AN ENVIRONMENTAL IMPACT ASSESSMENT FRAMEWORK FOR WAVE ENERGY INSTALLATIONS

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INTRODUCTION

The potential environmental stressors resulting from the deployment of wave energy converters (WECs) in coastal waters can be broadly categorized as static and dynamic devices, underwater noise, energy removal, electromagnetic forces (EMF) and chemicals associated with WECs (Copping et al 2016). With the exception of chemical leaching, all the above stressors are considered to pose a medium to high risk to the marine environment for large scale commercial WEC deployments. Limited data on the specific marine impacts of the above stressors can be a hindrance to permitting and siting of WECs. A typical approach in similar environmental assessments use numerical models so that the appropriate environmental stressors and receptors can be identified and assessed using spatial mapping tools. In this paper, a coupled hydrodynamic and wave modeling approach is adopted to investigate the impact of WEC energy removal on flow patterns with a focus on potential impacts to the benthic habitat.

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 impact of WECs on the wave climate and hydrodynamic flow is applied to two potential WEC devices: the floating two-body heaving converter (F-2HB) and the bottom-fixed heave-buoy array (BF-HBA) configured in two different array shapes. 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 (**Error! Reference source not found.**). 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.

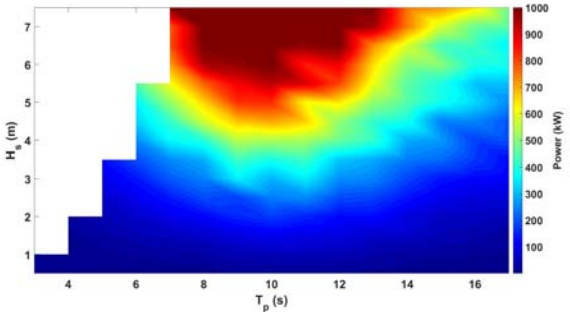

FIGURE 1. POWER MATRIX FOR F-2HB WEC.

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 devices and allows for evaluating hydrodynamic processes including wave-current interactions that have the ability to influence both nearshore circulation and wave parameters. A 3-dimensional nested model was developed to represent the Oregon coast around NETS. 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.

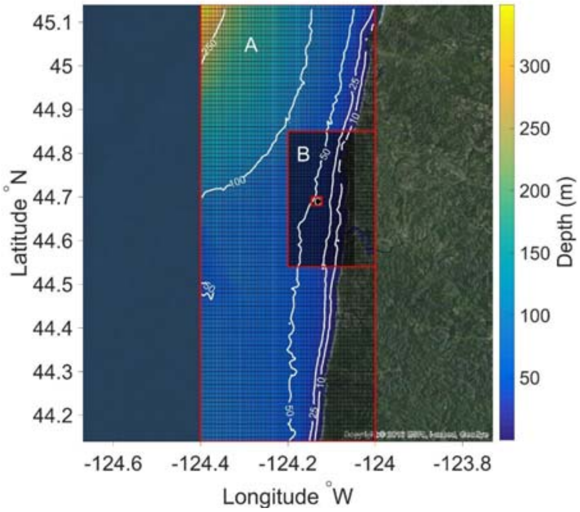

FIGURE 2. NUMERICAL FLOW MODEL GRIDS A, B, AND C.

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). Surface forcing was specified using time evolving wind data from the National Data Buoy Center (NDBC) station NWP03, located in Newport, Oregon. 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 (**Error! Reference source not found.**1). 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

2-dimensional wave spectra along the model boundary were available from a larger, calibrated, and validated wave model. Conditions were applied to the model every three hours, encompassing 25 frequencies, ranging from 0.04 to 0.5 Hz, along 72 nautical directions (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 (**Error! Reference source not found.**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. The use of spatially varying wind forcing is an ongoing effort.

WEC Cases

Two array configurations of 18 WEC devices were considered. A 3x6 arrangement uniformly space 250 m apart, and a semi-circular array with uniform spacing were modeled separately within the NETS site.

Results from the implementation of the four scenarios, two devices in two configurations, were compared to baseline west swell conditions in the absence of WEC devices over a five day period. The comparison was made to provide the foundation for identifying potential stressors to the physical environment.

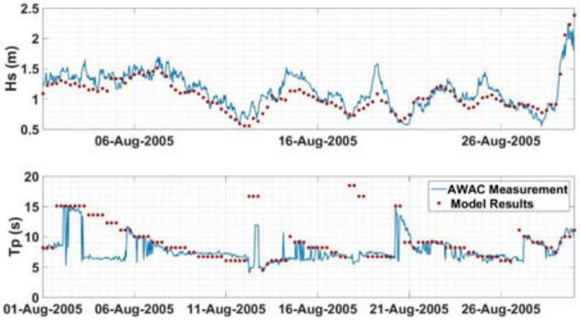

FIGURE 3. COMPARISON OF MODELED AND MEASURED WAVE PARAMETERS.

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.

Quantification of 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 dynamics. 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, potentially affecting larval settlement, and introducing changes in benthic habitat. Further, long term systemic changes have the potential to have greater ecological consequences compared to episodic events like an extreme winter storm which can allow for a gradual return to equilibrium conditions.

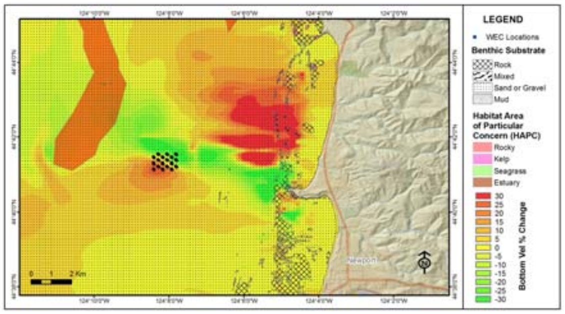

FIGURE 4. DIFFERENCE IN BOTTOM VELOCITY DUE TO PRESENCE BF-HBA WEC ARRAY.

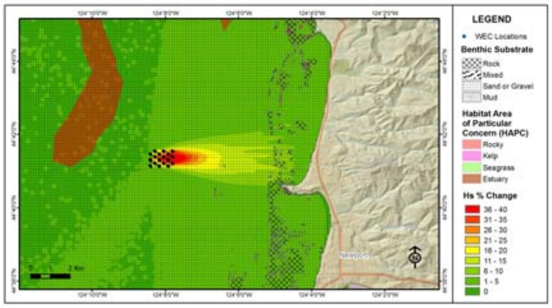

FIGURE 5. DIFFERENCE IN WAVE HEIGHT DUE TO PRESENCE OF BF-HBA WEC ARRAY.

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.

As for all simulations of the consequences of energy absorption by marine energy converters, a challenge is validation. However, confidence in these results is gained by recognizing that WEC power absorption studies have been extensively tank-tested, while hydrodynamic modelling around obstacles such as offshore pilings is a relatively mature field of study.

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.

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