# WAVE ENERGY CONVERTOR ARRAY ENVIRONMENTAL EVALUATION TOOLS

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## INTRODUCTION

Stakeholders and regulators in the U.S. are working to develop deeper understanding of the potential environmental impacts posed by deployments of marine and hydrokinetic (MHK) devices, and in particular wave energy conversion (WEC) devices, in coastal waters. The first pilot-scale WEC deployments in the U.S. have had to absorb unsustainable costs and delays associated with permitting to get devices in the water. As such, there is an urgent industry need to streamline the technical activities and processes used to assess potential environmental impacts. To enable regulators and stakeholders to become more comfortable and confident with developing effective MHK environmental assessments, a better understanding of the potential environmental effects induced by arrays of WEC devices is needed. A key challenge in developing this understanding is that the assessment of the WEC effects 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 maps.

Sandia National Laboratories (SNL) and the U.S. Department of Energy are fulfilling the industry-wide need to develop "WEC-friendly" open-source numerical modeling tools (SNL-SWAN 2015) capable of assessing potential changes to the ocean environment caused by the operation of WEC arrays. Studies using these tools will advance the nation's general knowledge of the interrelationships among the number, size, efficiency, and configuration of MHK arrays and the subsequent effects these relationships may have on the deployment environment. By better understanding these relationships, industry, stakeholders, and regulators will be able to work together to optimize WEC deployments such that environmental impacts are minimized while power output is maximized.

## WEC ARRAY CHARACTERISTICS

Moving an environmental assessment forward for a WEC deployment requires a delineation of the WEC characteristics that may pose stressors to the environment. Devices in WEC arrays come in all shapes, sizes, and operating modes. At present, there is no consensus on the manner in which arrays of WECs will be deployed. The potential variety of WEC devices and array designs creates a plethora of potential scenarios to consider. However, for the purposes of generic environmental assessments of WEC arrays, the characteristics can be separated into two groups:

- WEC device characteristics
  - Physical size
  - Energy removal efficiency (power rating)
  - Intended deployment locations (shallow/intermediate/deep-water)
- WEC array characteristics
  - Number and spacing
  - Array configuration (e.g., rectangular, staggered, honeycomb, spiral)
  - Array orientation (e.g., parallel to shore, rotated to incident wave direction)

After conceptual layouts are developed and metrics are evaluated for potential environmental stressors (discussed in the next section), a general basis for quantitative analysis using numerical modeling tools is formed. The case study developed in this work provides an example of the setup of an initial evaluation of WEC array alternatives.

### Physical Environmental Stressors

A primary receptor of any stressor induced by a WEC array is the physical environment. The physical environment is the ideal receptor for evaluation because most other biologic receptors have the potential to be impacted by the same stressors. For example, changes in sediment dynamics may alter benthic habitat and changes in currents/circulation may affect marine mammal/fish behavior, thereby altering fishing or other boating activities. Because of the inherent coupling of all marine receptors to the physical environment, a quantitative evaluation of its stressors provides the basis for any environmental assessment.

Introduction of WEC arrays into the marine environment has the potential to change wave propagation, circulation, sediment dynamics, and water quality. Many of these physical phenomena are interrelated, lending the opportunity to establish broader and more readily calculable metrics as a means to quantitatively describe a stressor to the system. By quantitatively describing any metric, one can narrow down scenarios to those of utmost interest. Although the physical environmental stressors stemming from a WEC array deployment will be site specific, some informative examples include changes to the physical parameters shown in Table 1. The list is intended to provide an example and not be comprehensive. One notable example excluded from the scope of the present work that is an important physical and biological stressor is acoustics. These stressors can be quantitatively evaluated for various WEC array configurations so that environmental effects can be minimized.

## NEWPORT, OREGON CASE STUDY

A case study has been developed for a site with ongoing plans for WEC deployment, Newport Oregon, as an example of the use of the Sandia developed WEC-friendly tools and methods. Preliminary calibration and validation of the model is conducted with available data and analysis at the site. A simple WEC array deployment is developed in this section to demonstrate the utility of the tools. The WEC locations were targeted at the North Energy Test Site (NETS) of the Pacific Marine Energy Center where future WEC deployments are planned.

**TABLE 1. PHYSICAL ENVIRONMENT STRESSORS POTENTIALLY RESULTING FROM THE INSTALLATION OF A WEC ARRAY**

| **Wave Character** | **Currents and Tides** | **Seabed Character** | **Water Quality** |
|---|---|---|---|
| Wave height reduction | Nearshore circulation alteration | Nearbed shear stress changes | Change in temp. profiles |
| Wave period alteration | Offshore current disruption | Induced scour or deposition | Change in salinity profiles |
| Spectral energy change | Water level changes | Alteration of grain size | Change in DO |
| Wave and seabed stress change | Nearshore inundation | Disruption of nearshore and shelf scale sediment budgets | Change in flushing |

### Model Setup and Validation

Using the SNL-SWAN model (SNL-SWAN 2015), a regular grid was set up extending from just west of NETS to the shore. The grid sizes are approximately 50 m square, which is a rough approximation of the size of the modeled device and the best available bathymetry for the site was obtained from Oregon State University (OSU) and interpolated to the grid (García-Medina et al. 2014). Study periods were chosen from 2009 to validate the model behavior. The cases represent a moderate southerly swell and a moderate western wave event. Data from NOAA buoy station 46050 was used to generate boundary conditions applied to the model as it provided the most complete and validated data set in the area. Each incident wave field was applied using a Jonswap spectrum with a directional spreading value of 10 degrees. Baseline simulations (absence of WECs) were carried out for model validation. The SNL-SWAN baseline model results were compared to the results from a validated OSU model at the NETS site (García-Medina et al. 2014). The model results for the peak of the event agree well with the offshore data and the validated OSU model at the NETS location. Additional validation was conducted by comparing model outputs with collected AWAC data.

**WEC Cases**

Only one type of WEC device was considered for the case study, the floating oscillating water column (F-OWC) inspired by the OE Buoy developed by Ocean Energy Ltd. (Barbarit et al. 2012), which has a diameter of 50 m and a power matrix shown below (Figure 1).

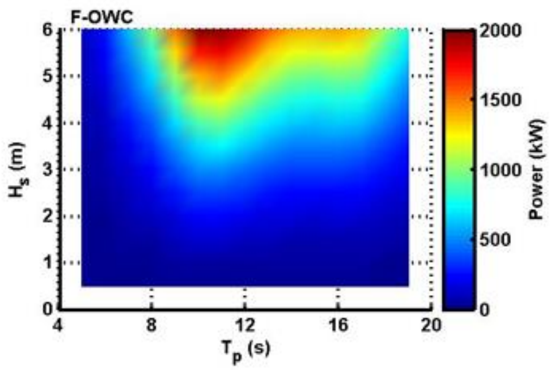


**FIGURE 1. POWER MATRICES COMPUTED FOR THE F-OWC WEC DEVICE AS A FUNCTION OF SIGNIFICANT WAVE HEIGHT AND PEAK WAVE PERIOD.**

Four WEC deployment configurations were considered for the initial wave case using a 2.5 m wave height condition from a southerly and westerly direction. In each WEC deployment configuration the devices were spaced 250 m (5 diameters [D]) apart in both the east–west and north–south directions (Figure 2). Each configuration consisted of three columns of WECs aligned north to south. The first configuration, called Uniform, has six rows of three devices in line along the same latitude. Three configurations using a staggered placement were also implemented. Staggered A has the same configuration as the Uniform case but the middle row is offset by 2.5D to the north. Staggered B1 and Staggered B2 have the same offset as the Staggered A array but vary the number of WECs in each column. Staggered B1 and Staggered B2 differ between which columns contain the varied number of devices. Future studies will investigate aligning the arrays with the depth contours because the wave direction tends to align with depth contours as it gets closer to shore.

Results from the implementation of the four array configurations 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 of spatial comparisons, the percent difference in significant wave height in the domain due to the presence of the uniform array is presented in Figure 3.

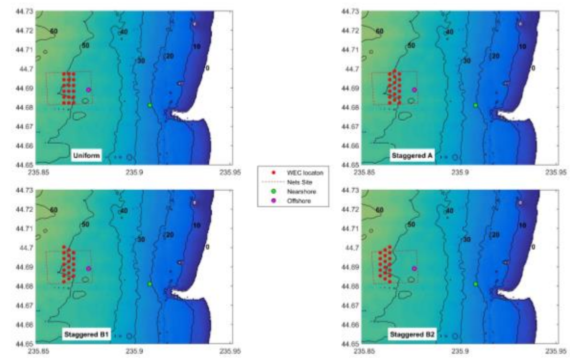


**FIGURE 2. ARRAY CONFIGURATIONS AND LOCATION OF OFFSHORE AND NEARSHORE COMPARISONS**

**THE PRIMARY WAVE PARAMETERS IDENTIFIED THAT COULD POSE POTENTIAL STRESSORS IDENTIFIED IN NEWPORT, OREGON CASE STUDY**

A case study has been developed for a site with ongoing plans for WEC deployment, Newport Oregon, as an example of the use of the Sandia developed WEC-friendly tools and methods. Preliminary calibration and validation of the model is conducted with available data and analysis at the site. A simple WEC array deployment is developed in this section to demonstrate the utility of the tools. The WEC locations were targeted at the North Energy Test Site (NETS) of the Pacific Marine Energy Center where future WEC deployments are planned.

Table are significant wave height, bottom orbital velocity responsible for sediment mobility, peak and mean period, and radiation shear stress, which is responsible for nearshore circulation. The change in these wave parameters are presented in Table 2 for the offshore and nearshore locations. The changes in these parameters throughout the coastal zone represent potential stressors to the overall physical and biological environment. Further discussion of these parameters and their use in an assessment framework is presented in the final section.

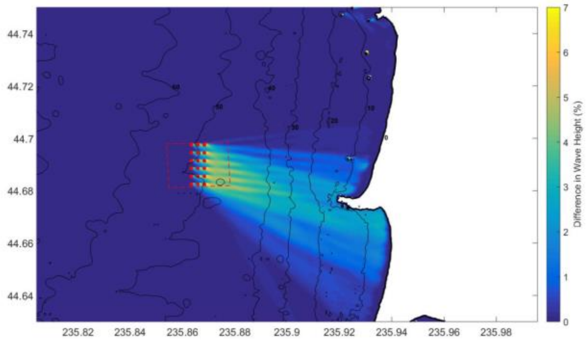


**FIGURE 3. PERCENT DIFFERENCE IN SIGNIFICANT WAVE HEIGHT FOR THE UNIFORM CONFIGURATION.**

**TABLE 2. SUMMARY OF PARAMETER DIFFERENCES AT TWO POINTS WITHIN THE DOMAIN**

| Wave Event | Case | Location | Wave Height (m) | Orbital Velocity (m/s) | Radiation Shear Stress (J/m^2) | Peak Period (s) |
|---|---|---|---|---|---|---|
| Westerly | Baseline | Offshore | 6.44 | 0.74 | 48019 | 17.74 |
| | | Nearshore | 7.04 | 1.35 | 73149 | 17.74 |
| Southerly | Baseline | Offshore | 4.9 | 0.26 | 12457 | 10.01 |
| | | Nearshore | 4.08 | 0.57 | 11288 | 10.01 |
| | | | | | % Difference | |
| Westerly | Uniform | Offshore | 2.78 | 2.51 | 5.48 | 0 |
| | | Nearshore | 1.15 | 0.98 | 2.29 | 0 |
| | Staggered B2 | Offshore | 2.11 | 1.9 | 4.17 | 0 |
| | | Nearshore | 1 | 0.86 | 2 | 0 |
| Southerly | Uniform | Offshore | 1 | 1.43 | 2.01 | 0 |
| | | Nearshore | 0 | 0 | 0 | 0 |
| | Staggered B2 | Offshore | 1.01 | 1.43 | 2.01 | 0 |
| | | Nearshore | 0 | 0 | 0 | 0 |

## DISCUSSION AND SUMMARY

Case studies were set up for multiple WEC configurations and wave cases at the Newport, Oregon NETS site. Two of the wave cases were compared to a previously validated OSU model, and validated with NOAA data and collected AWAC data. The primary wave parameters presented in Table 2 are fundamentally responsible for driving coastal wave and circulation processes. The changes in these parameters 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 orbital velocity can act to allow for excess deposition in a region, thereby affecting receptors ranging from benthic habitat to pelagic fish.

These results show that wave periods do not generally change in the presence of WECs. Further evaluation of wave spectral energy may reveal differences, but period is not a parameter that would likely be an environmental stressor. The alterations of wave heights, orbital velocities at the bed, and radiation shear stress in the lee of a WEC deployment do exhibit changes that could result in an environmental stressor. In the case of the southerly and westerly incident wave conditions, the alterations of the critical wave parameters varied spatially by a measurable amount. The examples illustrate that spatial maps must be used in conjunction with single point metrics to fully examine each scenario.

Spatial maps of site conditions and receptors can be combined with spatial maps of potential stressors in the area that are due to the presence of WEC arrays. The Bureau of Ocean Energy Management (BOEM) has developed MarineCadastre.gov (2015) to support renewable energy siting on the U.S. continental shelf. Spatial data has been made available on human uses and other physical and biotic datasets. The data provides an ideal backdrop for the initial evaluation of the potential physical stressors on local receptors. For example, data on Humpback Whale density and mid-water trawl fishing near the site are readily available. Assuming that mid-water trawl densities can be used as a proxy for fishery locations, the maps provide quantitative spatial information that can be coupled with the physical stressors to evaluate risk to biota from these stressors. Once incorporated into a quantitative framework, the modeling tools and methods developed within this project can be used to optimize WEC array deployment locations and configurations for the lowest overall impact.

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. In particular, changes in wave propagation, circulation, sediment transport, and water quality can all be stressors to a wide range of marine environmental receptors. The WEC optimization framework, when coupled with other data such as the MarineCadaster.gov, can be used to quantitatively evaluate the potential for environmental impact. Future studies will further assess the relationship between WEC array characteristics (e.g. footprint, power production, etc.) and the effects on the physical and biological environment to facilitate optimization of WEC placement to maximize power production while minimizing negative effects to the environment.

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