SAND2017-5798C

AN ENVIRONMENTAL IMPACT ASSESSMENT FRAMEWORK FOR WAVE ENERGY INSTALLATIONS

Samuel McWilliams[1]**, Kaustubha Raghukumar, Norman Maher, Craig Jones, and Grace Chang**
Integral Consulting
Santa Cruz, CA, USA

Jesse Roberts
Sandia National Laboratories
Albuquerque, NM, USA

[1]Corresponding author: smcwilliams@integral-corp.com

INTRODUCTION

The potential environmental impacts resulting from the deployment of wave energy converters (WECs) in coastal waters are largely uncertain. Consequently, proposed WEC deployments in the U.S. have faced unsustainable costs associated with environmental permitting, and delays in getting devices into the water. A key challenge to WEC development is that an understanding of the potential physical and biological impacts to the marine environment must come prior to deployment. A typical approach in similar environmental assessments is to use numerical models to simulate the WEC devices and array layouts so that the appropriate environmental stressors and receptors can be identified and assessed using spatial mapping tools.

A number of attempts have been made to develop "WEC-friendly" numerical modeling tools that help streamline the processes required to evaluate potential environmental impacts. One such example is the open-source numerical model Simulating Waves in the Nearshore (SWAN), modified by Sandia National Laboratories (SNL) to account for marine and hydrokinetic (MHK) devices (SNL-SWAN). This model was recently applied by Chang et al. (2016) and Jones et al. (2016) to characterize changes in wave dynamics in the lee of simulated WEC arrays off the coast of Santa Cruz, California, and Newport, Oregon, respectively. These studies primarily focused on changes to the wave climate in the lee of WEC arrays of various configurations and incident wave fields. The authors found that wave heights, orbital velocities at the bed, and radiation shear stress do exhibit changes in the vicinity of a WEC array, with the potential for these variables to be considered environmental stressors. Spatial patterns of the reduction in wave height varied with incident swell direction. However, changes in swell direction and wave period, as such, were found to be insignificant. The rich spatial structure in wave height variability as a consequence of WEC array deployment pointed to the further use of spatial maps, similar to those at MarineCadastre.gov, developed by the Bureau of Ocean Energy Management, to help site renewable energy projects.

This paper builds upon the above-mentioned work focusing on wave characteristics to include changes to hydrodynamic forces and seabed characteristics in the vicinity of WEC arrays. Changes to wave parameters are considered in conjunction with hydrodynamic forces, such as current velocities and resultant bed shear stress, resulting in a more holistic approach to determining effects of WEC arrays on the physical environment.

Here, the comprehensive environmental impact assessment is applied to two potential WEC devices: the floating two-body heaving converter (F-2HB) and the bottom-fixed heave-buoy array (BF-HBA). The environmental implications of a WEC array are examined by modeling two array configurations. The resultant spatial maps reflect potentially altered wave and circulation dynamics. These maps are then overlaid with benthic habitat maps that show ecologically significant areas such as kelp beds and rock reef that are habitats for sensitive marine species. The modeling tools and methods developed within this project can be used to optimize WEC array deployment locations and configurations for the lowest overall physical and biological impact.

WEC ARRAY CHARACTERISTICS

We consider two types of wave energy converters, both of which hold promise in future deployments. Each device is characterized by differing physical size, energy extraction method, and energy removal efficiency and is parameterized in the model as an obstacle to the wave field. The amount of energy absorbed at a specific wave period and significant wave height is defined by a device-specific power matrix, and the device width. The F-2HB device has a prescribed dimension of 9.5 m, with a peak power extraction of 1,000 kW at optimal conditions (Figure 1). The BF-HBA device is smaller, with a 5-m diameter and similar power matrix distribution as the F-2HB, but with a maximum power extraction of 170 kW during optimal conditions.

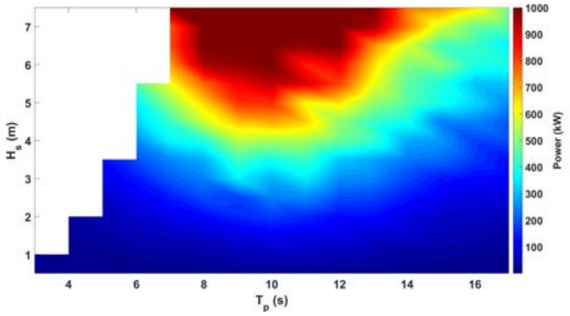

FIGURE 1. POWER MATRIX FOR F-2HB WEC.

NEWPORT, OREGON, CASE STUDY

The site of the present study is offshore of Newport, Oregon, north of Yaquina Head, in approximately 50-m-deep water and 3.7–5.5 km offshore. The targeted locations constitute the North Energy Test Site (NETS) of the Pacific Marine Energy Center where future marine renewable energy deployments are planned.

The waters off of Newport, Oregon, are characterized by a year-round energetic wave field. Swell heights range from 0 to 7 m, swell directions vary from 180° to 315°, and wave periods range from 4 to 20 seconds. The sea bottom around the NETS site is gently sloping and predominantly sandy, flanked by rocky habitats to the west and northeast. The nearshore water due east of the NETS site is a mix of rock and sand, providing a range of benthic habitats for marine life.

Model Setup and Calibration

A coupled wave and coastal circulation model of the Oregon coast was developed using the open source Delft3D nearshore circulation model. Waves in the steady state are modeled using the SNL-SWAN module built into Delft3D. The coupled Delft3D–SNL-SWAN model accommodates WEC arrays and allows for evaluating tidal and wave-driven circulation, including wave-current interactions that have the ability to influence both nearshore circulation and wave parameters. A 3-dimensional, depth-integrated, nested model was developed to represent the Oregon coast from −124.4°W to −124°W and 44.14°N to 45.14°N. The flow model consisted of three nested grids with increasing grid resolution (Figure 2). The flow grids consisted of five vertical layers with layer thickness specified in terms of a percentage of total water depth. The number of layers was found to strike a balance between computational efficiency and accuracy of modeled currents. Computed wind-driven surface currents compared favorably with coastal surface radar measurements provided by the Oregon State University (OSU) Ocean Currents Mapping Lab. Calculations of the wave field were performed using two nested grids with differing resolutions. A nested 50-m resolution grid extending all the way to shore ensured the ability to accurately capture the changes in wave conditions due to the WEC arrays and compare them with spatially varying benthic habitats.

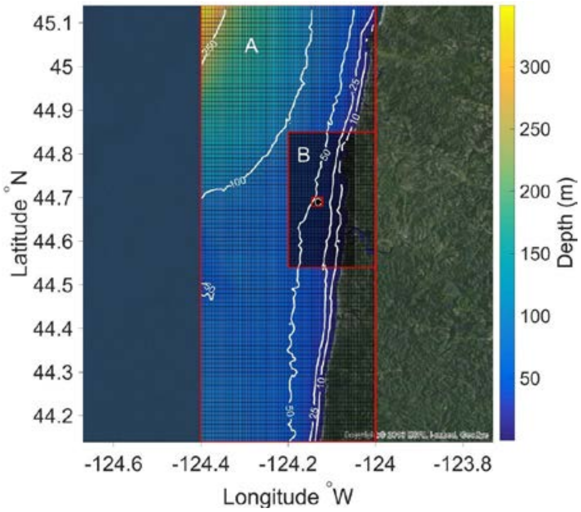

FIGURE 2. NUMERICAL FLOW MODEL GRIDS A, B, AND C.

Cell depths were defined by the bilinear interpolation of high-resolution U.S. Geological Survey bathymetry data onto each model cell of the computational grid.

Boundary conditions consisted of flow and wave boundary conditions. Flow boundary conditions were specified as tidal sea surface heights, which were applied at the northern, western, and southern edges of the domain, using a total of 11 tidal harmonics. These boundary conditions were derived using the global tidal model TPXO (OSU TOPEX/Poseidon Global Inverse Solution). Time evolving wind data from the National Data Buoy Center (NDBC) station NWP03, located in Newport, Oregon, were included as a boundary condition. The circulation model was first calibrated to the time period between October 1 and 28, 2009, a period during which surface current data were available (Table 1). Velocities were broken down into east-west (u) and north-south (v) components for the comparison. Overall, the model compared favorably with the measurements. The differences in modeled data with respect to the measured values were attributed to the lack of spatially varying wind fields and the daily averaging required for comparison.

TABLE 1. MODELED SURFACE CURRENT COMPARISON METRICS.

Metric	u (C1,C2)	v (C1, C2)
Skill	0.7, 0.7	0.9, 0.9
RMSE (cm/s)	5.6, 6	5.5, 6.3
Bias (model-data) (cm/s)	3.5, 4.1	−0.8, 1.4
Correlation	0.8, 0.8	0.9, 0.8
Avg. % difference	18.9%, 13.9%	9%, 7%

Note: RMSE = Root mean Square Error

Wave boundary conditions were specified as 2-dimensional wave spectra, available every 3 hours, at 90 locations along the model boundaries. Wave spectra were specified at 25 frequencies, ranging from 0.04 to 0.5 Hz, along 72 spectral nautical directions. Two-dimensional wave spectral boundary conditions were available from a long-term (2005–2011) calibrated and validated wave model run by OSU over a larger domain that encompassed the Delft3D domain (García-Medina et al. 2014). Results from the OSU model were linearly interpolated onto the outermost boundary of the present domain.

A 1-month period, August 2005, was chosen for calibration of the wave model, during which nearshore wave measurements were available within the domain. Wave model results were compared to acoustic waves and currents (AWAC) data collected by OSU. Overall, modeled wave parameters agreed favorably with measurements, particularly when wave periods were greater than 10 seconds (Figure 3). During durations when wave periods were less than 9 seconds, modeled wave heights were seen to be lower than those measured. This is largely due to the unavailability of spatially varying, wind-forcing boundary conditions that tend to drive wave dynamics with periods less than 9 seconds.

WEC Cases

Two array configurations consisting of 18 WEC devices were considered. Both configurations were contained within the NETS designated area.

The first configuration consisted of a 3×6 arrangement, uniformly spaced 250 m apart. The second configuration consisted of a semicircular pattern, again spaced 250 m apart.

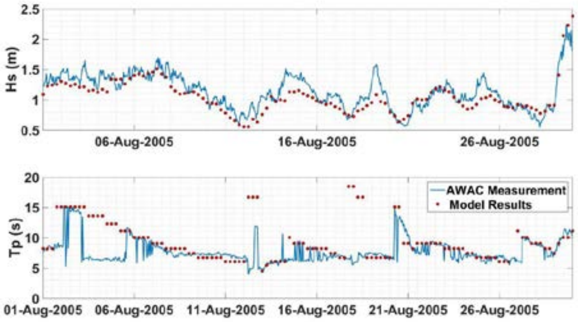

FIGURE 3. COMPARISON OF MODELED AND MEASURED WAVE PARAMETERS.

Each array represented 18 F-2HB or BF-HBA devices and was prescribed the related device dimension and power matrix. The combination of two devices and two configurations results in a total of four scenarios. All scenarios were modeled using the same westerly swell condition so that direct comparisons could be made between devices and array types.

Results from the implementation of the four scenarios were compared to baseline conditions in the absence of WEC devices. The comparison was made to provide the foundation for identifying potential stressors to the physical environment. As an example, the maximum percent difference in the magnitude of bottom velocity is shown in Figure 4, while changes in significant wave height in the domain due to the presence of the uniform array is presented in Figure 5. Changes in the magnitude of bottom orbital velocity (Figure 4) during the peak of the swell event are on the order of 50%, with the bulk of the changes largely in the lee of the WEC array. The magnitude of velocity changes, however, were found to very low (<0.5 m/s). The modulation of tidal circulation with wave-driven circulation results in both velocity reductions and increases across the domain. Changes in significant wave height (Figure 5) are largely confined to the lee of the WEC array, and are on the order of 40% in the area closest to the array, with negligible changes to wave heights in the nearshore.

The ability to quantify these factors is a key step in assessing the interaction between WEC devices and the environment. Stressors such as bottom shear stress, which impacts sediment accretion and erosion, are related to both wave and circulation factors. The following section highlights how these factors can be used to support investigations into alterations to marine habitats.

DISCUSSION AND SUMMARY

Case studies were set up for multiple WEC configurations and device types at the Newport, Oregon, NETS site. Hydrodynamic and wave conditions were modeled in conjunction with WEC parameters to determine changes to the coastal environment. The changes in these conditions throughout the coastal zone represent potential stressors to the overall physical and biological environment. Each parameter can stress a specific receptor. For example, the change in near-bed velocity can act to allow for excess deposition in a region, thereby affecting receptors ranging from benthic habitat to pelagic fish.

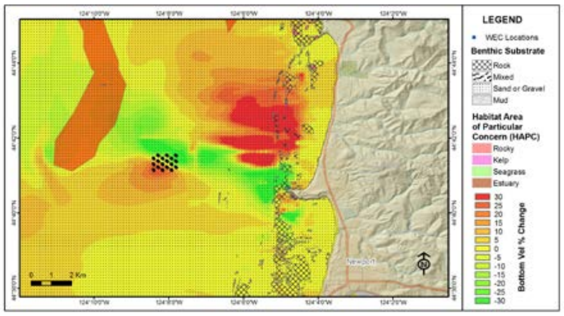

FIGURE 4. DIFFERENCE IN BOTTOM VELOCITY DUE TO PRESENCE BF-HBA WEC ARRAY.

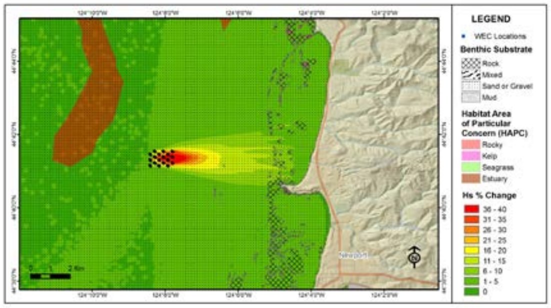

FIGURE 5. DIFFERENCE IN WAVE HEIGHT DUE TO PRESENCE OF BF-HBA WEC ARRAY.

Changes in the spatial variation of hydrodynamic and wave conditions due to device types were related to the amount of energy the devices extracted. However, one cannot simply scale the effect due to device parameters because the relationship between energy and stressor is not necessarily linear. The examples illustrate that spatial maps must be used in conjunction with single point metrics to fully examine each scenario.

The spatial maps of variation in potential physical stressors, when combined with various benthic habitats, provide insight into the siting of WEC arrays to minimize potential environmental impact. The data provide an ideal backdrop for the initial evaluation of the effect of potential physical stressors on local receptors. Wave conditions have been postulated to be the single largest control of net primary production by kelp forests (Reed et al. 2011). Demonstrated reductions in wave height during the conditions evaluated mainly occur offshore of the coastal rocky habitat where kelp forests might be expected to grow. While changes in bottom velocity as a percentage indicate an impact over an area composed of sandy and rocky habitats, in velocity magnitude these changes are based on is negligible to have any substantial impact on sediment mobility.

These WEC-friendly wave and circulation modeling tools and methods are capable of simulating the influence that WEC arrays have on the physical system, providing a baseline for evaluating potential stressors to the environment.

Future studies will further assess the relationship between WEC array characteristics (e.g., footprint, power production) and effects on the physical and biological environment to facilitate optimization of WEC placement and maximize power production, while minimizing negative effects to the environment.

ACKNOWLEDGEMENTS

The authors would like to thank the U.S. Department of Energy for supporting the work herein. In addition, the authors would like to thank Sharon Kramer at H. T. Harvey & Associates for assistance with benthic habitat maps, and Tuba Ozkan-Haller, Merrick Haller, and all of the staff at Oregon State University for sharing the data and modeling results that have helped make this work possible. Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

REFERENCES

Chang, G., K. Ruehl, C.A. Jones, J. Roberts, and C. Chartrand. 2016. Numerical modeling of the effects of wave energy converter characteristics on nearshore wave conditions. *Renewable Energy*, 89:636-648.

García-Medina, G., H.T. Ozkan-Haller, P. Ruggiero, and J. Oskamp. 2014. An inner-shelf wave forecasting system for the US Pacific Northwest. *Weather and Forecasting* 28.

Jones, C.A., S. McWilliams, G. Chang, and J. Roberts, 2016. Wave energy converter array environmental evaluation tools. METS 2016, Washington DC.

"MarineCadastre.gov" [Online]. Available: http://marinecadstre.gov. [Accessed: December 2015].

Reed, D.C., A. Rassweiler, M.H. Carr, K.C. Cavanaugh, D.P. Malone, and D.A. Siegel, 2011. Wave disturbance overwhelms top-down and bottom-up control of primary production in California kelp forests. *Ecology*, 92: 2108–2116.

"SNL-SWAN v1.0," *GitHub*. [Online]. Available: https://github.com/SNL-WaterPower/SNL-SWAN. [Accessed: December 2015].