregon coast. Shore-based observers tracked whales

The sound signal in 2013 included both a warble and a buzz signal (only a warble signal was used in 2012), as well as an increased amplitude, from 170 dB_{RMS} re 1 µPa in 2012 to 179 dB_{RMS} re 1 µPa in 2013. The goal of the amplitude increase was to increase the size of the hypothesized zone of influence from 500 m to 3 km around the deterrent, with the aim of having a sufficient number of whales passing through this zone for statistical analyses.

Observations were conducted on 43 days from January 4 – April 17, 2013. A total of 241 locations were collected during 99 scans, representing 403 whales and 68.7 scan hours. A total of 120 focal follows were conducted on groups ranging in size from 1-6 whales. An additional 45 gray whales/groups were located opportunistically. Basic migratory characteristics, such as migration timing, distances to shore, and travel speeds were similar between the two years.

Distances to the observation station longitude (as a proxy for distance to shore) and bottom depths of whale locations were not significantly different between southbound and the first phase of northbound migration (Phase A). Travel speeds, on the other hand, were significantly different between the two migration phases, with southbound whales being faster than northbound Phase A whales.

The proportion of experimental (deterrent ON) whale locations to total whale locations was not significantly different between our hypothesized zone of influence (within 3 km of the deterrent) and areas further from that zone. Thus, the sound signal did not seem to deter whales as we had hypothesized. The proportions were also not different when larger zones of influence were considered, such as 0-4 km and 0-5 km from the deterrent.

Distance to station longitude, however, was significantly different between experimental and control periods, with whales being closer to shore when the deterrent was on than when it was off. This significant relationship was driven by two out of ten days with both experimental and control periods (January 11 and March 29). There was no significant difference in whale travel speed between experimental and control periods.

While this study suggests a slight deterrent effect in some cases, it was not the desired effect. Our objective was to deflect gray whale movement minimally to either side of the deterrent. We did not intend to direct that movement unilaterally toward shore. While such an effect would not exclude gray whales from preferred feeding habitat close to shore or block their migration, it may put them at risk from coastal development or increased vessel traffic in nearshore areas. More work is needed to determine an acoustic signal that is both effective and safe for gray whales.

Deliverables

The following documents have been uploaded to the EERE site:

- National Marine Fisheries Service issued Permit No. 15483 on November 1, 2010 to take protected species for scientific purposes

Publications:

- B. Lagerquist, M. Winsor, and B. Mate, "Testing the effectiveness of an acoustic deterrent for gray whales along the Oregon Coast", Oregon State University Marine Mammal Institute, December 2012.
- B. A. Lagerquist, M. H. Winsor, H. Klinck, B. R. Mate, "Testing the Effectiveness of an acoustic deterrent for Eastern North Pacific gray whales along the Oregon coast", Oregon State University Marine Mammal Institute, December 2013.

4.6 Task 6.0 MOTB Project Manager

The MOTB Program Manager was responsible for development and implementation of the commercial aspects of the MOTB. Primary responsibilities of this person included: updating and implementing the MOTB Business Plan; with assistance from NREL, developing and manage a plan for test berth accreditation; collaborating with NNMREC researchers on projects associated with the MOTB, MOTB site environmental effect/impacts, MOTB site monitoring; developing and implementing a marketing plan; securing and maintaining insurance and bonding for MOTB; contracting with WEC device developers; managing of intellectual property agreements between NNMREC and WEC device developers; and interfacing with other marine testing centers.

Deliverables:

The following documents have been uploaded to the EERE site:

- Specifications and Requirements – Scaled MOTB
- Specification and Requirements – Umbilical Cable, Ocean Sentinel Instrumentation Buoy
- Business Plan for NNMREC's Mobile Ocean Test Berth
- NNMREC Collaboration and Intellectual Property Protection Plan

4.7 Task 7.0: Advancing Mobile Ocean Test Berth – Operations

This task consisted of development and execution of operational readiness plans for the Ocean Sentinel. NNMREC hired an Ocean Test Facilities Manager for day-to-day management of the Ocean Sentinel including planning, implementing, administering and supervising marine operations. This position served as the main point of contact for marine related issues for the Ocean Sentinel.

Deliverables:

The following documents have been uploaded to the EERE site:

- Hired Ocean Test Facilities Manager – Feb 2012.
- Guidelines for Open-Water Testing of Wave Energy Converters
- Open Water Testing Plan (generic) for NNMREC

- OSU Wave Energy Salvage Plan and Emergency Response
- Ocean Sentinel Maintenance

4.8 Task 8.0: MOTB Outreach/Education

Using the Marine Renewable Energy Education Outreach and Engagement Plan developed by Oregon Sea Grant as a guide, this task expanded NNMREC's initial outreach efforts to diverse community members to engage them in the Ocean Sentinel development. The Fishermen Involved in Natural Energy (FINE) committee became a tremendous partner in the mobile ocean test berth. Specific tasks that FINE was helpful in included:

- Selecting location for mobile ocean test berth
- Assisting with deployment of devices,
- Assisting in periodic checks on devices especially after incremental weather
- Helping "get the word out" to the fishing industry (both in Newport and outside of Newport) about deployments and use of the mobile ocean test area

Other groups engaged in outreach and education included (not a comprehensive list): Lincoln County Board of Commissioners

- City of Newport
- Port of Newport
- Port of Toledo
- Surfrider Foundation
- Lincoln County Planning Department
- Oregon Coastal Zone Management Association
- Confederated Tribes of Siletz Indians
- Lincoln County School District
- Recreational Fishing Alliance
- Fishermen's Advisory Committee for Tillamook
- Southern Oregon Ocean Resource Coalition
- FISHCRED
- Oregon Fishermen's Cable Committee

The NNMREC ocean test berth committee was also formed to give direct stakeholder feedback to NNRMEC PI's about the open ocean test berth. This committee included members of all ocean uses near the test berth, local governments, independent research, and community at large.

Deliverables

Engagement activities were submitted throughout the grant in the quarterly reports.

4.9 Task 9.0: MOTB Environmental Studies

Ecological and environmental studies at the PMEC-NETS were conducted to characterize and analyze potential impacts of marine energy infrastructure and devices on the marine ecosystems. The body of this work is presented in the following documents that have been uploaded to the EERE site.

Deliverables

- North Energy Test Site Annual Operations & Monitoring Report 2012
- PMEC NETS Annual Operations & Monitoring Report 2013

4.10 Task 10.0 Project Management and Reporting

All reports have been submitted according to the Federal Assistance Reporting checklist.

5 Accomplishments

Project accomplishments include publications and presentations that are available on our website: http://nnmrec.oregonstate.edu/biblio and documented in the Accomplishments and Impacts report compiled May 2013 (see appendix B).

6 Conclusions

Through the work and deliverables completed under these tasks, NNMREC has: developed an operational non-grid connected full wave resource open-ocean test facility for utility scale WECs off the coast of Newport Oregon, PMEC-NETS; constructed a mobile ocean test buoy, the Ocean Sentinel, for WEC testing; performed environmental characterization and monitoring of a WEC test at NETS and subsequent mooring study. The work supported under this task can be leveraged in several ways. The NETS facility provides a resource for WEC developers to prove their technologies, and environmental effects knowledge can be applied to other devices. The permitting structure at NETS facilitates device testing through existing permitting and licensing frameworks established by NNMREC in the WET-NZ test. The Ocean Sentinel design has been distributed to other testing organizations including the operators of Galway Bay ¼ scale site and to WavEC in Portugal. The Biological Assessment and Environmental Assessment documents were shared with the Hawaiian National Marine Renewable Energy Center as they were working to develop the WETS facility at Kaneohe Bay. Knowledge gained through establishing the NETS site is being leveraged to develop the grid-connected PMEC-SETS in Newport, Oregon.

7 Recommendations

Through this project, NNMREC successfully completed two seasons of WEC testing and research. This experience improved understanding for future needs to processes, capabilities, and equipment. Needs for future ocean testing operations include:

Scope projects, procure equipment, and begin planning as early as possible. It is recommended that planning begin at least one year prior to deployment. Reinforce relationships with existing critical supply chain resources, and seek to bolster the supply chain for future needs (maritime, ports, personnel).

- Advocate for enhanced maritime and port capabilities

Design or devise mooring systems that are capable of multiple seasons at sea with minimal maintenance. This may require different anchoring and mooring technologies, and could require specialized ROV equipment for inspections and maintenance.

- Devise safe, effective, and reliable methods for deploying and recovering of heavy components, including anchors, OS yoke, and tensioning / de-tensioning mooring lines. Improved vessel capability that will enable controlled placement of anchors is very desirable.
- Devise a safe, effective, and reliable method for deploying and recovering power and communications cables at sea. This will likely require the procurement of custom equipment, designed specifically for marine cable handling.
- Develop project plans that minimize, or negate the need for diving operations. Diving activities are currently utilized during equipment recovery and for subsurface inspections.
- Lastly, until the industry has the capacity to fund testing itself and provide a steady stream of fees to the test facility, DOE will need to continue to fund testing personnel in order for the facility to stay operational.

8 References

1. Marine Renewable Energy Education Outreach and Engagement Plan, Oregon Sea Grant, 2009.
2. "Oregon's Non-Consumptive Recreational Ocean User Community – Understanding an ocean stakeholder", C. Eardley and F. Conway, 2011.
3. "Science and Knowledge Informing Policy and People: The Human Dimensions of Wave Energy Generation in Oregon", Oregon State University, September 2009.
4. "Wave Measurement and Analysis at the Pacific Marine Energy Center North Energy Test Site (PMEC NETS)", B. Cahill, 2014.
5. "Mooring Analysis of the Ocean Sentinel through Field Observation and Numerical Simulation", JL Baker, M.S. Thesis, Oregon State University, November 2013. November 2013.
6. National Marine Fisheries Service issued Permit No. 15483, (Take Protected Species for Scientific Purposes), November 2010.
7. "Testing the effectiveness of an acoustic deterrent for gray whales along the Oregon Coast", B. Lagerquist, M. Winsor, and B. Mate, Oregon State University Marine Mammal Institute, December 2012.
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9. “Specification and Requirements – MOTB”, Northwest National Marine Renewable Energy Center, Oregon State University, 2011.
10. “Specification and Requirements – Umbilical Cable, Ocean Sentinel Instrumentation Buoy”, Northwest National Marine Renewable Energy Center, Oregon State University, 2012.
11. Business Plan, Mobile Ocean Test Berth
12. NNMREC Collaboration and Intellectual Property Protection Plan, Oregon State University, 2011.
13. Guidelines for Open-Water Testing of Wave Energy Converters, prepared for NNMREC, October 2013.
14. Open Water Testing Plan for the Wav-Wall 2000*, Northwest National Marine Renewable Energy Center, Oregon State University, July 2013.
15. OSU Wave Energy Salvage Plan and Emergency Response, Oregon State University, Electrical Engineering and Computer Science, C. Fletcher, June 2008.
16. Ocean Sentinel Maintenance, Nomad User Manual, Oregon State University, June 2012.
17. North Energy Test Site Annual Operations and Monitoring Report, Northwest National Marine Renewable Energy Center, Oregon State University 2012.
18. PMEC NETS Annual Operations and Monitoring Report, Northwest National Marine Renewable Energy Center, Oregon State University 2013.

9 Appendix A

Ocean Sentinel 2012 Deployment for WEC Testing

The Ocean Sentinel was deployed for the first time in August-September 2012 for the testing of a half-scale WEC, the WET-NZ device, which is the acronym for “Wave Energy Technology-New Zealand”. The Ocean Sentinel and WEC were moored at NNMREC’s PMEC-NETS open-ocean test site north of Newport, OR, for a six week period from August 22, 2012 until October 5, 2012 while the testing was performed. The WET-NZ device, shown during the deployment of the umbilical cable in Figure 4, is a self-reacting WEC that generates power through the rotation of an active float relative to a large submerged spar. The Ocean Sentinel power converter was used to control the electrical generator on board the WET-NZ device via the umbilical cable throughout these tests. This allowed WEC performance to be characterized while operating in several different control regimes and under a variety of sea conditions.

Figure 4 Deployment of the umbilical cable connecting the WET-NZ device under test to the Ocean Sentinel at NNMREC's open-ocean test site north of Newport, OR.

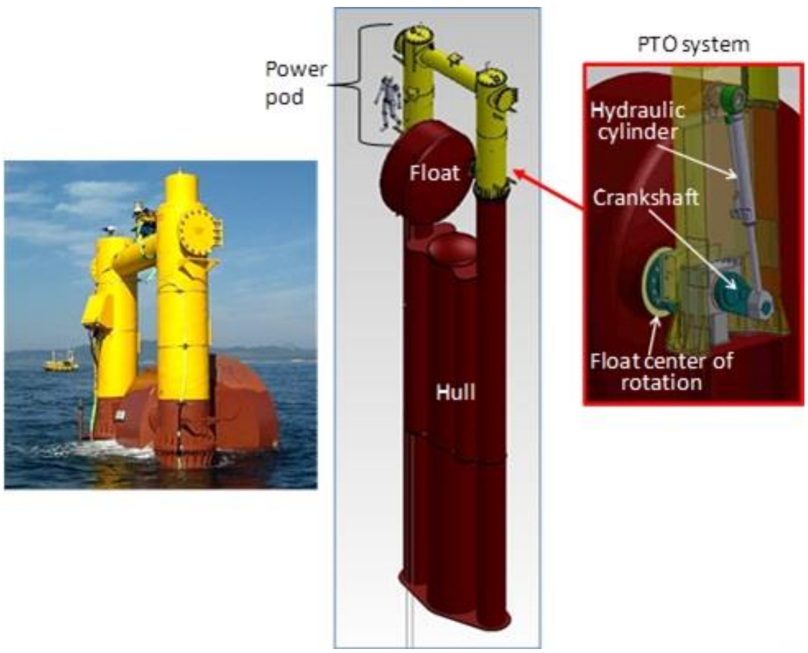

Figure 5 WEC Testing with Ocean Sentinel Instrumentation Buoy.
The WET-NZ Wave Energy Converter.

The WET-NZ tests had a number of objectives, as follows:

1. To deploy in open-ocean for the first time in US waters, demonstrate and characterize the performance of the WET-NZ concept at half scale.
2. To demonstrate operation of the Ocean Sentinel, and to gain experience testing a WEC with the Ocean Sentinel.
3. To gain experience deploying both the Ocean Sentinel and a WEC in the ocean.
4. To perform environmental monitoring during ocean testing of a WEC.

Another photo of the half-scale WET-NZ at sea with the Ocean Sentinel in the background is shown in Figure 5 together with a solid model rendering of the device and its power takeoff (PTO) system. The WET-NZ device tested was the product of a research consortium between Callaghan Innovation, a New Zealand Crown Entity, and Power Projects Limited (PPL), a Wellington, New Zealand private company. The Oregon deployment was project managed by Northwest Energy Innovations (NWEI), a Portland, OR firm. The device tested in 2012 was half-scale by length; output power scaling per the Froude similitude criteria was 1/11 relative to a nominal full scale device. (A full scale WET-NZ device is projected to operate across the full wave spectrum present in the open ocean.) The WET-NZ consists of a long submerged hull, with a power pod mounted on top that includes a cylindrical float and the PTO system. The hull of the half-scale WET-NZ tested with the Ocean Sentinel was fabricated at Oregon Iron Works in Portland, OR, and the Power Pod was fabricated and assembled in New Zealand.

The float of the WET-NZ is coupled through its shaft to the PTO system and rotates up and down in the waves to generate power. The WET-NZ is designed to be a slack-moored, self-reacting design; the hull is flooded with seawater to give it a large inertia for the float to react against. The natural period of the half-scale WET-NZ spar, which consists of the entire device other than the float, is 15 seconds, and the natural period of the half-scale float is 3.5 seconds. Due to these natural periods, Callaghan Innovation simulations predicted that the half-scale device would not generate significant power for portions of the wave spectra with periods longer than approximately 9 seconds. A full-scale device, however, is expected to have longer natural periods and to produce power from longer period waves.

The PTO system for the WET-NZ is shown in Figure 5**Error! Reference source not found.**, where a crankshaft that connects to the shaft of the float extends and retracts hydraulic cylinders. The hydraulic cylinders provide pressure to a hydraulic system that includes a hydraulic motor and a small accumulator. The hydraulic motor drives the permanent magnet generator that was controlled by the Ocean Sentinel power converter during the test. The hydraulic drive is configured such that the generator only rotates in one direction. An accumulator provides a selected amount of energy storage within the hydraulic system, so that the generator speed and torque do not necessarily decrease to zero when the shaft of the float reverses direction twice per ocean wave cycle.

Comprehensive technical details on the 2012 testing of the WET-NZ WEC with the Ocean Sentinel are provided in the attached paper:

T. Lettenmaier, A. von Jouanne, E. Amon, S. Moran, A. Gardiner, “Testing the WET-NZ Wave Energy Converter using the Ocean Sentinel Instrumentation Buoy”, Marine Technology Society (MTS) Journal, July/August 2013.

Ocean Sentinel Recovery Process

At the completion of the six-week testing period, all equipment was removed from the PMEC-NETS. During the second week of October, 2012, the Ocean Sentinel, umbilical cable, TRIAXYS wave measurement buoy and mooring, and the four corner-marker buoys and their moorings were recovered using the OSU research vessel RV Pacific Storm (see Figure 5 - Figure 8). Immediately following recovery of OSU's equipment from the test site, the NWEI team utilized a diving team, and tug service provider, from the RV Elahka, to recover the WET-NZ device from the PMEC-NETS. Once all equipment was removed, the anchors and anchor marker buoys were ready for recovery operations utilizing the salvage vessel the NRC Quest (see Figure 10).

The umbilical cable, TRIAXYS wave measurement buoy and its mooring, and corner-marker buoys and moorings were cleaned and transported back to Corvallis, OR, for storage. The Ocean Sentinel was towed back to the Toledo Boatyard for cleaning, data and equipment recovery, and short-term storage. Figure 11 shows the Ocean Sentinel after being removed from the water at the Toledo Boatyard. Post-deployment maintenance of the Ocean Sentinel was completed at OSU Ship Ops and at the Toledo Boatyard. The raw time-series wave data was retrieved from the TRIAXYS wave measurement buoy and processed. In addition, TRIAXYS wave spectral and statistics data collected throughout the deployment was analyzed to produce binned plots.

Figure 6 Ocean Sentinel being towed back to OSU Ship Ops by the RV Pacific Storm.

Figure 7 Recovered umbilical and corner-marker buoys.

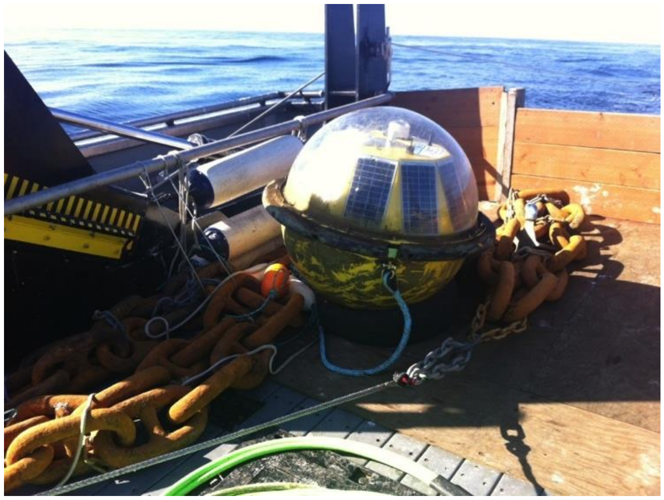

Figure 8 Recovered TRIAXYS wave measurement buoy and mooring on deck.

Figure 9 NRC Quest deck winches (center) and Ocean Sentinel concrete anchors (left).

Figure 10 NRC Quest during anchor recovery with yellow anchor-marker floats onboard

Figure 11 Ocean Sentinel at the Toledo Boatyard

Ocean Sentinel 2013 Deployment /Recovery for Mooring Systems Study

a. Planning

Experiences gained through successful 2012 testing operations resulted in the implementation of various modification and changes to the 2013 testing operations, including:

- New methods for tensioning mooring lines and lifting the Ocean Sentinel bow mooring yoke.
- New method for recovery of the Ocean Sentinel, including the disconnection of the mooring system.
- Leaving Ocean Sentinel anchors and anchor buoys at sea for the winter to study maintenance cycle requirements and the effects of long term anchor deployments.
- Deployment of a new Acoustic Wave and Current (AWAC) profiler.
- Integration of load cells into each of the Ocean Sentinel mooring lines.

b. Collaboration

The OSU community and industry relationships built over the past two years were leveraged to support 2013 testing operations, with the involvement of 5 units at OSU, 11 private industry groups, and 30 individuals with broad knowledge and expertise.

OSU Collaborations:

Hatfield Marine Science Center (HMSC), OSU Ship Operations (Ship Ops), Marine Mammal Institute (MMI), College of Earth, Oceanographic, and Atmospheric Sciences (CEOAS), OSU Risk, Ocean Observing Initiative (OOI), Oregon Sea Grant (OSG), Fishermen Involved in Natural Energy (FINE).

Industry Collaborations:

AXYS Technologies, Port of Toledo, Port of Newport, Pacific Energy Ventures, LLC (PEV), 3U Technologies, LLC (3U), Nortek AS, Sensing Systems Co., Ocean Innovations, Inc., Mooring Systems, Inc. (MSI), Englund Marine, Wiggins Tug & Barge, others.

c. Procurement and Integration of Equipment

Operations for 2013 required the procurement and integration of new equipment, including an AWAC and mooring line load cells. Existing equipment was modified to support the tests, including Ocean Sentinel data acquisition and control systems. The project required a new look at all aspects of past operations to ensure that new equipment would be safely and effectively utilized in the project.

d. Commissioning, Staging and Deployment

Newly integrated equipment was calibrated and revised deployment and recovery methods were developed to accommodate the new equipment. The load cells were calibrated and tested in dry dock to ensure proper operation. General systems were inspected and readied for deployment.

The experimental mooring testing was conducted with the Ocean Sentinel from July 29th to October 4th, 2013. The Ocean Sentinel was configured in a three-point mooring system with the load cells integrated into each mooring line, where all tension loads were recorded. In addition, the TRIAXYS surface wave measurement buoy and the newly acquired seafloor-mounted AWAC profiler both measured wave and ocean current data near the Ocean Sentinel. All equipment was transported to Ship Ops in Newport, in preparation for deployment activities. The Ocean Sentinel was lowered into the water in Toledo and towed down the river for staging at Ship Ops as well.

Equipment was deployed primarily from the R/V Pacific Storm, which is operated by the MMI under CEOAS. These operations occurred over a 4-day period, where weather was closely monitored. Each day of ocean deployment activities required very gentle seas, as difficulty and risk increases exponentially with elevated sea states. Certain operations are limited by the capabilities of the Rigid-Hulled Inflatable Boat (RHIB), which is critical to deployment activities.

e. Operations

The operations plan for this 2013 testing was straightforward: monitor sea states and collect data. Monitoring at the site continued for benthic habitat, acoustics, and opportunistic monitoring of mammals and sea birds. During the last few weeks of operation, the deployment experienced significant sea conditions, including a maximum wave height of over 39 feet. The Ocean Sentinel monitoring system received notification that the Ocean Sentinel had left its defined operational position boundary. The situation was viewed with the onboard cameras and the GPS location was tracked. When sea states allowed it, a local fisherman was asked to inspect the site, which appeared to be in order. The team assessment was that the anchors had physically moved some distance due to the extreme seas.

Operations become challenging when a problem arises and sea states prevent physical interventions or visual inspections. Gear and ocean debris entanglement could cause significant operational and recovery issues, especially for the floating power cable systems, which are used to connect devices to the Ocean Sentinel at sea.

f. Ocean Sentinel Recovery and Decommissioning

Recovery operations proceeded as planned, with one exception. The final day of recovery was delayed due to equipment issues, which led to operations moving late into the afternoon. Difficult conditions made diving operations impossible, requiring creative solutions to complete the recovery.

As suspected, the unseasonably large sea conditions caused the Ocean Sentinel anchors to move during the last few weeks of testing operations. The mooring system was designed to withstand a 41-foot wave, and to allow anchor movement during very high sea states, rather than causing the submersion of the Ocean Sentinel. Mooring system design and analysis was conducted in 2012, and additional computer modeling was conducted during this summer's planning period. The mooring system was found to be very robust.

Recovery and decommissioning operations for ocean testing projects are challenging. Ocean conditions can change quickly, and often become more severe in the afternoons. Activities such as diving operations, winching, lifting, and conveying become much more difficult as wave and current conditions change. Safety risks often change due to a variety of factors, and are often reconsidered during each activity while at sea.

Publications

- T. Lettenmaier, E. Amon, B. Bosma, A. von Jouanne, "Power Converter, Control and Emulator System Developed for Testing Wave Energy Converters with the Ocean Sentinel Instrumentation Buoy", IEEE Transactions on Sustainable, Energy, Special Issue.
- T. Lettenmaier, E. Amon, A. von Jouanne, "Power Converter and Control System Developed in the Ocean Sentinel Instrumentation Buoy for Testing Wave Energy Converters", ECCE 2013, Denver, CO, Sept. 2013.
- T. Lettenmaier, A. von Jouanne, E. Amon, S. Moran, A. Gardiner, "Testing the WET-NZ Wave Energy Converter using the Ocean Sentinel Instrumentation Buoy", Marine Technology Society (MTS) Journal, July/August 2013.
- von Jouanne, T. Lettenmaier, E. Amon, and S. Moran, Wave energy testing using the Ocean Sentinel Instrumentation Buoy, *Proceedings of the 1st Marine Energy Technology Symposium, GMREC-METS13*, WA DC, April 2013.

10 Appendix B

NNMREC Accomplishments and Impacts 2009-2013

Report #5 May 2013 (uploaded to EERE site) discusses NNMREC work primarily funded under the original NNMREC “core grant”. The accomplishments therein are synergistic to the work within this project.

In addition to the deliverables and publications listed throughout the report, the following presentations represent NNMREC Accomplishments and Impacts during the funded project.

Technical Presentations

- A.von Jouanne, T. Brekken, T. Lettenmaier, E. Amon, S. Moran, A. Yokochi, Research and Ocean Testing Solutions to Advance the Wave Energy Industry, PES GM, July 2014. (Panel and Poster Presentation)
- O’Dea, A.M. and M.C. Haller, “Analysis of the impacts of wave energy converter arrays on the nearshore wave climate”, Coastal & Ocean Engineering Brownbag Seminar, Oregon State University, June 30, 2014
- C. Black, “Analysis of waves in the near-field of wave energy converter arrays through image processing”, MS Defense, Oregon State University, June 12, 2014
- J. Baker, S.C. Yim, E. Amon, S. Moran, T. Letternaier and A. von Jouanne. (2014) “Mooring Analysis of a NOMAD Buoy through Experimental Testing and Numerical Simulation,” Offshore Mechanics and Arctic Engineering Conference, San Francisco, USA, June 8-13, 2014.
- J. Baker, S.C. Yim, E. Amon, S. Moran, T. Lettenmaier, A. von Jouanne, “Mooring Analysis of a NOMAD buoy through experimental and numerical testing”, OMAE Conf., SF CA, June 2014.
- A. von Jouanne, J. Baker, S.C. Yim, E. Amon, S. Moran, T. Letternaier, M. Bunn and A. Yokochi. (2014) “Wave Energy Research, Development and Testing Including Testing of Materials and Technology for Bio-Fouling and Corrosion Prevention,” Offshore Technology Conference, Houston, TX, USA, May 5-8, 2014.
- J. Baker, S.C. Yim, E. Amon, S. Moran, T. Letternaier and A. von Jouanne. (2014) “Numerical and Experimental Analysis of the Ocean Sentinel Instrumentation Buoy Mooring System to Enable Improved Modeling and Design,” Proceedings of the 2nd Marine Energy Technology Conference, Seattle, WA, USA, April 15-17, 2014.
- A. M. O’Dea, and M.C. Haller, “Analysis of the impacts of wave energy converter arrays on the nearshore wave climate”, presented at *2nd Marine Energy Technology Symposium (METS2014)*, Seattle, WA, April 2014.
- J Baker, S. Yim, E. Amon, S. Moran, T. Lettenmaier, A. von Jouanne, “Numerical and Experimental Analysis of the Ocean Sentinel Instrumentation Buoy Mooring System to Enable Improved Modeling and Design”, GMREC-METS, Seattle, WA, April 2014.

- A. von Jouanne, Advancing Wave Energy and Renewables Grid Integration through Research, Development and Testing, UC Irvine, March 5th, 2014.
- M. Haller, "Recent NNMREC Research on the Potential Nearshore Effects of Wave Energy Extraction", *Oregon Renewable Energy Conference VIII,* Astoria, OR, September 25, 2013.
- A. von Jouanne, Power Converter and Control System Developed in the Ocean Sentinel Instrumentation Buoy for Testing Wave Energy Converters, ECCE Conf., Denver, CO, Sept. 16th, 2013.
- A. von Jouanne, A. Yokochi, Advancing Ocean Wave Energy through Research, Development and Testing, Including Research on Materials and Technologies for Bio-Fouling Resistant Surfaces, SusTech Conf., Portland, OR, Aug. 2nd, 2013.
- B. Batten, Science Needs for US Offshore Energy Development: Marine and Hydrokinetic Energy, Second Annual American Geophysical Union Science Policy Conference, Washington, DC, June 2013
- B. Batten, Ocean Testing with the Northwest National Marine Renewable Energy Center, Future Energy Conference, Portland OR, April 17, 2013.
- B. Batten, Ocean Testing with NNMREC, Global Marine Renewable Energy Conference, Washington, DC. April 10-11, 2013
- A. von Jouanne, T. Lettenmaier, E. Amon, and S. Moran, Wave energy testing using the Ocean Sentinel Instrumentation Buoy, *Proceedings of the 1st Marine Energy Technology Symposium, GMREC-METS13*, WA DC, April 2013.
- S. Moran, Wave Energy Testing Using the Ocean Sentinel Instrumentation Buoy, 1st annual Marine Energy Technical Symposium 2013, Washington DC, April 2013.

Outreach and Engagement Presentations

- B. Batten, "Catching the Wave and Rising with the Tides: Marine Renewable Energy at NNMREC", Humboldt State University, Arcata, CA, 4 September 2014.
- B. Batten, "Northwest National Marine Renewable Energy Center MHK Research, Development & Testing Program" BOEM/NREL Offshore Renewable Energy Workshop, Sacramento, CA, 30 July 2014.
- B. Langley, R. Moon, J. Hough, E. Hodges – Organized and participated in OSU GEAR UP outreach for pre-college programs on the Oregon State campus June 24, 2014.
- K. Jacobson – May 22, 2014. NNMREC Community Forum in Newport, Oregon.
- K. Jacobson – Presentation to Surfrider Foundation May 15, 2014 Newport Chapter on wave energy, projects in Oregon and NNMREC.
- K. Jacobson, B. Batten, R. Moon – April 25, 2014 attended Fishermen's roundtable with Congressman Schrader.

- K. Jacobson - Provided an update on NNMREC PMEC SETS project to Yaquina Bay Ocean Observing Initiative April 21, 2014, an economic development group.
- K. Jacobson (formerly Hildenbrand) and R. Moon - Participated in Marine Science Day at HMSC, April 12, 2014. Interpreted at Wave Energy Exhibit and wave tanks with wave energy device models.
- R. Moon; met with Rep Boone regarding fishing community concerns about wave energy development in Oregon, February 20, 2014.
- R. Moon, teacher workshops in partnership with STEM and HMSC pertaining to wave energy curriculum, Nov. 16th and Oct. 11, 2013.
- A. von Jouanne, WESRF Renewables Research/NNMREC Wave Energy Research & Developments, Consumers Power President and CEO Roman Gillen and CPI Board of Directors, Nov. 27th, 2013.
- K. Hildenbrand presentation to Oregon Fish and Wildlife Commission on October 3, 2013
- B. Batten, Marine Renewable Energy and Spatial Planning, Ocean Sciences Board of the National Academies of Science, October 2013
- A. von Jouanne, Keynote Speaker, 2013 Consumer Power Annual Meeting, Riding the Waves: Advancing Ocean Wave Energy through Research, Development and Testing, Sept. 14th, 2013.
- M. Haller; U.S. Rep. Blumenauer visit to OSU; Led tour and wave talk at the Hinsdale Wave Research lab; May 29, 2013.
- B. Langley, S. Payments; booth at Hinsdale Wave Research lab for OSU Mom's Weekend event; May 4, 2013.
- B. Langley, S. Moran; OSU University Day at the Capitol, Salem, OR; April 17, 2013.
- B. Batten, Monitoring at North Energy Test Site, Newport OR, Developments in Research on Environmental Effects, Washington, DC. April 9, 2013