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Deployment Effects of Marine Renewable Energy Technologies

Wave Energy Scenarios

Prepared by RE Vision Consulting, LLC on behalf of the U.S. Department of Energy

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1. Introduction

Given proper care in siting, design, deployment, operation and maintenance, wave energy conversion could become one of the more environmentally benign sources of electricity generation. In order to accelerate the adoption of these emerging hydrokinetic and marine energy technologies, navigational and environmental concerns must be identified and addressed. All developing hydrokinetic projects involve a wide variety of stakeholders. One of the key issues that site developers face as they engage with this range of stakeholders is that, due to a lack of technical certainty, many of the possible conflicts (e.g., shipping and fishing) and environmental issues are not well-understood,.

In September 2008, re vision consulting, LLC was selected by the Department of Energy (DoE) to apply a scenario-based assessment to the emerging hydrokinetic technology sector in order to evaluate the potential impact of these technologies on the marine environment and navigation constraints.

The project's scope of work includes the establishment of baseline scenarios for wave and tidal power conversion at potential future deployment sites. The scenarios capture variations in technical approaches and deployment scales to properly identify and characterize environmental effects and navigational effects. The goal of the project is to provide all stakeholders with an improved understanding of the potential range of technical attributes and potential effects of these emerging technologies and focus all stakeholders on the critical issues that need to be addressed.

By identifying and addressing navigational and environmental concerns in the early stages of the industry's development, serious mistakes that could potentially derail industry-wide development can be avoided. This groundwork will also help in streamlining siting and associated permitting processes, which are considered key hurdles for the industry's development in the U.S. today. Re vision is coordinating its efforts with two other project teams funded by DoE which are focused on regulatory issues (Pacific Energy Ventures) and navigational issues (PCCI).

The results of this study are structured into three reports:

(1) Wave power scenario description
(2) Tidal power scenario description
(3) Framework for Identifying Key Environmental Concerns

This is the first report in the sequence and describes the results of conceptual feasibility studies of wave power plants deployed in Humboldt County, California and Oahu, Hawaii. These two sites contain many of the same competing stakeholder interactions identified at other wave power sites in the U.S. and serve as representative case studies.

Wave power remains at an early stage of development. As such, a wide range of different technologies are being pursued by different manufacturers. In order to properly characterize potential effects, it is useful to characterize the range of technologies that could be deployed at the site of interest. An industry survey informed the process of selecting representative wave power devices. The selection criteria requires that devices are at an advanced stage of development to reduce technical uncertainties, and that enough data are available from the manufacturers to inform the conceptual design process of this study. Further, an attempt is made to cover the range of different technologies under development to capture variations in potential environmental effects. Table 1 summarizes the selected wave power technologies. A number of other developers are also at an advanced stage of development, but are not directly mentioned here.

Table 1 – Selected wave power technologies

Manufacturer	Device Type	Deployment Location	Power Conversion System
Pelamis Wave Power	Attenuator	Offshore	Hydraulic
Ocean Power Technologies	Point Absorber	Offshore	Hydraulic
Wave Dragon	Overtopping	Offshore	Low Head Hydro
Aquamarine Power	Hinged Flap	Nearshore	freshwater-based hydraulic

Many environmental effects will largely scale with the size of the wave power plant. In many cases, the effects of a single device may not be measurable, while larger scale device arrays may have cumulative impacts that differ significantly from smaller scale deployments. In order to characterize these effects, scenarios are established at three deployment scales which nominally represent (1) a small pilot deployment, (2) a small commercial deployment, and (3) a large commercial scale plant.

It is important to understand that the purpose of this study was to establish baseline scenarios based on basic device data that was provided to use by the manufacturer for illustrative purposes only. Devices need to be optimized to a particular site and most device manufacturers are pretty flexible in adapting their technology to a particular site (such as using a different mooring system). No such optimization has been carried out and this report should therefore not be used to compare parameters such as performance. The references to PG&E's WaveConnect are for awareness and information only. These references are based upon an early conceptual design in the public domain. Many specifics and design details are currently under development. No conclusions should be drawn from this report to the permitting process presently underway because scale, installation duration and engineering details may differ significantly from this study.

The four technologies and scales at the selected site results in a total of 24 deployment scenarios outlined in this report. The approach to developing the individual scenarios has followed a typical conceptual level design and performance assessment methodology previously utilized by the Principal Investigator for studies carried out for the Electric Power Research Institute.

For consistency, mostly metric units are used in this report. We realize that different stakeholders may be accustomed to different units and not be familiar with the metric system. The most common units and conversion factors are included below for reference.

Linear

1 meter(m) = 3.28feet (ft)

1 kilometer = 0.62 miles (mi) = 0.54 nautical miles (Nm)

Area

1 square meter (m^2) *= 10.76 square feet (sqft)*

1 square kilometer (km^2)= 0.386 square miles (mi^2) *= 0.292 square nautical miles* (Nm^2) *= 247 acres*

Volume

1 cubic meter (m^3) *= 35.3 cubic feet* (ft^3) *= 264 Gallons*

2. A Primer on Wave Energy Conversion

Wave energy is generated by the influence of wind on the ocean surface. Kinetic energy exists in the moving waves of the ocean, and this energy can be harnessed by various types of wave energy conversion devices. In general, large waves are more powerful than small ones. The north and south temperate zones (between the tropics and polar circles) have the best sites for capturing wave power. The prevailing westerlies (winds in the middle latitudes between 30 and 60 degrees latitude) in these zones blow strongest in winter. Representing an integration of all the winds on an ocean surface, ocean waves are very consistent and sea states can be predicted accurately more than 48 hours in advance[1].

2.1 Resource Characteristics

Ocean waves are composed of orbiting particles of water. Near to surface, the orbits are the same size as the wave height. The orbit amplitude decreases exponentially with depth, such that 95% of the wave energy is stored between the surface and a depth equal to a quarter of the wavelength. The figure below shows particle orbits for different water depths. As waves approach a shoreline, shallow water effects come into play, reducing wave power densities and orienting waves parallel to the shoreline.

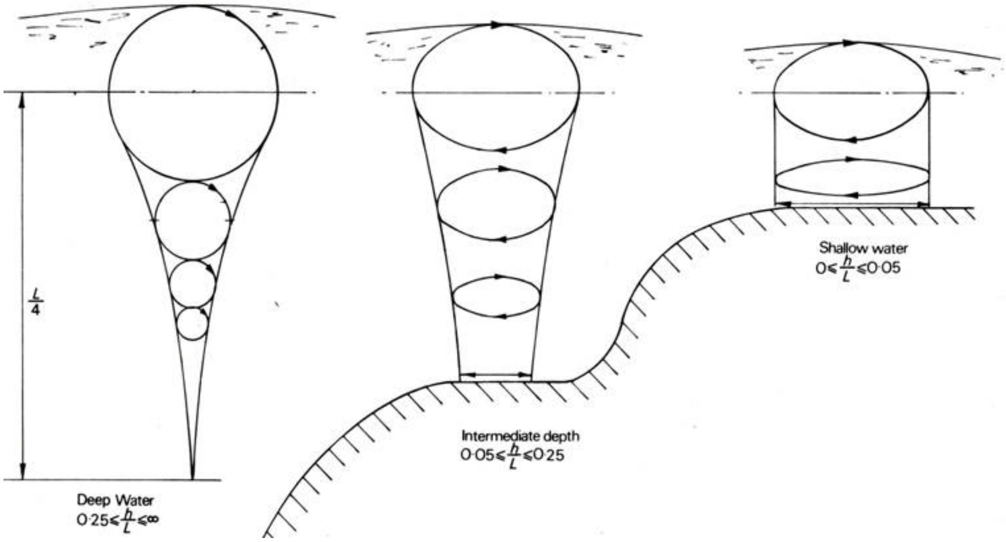

Figure 1 - Water particle orbits of an ocean wave

Ocean waves are a complex, strongly variable phenomenon. Real seas contain waves that vary considerably in height, period and direction. The following illustration shows a time-series of the surface elevation of the sea over a 300-second time period.

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[1] NOAA's WAVEWATCH III model is an example of a 3rd generation wind-wave model allowing wave predictions more than 48 hours in advance.

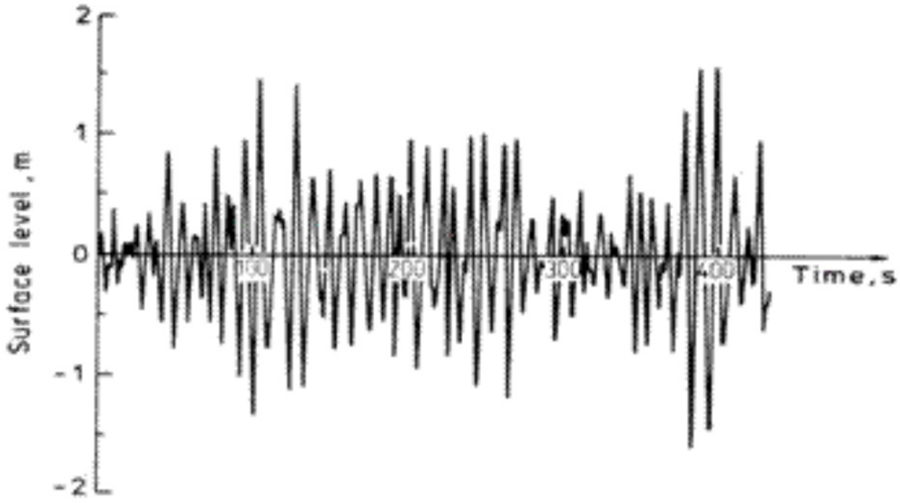


Figure 2 - Short-term variability of ocean waves

However, real seas remain relatively constant (wave grouping occurs with repeating patterns having a timeframe of a few minutes) over the period of a few hours, thereby comprising a sea state that can be described by a directional spectrum. The directional spectrum shows the distribution of energy in frequency f and direction θ. In order to describe such sea states and to determine their characteristics relevant to wave energy utilization, statistical parameters derived from the wave energy spectrum must be used. Sea states are often summarized in terms of wave height, period, direction and spectral distribution parameters. The parameters used in the characterization of wave energy resource are the significant wave height (Hs), energy period (Te), mean direction (O) and wave power level (P) (i.e., the flux of energy per unit length of wave crest). The variation in sea states during a period of time (e.g. month/season/year) can be represented by a scatter diagram, which indicates how often a sea state with a particular combination of H_s and T_e occurs. A typical table showing the number of occurances as a function of Hs and Tp.

Table 2 – Frequency of occurrence Distribution-significant wave height (Hs) vs. Dominant Wave Period (Tp). Total number of occurrences is 1000.

		Tp (s)											
		4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5
Hs (m)	0.25	0	0	0	0	0	0	0	0	0	0	0	0
	0.75	1	1	2	8	9	6	4	5	2	2	1	1
	1.25	2	19	18	32	46	42	17	21	12	8	6	3
	1.75	0	16	50	59	72	61	23	29	21	11	9	5
	2.25	0	1	17	40	64	45	15	18	16	9	8	4
	2.75	0	0	1	8	23	26	12	11	6	4	3	1
	3.25	0	0	0	1	4	9	5	4	2	1	1	0
	3.75	0	0	0	0	0	1	1	2	1	0	0	0
	4.25	0	0	0	0	0	0	0	0	0	0	0	0

In deep water (i.e., when the wavelength is smaller than twice the water depth), the power level in each sea state can be computed by:

$$P = 0.49\, H_s^2\, T_e = 0.412\, H_s^2\, T_p$$

If H_s is expressed in meters and T_e in seconds, P is given in kW/m. The average wave power level P_{ave} during a period of time can be determined from a scatter diagram corresponding to the same time period by:

$$P_{ave} = \Sigma P_i\, W_i \,/\, \Sigma W_i$$

Where W_i is the number of times that sea states with power levels P_i occur. Due to the strong seasonal and inter-annual variability of ocean waves, assessment of wave energy resource should be based on a long time series of wave data. The recommended duration is 10 years. A five-year period is considered to be satisfactory, however, and assessments based on a shorter period (two or three years) still provide a valuable estimate.

In the deep waters of the open ocean, the wave energy resource is consistent over distances on the order of a few hundred kilometers. This applies to large ocean basins, such as the Pacific Ocean. As waves approach the shore through waters of decreasing depth, waves are modified by a number of phenomena such as refraction and diffraction. As a result, the wave energy resource can vary significantly over distances of 1 km or much less in shallow waters, depending on the local bathymetry. The energy level close to shore is usually significantly lower than offshore due to bottom friction. However, recent studies indicate that the convertible energy resource is not much lower, because the average wave power density reduction is largely attributed of energy losses of large waves in the near-shore environment, which can not easily be converted into electricity. In addition, wave crests tend to become parallel to the shoreline in shallow waters. The local influence of the bathymetry can also have a focusing effect on ocean waves, resulting in local “hot-spots” that are favorable for near-shore or shore-based wave power conversion.

As with most renewable energy sources, the power density of the resource is the primary indicator of the economic attractiveness of a particular deployment site. The energy of ocean waves is measured in kilowatt per meter wave front (kW/m). The following map shows average deep-water power densities in various locations around the world. Power density is one of the primary indicators for economic competitiveness of renewable energy resources.

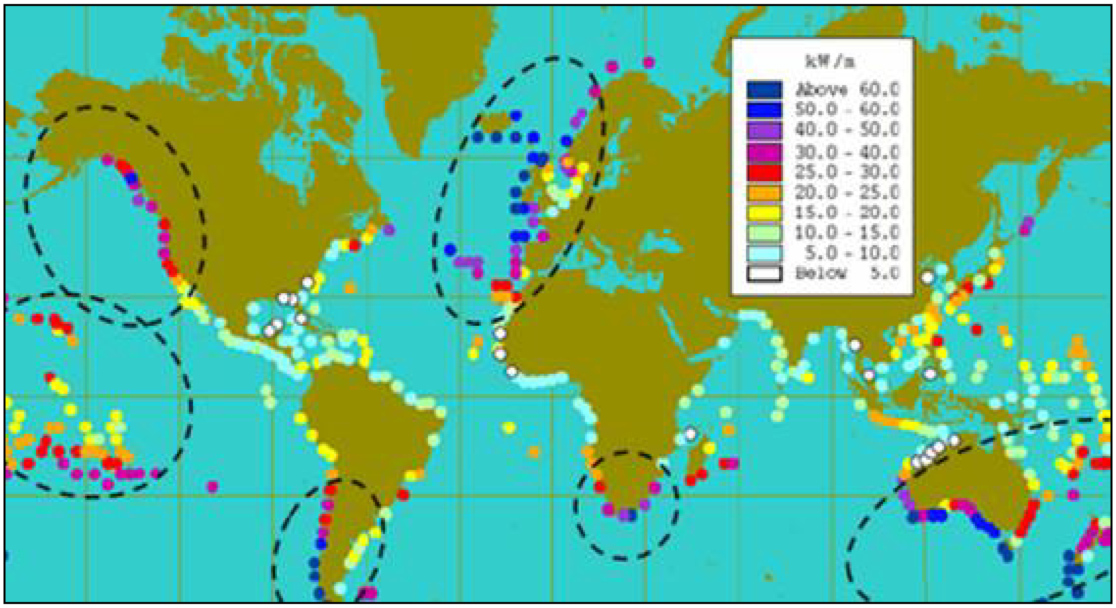


Figure 3 - Annual average wave power densities worldwide in kW/m

As shown in the figure above, the U.S. West Coast, Alaska and Hawaii have suitable wave power resources that could make wave energy an attractive resource.

2.2 Technology Attributes

More than 1000 patents were filed for wave power conversion (WEC) machines over the last 50 years, with a number of device types proving to have technical and commercial potential. A focus is given to technologies that are nearing commercial readiness to provide the reader with an understanding of technologies in respect to commercial readiness. As such, only devices that, at the time of writing, are undergoing sea-trials are being considered.

Wave power conversion devices can be classified by different attributes. The following illustrates the classification by installation location and device category.

Because there are few locations that would permit the implementation of shore-based WEC devices, the main focus here has been on near-shore and offshore technologies. The following presents a high-level device classification based on the installation location.

Shoreline Device – Shoreline devices have lower maintenance and installation costs than offshore devices and do not require moorings and long underwater electrical cables. The less energetic wave climate at the shoreline can be partly compensated by the concentration of wave energy that occurs naturally at some locations by refraction and/or diffraction. The three major classes of shoreline devices are the oscillating water column (OWC), which has a demonstrated field case; the convergent channel (TAPCHAN); and the Pendulor. Several shoreline OWC prototypes have been built in Norway, China, UK (LIMPET), Portugal (Pico Island); incorporated in a breakwater (harbour of Sakata, NW Japan) or placed outside it (Trivandrum, India). No representative device from this device category has been chosen for this study.

Near-Shore Devices – In recent years near-shore oscillating wave surge convertors (OWSC) have become the main type of device considered for such locations, with growing interest in near-shore surging hinged flap devices. The OWC is the main type of device being considered for such locations. In more recent years a few companies and universities have begun research efforts on surging flap-type devices that may be placed near-shore and at least one company, Aquamarine Power, has deployed a working prototype device based on the surging flap concept in the water. This device is currently generating power to the grid at EMEC in Orkney, Scotland

Offshore Devices – Offshore devices are situated in water depths of more than 40 m. Several prototypes have been deployed worldwide, with many more under development. The current state of wave energy conversion technology is comparable to the status of wind energy in the 1980s: developers are pursuing a wide array of technological approaches, and it is not yet clear which technology will prove the most economic choice.

While devices for the on-shore and near-shore environment are tethered or rigidly mounted, offshore devices are usually deployed freely floating. It is almost impossible to classify all the device types under development. For illustration purposes a few of the more popular concepts are outlined below.

Overtopping – This consists of a structure over which the waves topple, a reservoir to collect the water and hydro turbines installed at the bottom of the reservoir. The head of collected water turns the turbines as it flows back out to sea, while the turbines are connected to generators to produce electricity. This is analogous to very low head conventional hydropower.

Point absorber – This is a floating structure that absorbs energy in all directions by virtue of its movements at or near the water surface. It may be designed so as to resonate – that is, move with larger amplitudes than the waves themselves. This feature can maximize the amount of power captured. Power take-off systems may take a number of forms, depending on the configuration of displacers/reactors.

Oscillating Water Column (OWC) – The OWC is a form of terminator; it comprises a partly submerged structure ('collector') which is open to the sea below the water surface so that it contains a column of water. Air is trapped above the surface of the water column. As waves enter and exit the collector, the water column moves up and down, acting like a piston on the air and pushing it back and forth. The air is channeled towards a turbine and forces it to turn. The turbine is coupled to a generator to produce electricity.

Attenuator – This device is a long floating structure like the terminator, but is orientated parallel to the waves rather than normal to them. It rides the waves like a ship; movements of the device at its bow and along its length can be restrained so as to convert energy via an internal working fluid and turbine arrangement.

Surging Hinged Flap – This type of device has been investigated further in recent years and typically consists of a vertical plate that moves in surge in response to the ocean wave energy action. This surging movement is then converted into electricity by use of a hydraulic pumping mechanism.

2.3 Power Conversion Turbo-Machinery

The challenge to overcome is converting the slow oscillating motion of ocean waves into the fast rotational motion typically required for a generator. At the same time, the system should have some form of energy storage capability to smooth power output over multiple wave crests, plus the ability to tune itself to optimize power capture based on incident wave power levels. A wide variety of power conversion systems are under development. Designs in current states of maturity are using air turbines for oscillating water column devices, hydraulic absorber systems for buoy systems and low-head water turbines for overtopping devices. Direct linear induction generators have been evaluated for wave power conversion, however, costs have been prohibitively high for the solution to be considered for commercial application.

Oscillating water column devices use air turbines to convert airflow into electricity. The most well-known development in this area has been the Wells turbine, which converts the bi-directional flow of the air in an oscillating water column into a unidirectional output using symmetrical aerofoil blades. The Wells turbine has fixed symmetrical blades and has proven to be a reliable and simple conversion mechanism. The maximum efficiency of the turbine is around 65%, but part-load efficiencies are relatively low. Because of the variable nature of ocean waves, it will operate most of the time under partial load conditions, which results in average efficiencies of around 25%. To solve the issue of inherently low power conversion efficiency, some developers have employed variable pitch turbine designs to optimize power output, and added active controls to be able to better tune the system to the incident wave power levels and optimize overall device performance. Average power conversion efficiencies for variable pitch turbines are > 60%, which is an almost three-fold increase over fixed pitch designs. This is balanced against higher cost and complexity.

Most of the buoy-based and hinged contour devices feature a hydraulic power conversion system. In such a system, piston rams convert the motion of the absorber device into hydraulic pressure, which in turn drives a generator. Hydraulic accumulators can be used to smooth the power output and increase the power quality for a given device. The advantage of hydraulic power conversion systems is that the components are readily available and are widely used in the offshore oil & gas industry. A typical hydraulic conversion train, which converts the slow movement of an absorber system first into hydraulic pressure and then into electricity using a standard generator, shows average efficiencies of about 80%. Further increases in efficiency can be achieved by using specialized components (digital hydraulics), which are better adapted to the requirements of a wave power conversion device in terms of useful life and efficiency. Hydraulic systems also have the unique advantage of being able to make rapid adjustments within milliseconds, making them viable options for the purpose of rapid tuning.

Low-head water turbines are used in overtopping devices and are based on available technology from the hydropower industry. Efficiency levels are high and the adaptation of low-head turbines using variable speed power conversion systems allow for variable power output and optimized control over the flow rate.

Linear direct induction generators have been evaluated for wave power conversion because they could potentially provide very low maintenance solutions. Because these devices eliminate an intermediary conversion step, they have the potential to reduce many of the maintenance issues associated with the energy conversion process and could potentially increase power conversion efficiency. Archimedes Wave Swing recently deployed a 2MW pilot unit, which features a linear, direct induction generator. However, electrical machines are most cost-effective at high speeds. The slow motion of wave power conversion machines makes direct-induction solutions inherently expensive for commercial applications.

2.4 Foundation/Mooring

Anchoring and electrical interconnection of a wave power conversion device is a key aspect of its design and can have critical implications on installation and operation of the device. While a few devices are directly mounted on seabed, the discussion here focuses on floating devices moored to the seabed by catenary lines.

Floating devices under development typically react against subsea inertial masses or against themselves. The device itself will often undergo large amplitude motion during operation and needs to be able to ride out extreme waves. The mooring system's primary purpose is to keep the system on station so that it does not drift away, while allowing the system to freely move in order to absorb the maximum amount of wave power. Design considerations include: peak current velocities, extreme wave conditions, wave drift loads and wind-induced loads on the structure. Loads induced by currents can create quite large drift-forces, especially with the devices that use large sub-surface structures to tune the device into resonance.

Large amplitude motion also influences the flexible umbilical connection required to connect the device to the seabed. Cyclic fatigue is a key consideration for these types of cables.

Some developers are working on bottom standing devices, which typically feature a gravity base. Important considerations for bottom-standing devices include seabed preparation and scour-protection, as well as device stability during installation.

3. Device Selection and Site Selections

It is likely that there will be different technologies designed to capture energy at nearshore, shoreline and deepwater locations – it remains to be seen which type of technology will dominate in each of these locations. Over 100 active device developers were identified in the initial scoping process of this study. Very few of them have tested their devices at full-scale and even fewer devices are ready for early adoption in commercial development projects. This technological uncertainty impedes the ability to clearly identify environmental and navigational issues because each approach will have its unique set of potential impacts. In order to address this issue, the technological approaches currently being pursued by device manufacturers were brought under review. Based on the review, the technical approaches were categorized and devices selected that are representative of the environmental and navigational footprint of their respective categories. To reduce technical uncertainties to an absolute minimum, selection is limited to devices in an advanced stage of development. As such, baseline impacts are described for devices that have passed the stage where they are likely to undergo fundamental design changes. The following is a summary of the devices selected as a part of this process. Detailed device descriptions may be found in subsequent sections.

Table 3 - Devices chosen for scenario-based analysis

Manufacturer	Deployment Water Depth	Power Take-Off	Rated Power	Mooring Type
Pelamis Wave Power	> 50m	Hydraulic	750kW	Catenary
Ocean Power Tech	> 50m	Hydraulic	150kW	Catenary
Wave Dragon	> 40m	Low head hydro	4-7MW	Catenary
Aquamarine Power	10-15m	Water hydraulics	2MW	Tension Anchors

The two main characteristics of quantifying these marine renewable resources are power density and the size of the recoverable resource. The power density is a good indicator of how cost-effectively the power from a resource can be converted (i.e., higher power densities yielding lower cost of electricity). In addition, the power to weight ratio of devices gives an indication of the ultimate cost of power of competing devices. The recoverable resource size provides an understanding of the potential impact of the resource on meeting future energy needs and is therefore important in determining whether substantial investments into the sector are warranted. This paper focuses on the resources available for large-scale generation of power which could thus meet a significant portion of future U.S. electricity demand.

EPRI studies [1,2] have shown that ocean wave energy with suitable power densities can be found primarily on the U.S. West Coast (California, Oregon, Washington), as well as Alaska and Hawaii.

Power densities on the U.S. East Coast are too low to be economically competitive in the near-term. The total deep water resource is estimated to be 2,100 TWh/year. If 15% of the resource is converted into electricity using wave power conversion machines with 80% power conversion efficiency and 90% availability, wave power could provide around 250 TWh/year of electricity.

Most sites in Alaska are remote and not nearby any substantial grid infrastructure. With the exception of some niche market opportunities to provide power for remote coastal communities, Alaska has limited near-term potential for wave power deployments. This leaves the US West Coast (California, Oregon and Washington) and Hawaii as focus areas for this study. In order to capture major differences in site conditions, one site in Hawaii and one site on the US West Coast (California) were chosen. Both sites have previously been evaluated for wave power deployment and are being actively considered for development. As such, there is sufficient baseline data in place for this study.

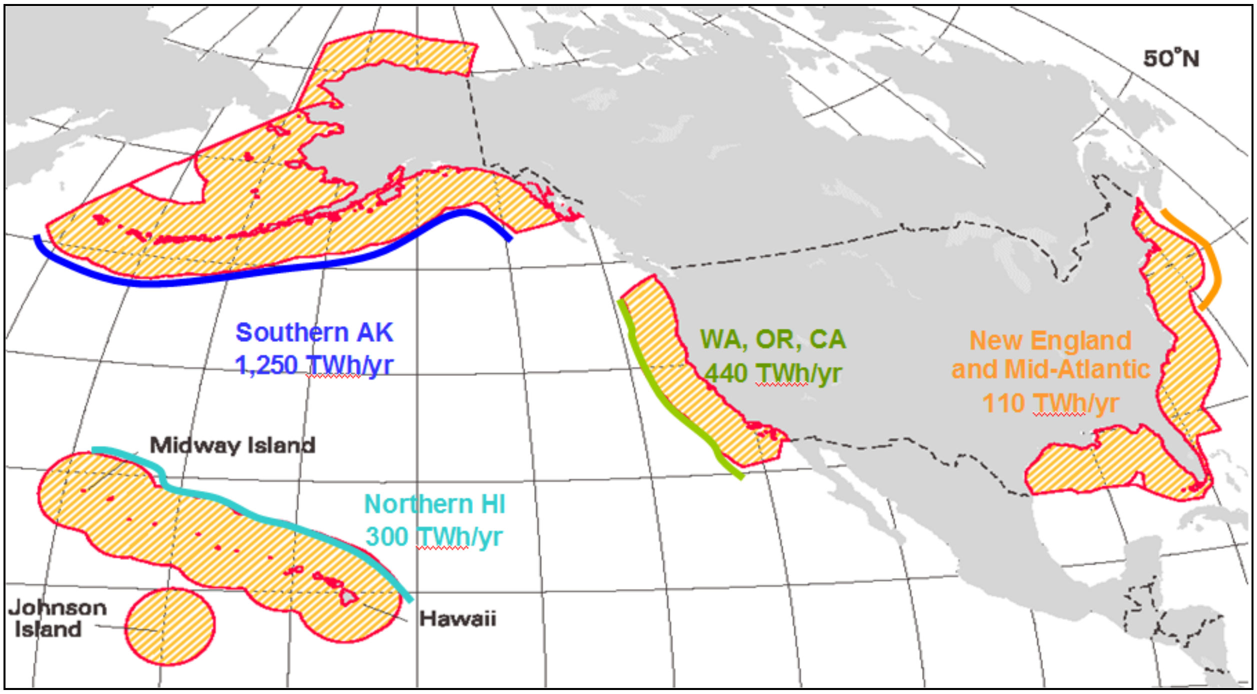


Figure 4 - U.S. Wave Energy potential (annual energy in areas with power density >10kW/m)

4. Project Components

When evaluating potential project impacts, not only the device technology, but all project components need to be evaluated in a comprehensive way. The following illustration shows the UK WaveHub as an example of different project elements. The subsequent text describes each one of these components in a short paragraph.

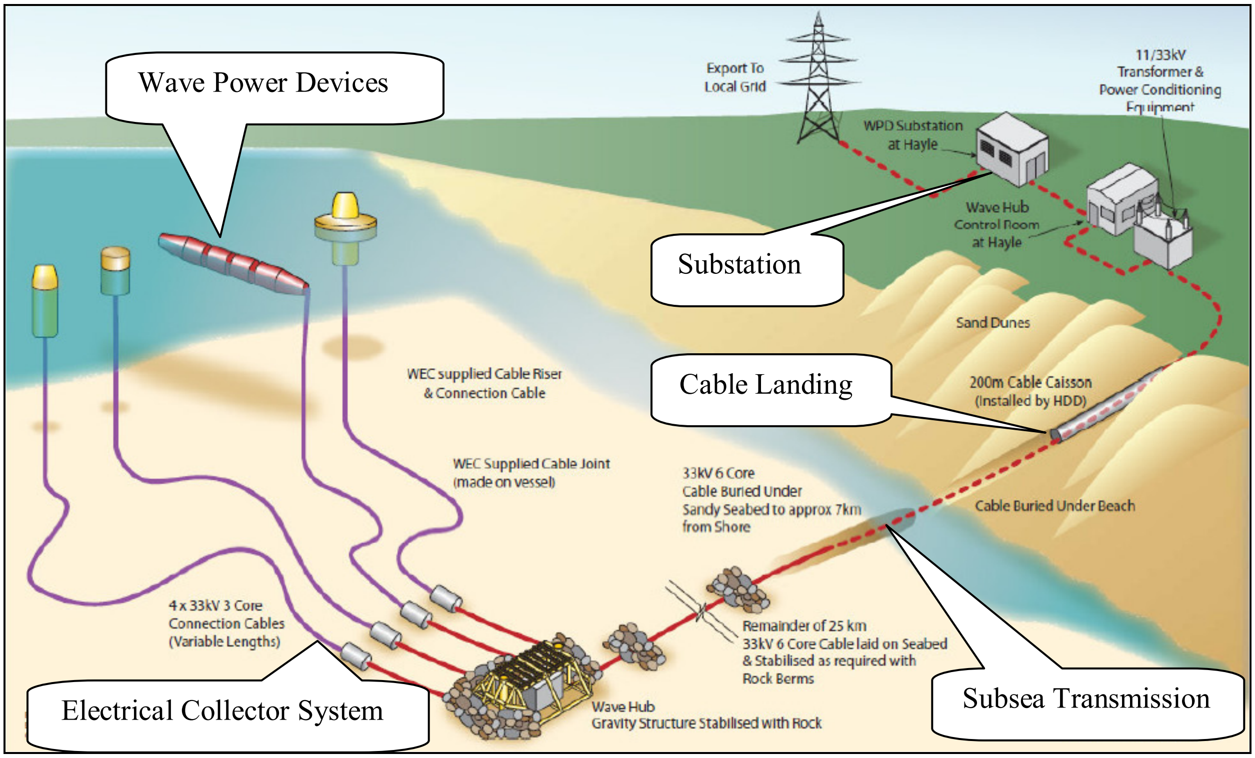


Figure 5 - Wave Power Project Elements

Some nearshore devices use pressurized water to tranfer power to shore where it is converted into electricity. An example of such a system can be found in the Oyster device description section. In such a system the subsea transmission cable is replaced by subsea pipelines and the power conversion station is located on shore.

Substation – The substation is typically the connection point for any power generation facility. The substation connects the electrical transmission system to the lower-voltage distribution lines or to the generation facilities and houses transformers, electrical conditioning equipment and safety devices. Electrical conditioning near the substation is typically used to insure that power-quality standards are met suitable for integration with the grid.

Overland Transmission – Typically, an overland transmission line is required to bridge the distance from the cable landing to the nearest electrical interconnection point. Such a transmission line can go overhead or underground. Underground options tend to be very costly and are not typically utilized, except for short distances. In some cases, existing distribution lines can be reconfigured to accommodate additional wires; or, for very small deployment scales, the plant can be directly connected to the distribution line.

Cable Landing – An important part of bringing power back to shore is the cable landing. Existing easements should be used wherever possible to drive down costs and avoid permitting issues. If they do not exist, directional drilling is the method with the least impact on the environment. Horizontal Directional Drilling (HDD) is a well-established method to land such cables from the shoreline into the ocean and has been used quite extensively to land fiber optic cables on shore.

HDD drill rigs are operated on shore and drill out to sea. Drilling is done with the help of a fluid called drilling fluid. It usually contains water and bentonite or polymer, which is pumped to the cutting head or drill bit and facilitates the removal of cuttings, cools the cutting head, lubricates the passage of the product pipe and stabilizes the bore hole. One of the environmental concerns is that some of this drilling fluid will enter into the marine environment. If done properly, such fluid spillage can be minimized.

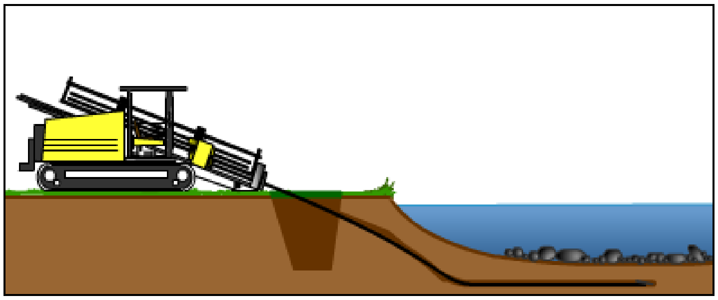
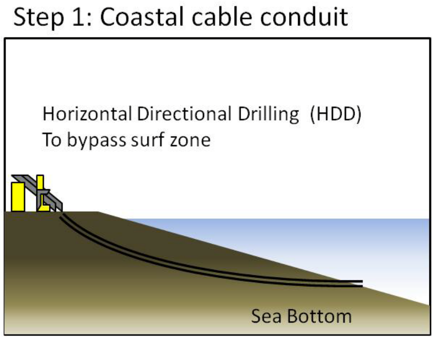
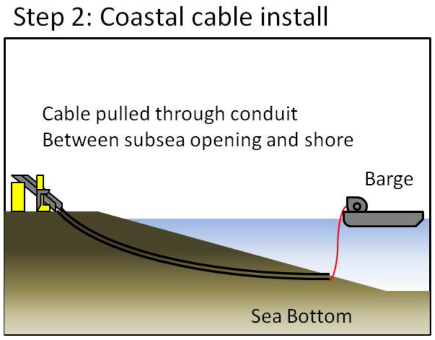


Figure 6 - Directional Drill Rig

For a subsea cable landing, the installation starts by positioning a barge with the cable spool above the conduit outfall. Then the cable is pulled through the conduit from the shoreline. Pulling forces need to be carefully monitored during this process to avoid damage to the cable.





Subsea Transmission Cable – Umbilical cables are being used in the offshore oil and gas industry to connect turbines to shore, and for the inter-connection of different locations or entire islands. In other words, it is well-established technology with a long track-record. In order to make these cables suitable for in-ocean use, they are equipped with water-tight insulation and additional armor, which protects the cables from the harsh ocean environment and the high stress levels experienced during the cable laying operation. Submersible power cables are vulnerable to damage and need to be buried into soft sediments on the ocean floor. While traditionally, sub-sea cables have been oil-insulated, recent offshore wind projects in Europe showed that the environmental effects prohibit the use of such cables in the sensitive coastal environment. XLPE insulation has proven to be an excellent alternative, having no such potential hazards associated with its operation. Figure 7 shows the cross-sections of armored XLPE insulated submersible cables. In most cases, these subsea cables also accommodate optical fibers to transmit data between the devices and the operator on shore.

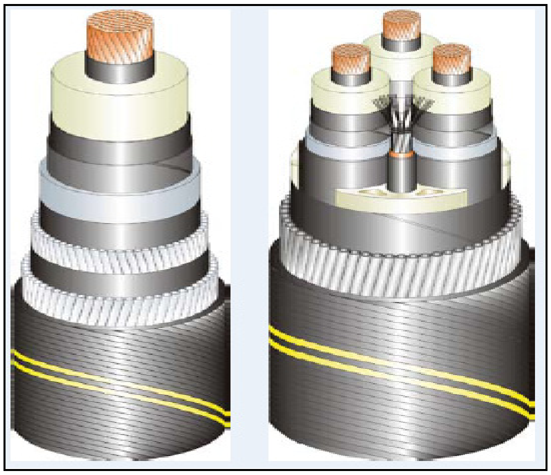


Figure 7 – Armored submarine cables (Source: ABB)

In order to protect the cable properly from damaging influences such as the anchor of a fishing boat, the cable can be buried into sediments along a predetermined route. In order to bury a cable, either a plow or a water-jet system is used to establish a trench and lay the cable. Typical burial depth is about six feet.

Electrical Collector System – The electrical collector system "collects" the outputs of the individual units offshore before it is transmitted back to shore. Depending on the deployment scale and distance to shore, different topologies may be deployed. For larger systems, the collector system will distribute a number of units onto a single collector circuit, allowing that circuit to be isolated in case of an electrical fault. Further, some larger scale deployments may require that the electrical voltage be stepped up before transmission back to shore to minimize transmission line losses. Electrical voltage levels on the collector system are usually limited by the rating of electrical connectors and switch-gear and will be below 40kV. Transmission back to shore may require higher voltage levels, depending on distance and required power capacity.

Subsea Pipelines – Subsea pressurized pipelines can be used to bring power back to shore. In this case, the offshore unit pumps either salt water or fresh-water (will require a low pressure return pipelines) to shore, where it can be used to generate electricity using adapted hydroelectric equipment. Such pipelines will likely only be attractive for near-shore locations, because power transmission losses and cost can become significant project feasibility factors at longer distances**.**

Moorings/Foundation – The device moorings or foundation is device-specific and prevents the device from drifting away under the influence of external forces, such as wind, waves or currents. The foundation installation typically precedes device installation and involves a different set of installation equipment.

Devices – The device is usually deployed and commissioned once all other infrastructure and moorings are in place. Installation procedures and access arrangements are very device-specific. Detailed descriptions of representative devices may be found in subsequent chapters.

Navigation Buoys – Navigation buoys are typically required to mark the deployment area and, if required by the U.S. Coast Guard, provide a safety zone or Area To Be Avoided (ABTA). Such navigation markers should comply with standards and best practices established by the US Coast Guard.

Harbor Infrastructure – Port infrastructure is important from an installation and operational point of view. Because maintenance access is critical to assure plant availability, being in close proximity to good port infrastructure is critical. Some of the key elements in the port infrastructure include having access to suitable crane lifting capabilities and space for O&M. Further, the type and water depth of the port entrance and sheltering will dictate the type of wave conditions during which the port can be accessed safely. This in turn has direct implications on a plant's availability.

5. Offshore Operational Aspects

Operational aspects in all phases of a hydrokinetic project need to be properly understood because they are a main contributor to potential environmental and navigation impacts in any hydrokinetic project. This section outlines the likely operational procedures and equipment required in order to make a determination of their potential effects. It is important to understand that the specific procedures chosen for an installation depend on many variables that require detailed implementation planning as well as, ultimately, on the contractor's comfort level with certain procedures. As such, this is by no means a definitive guide to how exactly such operations are carried out, but is intended for illustrative purposes. Operational impacts are concentrated in the project area and tend to be more dispersed as distance from the project location increases. There will also be increased operational activities on main transit routes and in ports. However, because ports tend to be industrialized areas, the potential effects will not be environmentally as significant as in the deployment area.

5.1 Weather Windows

In order to operate in the open ocean, certain wave, wind and visibility conditions must be met. Typically, such weather windows are evaluated statistically and depend largely on the type of operation that is being carried out. Because wave conditions are much more benign during summer months than in winter, installation and routine maintenance operations tend to be carried out during the summer months (typically May through early September for the US West Coast and Hawaii). Access during more severe winter conditions tends to be restricted due to operational limitations of the vessel, the accessibility of the device itself, and the accessibility of the Harbor. Wind, visibility and wave conditions oftentimes will prevent a vessel from safely accessing a device. Because device availability and operational safety are critical considerations from a device developer's point of view, a key effort is directed toward the design of special-purpose vessels and devices that allow for operational access during more severe conditions.

5.2 Major Project Phases

Wave power projects can be divided into four distinct phases with different types and levels of potential effects. They are as follows:

5.2.1 Pre-Construction

Pre-Construction activities are used to support permitting, detailed design and subsequent construction activities at the site. The main purpose of these activities is to gather detailed site-specific information to allow design and permitting activities to move forward. The following is a list of the typical activities that progress during this phase:

- Side-scan sonar to collect detailed bathymetry at the site. Oftentimes, this includes surveying a broader area to allow for micro-siting activities to move forward. For the siting of shallow water wave power conversion devices as well as for tidal power conversion devices, such bathymetry data is often used to perform detailed resource modeling.
- Sub-bottom profiling is used to identify the depth of sediments and allows identification of obstacles along cable routes and in areas of mooring deployments.
- Resource measurements are required to validate resource models and acquire additional parameters that may not be available through generally available data-sets. For wave power conversion, this would typically require gathering wave and current data at the site over the period of about a year.
- Geotechnical Survey of the cable landing route – Subsea cable landing to shore can occur in one of three ways: through existing easements such as effluent pipelines, trenched through the beach area or directionally drilled through from shore to a suitable water depth. The cable landing needs to be surveyed for detailed design purposes and to identify critical issues that may need to be addressed. If directional drilling is used to bring the power cable to shore, a geotechnical survey is required to assess the suitability of the site.
- Environmental baseline studies may be required. These environmental baseline studies typically complement existing data-sets and fill in knowledge gaps at the project site. A variety of instrumentation may be deployed to allow for gathering of this data. The scope of such studies is usually negotiated as part of the permitting process.
- Many device moorings are sensitive to the type and thickness of the top sediment layer, as these elements drive the mooring design and related cost. In order to determine these mooring requirements, sediment cores need to be collected, which requires the mobilization of an appropriate vessel.

5.2.2 Construction

These are activities that will have the most significant potential effects over the project life and are compressed in a relatively short (one- to two-year) timeframe. Offshore construction activities are dependent on weather windows at the site and will occur during summer, when seas are relatively calm. For the two sites under consideration, this construction time-period is likely constrained to the May through early September time period. The type of vessels and equipment used to carry out construction activities depends heavily on the type of vessel that can be mobilized within the region, site conditions and the operator's familiarity and preference with the type of installation procedures required. Construction activities typically include the following elements:

- Directional drilling from shore to establish a cable landing
- Laying of subsea transmission cable
- Foundation/Mooring installation
- Collector System Installation
- Device Deployment and Commissioning

5.2.3 Operation

Operation and Maintenance (O&M) activities can be divided into planned and unplanned activities. The majority of operational activities will occur during summer months, when relatively calm weather conditions allow these operations to be carried out safely. Some unplanned maintenance activities may need to be carried out during the winter season as a result of failures that require immediate intervention. Many of the device developers are focusing on measures to increase the percentage of time during which they can access their devices for operational purposes. These measures include: purpose-built vessels, custom device access arrangements and quick connect/disconnect systems. By increasing the percentage of time during which devices can be repaired, availability is maximized and economic viability improved.

Because there is little operational data on the reliability of these emerging technologies, little can be concluded about the required intervention frequency. Remote diagnostic capabilities, built-in redundancy and improvements in machine reliability are all factors that affect the number of interventions required over the design life. For surface-accessible devices, typical manufacturers' targets are on the order of one to two years, while for fully submersed devices these targets are on the order of four to six years. To what extent such targets are attainable in commercial projects remains to be seen. Certainly, initial pilot projects require inspection and repairs on a much more frequent basis.

All elements, including underwater elements such as mooring lines, need to be inspected to insure continued operation of the plant. Presently there are few established standards specifically targeting wave power technology, and much progress will be needed on that front to define suitable standards. Until such standards are established, existing offshore standards will be applied to these emerging technologies, and technologies will be certified by established bodies. It is typical for offshore projects to require inspection at a pre-determined interval.

Device manufacturers generally pursue three main operational strategies: (1) Device recovery to pier-side, whereby O&M activities can be carried out in a sheltered area; (2) On-site operation, whereby most O&M activities are carried out on the device, while the device is on station; if required, subsystems can typically be quickly replaced and brought back to shore for repair; or (3) A mixture of #1 and #2, whereby a module or cassette that contains all the critical machinery elements is recovered to shore for O&M purposes. This module can then be quickly replaced.

5.2.4 Decommissioning

Decommissioning occurs at the end of the project life (typically 15-25 years). Decommissioning activities will probably be carried out over one to two summer seasons, depending on the project scale. Decommissioning activities tend to utilize similar equipment and procedures as installation activities. In some cases, it may not be practical to completely remove certain device elements, such as the device foundation or a directionally drilled conduit. A typical example is large diameter grouted piles that would be extremely difficult to remove. In many such cases, the foundation could be cut off at the mud-line. In some cases, it may be desirable to leave the foundation in place because it provides habitat and shelter for marine life. A typical example is oil rigs in Southern California that are now prime diving spots for recreational divers because of the abundance of different fish species.

5.2.5 Vessels

Operational procedures are usually designed with the types of vessels in mind that can be readily mobilized in the vicinity of the deployment location. In the UK, device developers have been relying heavily on equipment used in the offshore oil & gas industry. The US West Coast and Hawaii do have limited capabilities in this respect, largely because there is limited activity in the offshore oil & gas industry. Most construction activities will have to rely on a combination of smaller vessels, tugs, crane barges and transport barges. These types of vessels can be readily mobilized within the Pacific (Hawaii, US West Coast, Canada and Alaska) and can be outfitted for specific jobs. In some cases, heavier equipment may need to be mobilized from the Gulf of Mexico through the Panama Canal. The type of vessel mobilized for a certain job depends on vessel availability as well as project scale. For smaller projects, vessel mobilization costs tend to dominate, while for larger projects, the mobilization cost plays a less important role and operational efficiencies become more important considerations when deciding what type of equipment should be used. At larger project scales, it is also likely that dedicated vessels are used over the project life. In that case, the vessel can be designed to meet the exact requirements of the technology it needs to install and service. Below is a short description for the main types of vessels available within the Pacific region (Hawaii and California).

Crane Barges – Most installation and maintenance activities can be carried out from a derrick barge. These barges are in operation all over North and Central America and are used for a large variety of construction projects. Figure 8 shows Manson Construction's 600-ton derrick barge, WOTAN, performing construction work on an offshore drilling rig. Two tug boats are used for positioning the derrick barge and set moorings if required. The WOTAN is one of the largest Derrick barges operating on the US West Coast.

Figure 8 - Manson Construction 600-ton Derrick Barge WOTAN operating offshore

Figure 9 - Fugro Derrick Barge

In heavy currents these barges use a mooring spread that allows them to keep on station and accurately reposition themselves continuously, using hydraulic winches which are controlled by the operator.

Tugs – Tugs are the workhorses for offshore operational activities and are used for towing and positioning operations. Most tugs on the US West Coast are used in sheltered waters. In order to operate in the harsh offshore environment, tugs need to be offshore-capable. Offshore construction tugs tend to be equipped with better navigation systems and have a more rugged hull, making them less susceptible to damage from impacts.

Research Vessels – Various smaller research vessels are available within the area of interest and are used to carry out data collection and measurement tasks. University systems, national labs and private contractors operate such research vessels that can be used for the deployment of measurement devices and other project development activities.

Rigid Inflatable Boats (RIBs) – RIBs tend to have a limited range but are a cost-effective means of carrying out smaller tasks in the harsh marine environment, such as transferring personnel to nearby platforms or structures.

Figure 10 - Typical Rigid Inflatable Boat (RIB)

Barges – Barges are used to transport a wide range of goods along the coast and can be readily outfitted with additional capabilities, such as strand-jacks and winches, to provide an operating platform. Most barges are not powered and will require tugs to move them.

Purposed-built or converted vessels – Many of the wave power companies are designing their own vessels or are converting existing vessels to exactly fit the requirements of their installation/recovery and operational procedures. By designing the vessel to match their operational requirements, the device manufacturers can improve operational efficiency and reduce cost. It is likely that any wave farm with more then a few devices will have their own dedicated service vessel.

Remote Operated Vehicles (ROV) – These systems increasingly replace divers and are used to monitor the subsea operation, visual inspections, and carry out various manipulation tasks such as connecting and disconnecting guide wires, unplugging electrical cables, etc. Technological advances have made these submersibles increasingly capable, in many instances eliminating the need to send down divers. They are likely to play an important role in the area of inspection and certification. Such un-manned intervention has the potential to significantly reduce cost of offshore operations, while reducing operational risks.

Figure 11 - Deep Oceans Phantom ROV

Figure 12 - Seabotix Crawler ROV

6. Device Performance

In order to evaluate the energy production from the selected devices, the following studies had to be completed: (1) a deep water wave energy resource assessment for both sites, (2) a shallow water wave energy resource assessment for both sites, (3) device performance assessments for all devices that were selected for this study, and (4) the annual energy output calculated based on the resource data and device performance. This section provides some background on the methodology and results of these four study tasks.

6.1 Deep Water Wave Resource Assessment

The deep-water wave energy resource was characterized in Hawaii and California by using NDBC data buoy measurement data at both sites of interest. Because the purpose of this study was to establish indicative device performance for plant layouts, data was simply post-processed and frequency distribution tables established. The following report shows some high-level wave data results from the two deep water sites of interest, along with the frequency distribution tables.

NDBC 51202 – Mokapu Point, HI

Coordinates	21.42 N, 157.67 W
Water Depth	100 m
Annual Average Wave Power Density	14kW/m
Average Wave Height	1.75 m
Average Dominant Wave Period	8.5 seconds

Table 4 – Frequency of occurrence Distribution-significant wave height (Hs) vs. Dominant Wave Period (Tp). Total number of occurrences is 1000.

		Tp (s)											
		4.5	**5.5**	**6.5**	**7.5**	**8.5**	**9.5**	**10.5**	**11.5**	**12.5**	**13.5**	**14.5**	**15.5**
Hs(m)	**0.25**	0	0	0	0	0	0	0	0	0	0	0	0
	0.75	1	1	2	8	9	6	4	5	2	2	1	1
	1.25	2	19	18	32	46	42	17	21	12	8	6	3
	1.75	0	16	50	59	72	61	23	29	21	11	9	5
	2.25	0	1	17	40	64	45	15	18	16	9	8	4
	2.75	0	0	1	8	23	26	12	11	6	4	3	1
	3.25	0	0	0	1	4	9	5	4	2	1	1	0
	3.75	0	0	0	0	0	1	1	2	1	0	0	0
	4.25	0	0	0	0	0	0	0	0	0	0	0	0

NDBC 46212 – Humboldt Bay South Spit, CA

Coordinates	40.75 N, 124.31 W
Water Depth	40m
Average Wave Power Density	28.5 kW/m

Table 5 – Frequency Distribution-significant wave height (Hs) vs. Dominant Wave Period (Tp)

									Tp Bins (s)								
		4.5	**5.5**	**6.5**	**7.5**	**8.5**	**9.5**	**10.5**	**11.5**	**12.5**	**13.5**	**14.5**	**15.5**	**16.5**	**17.5**	**18.5**	**20.5**
Hs(m)	**0.25**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0.75	0	0	0	1	4	7	1	1	6	22	0	5	4	0	0	0
	1.25	3	14	2	75	48	53	49	35	14	32	0	54	20	0	3	0
	1.75	0	12	22	71	31	91	77	79	37	18	0	19	16	0	5	0
	2.25	0	9	39	119	23	81	96	73	94	37	0	14	8	0	6	0
	2.75	0	0	0	99	67	57	64	84	62	86	0	23	12	0	5	3
	3.25	0	0	0	31	53	27	49	74	70	47	0	30	5	0	1	3
	3.75	0	0	0	5	22	12	16	31	61	32	0	23	4	0	2	0
	4.25	0	0	0	0	0	1	3	33	33	22	0	19	13	0	4	1
	4.75	0	0	0	0	1	1	1	5	18	18	0	5	5	0	2	0
	5.25	0	0	0	0	0	1	2	3	4	6	0	1	2	0	1	0
	5.75	0	0	0	0	0	0	0	1	5	3	0	5	0	0	0	0
	6.25	0	0	0	0	0	0	0	0	3	4	0	2	0	0	0	0
	6.75	0	0	0	0	0	0	0	1	1	2	0	6	0	0	0	0
	7.25	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
	7.75	0	0	0	0	0	0	0	0	1	1	0	2	0	0	0	0
	8.25	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
	8.75	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0

6.2 Shallow Water Wave Resource Assessment

Because one of the representative technologies selected is a near-shore device, which is deployed in about 13m water depth, the near-shore wave energy resource had to be characterized. In order to do so, the shallow water wave transformation code SWAN was used to establish the near-shore wave energy climate.

SWAN is a third-generation wave model for obtaining realistic estimates of wave parameters in coastal areas, lakes and estuaries from given wind, bottom and current conditions. However, SWAN can be used on any scale relevant for wind-generated surface gravity waves. The model is based on the wave action balance equation with sources and sinks.

Directional wave data from Wavewatch III was used to define the offshore boundary condition. Bathymetry data were obtained from NOAA. A total of 2920 SWAN runs were completed for each site by propagating the deep water wave energy resource over the spatial domain in three-hour intervals. This corresponds to a full year of Wavewatch III data. The year 2008 was chosen as reference year.

Data output from these 2920 SWAN runs was then post-processed and relevant statistical information was extracted for the deployment site at 13m water depth. The following shows some high-level results for the two deployment sites in Hawaii and California.

Hawaii Site

Water Depth	15m
Distance to shore	2.5 km
Average Power Density	6.5kW/m

Shallow water wave transformation has an effect on the wave power density. The following map shows the annual average significant wave height over the computational domain, which was computed by SWAN for this project. As expected, the annual average wave height (a good indicator for wave power density) is reduced closer to shore.

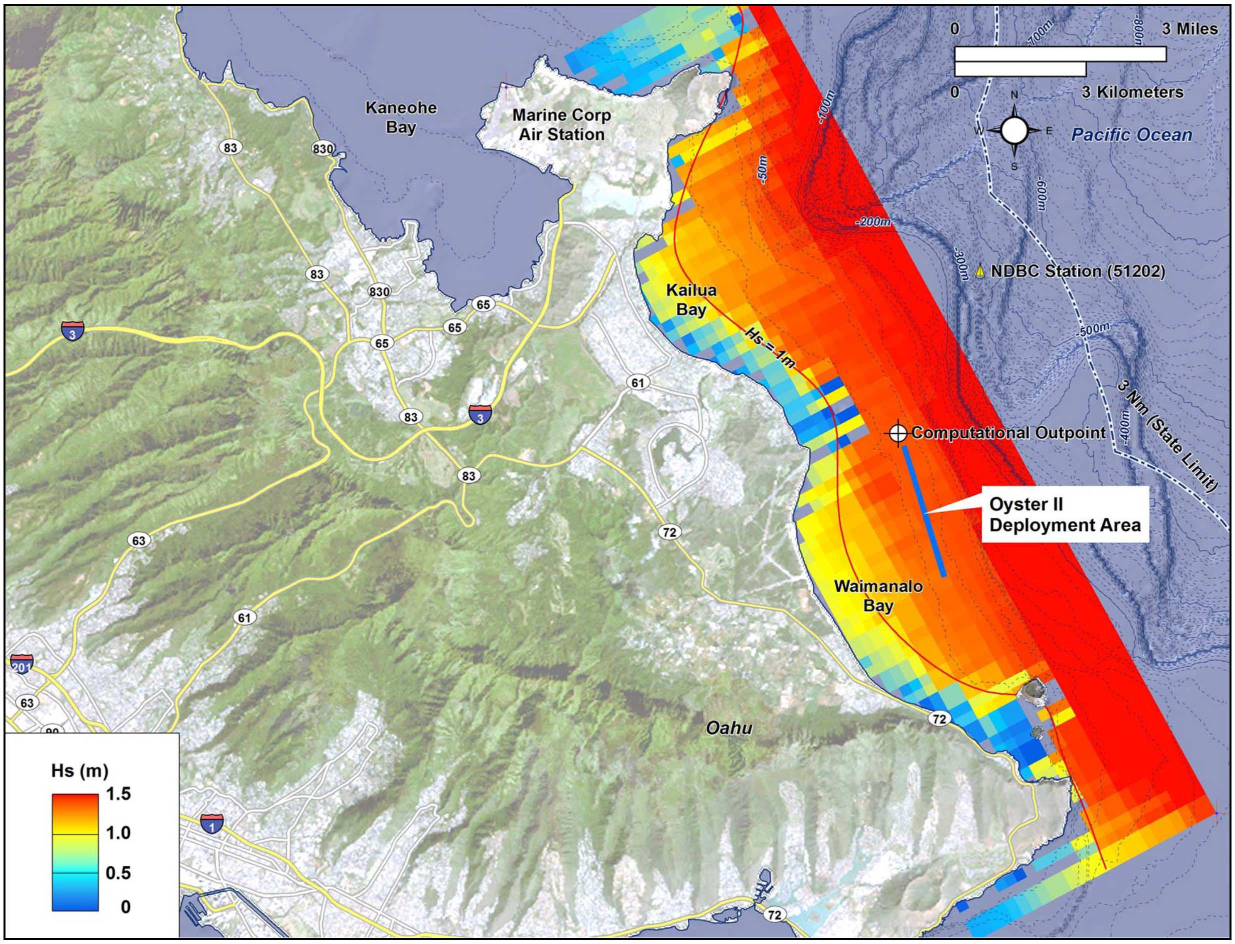


Figure 13 - Significant wave height over project area

Detailed statistics were generated for the likely deployment location and a frequency distribution of seastates was generated. The following table shows the frequency of sea-state reoccurrence as a function of significant wave height (Hs) and zero cross period (Tz) at the single output location shown in the figure above.

Table 6 - Frequency of reoccurrence of sea-states at potential Oyster deployment site. Out of a total of 1000.

	Tz (s)							
Hs (m)	**2.5**	**3.5**	**4.5**	**5.5**	**6.5**	**7.5**	**8.5**	**9.5**
0.25	0	0	7	1	18	4	0	0
0.75	7	181	179	117	79	28	21	4
1.25	0	510	417	163	79	21	7	5
1.75	0	72	529	97	18	23	1	0
2.25	0	0	181	81	9	2	0	0
2.75	0	0	3	38	14	2	0	0
3.25	0	0	0	15	1	0	0	0
3.75	0	0	0	0	6	0	0	0

California Site

Water Depth	15m
Distance from shore	1.2 km
Average Power Density	25kW/m

The California site allowed for some fundamental verification of the modeled data. A wave measurement buoy (NDBC 46212) located in about 40m water depth was used to compare significant wave heights at that location. Overall, the measured and modeled results showed excellent agreement and confirmed overall model setup. However, in the absence of shallow water wave data, the near-shore wave energy resource could not be confirmed.

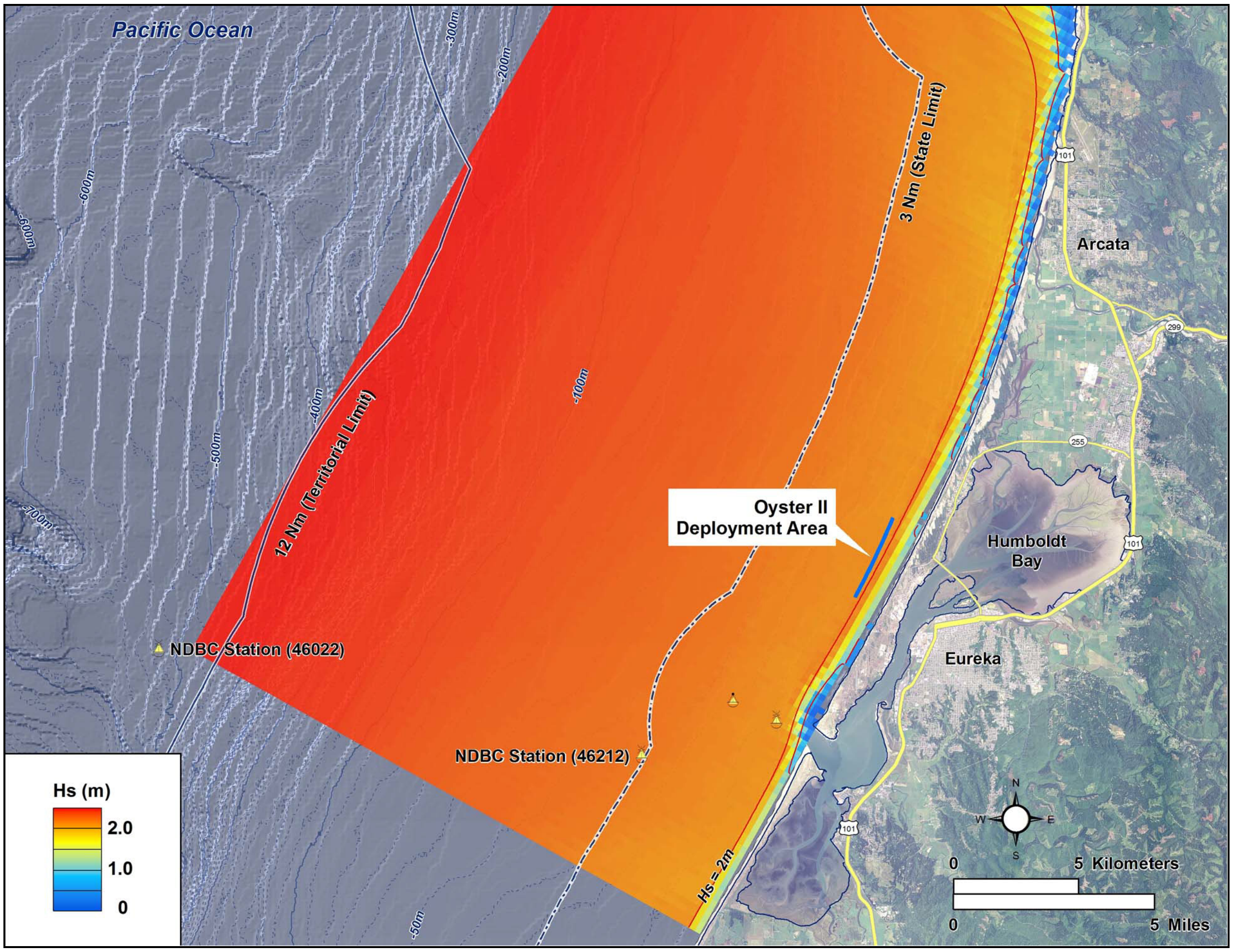
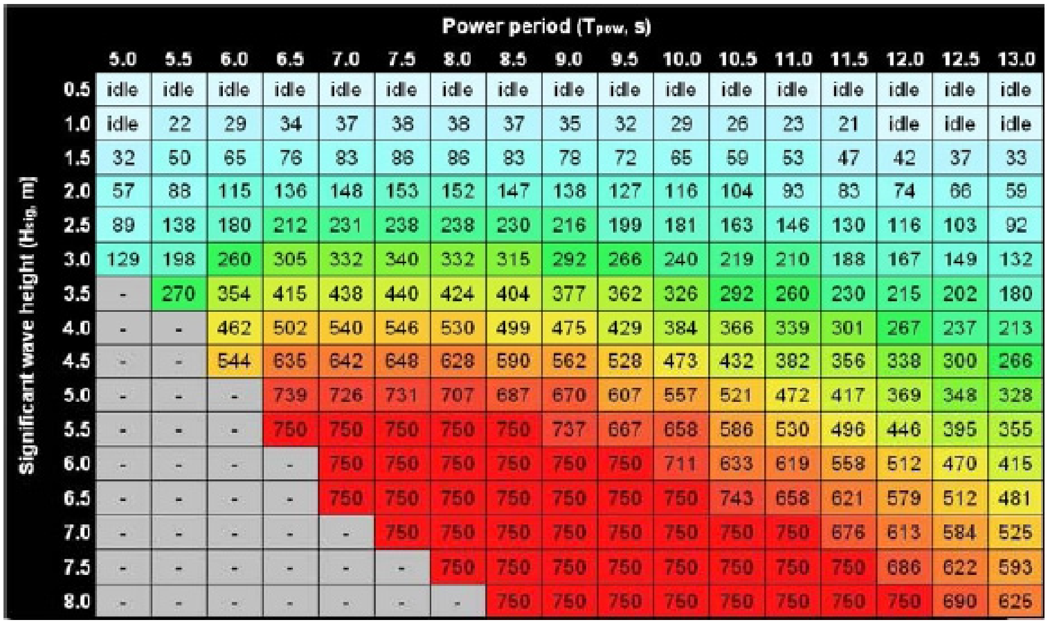


Figure 14 - Significant wave height over California Computational Domain

6.3 Performance Assessment and Results

The purpose of this performance assessment is to provide indicative performance numbers for the selected technologies. Device performance of most devices can be described as a function of significant wave height (Hs) and wave period (T). Three device developers (Wave Dragon, Pelamis, and Aquamarine Power) provided their device electrical output in the form of a scatter diagram. The scatter diagram provides the indicative electrical output as a function of seastate. By multiplying the scatter diagram with the frequency distribution (which describes how many hours a particular sea-state occurs over the period of a year), the annual energy output for the machine can be calculated at the site. The following shows an example of a device's performance.

Table 7 - Pelamis Device Performance Matrix (Source: www.oceanpd.com)



Significant wave height (H_{sig}, m)	Power period (T_{pow}, s)																
	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0
0.5	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle	idle
1.0	idle	22	29	34	37	38	38	37	35	32	29	26	23	21	idle	idle	idle
1.5	32	50	65	76	83	86	86	83	78	72	65	59	53	47	42	37	33
2.0	57	88	115	136	148	153	152	147	138	127	116	104	93	83	74	66	59
2.5	89	138	180	212	231	238	238	230	216	199	181	163	146	130	116	103	92
3.0	129	198	260	305	332	340	332	315	292	266	240	219	210	188	167	149	132
3.5	-	270	354	415	438	440	424	404	377	362	326	292	260	230	215	202	180
4.0	-	-	462	502	540	546	530	499	475	429	384	366	339	301	267	237	213
4.5	-	-	544	635	642	648	628	590	562	528	473	432	382	356	338	300	266
5.0	-	-	-	739	726	731	707	687	670	607	557	521	472	417	369	348	328
5.5	-	-	-	750	750	750	750	750	737	667	658	586	530	496	446	395	355
6.0	-	-	-	-	750	750	750	750	750	750	711	633	619	558	512	470	415
6.5	-	-	-	-	750	750	750	750	750	750	750	743	658	621	579	512	481
7.0	-	-	-	-	-	750	750	750	750	750	750	750	750	676	613	584	525
7.5	-	-	-	-	-	-	750	750	750	750	750	750	750	750	686	622	593
8.0	-	-	-	-	-	-	-	750	750	750	750	750	750	750	750	690	625

The table above shows some very typical features of a wave energy conversion device performance. In the case of very small waves, the device doesn't produce any power, since the amount of energy available in the ocean waves does not prompt the machine to begin generating electricity. In the case of very large waves, the device starts to plateau its power production because the power conversion system reaches its rated capacity. At that stage, the primary objective of the machine is to dissipate excess structural loads on the structure to insure survivability, while continuing to generate power at rated capacity.

For one of the selected devices, the OPT Powerbuoy, no device performance table was made available by the device manufacturer. Device performance was, however, known for OPT's Reedsport (Oregon) site from their FERC filing documents. The wave energy resource in Reedsport was previously assessed by an EPRI study, and the wave climate is very similar to the selected California site. It was therefore assumed that the device would have the same capacity factor in California. For the Hawaii site, device performance was estimated based on the performance difference (between the two sites) of similar devices under investigation.

The capacity factor of a technology is oftentimes thought of as being an indicator of a device's competitiveness. In reality, the capacity factor is a variable that is a result of the manufacturers design decisions.

In order to level the playing field and make subsequent analysis simpler, device rated capacity was adjusted so every device would yield a capacity factor of 30%. Availability was assumed to be 95% across all devices and was used to compute the annual energy output. Transmission losses were neglected.

Table 8 - Indicative Device Performance for California Deployment Site

Device	Annual Output	Rated Capacity	Capacity Factor
Pelamis	1,911 MWh/year	760 kW	30%
Wave Dragon	15,680 MWh/year	7,300 kW	30%
OPT Powerbuoy	374 MWh/year	150 kW	30%
Aquamarine Oyster II	3,660 MWh/year	1,460 kW	30%

Table 9 - Indicative Device Performance for Hawaii Deployment Site

Device	Annual Output	Rated Capacity	Capacity Factor
Pelamis	1,290 MWh/year	517 kW	30%
Wave Dragon	8,500 MWh/year	3,400 kW	30%
OPT Powerbuoy	250 MWh/year	100 kW	30%
Aquamarine Oyster II	820 MWh/year	320 kW	30%

7. Effects of Energy Conversion on Wave Energy Resource

Converting energy from ocean waves into electricity will result in reduced wave heights and wave power levels behind a deployed array. This reduced wave energy level could potentially affect physical coastal processes, such as sediment transport, which in turn could also potentially affect biological processes. In order to understand the extent of these potential effects, some basic principles need to be understood.

Energy Conversion – The wave energy device performance (and therefore the amount of energy converted from the wave energy resource) is a function of the wave height and wave period (seastate). The amount of energy converted from the resource can be expressed as the device capture width, which is the ratio between device power output and wave energy available within the device's width (significant linear dimension perpendicular to the wave direction). It is important to understand that this capture width is a function of the seastate, so depending on wave conditions, the amount of conversion changes. While every machine has different wave capture characteristics, it is an inherent design goal to maximize device performance at small wave heights through optimal tuning and limit energy production (and hence structural loads) in large waves.

Device Spacing – Within a wave farm, it is not the case that the whole linear width of the plant is occupied with devices. Devices need to be appropriately spaced to make sure that they do not interfere with each other. Representative device layouts are shown in the device description section (section 9). Device spacing could be strategically be used to reduce wave energy reduction impacts and disperse the effects.

Near-field effects – Hydrodynamic interactions within an actual array are complex and can result in constructive or destructive device interference, affecting device performance. As a result, device spacing needs to be optimized to maximize individual device performance. Such near-field hydrodynamic effects are not well understood at present, as they are highly device-specific and it is beyond the scope of this report to characterize them. It is not expected that near-field effects will have any significant effects on navigation. However, the increased turbulence and sheltering effects of the device structure from predator species has been recognized in fisheries to create an artificial reef effect, increasing biological activity. Near-field effects may also play an important role for technologies deployed in shallow waters. This artificial reef effect is well established for buoys in tropical waters, but not temperate waters. Also, the reef effect comes from the solid structure substrate provided by the moorings and cables. This is what may attract a higher density and diversity of fish species – which in turn may attract a higher density of predators to them. Further research should be directed toward addressing near-shore device effects on sediment transport issues.

Far-field effects – As distance increases, effects become more uniform and start to disperse. Diffraction effects will start to rebuild wave energy levels in the wave shadow of wave energy devices. These far-field effects can be quantified numerically using shallow water wave transformation models. It is important to understand that such effects are dependent on: (1) device technology and its performance characteristic, (2) device spacing and (3) distance from wave energy conversion device. Quantifying these effects for all different technologies may be an area of future research.

In order to evaluate potential effects of different technologies, some simplifying assumptions are made. A hypothetical device array consists of devices arranged in a row facing the principal wave direction. The principal parameters defining the array are: (1) the device spacing, (2) the device capture width (performance), (3) the device width and (4) the array width. Device spacing and device width can be obtained by reviewing the information in the detailed device information in subsequent sections of this report and are summarized here.

Table 10 - Device Spacing Summary

	Device Width	Machine Separation	Linear Device Density
Pelamis	6m	120m	5%
Wave Dragon	170m	647m	26%
OPT Powerbuoy	11m	49m	22%
Oyster II	26m	26m	50%

Based on the above reference data, one can quickly see that the device density is a function of device width and device spacing. It is important to recognize that the device spacing is a design variable that could be changed to mitigate potential impacts.

Because the detailed device performance data are confidential by nature, a generic performance curve was established and applied to all devices equally. The performance is expressed as a function of significant wave height and assumes a 100% capture width for all seastates up to 3m significant wave height. Once that height is reached, capture width reduces to allow the absorbed wave power to remain the same. The following curve illustrates this device performance. The solid line represents the available power per meter wave crest width, and the dashed line represents the device's power capture for each meter of device width.

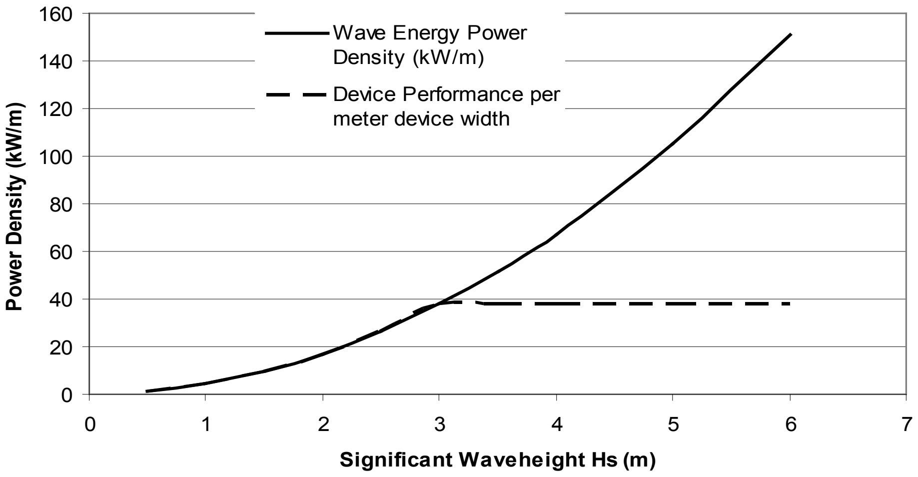


Figure 15 - Generic Device Performance

The device capture efficiency is defined as the ratio of converted power/available power within the device width. The following chart shows the capture efficiency of our hypothetical device. It shows that capture efficiency is high in smaller waves and starts to reduce as the machine reaches its rated capacity and therefore is beginning to shed more and more of its energy.

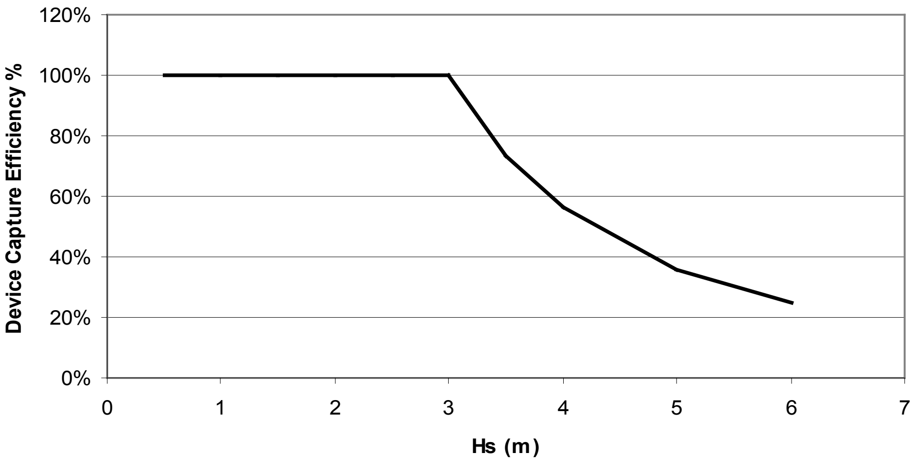


Figure 16 – Generic Device Capture Efficiency as a function of Significant Wave Height. Frequency dependency is ignored to reduce complexity.

Using a dispersion relationship, wave height reduction was estimated for the extreme conditions. A formulation that was developed by Pelamis Wave Power was used. The formulation is specific to the Pelamis device and in reality, the formulation would have to be adapted to other devices. However, given the hydrodynamic function of the Pelamis, it probably represents a worst-case scenario.

Wave Height Reduction (%) $= \frac{w_c}{2L} \bullet \sqrt{\frac{NL}{2D\tan\theta^o}}$

Wc = Device Capture Width (m)

L = Machine Separation (m)

N = Number of machines

$Tan\theta = \sqrt{3}$[2]

D = Distance to shore

Based on this example, two cases were run to determine the effective wave reduction as a function of downstream distance from device array. The two examples correspond to the lowest linear device density and the highest linear device density of wave power conversion systems evaluated in this study (see table 10). Only deep water devices were assessed using this approach because spatial variations in the near-field will be dominant for a near-shore device such as Oyster, and this proposed approach does not work well for this type of device. It is important to note that this exercise is for illustrative purposes for the range of potential far-field effects and does not illustrate the effects of any particular device, because no actual device data was used.

The first case is based on a linear device density of 5% and a wave farm array width of 5000m. The following chart shows the expected wave height reductions on the shoreline for a dominant wave period of 10s as a function of distance from shore. Results will vary as a function of wave period as well, which is not shown here.

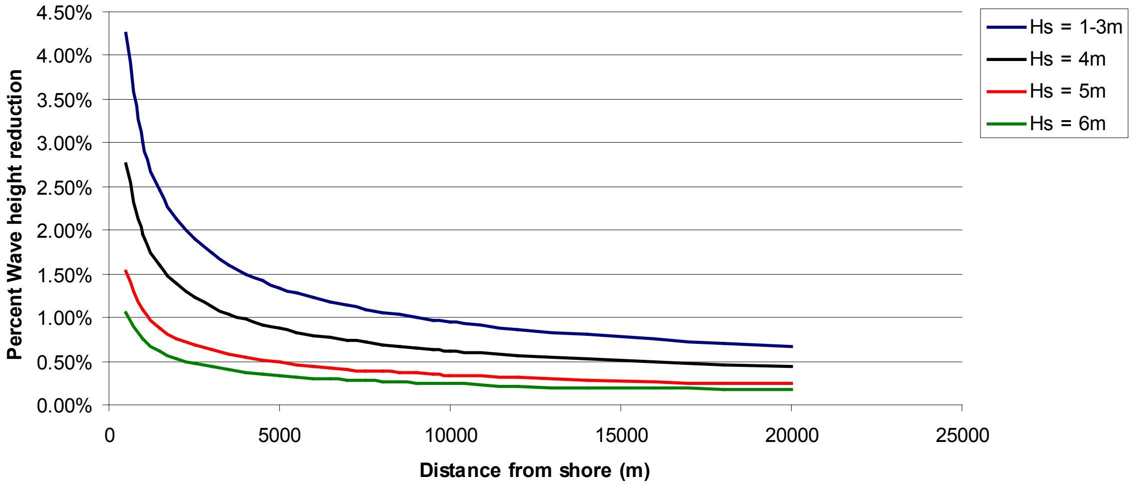


Figure 17 - Wave Height reduction as a function of distance

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[2] This factor is device-specific, was determined for Pelamis and comes from the angular dependence of waves radiated downstream from Pelamis. Reference: R.C.T Rainey 2001, "The Pelamis Wave Energy Converter: It may be jolly good in practice, but will it work in theory?"

The next case is assuming a very densely packed array. It is based on a linear device density of 26% and a wave farm array width of 5000m. The following chart shows the expected wave height reductions on the shoreline for a dominant wave period of 10s as a function of distance from shore.

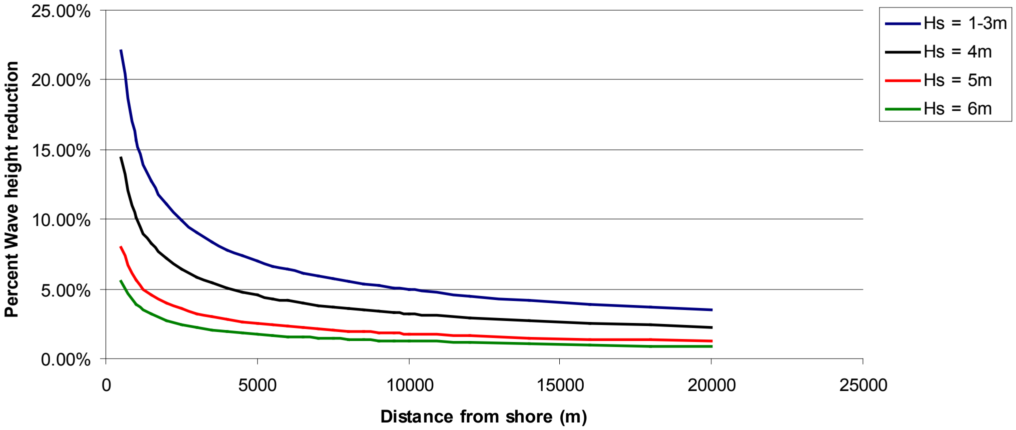

Figure 18 - Wave Height reduction as a function of distance

Typical early adopter deep water sites on the US West Coast are located 3-8 km from shore. However, some suitable sites may be as far as 50 miles from the coast (i.e. San Francisco bay and Southern California).

While these two examples illustrate wave height reductions that could be expected for different devices under development, the analysis is based on a very simple approach that does not take into account variations in device performance, downstream wave radiation differences and other factors important for a device-specific determination of wave height reduction effects. It also does not address detailed spatial variability of wave reduction effects. As such, it should only be used for illustrative purposes.

8. Navigation

As with all project elements, navigation safety will need to be addressed through a consultation process with the relevant stakeholders. In broad terms, navigation safety should address the interaction of the device array and its operation with other users of the sea-space and should minimize effects for all users. For details on navigational considerations related to wave and tidal power projects, the reader is encouraged to review a document recently released by PCCI (Marine and Hydrokinetic Renewable Energy Technologies: Potential Navigational Impacts and Mitigation Measures, December 2009). PCCI also released a checklist that can be used by project developers to insure that they address potential aspects affecting navigation during the siting process.

The U.S. Coast Guard (USCG) and other agencies will participate in the National Environmental Policy Act (NEPA) review process conducted by the primary licensing agency. That participation will include advice on potential navigational hazard issues that may result from a proposed Renewable Energy Installation (REI) and possible mitigation for those issues.

8.1 USCG Concerns over Hazards

The USCG's[3] concerns over possible hazards that result from an REI may vary, depending on the project phase. These phases include: design, construction, transportation to and from the site, installation, operations and finally decommissioning. For each of these phases the USCG requests developers to consider potential navigational impacts of the installation, including;

Platform, Stationkeeping, Device, Mooring, Transmission Cable and other design considerations

- Visual Navigation and Collision Avoidance
- Effects on Communications, Radar and Positioning Systems

Site and Waterway considerations

- Effects upon Tides, Tidal Streams, and Currents
- Effects upon seafloor soil movement
- Effects of varying weather and sea state
- Effects of ice where applicable

Maritime Traffic and Vessel Considerations

- Traffic Survey Recommendations
- Risk of Collision, Allision, or Grounding

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[3] These concerns are included in USCG policy guidance:Navigation and Vessel Inspection Circular 02-07, which is available online at http://www.uscg.mil/hq/cg5/NVIC/pdf/2007/NVIC02-07.pdf

- REI Structure Clearances and Responseto allision
- Access to and Navigation Within, or close to, the REI

USCG Mission Considerations

- Recommended design requirements, operational requirements, and operational procedures for installation shutdown in the event of a Search and Rescue (SAR), Pollution, or Homeland Security Operation
- Recommendation to work with the USCG to assess likely impacts on USCG SAR, Marine Environmental Protection (MEP) and Homeland Security missions

8.2 Key Mitigation Measures

Consultation with Stakeholders

Developers should schedule meetings/events with stakeholders to understand siting conflicts. These meetings/events should begin early and continue through the licensing or permitting process.

Navigation Studies and Risk Assessment

A key mitigation measure involves undertaking the requisite navigational studies and evaluating the navigational risk of proposed projects. These studies will be required to provide the information necessary for environmental assessments, environmental impact statements and permit applications. Based on the results of navigation studies and risk assessment, a developer may want to consider mitigation measures, including alternative siting and incorporating stakeholder concerns. It is the responsibility of the developer to fund or provide the studies and analysis to support ecommendations for their installation.

IALA Recommendation O-139

Another key mitigation measure involves incorporating the marking schemes in International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) Recommendation O-139 (2008)[4] in developers' proposals, with the realization that the USCG may modify an initial marking scheme proposal, based on its review of traffic, risk and other factors.

Private Aids to Navigation (PATON)

The U.S. Aids to Navigation System is administered by the USCG. It consists of federal aids operated by the USCG, by the other armed services, and private aids to navigation operated by other persons.

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[4] http://site.ialathree.org/pages/publications/documentspdf/-doc_225_eng.pdf

The U.S. System is consistent with the IALA Maritime Buoyage System, but as of 2009, its regulations do not incorporate specific IALA recommendations for PATON covering offshore wave and tidal energy devices. USCG policy guidance recommends incorporating the marking schemes in IALA recommendation O-139 as providing an equivalent level of safety and environmental protection to marking schemes specified in USCG regulations.

8.3 Demarcation Measures

From a navigation point of view, the deployment of many individual wave or tidal power conversion units arranged in arrays raises the question of how these devices are best marked to avoid potential vessel allisions[5]. Navigation demarcation may include: (1) paint color, (2) lighting, (3) active and passive radar aids, (4) warning sounds and (5) an automatic identification system. How exactly they need to be applied begins with the developer's evaluation of potential effects on navigation and proposal of navigational demarcation for the proposed site. The final demarcation scheme will be determined through open consultation with stakeholders such as Coast Guard and affected waterways users. This section provides general demarcation schemes for illustrative purposes only.

Wave power conversion farms may have a number of surface piercing and non-surface piercing elements such as sub-surface buoys, mooring lines, anchors and power cables; therefore it is of major interest to establish a safety zone or Area to Be Avoided (ATBA) around the devices to provide a navigational buffer. The navigational markings and safety zone work together to prevent damages to the power conversion installation, vessels, personnel and the environment. A typical wave power device array has a certain footprint and will cover a stretch of coastline along a relatively narrow water depth contour. The device deployment zone is constrained by suitable water depths and the need for exposure to the principal wave direction. If the array spans a significant width, ship transfer lanes may be required to allow existing ocean users to pass safely between arrays. Figure 19 - Navigation safety zone or ATBA conceptbelow illustrates an example of safety zones or ATBA surrounding more than one array.

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[5] An allision is a term of reference that is used when a moving object strikes a stationary object. This is in contrast to a collision, where both objects are in motion when a strike occurs.

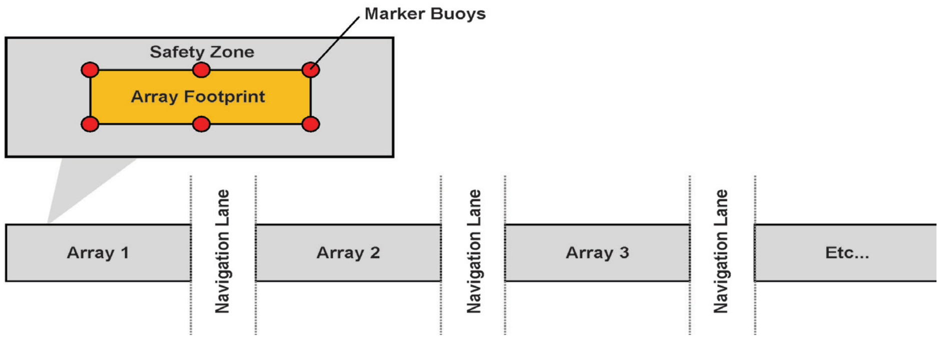

Figure 19 - Navigation safety zone or ATBA concept

In order to provide indicative project area dimensions, reference conceptual arrays were established using the reference technologies chosen for this study. The following table shows the indicative footprint of different devices under consideration in this study. While the depth of the array stays about the same, the length will increase as a function of installed capacity (or number of devices deployed). This is very typical because additional device stacking would reduce the amount of energy available to subsequent devices and hence reduce their commercial viability.

Table 11 - Reference Footprints for Devices under Consideration

	Humboldt, CA				**Oahu, HI**			
	Absorber Dimensions		**Foot print**		**Absorber Dimensions**		**Foot Print**	
Pilot (Single Unit)	**Length (m)**	**Width (m)**	**Length (m)**	**Width (m)**	**Length (m)**	**Width (m)**	**Length (m)**	**Width (m)**
Pelamis	180	6	360	120	180	6	360	120
Wave Dragon	170	300	820	820	170	300	820	820
OPT Power Buoy	11	11	200	200	11	11	200	200
Oyster	26	13	100	26	26	13	100	26
	Farm Arrangement		**Footprint**		**Farm Arrangement**		**Footprint**	
Small Commercial	**Devices (#)**	**Rows (#)**	**Length (km)**	**Width (km)**	**Devices (#)**	**Rows (#)**	**Length (km)**	**Width (km)**
Pelamis	13	2	1.6	0.5	20	2	2.5	0.5
Wave Dragon	2	2	1.1	0.8	3	2	1.9	0.8
OPT Power Buoy	67	4	3.3	0.8	100	4	4.9	0.8
Oyster	7	2	0.4	0.1	31	2	1.6	0.1
	Farm Arrangement		**Footprint**		**Farm Arrangement**		**Footprint**	
Large Commercial	**Devices (#)**	**Rows (#)**	**Length (km)**	**Width (km)**	**Devices (#)**	**Rows (#)**	**Length (km)**	**Width (km)**
Pelamis	66	2	8	0.5	39	2	4.8	0.5
Wave Dragon	7	2	9.1	0.8	6	2	3.9	0.8
OPT Power Buoy	333	4	16.5	0.8	*N/A* [6]	*N/A*	*N/A*	*N/A*
Oyster	14	2	0.7	0.1	62	2	3.2	0.1

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[6] Large Commercial OPT Power Buoy Scenario at the Hawaii site is not considered feasible due to deployment site constraints at Hawaii site.

The different components of a navigation scheme are first summarized; applications to different marine renewable schemes are then outlined:

Paint Scheme	Paint Color and scheme is standardized for different navigation obstacle types. In addition, visual aids such as reflective materials and numerical characters may be required for proper identification of a structure at sea.
Lighting	Lighting color, flashing synchronization and visibility range will depend on the specific application.
Sound Signals	Fog-horns are typically used and should be considered for marking marine energy structures and arrays. Minimal audible range is 2Nm.
Radar Reflector	For structures that do not provide a good radar signature, consideration for a radar reflector mounted on top of the structure should be given. Radar reflectors are designed to best reflect radar signals.
AIS	Automatic Identification System (AIS) is a short-range coastal tracking system used on ships and by Vessel Traffic Services (VTS) for identifying and locating vessels by electronically exchanging data with other nearby ships and VTS stations. AIS was developed with the ability to broadcast positions and names of objects other than vessels, like navigational aid and marker positions.
RACON	RAdar BeaCON, also called radar responders or radar transponder beacons, are receiver/transmitter transponder devices used as a navigation aid, identifying landmarks or buoys on a shipboard marine radar display. A racon responds to a received radar pulse by transmitting an identifiable mark back to the radar set. The displayed response has a length on the radar display corresponding to a few nautical miles, encoded as a Morse character beginning with a dash for identification. The inherent delay in the racon causes the displayed response to appear behind the echo from the structure on which the racon is mounted.
SPS	Significant Peripheral Structure (SPS) - Significant Peripheral Structure (SPS) is a corner or other significant point on the periphery of the array. Every SPS should be fitted with light, visible in all directions in the horizontal plane. These lights should be synchronized to display a “Special Mark” characteristic, flashing yellow, with a range of not less than five nautical miles. The distance between SPS's should not normally exceed three nautical miles.

Scheme 1: Floating surface piercing devices – Single Device

Device Examples	Wave Dragon, PowerBuoy, Pelamis, Oyster
Paint Scheme	Marked for isolated danger. These marks are colored black with one or more broad horizontal red bands and are equipped with a topmark of two black spheres, one above the other. Consideration should be given to the use of additional retro-reflective material (i.e. visually reflective material in addition to lighting)
Lighting	White light – a group flash light Fl(2), with two flashes in a group. Required range is not less than five nautical miles.
Sound Signal	Consideration may be given to sound signals, where appropriate.
AIS	Consideration should be given to the provision of AIS.
SPS	No SPS needed for single device.

Scheme 2: Floating surface piercing devices – Array

Device Examples	Wave Dragon, PowerBuoy, Pelamis, Oyster
Paint Scheme	Yellow paint
Lighting	Yellow flashing lights with 2Nm visibility on each device, synchronized lighting. SPS buoys - synchronized flashing yellow lights with 5Nm visibility.
Acoustic Signal	Acoustic signal required about every ½ mile.
AIS	AIS on SPS buoys required
SPS	SPS on each corner (four total, or 2 if array is narrow, such as Aquamarine Oyster)

Scheme 3: Completely Submersed Structures (no interference with surface navigation)

It may be reasonable to mark subsurface arrays, even though the clearance and safety factor would indicate no interference. Marking upper and lower extremes of the channel sides with yellow Special Mark buoys/pilings/small structures with yellow lights is recommended, a total of four being reasonable. Additional features of retro-reflecting material and RACONs on each buoy/piling/small structure would also be reasonable. For completely submersed structures in the open ocean, only an entry in navigation charts may be required.

Construction and Operation – The Developer would propose a Safety Zone or an Area to Be Avoided (ATBA) in the application for private Aid to Navigation and include the information in submittal of environmental information in the EIS process. Coast Guard would also distribute Notices to Mariners and publish the Safety Zone or ATBA in the Federal Register. Lighting during construction/deconstruction is achieved by keeping lighted vessel/work barge on site.

9. Wave Energy Device Descriptions

9.1 Pelamis Wave Power

Figure 20 - Pelamis Wave Power Devices

Specifications Pelamis P-2

Length	180m
Width	6m
Steel Weight	750 T
Ballast Weight	800 T
Mooring type	Catenary Moored
Anchor type	Stevpris type embedment anchors
Total Anchor Weight	14.5 T
Total mooring chain weight	100T
Additional mooring	20T steel-wire rear yaw line and clump weight
Rated power output	750kW
Power conversion	Electro-hydraulic power conversion system
Power Smoothing Storage	High pressure Accumulators
Hydraulic Fluid volume	12,800 Liter

Company Information

Company Name	Pelamis Wave Power
Website	www.pelamiswave.com

Principle of Operation - The Pelamis P2 is a freely-floating, hinged contour device. The device consists of four tubular sections, connected by three hinged power conversion modules (PCM). Each PCM contains a heave and sway joint, providing two degrees of freedom, as illustrated in Figure 21. The wave-induced motion of each joint is resisted by sets of hydraulic rams configured as pumps. These pump oil into smoothing accumulators which then drain at a constant rate through a hydraulic motor coupled to an electrical generator. All hydraulic components are contained within the device cylinders.

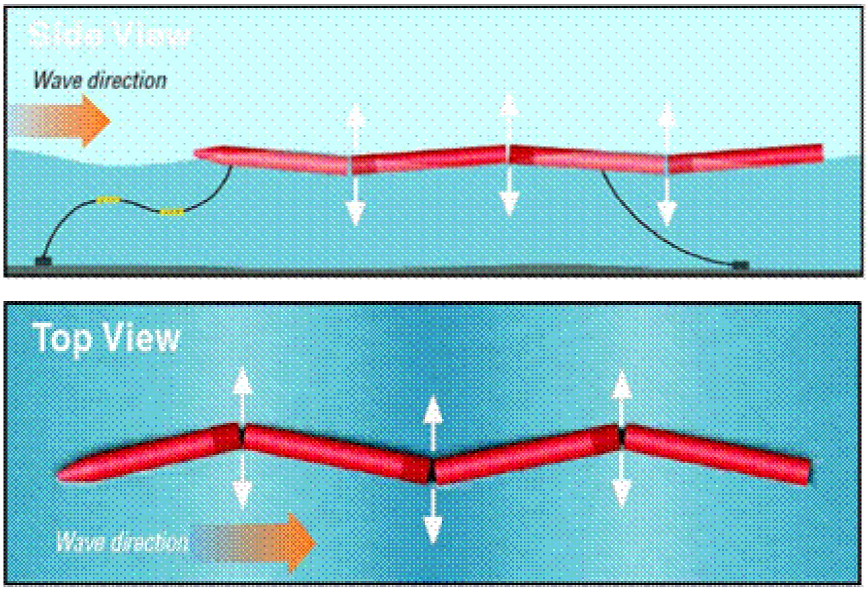

Figure 21 – Pelamis operation

The accumulators are sized to allow continuous, smooth output across wave groups. Oil-to-water heat exchangers are included to dump excess power in large seas and provide the necessary thermal load in the event of loss of the grid. Overall power conversion efficiency (mechanical to electrical) ranges from around 70% at low power levels to over 80% at full capacity. Each of the four generator sets are linked by a common 690V, 3-phase "bus" running the length of the device. A single transformer is used to step-up the voltage to an appropriate level for transmission to shore. High Voltage power is fed to the sea bed by a single flexible umbilical cable, then to shore via a conventional sub-sea cable. The design has inherent survivability with a very small frontal area subjected to the hydrodynamic forces of large waves.

Device Anchoring & Footprint - The Pelamis uses a caternary mooring system and is slack-moored with a mooring configuration that allows the machine to self-reference and point into the incident waves. An overview of the mooring configuration that has been used for the device is shown in Figure 22 below.

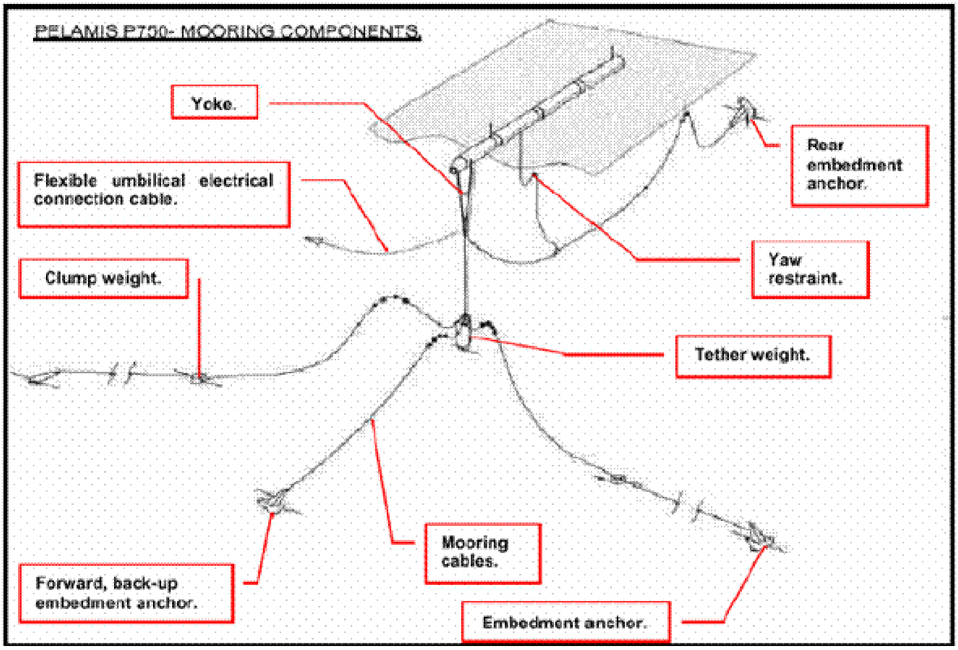

Figure 22 - Pelamis P750 mooring configuration

Survival conditions, maximum current velocity, water depth, seafloor soil densities and other factors will need to be considered in a detailed design phase. For the purpose of this project, the reference mooring system used for the Pelamis prototype testing was used. This is an existing design for a sandy bottom.

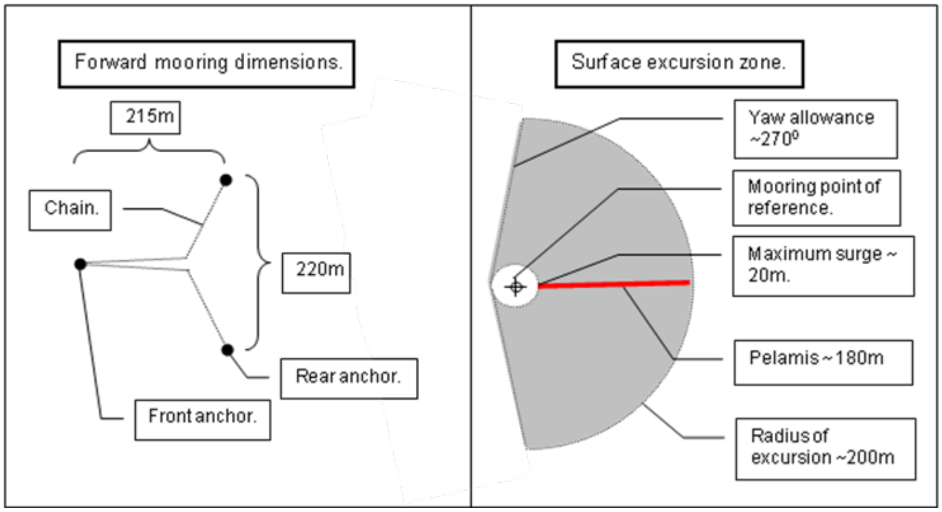

Figure 23 - Pelamis P2 mooring top view

The mooring size and general configuration is shown in

Figure **23** from the top view. Given the weights of cables, the tensions experienced between weights and floats will be on the order of tons, and thus are not expected to be able to be moved. Slack cable conditions are an undesired design characteristic and are not expected to occur during regular operation.

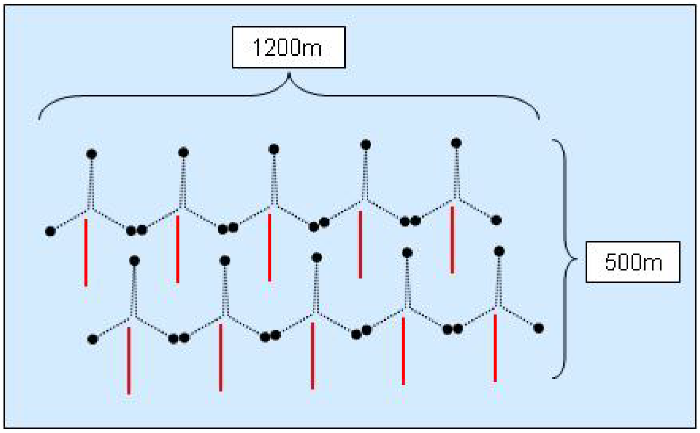

Figure 24 - Example array of 10 devices, top view

Multiple systems may be arranged in an array with separation that takes into account the mooring space, yaw and device surge allowance. An example of a two row array of 10 devices is shown in Figure 24.

Operation & Maintenance - Device maintenance will be carried out pier-side, or at modest pontoon facilities in sheltered water areas, minimizing hazardous operational activities offshore. The device is designed to be quickly disconnected from its mooring and towed to a nearby maintenance facility for maintenance overhauls. Many subsystems and components are designed in such a way that they can be lifted out with a standard three-ton crane and replaced with a tested subsystem. Remote diagnostic capability, extensive instrumentation and a high level of redundancy will minimize the need for physical intervention and will allow O&M activities to be carried out during suitable weather windows. Recently, Pelamis Wave Power developed a quick connect/disconnect system, allowing the rapid deployment and recovery of the device with a relatively small vessel. Pelamis wave power has also developed a “habitat” system, which can seal off a portion of the tubular section and provide dry access to the areas of the Pelamis machine below the waterline. This is especially important for repairs to the joints, which means that the device does not need to be recovered to land for standard O&M operations or most non-standard extended repair/replacement operations.

Operation Procedures - The following operational activities and time-frames are estimated for a deployment at three different scales. In absence of detailed design and engineering studies, the time-frames and intervention intervals represent initial estimates and are to be used for illustrative purposes only. Time estimates refer to operational time within the general deployment area and includes mobilization time.

The first set of operational activities are outlined for pre-construction activities that are used to support permitting, detailed design and subsequent construction activities at the site.

Table 12 - Site pre-installation resources and duration

Activity	Resources	Duration
Survey to map high-resolution bathymetry at deployment site and cable route	Survey vessel	< 1 week
Sub-bottom profiling to identify sedimentation layer thickness at deployment site and along cable route in areas of soft substrate	Survey vessel	< 1 week
Cone penetration and Vibrocore sampling	Barge and Tug Boat	< 1 week
Visual inspection of seabed in deployment area and along cable route	Survey vessel ROV or diver	< 1 week
Wave Resource Characterization using ADCP or directional measurement buoy	Survey Vessel or RIB	1 year
Environmental baseline studies	Survey vessel, Stand-alone instrumentation	1-2 years

The second set of activities represent project construction activities. These are activities that will have the most significant potential impacts over the project life and are compressed in a relatively short (one- to two-year) timeframe. Offshore construction activities are dependent on weather windows at the site and would occur during times when there is a high likelihood of calm seas. Due to weather considerations, this construction time-period is likely constrained to the May through early September time period for the two sites of interest in Hawaii and California.

Table 13 - Pelamis installation resources and duration (spread over a two year period)

Activity	Resources	Duration		
		1-Unit	10-Units	100-Units
Directional drilling to land power take-off cable on shore	Drill rig	< 2 months	< 2 months	< 2 months
Subsea cable installation	Cable Install. Vessel Supply boat	< 2 weeks	< 2 weeks	< 2 weeks
Moorings System Installation	Derrick barge, 2 Tugs Supply boat	1 week	3 weeks	30 weeks
Electrical Collector System Installation	Derrick barge, 2 Tugs Supply boat	1 day	1 week	5 weeks
Device Deployment & Commissioning	Custom Vessel	1 week	3 weeks	15 weeks

Operation and Maintenance activities can be divided into planned and unplanned activities. The majority of operational activities will occur during summer months, when relatively calm weather conditions allow these operations to be carried out safely. Some unplanned maintenance activities may need to be carried out during the winter season as a result of failures that require immediate attention.

Table 14 - Pelamis operational activity resources and duration

Activity	Resources	Frequency
Recovery and Re-deployment	Custom Vessel	Annual
Un-planned Maintenance	Custom Vessel	Every 4 years
Visual Inspection of underwater elements	Research Vessel, ROV	Every 4-5 years
Replacement/Refurbishment of Moorings and Electrical Collector System	Derrick Barge 2 Tugs Supply Boat	20-25 years

Decommissioning occurs at the end of the project life (typically 15-25 years). Decommissioning activities will probably be carried out over one to two summer seasons, depending on the project scale.

Table 15 - Pelamis decommissioning resources and duration

Activity	Resources	1-Unit	10-Units	100-Units
Recover Devices	Custom Vessel	1 day	8 days	50 days
Recover Device Moorings	2 x Tug Derrick Barge Supply Boat	1 week	3 weeks	30 weeks
Collector System Removal	Cable Handling Vessel	1 day	1 week	5 weeks
Subsea cable removal	Cable Handling Vessel	2 weeks	2 weeks	2 weeks

9.2 Ocean Power Technologies

Figure 25 - OPT PowerBuoy Device

Specifications for 150kW rated machine

Float Diameter:	11m
Float Height:	2m
Height above water:	8m
Draft:	36m
Mass:	150 T
Mooring Type:	Catenary Moored
Anchor Type:	Concrete block
Anchor Mass:	165 T each
Anchor Dimensions:	6m x 6m x 3.1m
Average Power:	52kW (in Oregon wave climate with power density of 21.5kW/m)
Rated Power:	150kW
Power conversion	Hydraulic
Hydraulic fluid volume:	~2500 L[7]

Company Information

Company Name:	Ocean Power Technologies
Web site:	www.oceanpowertechnologies.com

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[7] Based on engineering estimates by re vision consulting

Principle of Operation - The Power Buoy is a heaving point absorber, reacting against a subsea reaction plate. The relative movement between the absorber buoy and the reaction plate is converted into electricity using an electro-hydraulic power conversion system. The device is catenary-moored in such a way that the mooring allows the device to move unrestricted in heave, but is constrained from drifting. An illustration of the PowerBuoy rated at 150kW is shown in Figure 26.

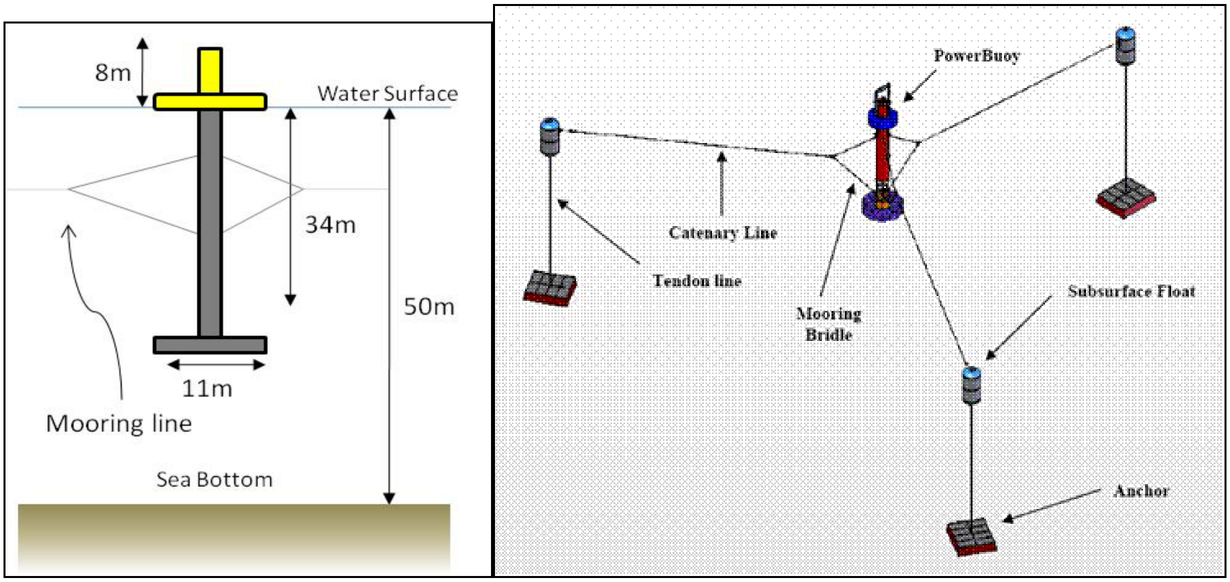

Figure 26 - Power Buoy and dimensions

Device Mooring & Footprint - As shown in Figure 26, the system is moored between three surface piercing mooring buoys. The mooring buoys are moored to the concrete block, sitting on the seabed. A top view is shown in Figure 27. Pre-tension levels on the mooring lines and the inter-device spacing are likely high enough that they are not considered an issue for entanglement.

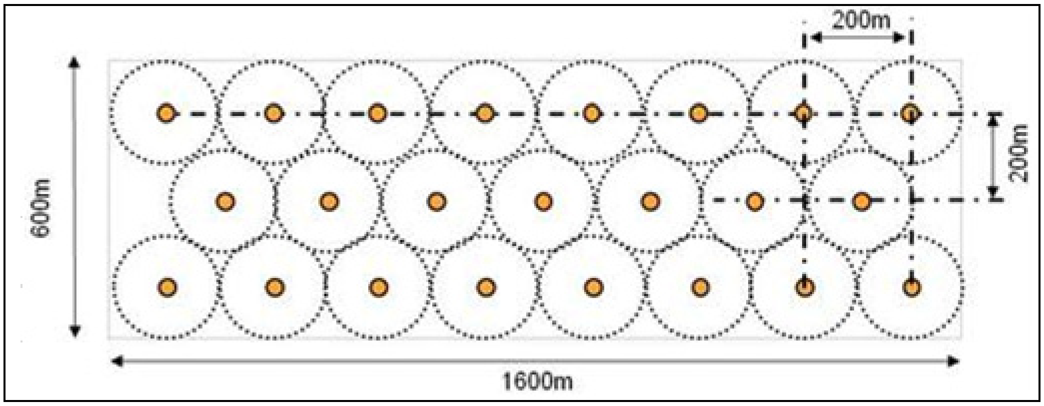

Figure 27 - OPT Buoy Example Array

Operation & Maintenance - The maintenance intervals for the OPT buoy have not been published. However, based on information for other devices that are based on hydraulic power take-off mechanisms, it is assumed that an annual inspection and maintenance procedure will be performed. Given the small device size, it is likely that the device has to be recovered to carry out O&M activities at the pier-side.

Additional Information - OPT expects that the device will be up-scaled over time to a unit size of about 500kW, which would increase the overall device scale and affect operational considerations. In particular, it is likely that at larger scale, more operational procedures could be carried out on-board the device, instead of having to recover it back to shore.

Operational Procedure - The following operational activities and time-frames are estimated for a deployment at three different scales. In absence of detailed design and engineering studies, the time-frames and intervention intervals represent initial estimates and are to be used for illustrative purposes only. Time estimates refer to operational time within the general deployment area and include mobilization time. The first set of operational activities are outlined for pre-construction activities that are used to support permitting, detailed design and subsequent construction activities at the site. Pre-installation activities will not differ significantly as a function of scale.

Table 16 - Site pre-installation resources and duration

Activity	Resources	Duration
Survey to map high-resolution bathymetry at deployment site and cable route	Survey vessel	< 1 week
Sub-bottom profiling to identify sedimentation layer thickness at deployment site and along cable route in areas of soft substrate	Survey vessel	< 1 week
Visual inspection of seabed in deployment area and along cable route	Survey vessel, ROV or diver	< 1 week
Wave Resource Characterization using ADCP or directional measurement buoy	Survey Vessel or RIB	1 year
Environmental baseline studies	Survey vessel, Stand-alone instrumentation	1-2 years

The second set of activities represent project construction activities. These are activities that will have the most significant potential impacts over the project life and are compressed in a relatively short (one- to two-year) timeframe. Offshore construction activities are dependent on weather windows at the site and would occur during times when there is a high likelihood of calm seas. Due to weather considerations, this construction time-period is likely constrained to the May through early September time period at the two sites of interest (California and Hawaii). It is likely that in reality the type of equipment mobilized would depend on project scale, because for larger projects, operational efficiencies become more important cost drivers than for smaller projects, where mobilization cost tends to dominate. Addressing this equipment choice in detail is beyond the scope of this study.

Table 17 - Site pre-installation resources and duration

Activity	Resources	Duration		
		1-Unit	10-Units	100-Units
Directional drilling to land power take-off cable on shore	Drill rig	< 2 months	< 2 months	< 2 months
Subsea cable installation	Cable Install. Vessel Supply boat	< 2 weeks	< 2 weeks	< 2 weeks
Moorings System Installation	Derrick barge, 2 Tugs Supply boat	1 week	3 weeks	30 weeks
Electrical Collector System Installation	Derrick barge, 2Tugs, Supply boat	1 day	1 week	5 weeks
Device Deployment & Commissioning	Derrick barge, 2 Tugs, Supply boat	1 week	3 weeks	15 weeks

Operation and Maintenance activities can be divided into planned and unplanned activities. The majority of operational activities will occur during summer months, when relatively calm weather conditions allow these operations to be carried out safely. Some unplanned maintenance activities may need to be carried out during the winter season as a result of failures that require immediate attention.

Table 18 - Power Buoy operational activity resources and duration

Activity	Resources	Frequency
Recovery and Re-deployment	Custom Vessel	Annual
Un-planned Maintenance	Custom Vessel	Every 4 years
Visual Inspection of underwater elements	Research Vessel, ROV	Every 4-5 years
Replacement/Refurbishment of Moorings and Electrical Collector System	Derrick Barge, 2 Tugs, Supply Boat	10-15 years

Decommissioning occurs at the end of the project life (typically 15-25 years). Decommissioning activities will probably be carried out over one to two summer seasons, depending on the project scale.

Table 19 - Power Buoy decommissioning resources and duration

Activity	Resources	1-Unit	10-Units	100-Units
Recover Devices	Custom Vessel	1 day	8 days	50 days
Recover Device Moorings	2 x Tug Derrick Barge Supply Boat	1 week	3 weeks	30 weeks
Collector System Removal	Cable Handling Vessel	1 day	1 week	5 weeks
Subsea cable removal	Cable Handling Vessel	2 weeks	2 weeks	2 weeks

9.3 Wave Dragon

Figure 28 - Wave Dragon Device

Specifications

	12kW/m	*24 kW/m*	*36kW/m*	*48kW/m*
Weight:	6,500tons	22,000tons	33,000tons	54,000 tons
Width:	170m	260m	300m	390m
Length:	96m	150m	170m	220m
Wave reflector length:	84m	126m	145m	190m
Height:	12m	16 m	16.8m	18.1m
Number of turbines:	8	16	16-20	16-24
Generator type:	*Permanent magnet generators*			
Generator rating:	8 x 185kW	16 x 250kW	16-20x350kW	16-24x500kW
Device Rated Power:	1.5MW	4MW	7MW	12MW
Water Depth:	>15m	>20m	>25m	>30m
Mooring type:	Single Point Mooring with 5 - 8 legs			

Company Information

Company Name:	Wave Dragon
Web site:	www.wavedragon.net

Principle of Operation - The Wave Dragon is an overtopping device that combines a double curved overtopping ramp and two reflector wings, which focus energy onto the overtopping basin. Variable speed propeller turbines are used to convert this low pressure head into electricity. The variable speed operation allows for higher efficiency levels to be attained.

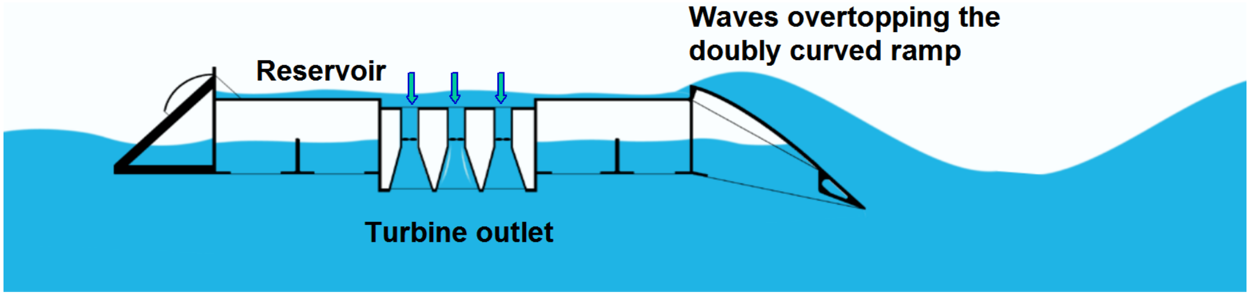

Figure 29 - WaveDragon Operational Principle

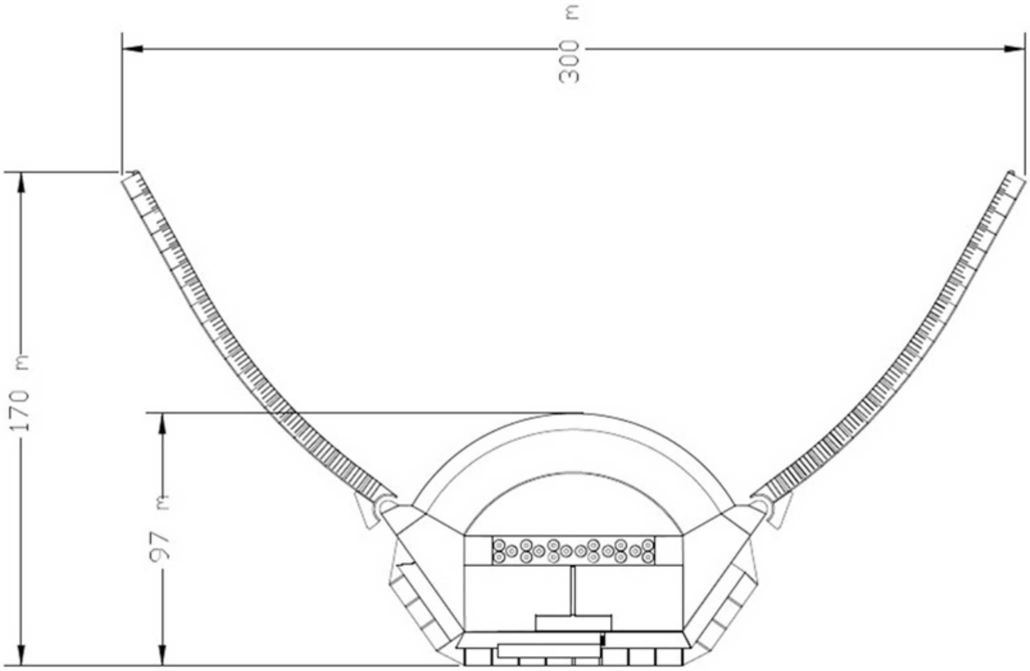

Figure 30 - Major Device Dimensions

Device output depends on the wave climate and is in the range of 1.5-12MW. The Wave Dragon is the largest device (by rated capacity and physical size) under development. The device is slack-moored and is able to swivel around its mooring in order to always face the wave direction. The amount of rotation possible is dependent on the wave climate.

Device Anchoring & Footprint - In order to provide a point around which device may swivel, a single buoy mooring system is used. The buoy is anchored using a catenary style spread of anchor lines as shown in Figure 31. The number of anchor legs depends on device size and bottom conditions. For the 7MW device, six to eight mooring legs are used.

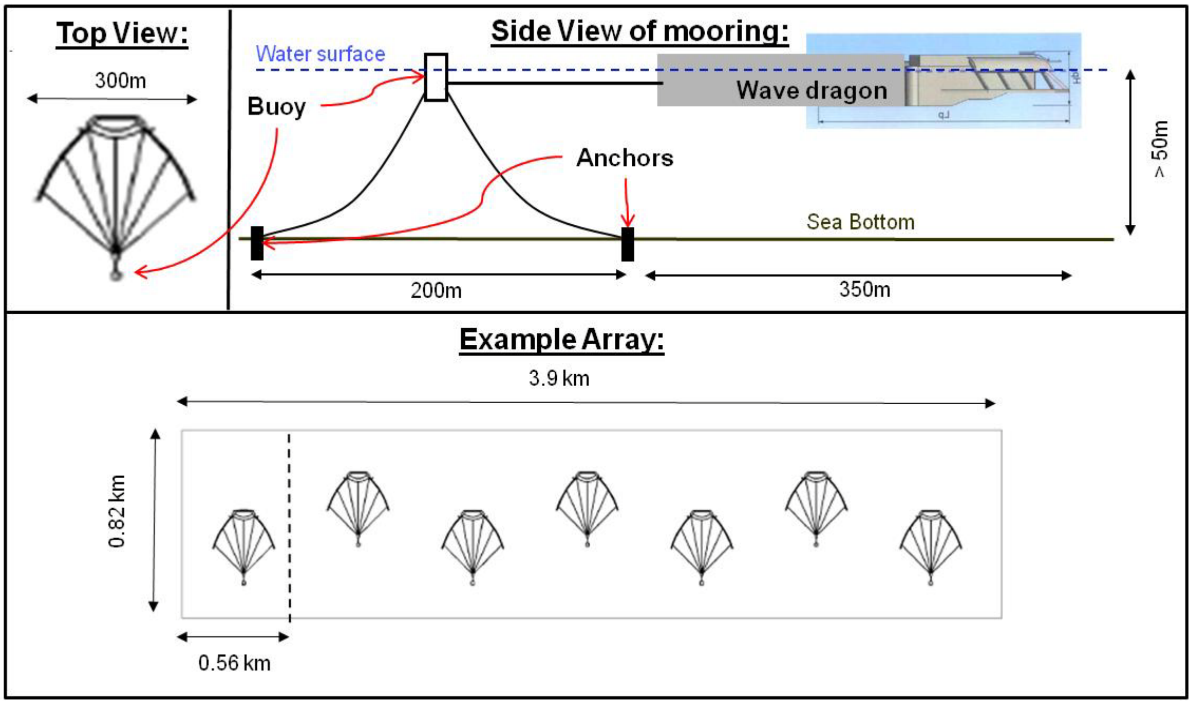

Figure 31 - Mooring Configuration

Devices in an array must be spaced to allow sufficient clearance to avoid collision. An example array is shown for the 7MW case in Figure 31.

Operation & Maintenance - The Wave Dragon systems are designed to be inspected and maintained at sea. Mooring connections and lines will be inspected by diver and/or ROV every 24 to 36 months. The rest of maintenance operations may be conducted onboard the device by work crew and a small work vessel. The device structure has an estimated life of 50+ years. The turbines are easily lifted of the reservoir platform and will undergo planned maintenance on shore every 5 years – i.e. 4 – 5 turbines will be refurbishes during summertime.

Additional Information - Overtopping of water and relative hydraulic head can be optimized to the particular sea-state by using air floatation chambers. Such changes in adjustment of overtopping ramp height is done slowly over time periods of a few hours to adjust for different sea conditions. Being a very large device by design, most operational activities will need to be carried out on the device while it is on station. The physical size of this platform will make it impossible to recover the device to land in most locations. Since most of the structure is concrete, anti fouling paint is only applied to the turbine structures. The turbines are variable RPM dependant on flow. Screens for debris are provided.

Operation Procedures - The following operational activities and time-frames are estimated for a deployment at three different scales. In absence of detailed design and engineering studies the time-frames and intervention intervals represent initial estimates and are to be used for illustrative purposes only. Time estimates refer to operational time within the general deployment area and includes mobilization time. Only offshore activities that are directly affecting the marine environment are outlined here to provide the reader with a better understanding of operational impacts on the environment.

The first set of operational activities are outlined for pre-construction activities that are used to support permitting, detailed design and subsequent construction activities at the site. Pre-installation activities will not differ significantly as a function of scale or technology choice.

Table 20 - Site pre-installation resources and duration

Activity	Resources	Duration
Survey to map high-resolution bathymetry at deployment site and cable route	Survey vessel	< 1 week
Sub-bottom profiling to identify sedimentation layer thickness at deployment site and along cable route in areas of soft substrate	Survey vessel	< 1 week
Visual inspection of seabed in deployment area and along cable route	Survey vessel ROV or diver	< 1 week
Wave Resource Characterization using ADCP or directional measurement buoy	Survey Vessel or RIB	1 year
Environmental baseline studies	Survey vessel Stand-alone instrumentation	1-2 years

The second set of activities represent project construction activities. These are activities that will have the most significant potential impacts over the project life and are compressed in a relatively short (one- to two-year) timeframe. Offshore construction activities are dependent on weather windows at the site and would occur during times when there is a high likelihood of calm seas. Due to weather considerations, this construction time-period is likely constrained to the May through early September time period. It is likely that in reality the type of equipment mobilized would depend on project scale, because for larger projects, operational efficiencies become more important cost drivers than for smaller projects, where mobilization cost tends to dominate. Addressing this equipment choice in detail is beyond the scope of this study. Installation activities do not usually occur in sequence. The time estimates shown below account for total operational time and include downtime due to weather windows and mobilization.

Table 21 - Installation resources and duration (spread over a two year period)

Activity	Resources	Duration		
		1-Unit	**2-Units**	**12-Units**
Directional drilling to land power take-off cable on shore	Drill rig	< 2 months	< 2 months	< 2 months
Subsea cable installation	Cable Install. Vessel Supply boat	< 2 weeks	< 2 weeks	< 2 weeks
Moorings System Installation	Derrick barge 3 Tugs Supply boat	2 weeks	3 weeks	15 weeks
Electrical Collector System Installation	Derrick barge 2 Tugs Supply boat	1 day	1 week	4 weeks
Device Deployment & Commissioning	Derrick barge 3 Tugs Supply boat	1 week	3 weeks	15 weeks

Operation and Maintenance activities can be divided into planned and unplanned activities. The majority of operational activities will occur during summer months, when relatively calm weather conditions allow these operations to be carried out safely. Some unplanned maintenance activities may need to be carried out during the winter season as a result of failures that require immediate attention.

Table 22 - Operational activity resources and duration

Activity	Resources	Frequency
Planned refurbishment of 4 - 5 turbines a year	Custom Vessel	Annual
Un-planned Maintenance	Custom Vessel	Every 4 years
Visual Inspection of underwater elements	Research Vessel, ROV	Every 2-3 years
Replacement/Refurbishment of Moorings and Electrical Collector System	Derrick Barge 2 Tugs Supply Boat	10-15 years

Decommissioning occurs at the end of the project life (typically 25-50 years). Decommissioning activities will probably be carried out over one to two summer seasons, depending on the project scale.

Table 23 - Decommissioning resources and duration

Activity	Resources	1-Unit	10-Units	100-Units
Recover Devices	Custom Vessel	1 day	8 days	50 days
Recover Device Moorings	2 x Tug Derrick Barge Supply Boat	1 week	3 weeks	30 weeks
Collector System Removal	Cable Handling Vessel	1 day	1 week	5 weeks
Subsea cable removal	Cable Handling Vessel	2 weeks	2 weeks	2 weeks

9.4 Aquamarine Power

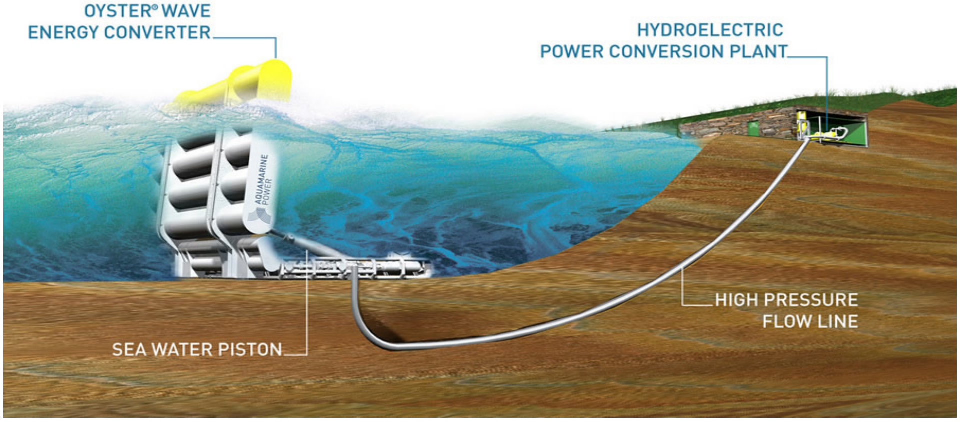

Figure 32 – Oyster 1 prototype operation

Specifications (Oyster II commercial device)

Water Depth	12-16m typical, 10-20m possible
Flap Width	26m
Flap Depth	13m
Total Weight	about 450T, including foundations
Power Conversion	Water Hydraulics
Generator	3-phase Induction generator
Converter	step up transformer, to 11/33kV
Rated power output	2 MW (depending on deployment site)
Anchor type	Site-specific, e.g. a novel tension anchor solution has been developed for hard rock substrates, other substrates such as deep sand will use conventional offshore foundation solutions such as suction cans.
Hydraulic fluid	Pressurized fresh water (closed loop system)

Company information

Company Name:	Aquamarine Power Limited
Website:	www.aquamarinepower.com

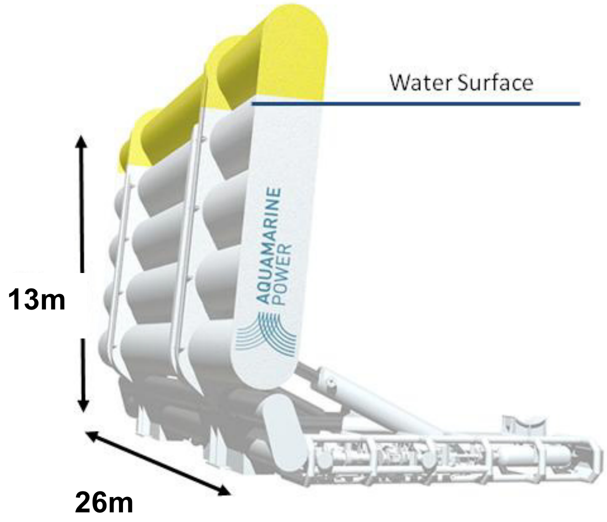

Figure 33 – Oyster II basic dimensions

Principle of Operation - The Oyster concept is a large buoyant oscillator that completely penetrates the water column from the water surface to the sea bed. It is a near shore device, typically deployed in 10 to 20 meters water depth, designed to capture the amplified surge forces founds in these near shore waves. The surge component in the waves forces the bottom hinged “flap” to oscillate, which in turn compresses and extends two hydraulic cylinders mounted between the flap and the sub-frame, pumping water at high pressure through a pipeline back to the beach.

Onshore is a modified hydro-electric plant consisting of a Pelton wheel turbine driving a variable speed electrical generator coupled to a flywheel. The Pelton turbine is an impulse turbine, commonly used in the hydropower industry. Impulse turbines are known to have high efficiencies at high pressure levels (typically >20 bars) and are considered proven technology. Power flow is regulated onshore using a combination of hydraulic accumulators, an adjustable spear valve, a flywheel in the mechanical power train and rectification and inversion of the electrical output. The low pressure return-water passes back to the device in a closed loop via a second pipeline. A key design philosophy is to keep the offshore components as few and as simple as possible. The Oyster device has no major electrical components or active control functions operating in the offshore environment.

Device Anchoring & Footprint - The Oyster wave power device differs from all other wave power devices in this project both because it is anchored directly to the sea floor and because it operates in relatively shallow water. An example array including device footprint size, pipeline layout and spacing between devices for a 5MW deployment is shown in Figure 32. An initial foundation concept has been developed for rocky substrates, using tension anchors to provide high friction between the device and the seabed. Other foundation solutions are under development for substrates including deep sand and sand-over-rock.

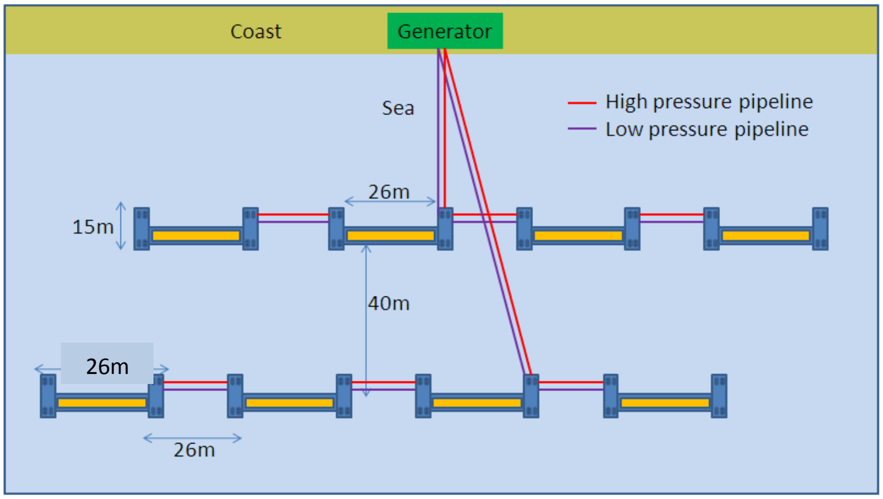

Figure 34 –Indicative device array and pipeline layout for a 5MW (peak) Oyster 2 farm

Operation & Maintenance - The offshore device units are designed with a minimal number of moving elements: two hinges, four non-return valves and an accumulator. Each moving part is designed for low-cost modular replacement using non-specialist marine vessels on a five-year preventative maintenance cycle. The fixed steel "flap" structure is designed for an operating lifetime of 20 years in high-energy sea environments, without replacement. This low-complexity design will likely result in extended periods of operation, during which no maintenance and/or repair is required. The Pelton wheel and turbine are located in a permanent onshore structure and thus readily accessible on a 24/7 basis, in all weather conditions, for inspection and maintenance purposes.

Additional Information - The infrastructure of a project using Aquamarine technology will differ quite significantly from other deep water projects. Instead of an electrical cable back to shore, a pipe is used to transport pressurized freshwater back to shore, where it is used to generate electricity. This has implications on operational activities and related risks. As compared to other projects, this would mean:

- No electricity is generated or transmitted through the water, eliminating any EMF concerns;
- A larger diameter conduit would need to be used to bring the high-pressure pipe to shore;
- The lower complexity of the in-water portion of the project will result in fewer interventions over the project life;
- The hydraulic power take-off uses a closed loop freshwater system, eliminating entrainment concerns.

Operation Procedures - The following operational activities and time-frames are estimated for a deployment at three different scales. In absence of detailed design and engineering studies, the time-frames and intervention intervals represent initial estimates and are to be used for illustrative purposes only. Time estimates refer to operational time within the general deployment area and includes mobilization time. Only offshore activities that are directly affecting the marine environment are outlined here to provide the reader with a better understanding of potential operational effects on the environment.

The first set of operational activities are outlined for pre-construction activities that are used to support permitting, detailed design and subsequent construction activities at the site. Pre-installation activities will not differ significantly as a function of scale or technology choice.

Table 24 – Pre-installation resources and duration

Activity	Resources	Duration
Survey to map high-resolution bathymetry at deployment site and cable route	Survey vessel	< 1 week
Sub-bottom profiling to identify sedimentation layer thickness at deployment site	Survey vessel	< 1 week
Visual inspection of seabed in deployment area and along cable route. Soil Sampling where required.	Survey vessel ROV or diver	< 1 week
Wave Resource Characterization using ADCP or directional measurement buoy	Survey Vessel or RIB	1 year
Environmental baseline studies	Survey vessel Stand-alone instrumentation	1-2 years

The second set of activities represent project construction activities. These are activities that will have the most significant potential impact over the project life and are compressed in a relatively short (one- to two-year) timeframe. While onshore construction and pipeline drilling works can take place during the winter months, offshore construction activities are dependent on weather windows at the site and would occur during times when there is a high likelihood of calm seas. Due to weather considerations, the offshore construction time-period is likely constrained to the May through early September time period. It is likely that in reality, the type of equipment mobilized would depend on project scale because for larger projects, operational efficiencies become more important cost drivers than for smaller projects, where mobilization cost tends to dominate. Addressing this equipment choice in detail is beyond the scope of this study.

Table 25 – Installation resources and duration

Activity	Resources	Duration		
		1-Unit	10-Units	100-Units
Directional drilling to land high-pressure water pipeline to shore	Drill rig	< 2 months	< 2 months	< 6 months
Construction of onshore powerhouse	Standard excavation and construction equipment	< 3 months	< 3 months	< 6 months
Foundation Installation	2 Tugs, Barge, Supply boat	2 weeks (including weather downtime)	3 weeks	20 weeks
Connect High-pressure collector system	Supply boat & Diver	1 week (including weather window)	2 weeks	20 weeks
Device Deployment and Commissioning	Barge, 2 Tugs, Supply boat	2 weeks (including weather downtime)	3 weeks	20 weeks

Operation and Maintenance activities can be divided into planned and unplanned activities. The majority of operational activities will occur during summer months, when relatively calm weather conditions allow these operations to be carried out safely. Some unplanned maintenance activities may need to be carried out during the winter season as a result of a failure that requires immediate attention.

Table 26 – Operational activity, resources and intervention frequency estimates

Activity	Resources	Frequency
Planned maintenance (offshore)	Standard mid-size boat	Every 5 years
Un-planned Maintenance (offshore)	Standard mid-size boat, diver	Every 4-5 years
Visual Inspection of underwater elements	Research Vessel, ROV	Every 2 years
Replacement/Refurbishment/Decommissioning of offshore Power Capture Unit and Foundation	Derrick Barge 2 Tugs Supply Boat	20 years

Decommissioning occurs at the end of the project life (typically 20 years). Decommissioning activities will probably be carried out over one to two summer seasons, depending on the project scale.

Table 27 – Decommissioning, resources and duration

Activity	Resources	1-Unit	10-Units	100-Units
Recover Devices	Custom Vessel	1 week	2 weeks	20 weeks
Recover Device Foundation	2 x Tug Barge Supply Boat	1 week	2 weeks	20 weeks
Hydraulic Collector System Removal	2 x Tug Barge Supply Boat	1 week	2 weeks	20 weeks

10. Site Description - Hawaii

The Hawaiian reference site is located on the north-east facing coast on Oahu, Hawaii, near Waimanalo bay and Kailua bay. The site is well-exposed to the dominant wave direction and is a likely early adopter site candidate. This section describes the physical attributes of the site, including: wave energy resource, bathymetry, seabed composition, grid connection options, and conflicting uses (navigation). In order to present the data in a spatial format, a set of GIS layers were assembled to develop a series of relevant maps.

The shallow and deep water areas of interest are shown in the following figure and represent potential deployment areas for the selected candidate technologies based on water depth in the area. A NDBC wave measurement buoy (NDBC 50212) is located in about 100m water depth on the seaward boundary of the project area.

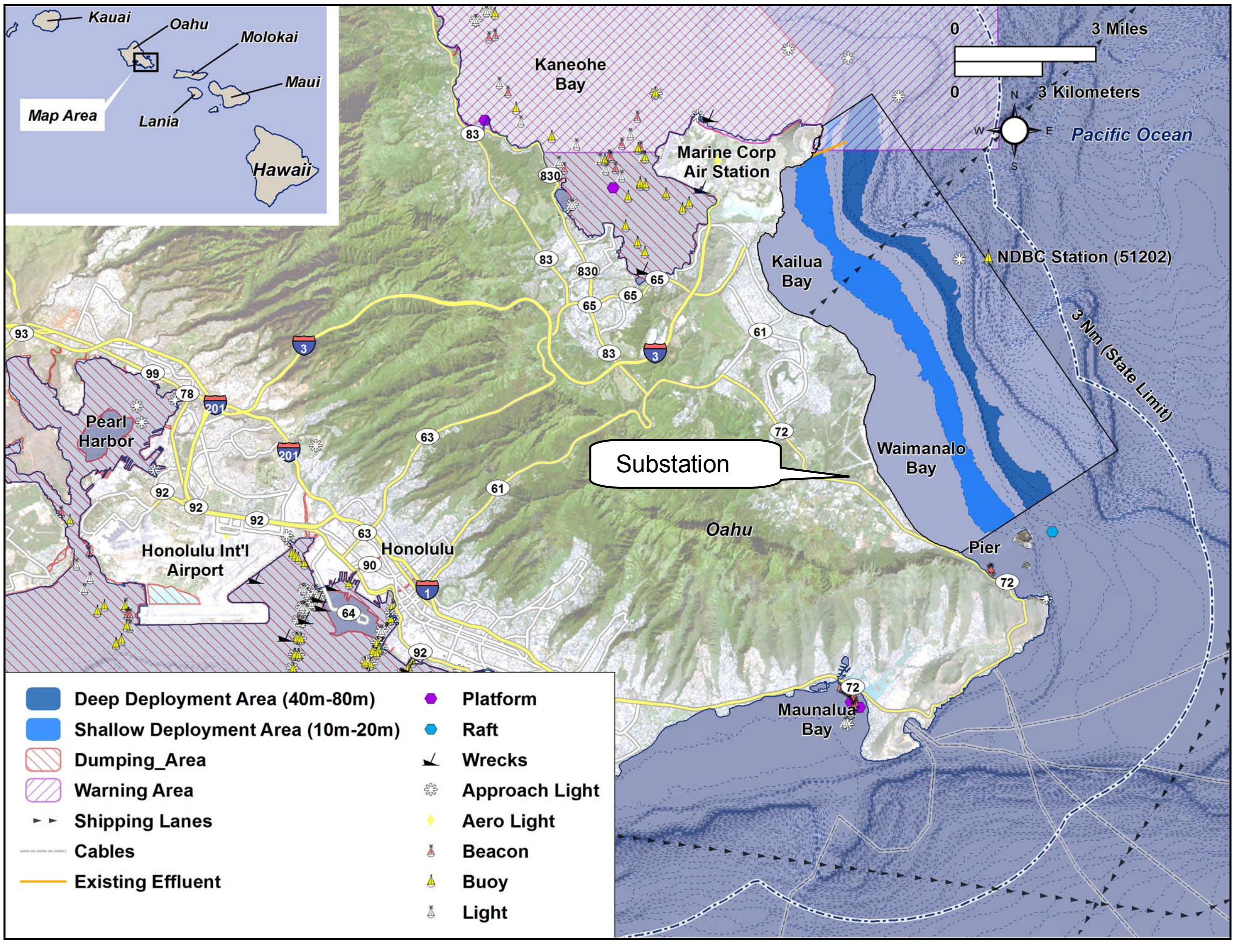

Figure 35 - Location Overview Map

10.1 Grid Interconnection Options

Smaller wave farms up to about 6MW could be connected directly to the distribution line that runs along the coastline within a couple hundred yards in most of the places. For a larger scale commercial plant, the Waimanalo beach substation is the closest interconnection point to export larger amounts of power.

10.2 Nearby Port Facilities

Honolulu is likely the best area for support of the site area. Honolulu Harbor is the major port facility for Hawaii, and the waterfront of Honolulu itself has over 60 wharves and piers that could be used to stage operational procedures. To deploy smaller vesssels, the Makaii pier on the windward side near Makapuu point could be used to launch, and Kailua Bay has a small harbor. However, operations from the windward side of the coast will likely be limited to smaller crafts.

10.3 Bathymetry

The local bathymetric contours are shown Figure 34 with ocean depth in meters. As may be observed, there is a steep shelf between 100m and 200m depths. Most of the wave devices have an operational depth of 50m, putting them approximately 5 km off shore.

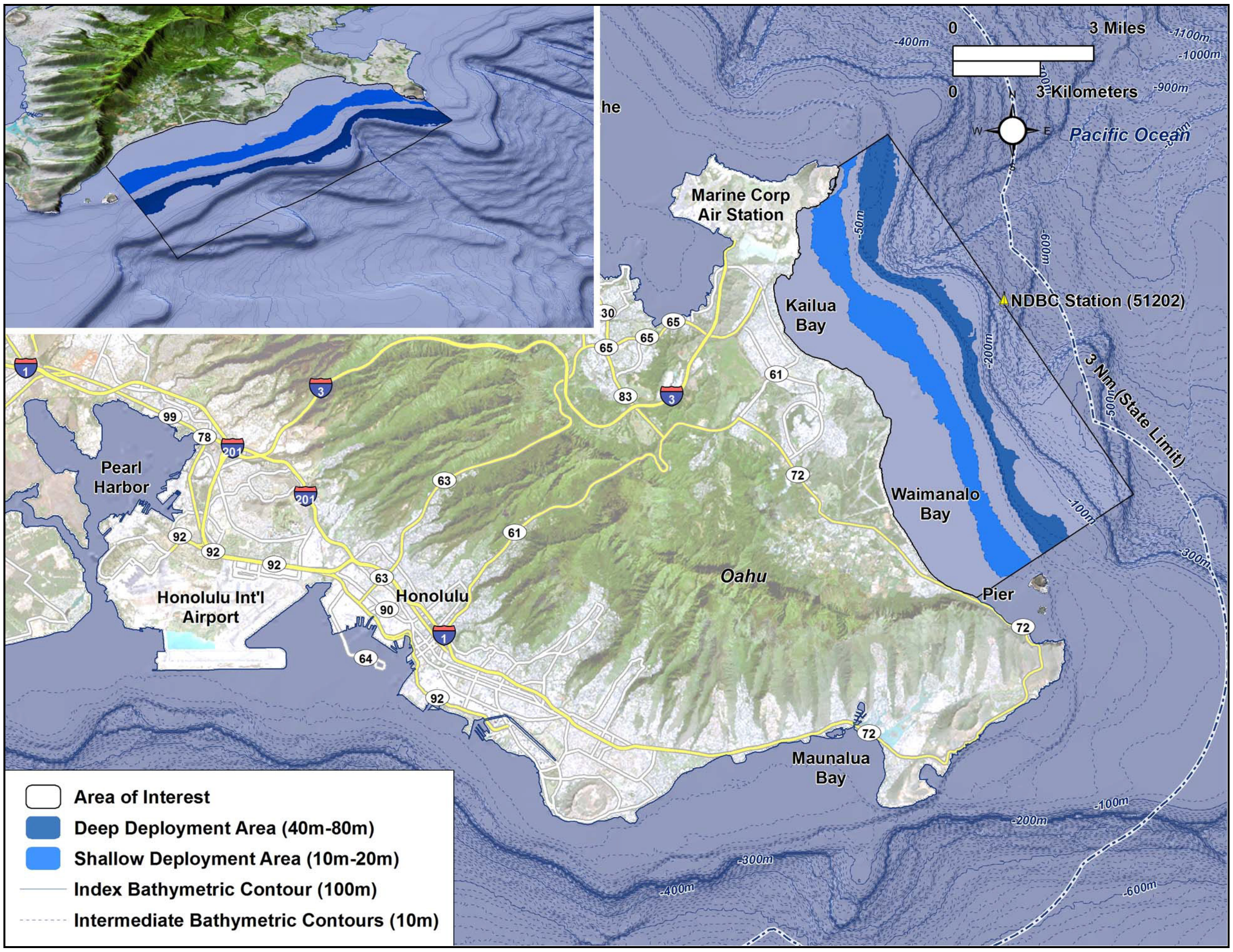

Figure 36 - Local site bathymetry in plan and perspective showing the water depth in meters

10.4 Seabed Composition

The seabed composition within the area of interest is highly varied, as shown by the relatively coarse sampling in the following figure. It includes sand, limestone, reef areas and rocky outcrops. Without any further detailed mapping of the project area, it will be impossible to draw conclusions on the suitability of certain areas for device deployment, moorings and cable routes. For the purpose of this study, it was assumed that there are no areas that need to be excluded from deployment. However if project development is moving ahead in this area, there is a critical need for bathymetric and geophysical surveys.

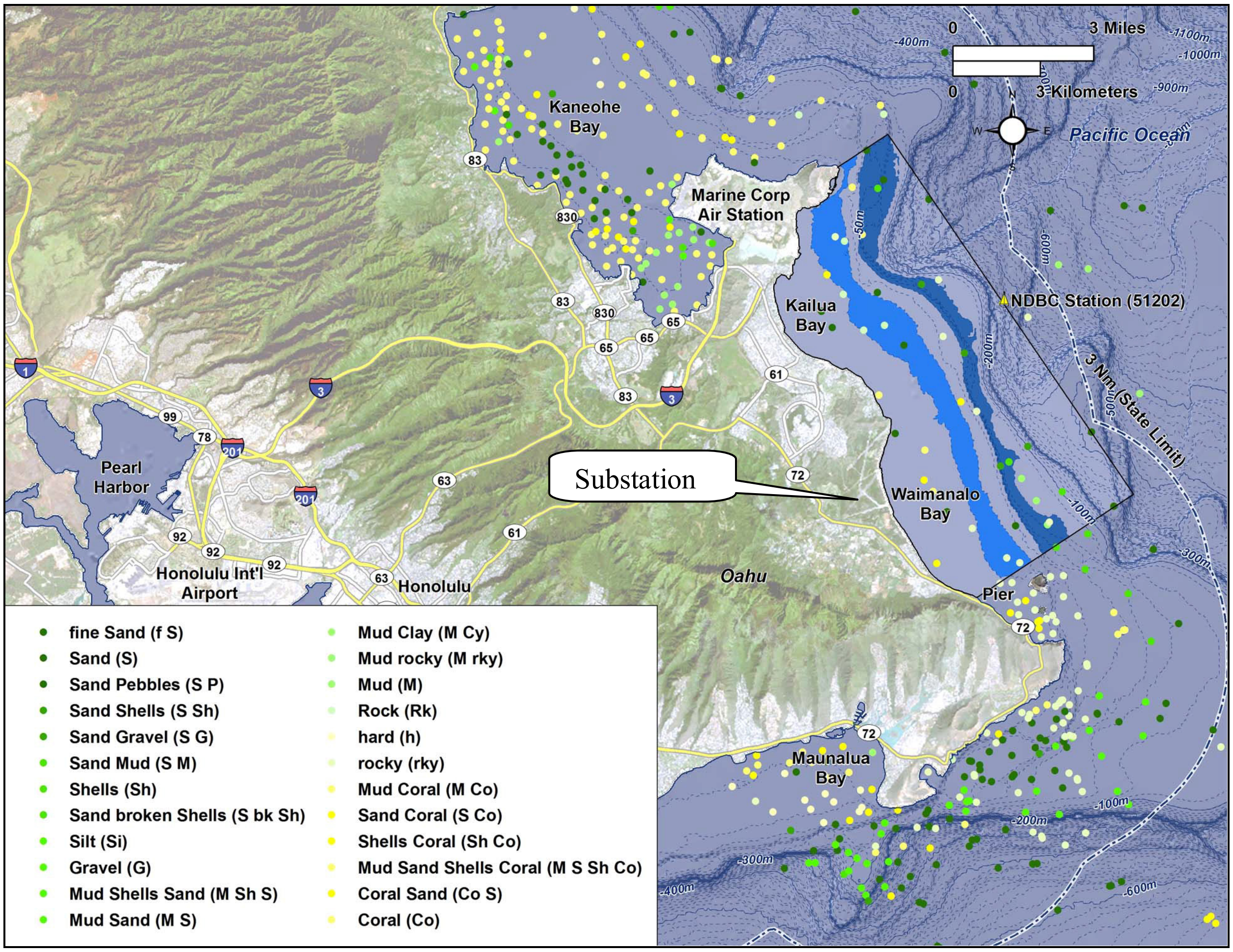

Figure 37 - Seabed Classification

10.5 Navigation

The following nautical chart shows an overview of the potential conflicting uses within the area. Kailua has a small harbor from which boats launch, and there is likely to be activity from recreational, military and fishery uses. Such usage conflicts would have to be resolved during consultations with the stakeholders currently using the area for various purposes. A detailed navigation risk assessment will be essential to identify conflicting uses and ship-routes, which in turn will inform the siting process. For the purpose of this study, obvious areas, such as the shipping lane coming out of Kailua Bay and the environmentally sensitive area near Rabbit Island will be provided with exclusion areas from deployment.

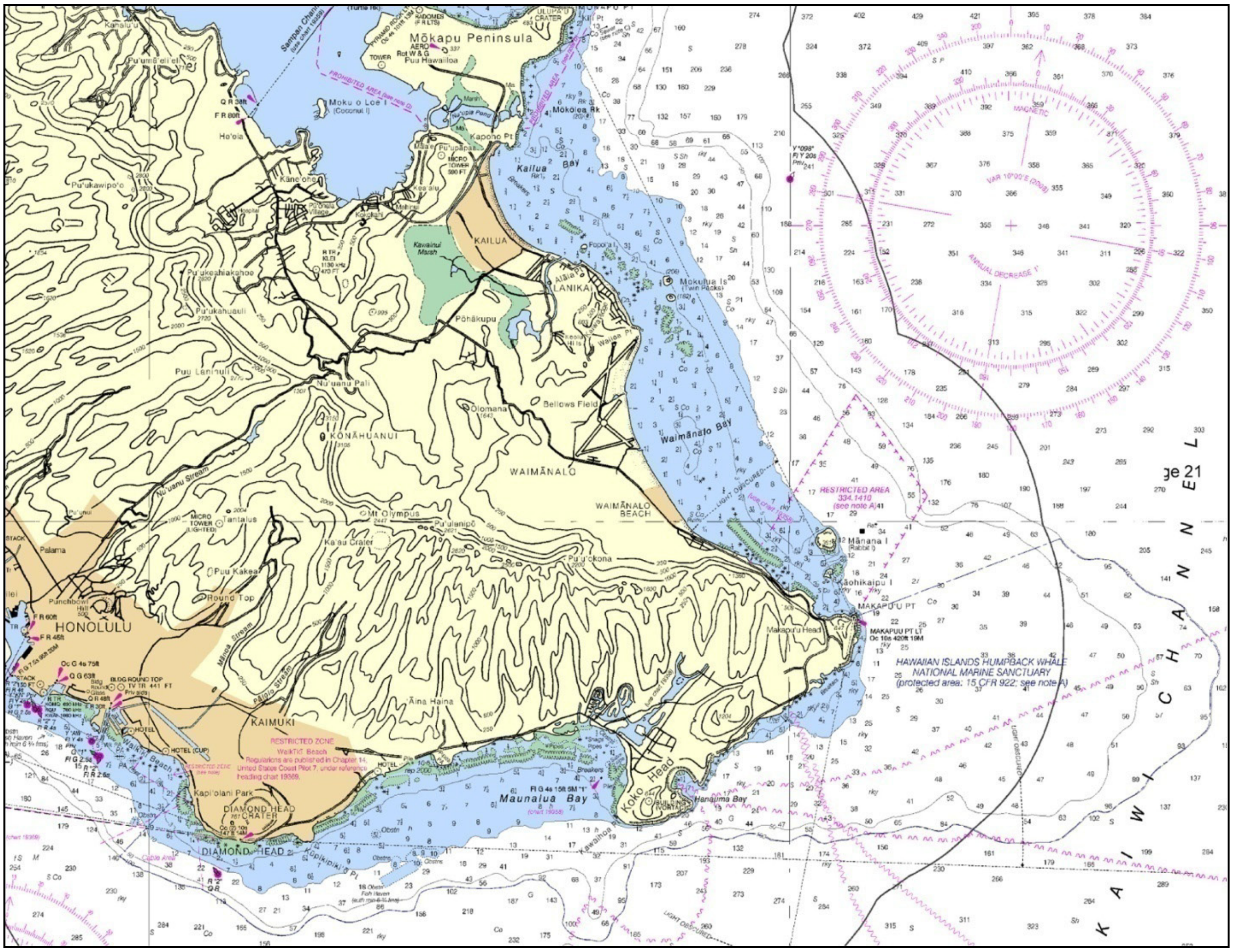

Figure 38 - NOAA Nautical Chart (Oahu Island)

10.6 Marine Sanctuary

The Hawaiian Islands have a National Marine Sanctuary for Humpback Whales, as shown in the following figure. While all whales are under the protection of the Marine Mammal Protection Act (MMPA), because the Humpback whale population has been increasing in Hawaii, the National Marine Fisheries Service considered de-listing the species last year, but did not do so. The species is still listed as 'endangered' under the Endangered Species Act and therefore for obvious reasons, the marine sanctuary is excluded from commercial development. The map shows that the area of interest does not include the sanctuary.

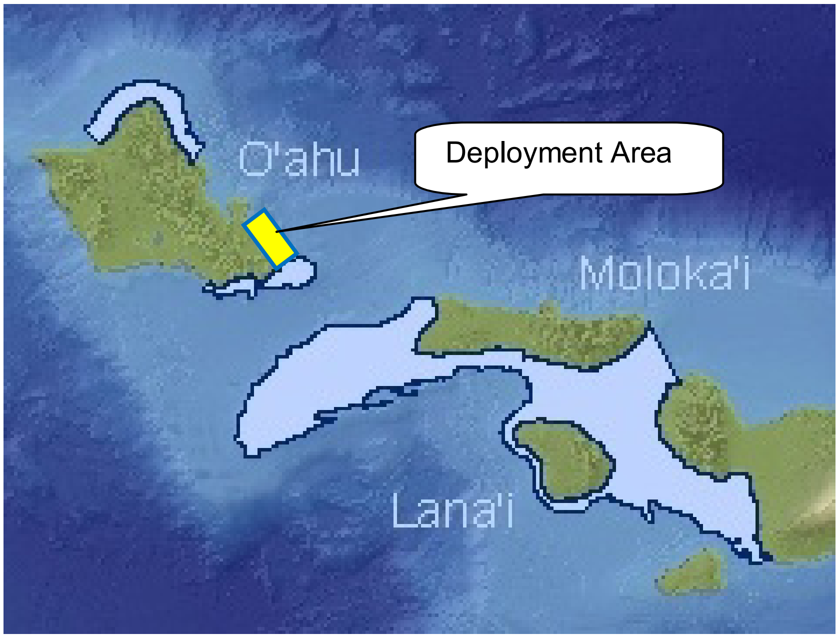

Figure 39 - Humpback Whale National Marine Sanctuary (Light blue areas show marine sanctuary boundaries)

11. Site Description - California

The site of interest on the northern California coast is off shore from Humboldt Bay, as shown in the illustration below. The site is presently being developed by Pacific Gas & Electric (PG&E) for the development of the WaveConnect project. WaveConnect is a facility that is designed to demonstrate and test early adopter commercial wave power technologies. The project has been funded by the Department of Energy (DoE) and the California Public Utilities Commission, and has been granted a preliminary permit from FERC. While the project study site is closely co-located with the PG&E site, no conclusions from this study should be drawn for the PG&E process.

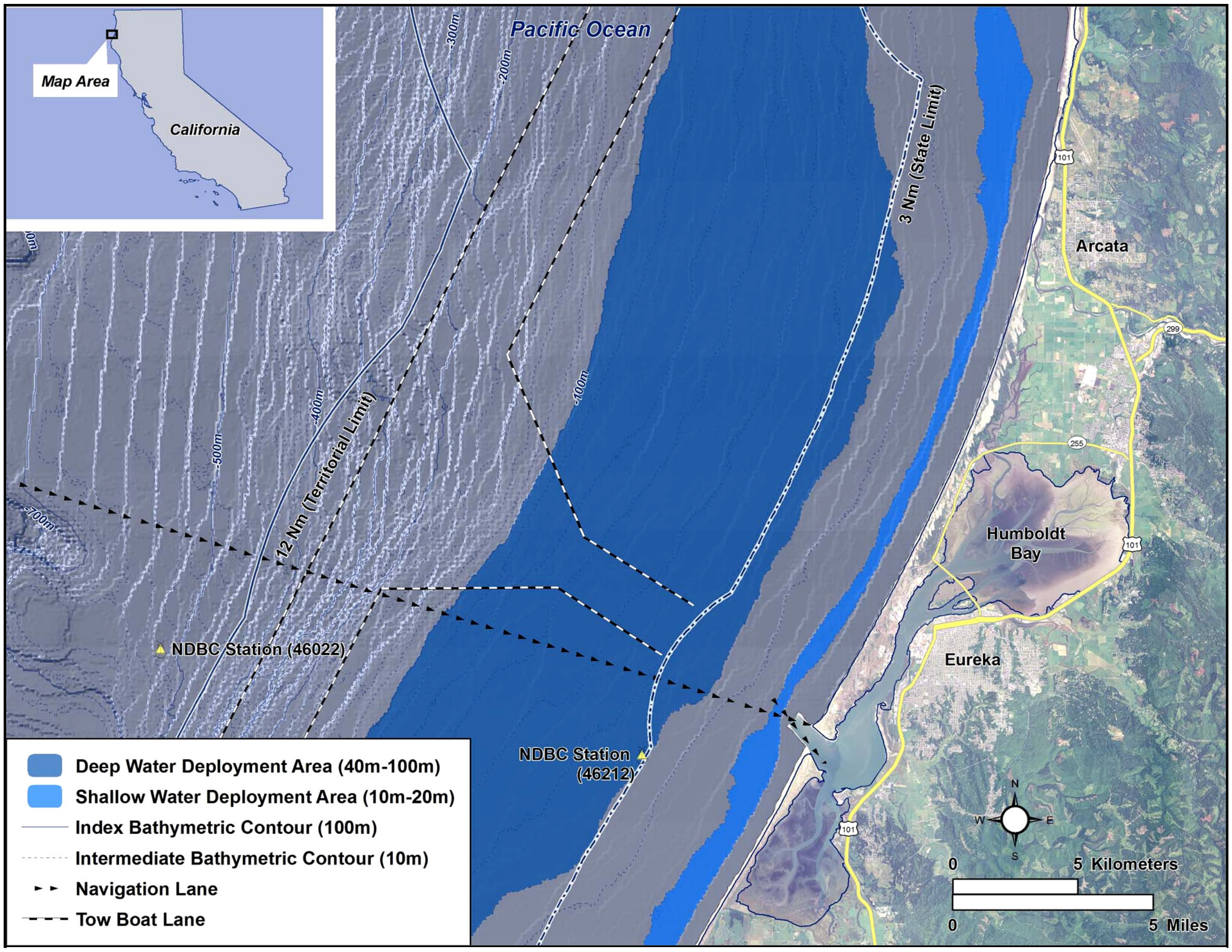

Figure 40 - Humboldt Site Location

The area chosen for this site is slightly north and directly off shore from the Humboldt Bay deep water channel, where port facilities are available to stage installation and operation activities. A 60KV substation, just north of the bay inlet, was chosen for connection to the grid.

11.1 Grid Interconnection Options

Approximately 5 miles north of the Humboldt Bay inlet, there is a 60kV substation in very close proximity to the coastline. This station will serve as the interconnection point to the local electrical grid. An existing outfall location is shown in orange in the following figure, which could be used to accommodate the proposed electrical subsea cable. This easement may eliminates the need to directionally drill to shore to accommodate the power cable landing. However, as details of specific sites are clarified, use of existing outfalls, particularly an outfall that is still in service, is more complex and may not be a viable alternative.

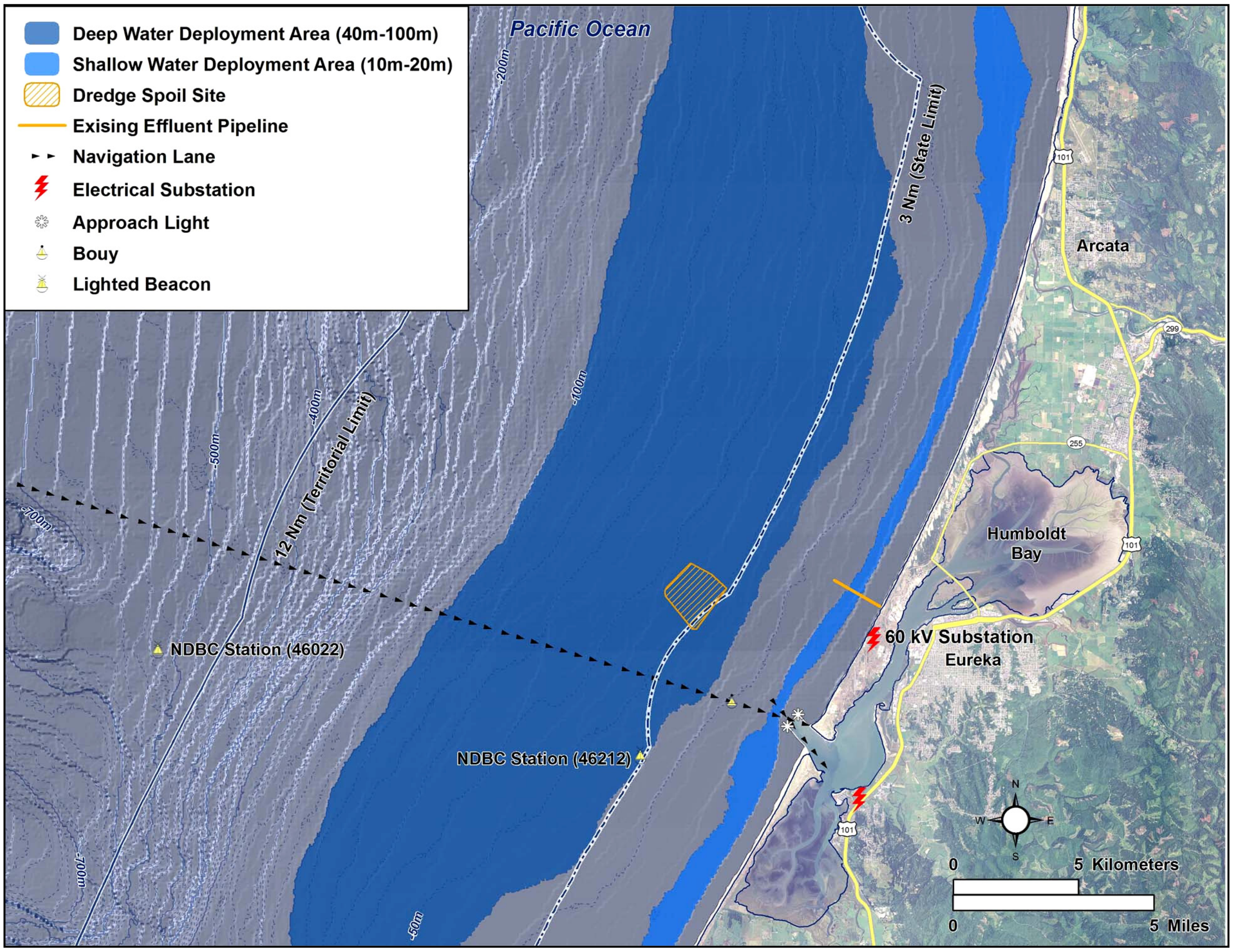

Figure 41 - Proposed Grid Interconnection

11.2 Port Facilities

The port nearest to the area is located in the Humboldt Bay. This is the only deep-water port on California's North Coast and has excellent facilities for the operation of wave farms. There are multiple piers within the bay, making it a good site from which to launch installation and operation activities. The following illustration shows a nautical chart of the area of interest.

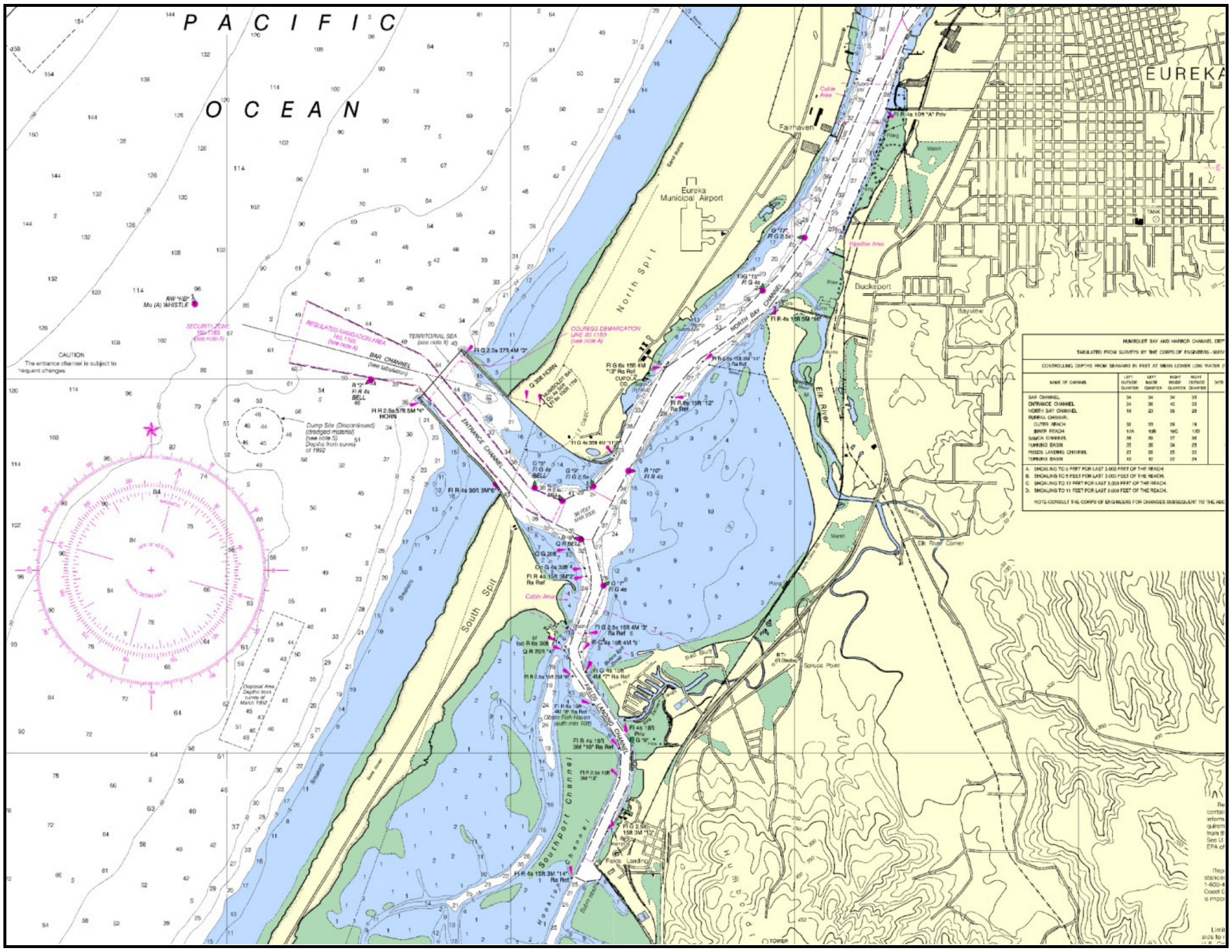

Figure 42 - NOAA Nautical Chart (Humboldt Bay)

11.3 Bathymetry

As shown in the following figure, the deployment site features a gently sloping seabed without many irregularities (such as canyons) that could disturb the local wave field. It is therefore likely that the wave-field is homogeneous over the deployment area of interest. Deep-water deployment sites are located approximately along the 70m contour line, which is located about 3Nm from shore. Water depths suitable for the Aquamarine Oyster are much closer to shore at a distance of less than 1000 yards. Shallow water and deep water deployment areas are identified in the following illustration.

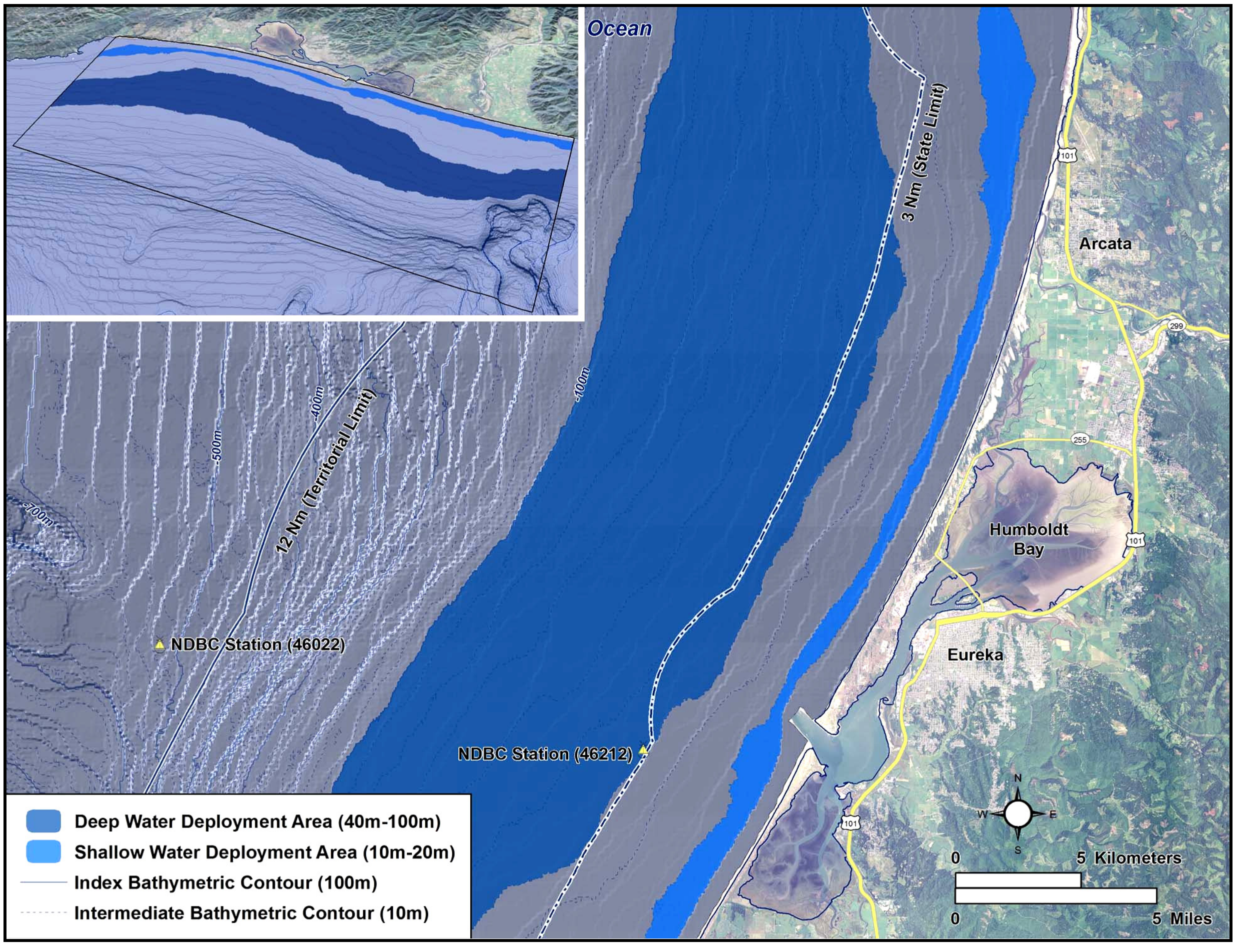

Figure 43 - Local site Bathymetry Plan and perspective showing the water depth in meters

11.4 Seabed Composition

Most of the seabed in the near shore region of the Humboldt site consists of soft sediments (sand and clay). There are rocky areas near Trinidad Head to the north, but these may be readily avoided. Sediments within the proposed cable route and deployment area are well suited for subsea cable burial and anchoring.

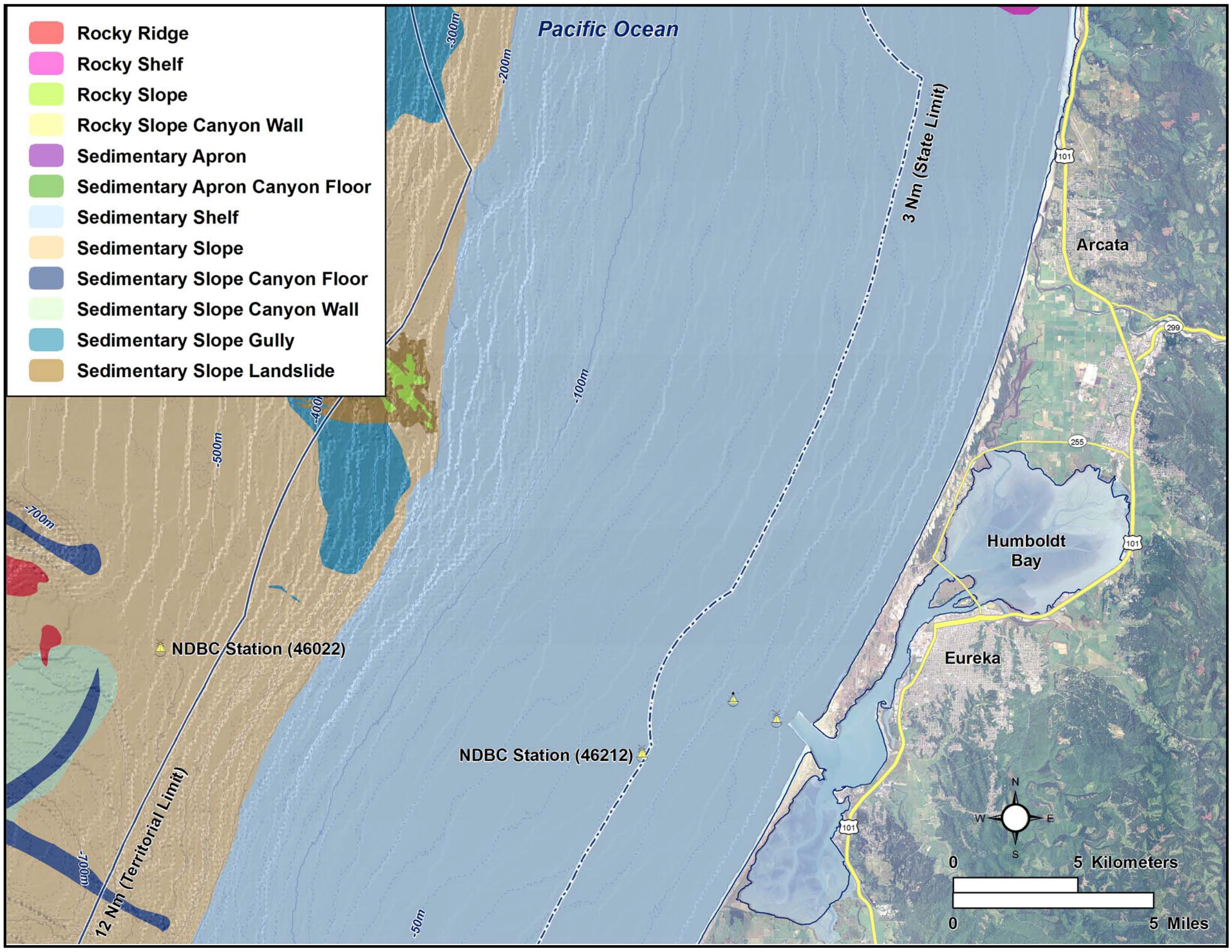

Figure 44 - Seabed Classification

11.5 Navigation

The following nautical chart shows an overview of the potential conflicting uses within the area. The key area of interest is the Humboldt Bay entrance that should be kept free from obstruction. There is also frequent use by recreational boaters and fishermen. Such usage conflicts would have to be resolved during consultations with the stakeholders currently using the area for their purposes. A detailed navigation risk assessment will be essential to identify conflicting uses and ship-routes, which in turn will inform the siting process. For the purpose of this study, obvious areas such as the shipping lane coming out of Humboldt Bay and the existing dump area will be excluded from deployment.

12. Scenario Description

This section describes the scenarios that were developed for the two wave power sites of interest. A scenario describes the results for a conceptual design feasibility study (technology at particular deployment in one of the two sites). A total of 23 wave power scenarios are presented. The following table shows a breakdown with the scenario index number. The large commercial scenario is different for California than it is for Hawaii because the California scenario offers a larger potential deployment area compared to Hawaii.

Table 28 - Wave Power Scenario index

	Hawaii			California		
Device	**1MW**	**10MW**	**20MW**	**1MW**	**10MW**	**50MW**
Pelamis	1	2	3	4	5	6
OPT Buoy	7	8	NA[8]	10	11	12
Wave Dragon	13	14	15	16	17	18
Oyster	19	20	21	22	23	24

The background on the technology and sites are covered in previous chapters. This section only outlines the likely configuration and provides overview maps and technical summary tables to illustrate major differences. It is important to understand that these scenarios were developed based on high-level site and device data and can by no means be compared to a complete permit application document or a real project. The scenarios were developed for illustrative purposes only to inform stakeholders of what such deployments could look like and to initiate discussions on potential conflicts and generic market adoption considerations of this emerging technology. Each technology forms three scenarios at the two deployment sites. A summary table and an overview map are presented for each group of three scenarios to illustrate major attributes.

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[8] Large Commercial Scenario is not presented for Hawaii since, from a spatial point of view, it is unrealistic and therefore excluded.

12.1 Scenario 1-3: Hawaii – Pelamis

Project			
Site	Hawaii		
Scale	Pilot	Sm. Comm.	Lg. Comm.
Technology	Pelamis		
Scenario Index	1	2	3
Device			
Rated Electrical Power	517kW		
Capacity Factor	30%		
Average Electrical Output	155 kW		
Device Type	Attenuator / Line Absorber		
Foundation Type	Catenary Moored		
Total Weight	700 tons		
Device Length	180m		
Device Width	6m		
Hydraulic Fluid Volume	12.8m^3		
Operational Considerations			
Installation/Decommissioning time	1 summer	1 summer	2 summers
Planned operational interventions per year	1	25	48.75
Project life	20 years	20 years	20 years
Site/Array			
Seabed composition	Sand / Limestone		
Average Power density (kW/m)	14 kW/m		
Average Distance to shore	3.2 km		
Water Depth	50m		
Array Length - km (parallel to shoreline)	0.36	2.5	4.8
Array Width - km	0.35	0.5	0.5
Array Surface Area - km^2	0.1	1.2	2.4
Average Linear Array Density	1.7%	4.9%	4.9%
Cumulative Hydraulic Fluid Volume (m^3)	12.8	256	499
Array Performance			
Number of devices	1	20	39
Average electrical power (MW)	0.2	3.1	6.0
Rated electrical power (MW)	0.517	10.3	20.2
Annual Energy Delivered to Grid (MWh/year)	1,400	27,200	53,000
Average # of Households	119	2,385	4,650
Displaced CO2 (tons)	840	16,320	31,800

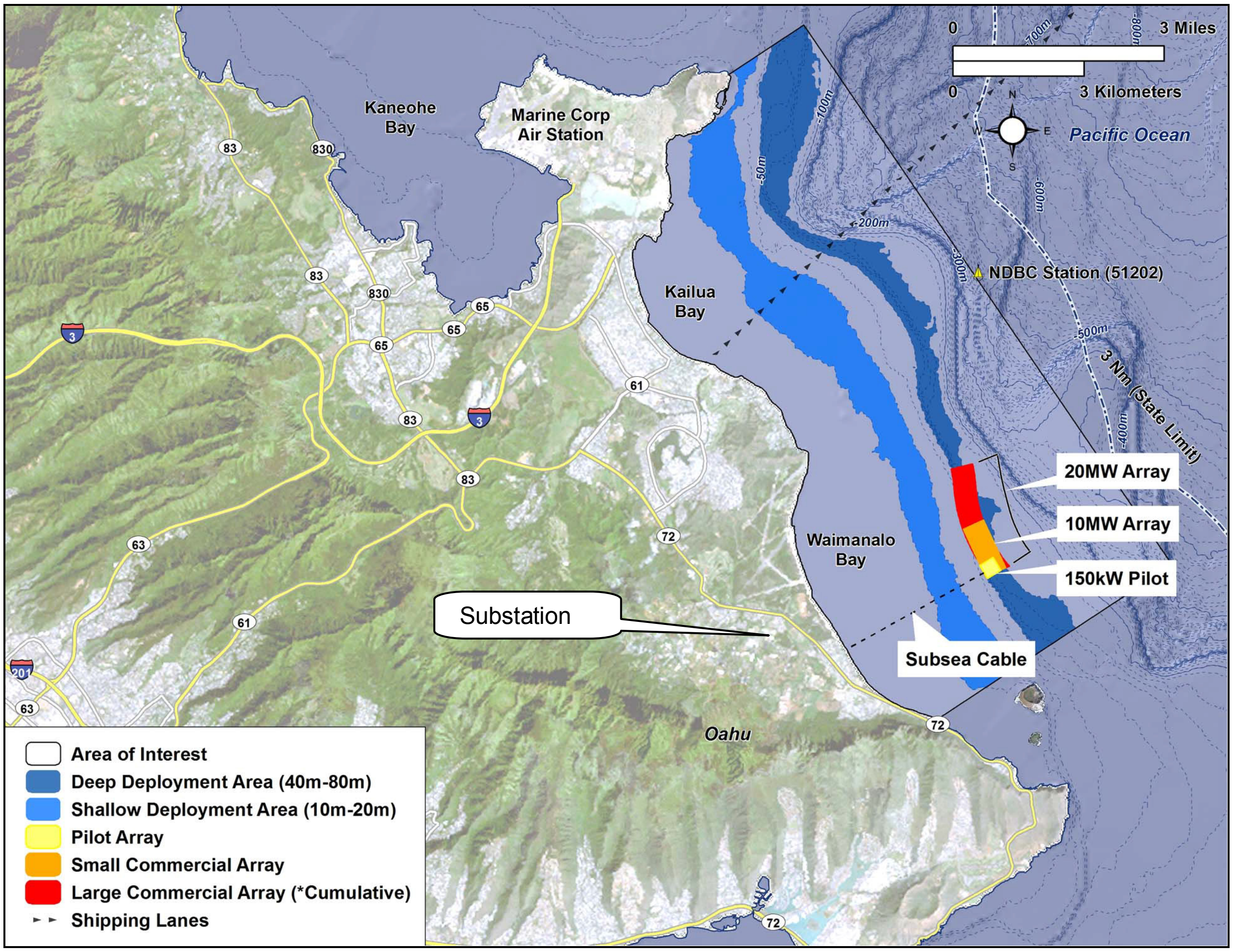

Figure 45 - Pelamis Scenario Options (Hawaii)

12.2 Scenario 4-5: California - Pelamis

Project			
Site	California		
Scale	Pilot	Sm. Comm.	Lg. Comm.
Technology	Pelamis		
Scenario Index	4	5	6
Device			
Rated Electrical Power	760kW		
Capacity Factor		30%	
Average Electrical Output	228 kW		
Device Type	Attenuator / Line Absorber		
Foundation Type	Catenary Moored		
Total Weight	700 tons		
Device Length	180m		
Device Width	6m		
Hydraulic Fluid Volume	$12.8m^3$		
Operational Considerations			
Installation/Decommissioning time	1 summer	1 summer	2 summers
Planned operational interventions per year	1	16	82.5
Project life	20 years	20 years	20 years
Site/Array			
Seabed composition	Sand / Mud		
Average Power density (kW/m)	30 kW/m		
Average Distance to shore	6.4 km		
Water Depth	70m		
Array Length - km (parallel to shoreline)	0.36	1.6	8
Array Width - km	0.35	0.5	0.5
Array Surface Area - km^2	0.126	0.8	4
Average Linear Array Density	1.7%	4.9%	5.0%
Cumulative Hydraulic Fluid Volume (m^3)	12.8	166	845
Array Performance			
Number of devices	1	13	66
Average electrical power (MW)	0.2	3.0	15.0
Rated electrical power (MW)	0.8	9.9	50.2
Annual Energy Delivered to Grid (MWh/year)	2,000	26,000	131,800
Average # of Households	175	2,280	11,575
Displaced CO2 (tons)	1,200	15,600	79,080

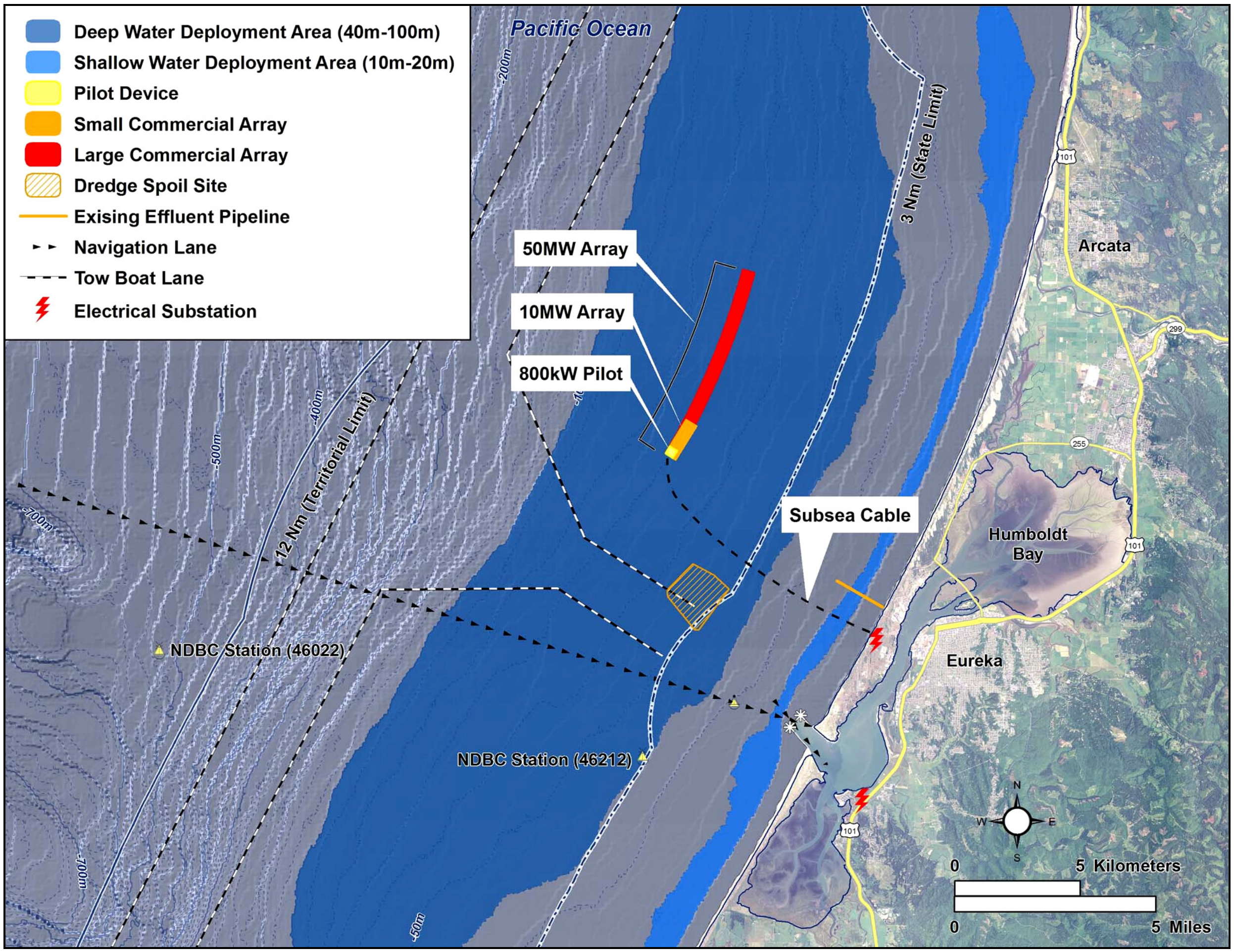

Figure 46 - Pelamis Scenario Options (California)

12.3 Scenario 7-9: Hawaii - OPT PowerBuoy

Project			
Site	Hawaii		
Scale	Pilot	Sm. Comm.	Lg. Comm.
Technology	OPT Powerbuoy		
Scenario Index	7	8	9
Device			
Rated Electrical Power	100kW		
Capacity Factor	30%		
Average Electrical Output	30 kW		
Device Type	Point Absorber		
Foundation Type	Catenary Moored		
Total Weight	150 tons		
Device Length	11m		
Device Width	11m		
Hydraulic Fluid Volume	$2.5m^3$		
Operational Considerations			
Installation/Decommissioning time	1 summer	2 summers	NA
Planned operational interventions per year	1	125	NA
Project life	20 years	20 years	NA
Site/Array			
Seabed composition	Sand / Limestone		
Average Power density (kW/m)	14 kW/m		
Average Distance to shore	3.2 km		
Water Depth	50m		
Array Length - km (parallel to shoreline)	0.2	4.9	NA
Array Width - km	0.2	0.8	NA
Array Surface Area - km^2	0.0	3.9	NA
Linear Array Density	3.0%	12.2%	NA
Cumulative Hydraulic Fluid Volume (m^3)	2.5	250	NA
Array Performance			
Number of devices	1	100	NA
Average electrical power (MW)	0.0	3	NA
Rated electrical power (MW)	0.15	10	NA
Annual Energy Delivered to Grid (MWh/year)	300	26,300	NA
Average # of Households	23	2,308	NA
Displaced CO2 (tons)	180	15,780	NA

Note: 20MW Hawaii scenario requires too large a deployment area to be viable

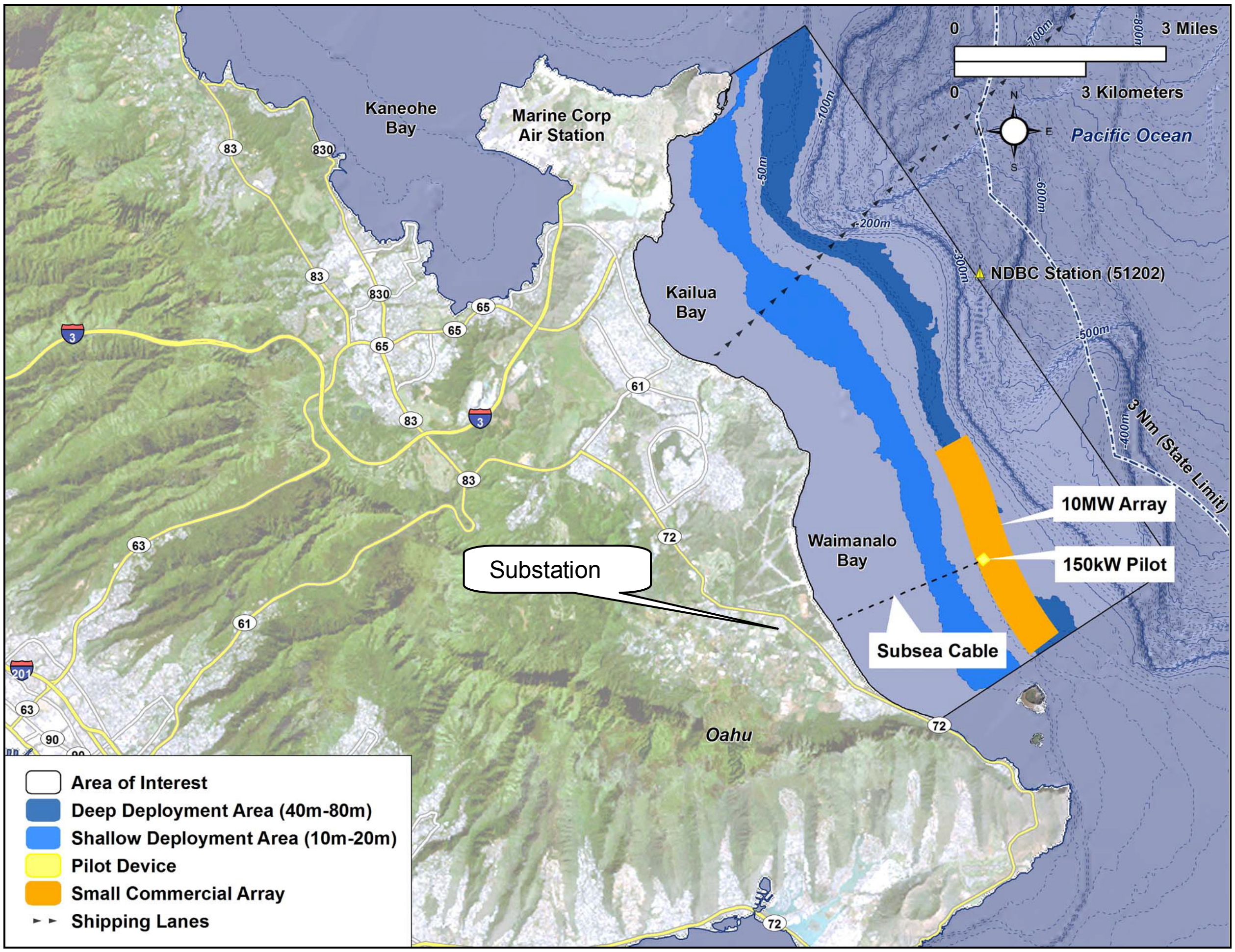

Figure 47 - OPT PowerBouy Scenario Options (Hawaii)

12.4 Scenario 10-12: California - OPT PowerBuoy

Project			
Site	California		
Scale	Pilot	Sm. Comm.	Lg. Comm.
Technology	OPT Powerbuoy		
Scenario Index	10	11	12
Device			
Rated Electrical Power	150kW		
Capacity Factor	30%		
Average Electrical Output	45 kW		
Device Type	Point Absorber		
Foundation Type	Catenary Moored		
Total Weight	150 tons		
Device Length	11m		
Device Width	11m		
Hydraulic Fluid Volume	$2.5m^3$		
Operational Considerations			
Installation/Decommissioning time	1 summer	1 summer	2 summers
Planned operational interventions per year	1	84	416
Project life	20 years	20 years	20 years
Site/Array			
Seabed composition	Sand / Mud		
Average Power density (kW/m)	30 kW/m		
Average Distance to shore	6.4 km		
Water Depth	70m		
Array Length - km (parallel to shoreline)	0.2	3.3	16.5
Array Width – km	0.2	0.8	0.8
Array Surface Area - km^2	0.0	2.6	13.2
Linear Array Density	3.0%	12.2%	12.1%
Cumulative Hydraulic Fluid Volume (m^3)	12.8	858	4,262
Array Performance			
Number of devices	1	67	333
Average electrical power (MW)	0.0	3	15
Rated electrical power (MW)	0.15	10	50
Annual Energy Delivered to Grid (MWh/year)	400	26,400	131,300
Average # of Households	35	2,319	11,527
Displaced CO2 (tons)	240	15,840	78,780

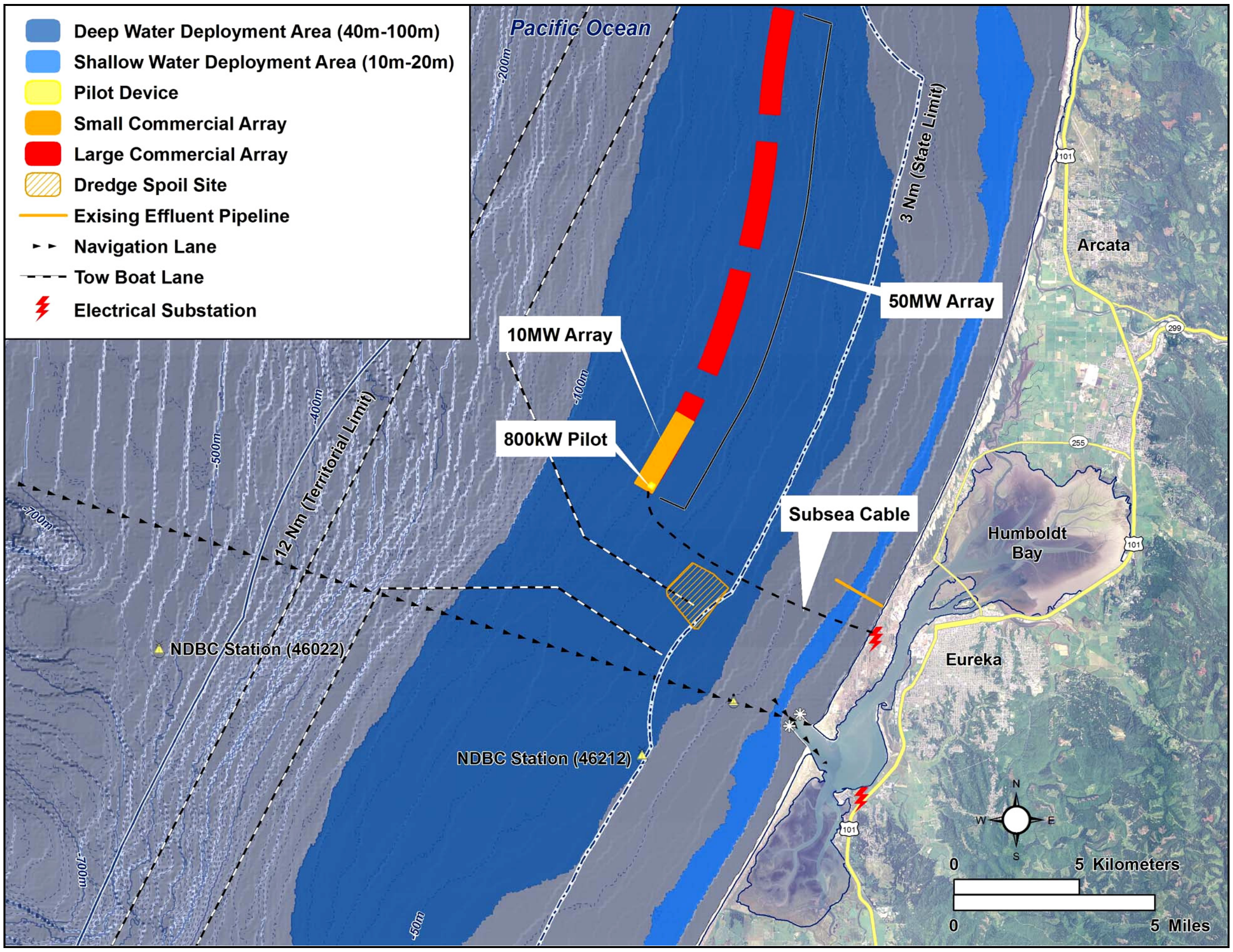

Figure 48 - OPT PowerBuoy Scenario Options (California)

12.5 Scenario 13-15: Hawaii - Wave Dragon

Project			
Site	Hawaii		
Scale	Pilot	Sm. Comm.	Lg. Comm.
Technology	Wave Dragon		
Scenario Index	13	14	15
Device			
Rated Electrical Power	3,400 kW		
Capacity Factor	30%		
Average Electrical Output	1,020 kW		
Device Type	Overtopping Device		
Foundation Type	Catenary Moored		
Total Weight	33,000 tons		
Device Length	170m		
Device Width	300m		
Hydraulic Fluid Volume	None		
Operational Considerations			
Installation/Decommissioning time	1 summer	1 summer	2 summers
Planned operational interventions per year	1	4	7.5
Project life	20 years	20 years	20 years
Site/Array			
Seabed composition	Sand / Limestone		
Average Power density (kW/m)	14 kW/m		
Average Distance to shore	3.2 km		
Water Depth	50m		
Array Length - km (parallel to shoreline)	0.82	1.9	3.9
Array Width - km	0.82	0.82	0.82
Array Surface Area - km^2	0.7	1.6	3.2
Average Linear Array Density	36.6%	46.4%	46.4%
Cumulative Hydraulic Fluid Volume (m^3)	None	None	None
Array Performance			
Number of devices	1	3	6
Average electrical power (MW)	1.0	3.1	6
Rated electrical power (MW)	3.4	10.2	20
Annual Energy Delivered to Grid (MWh/year)	8,900	17,800	53,600
Average # of Households	785	1,569	4,708
Displaced CO2 (tons)	5,340	10,680	32,160

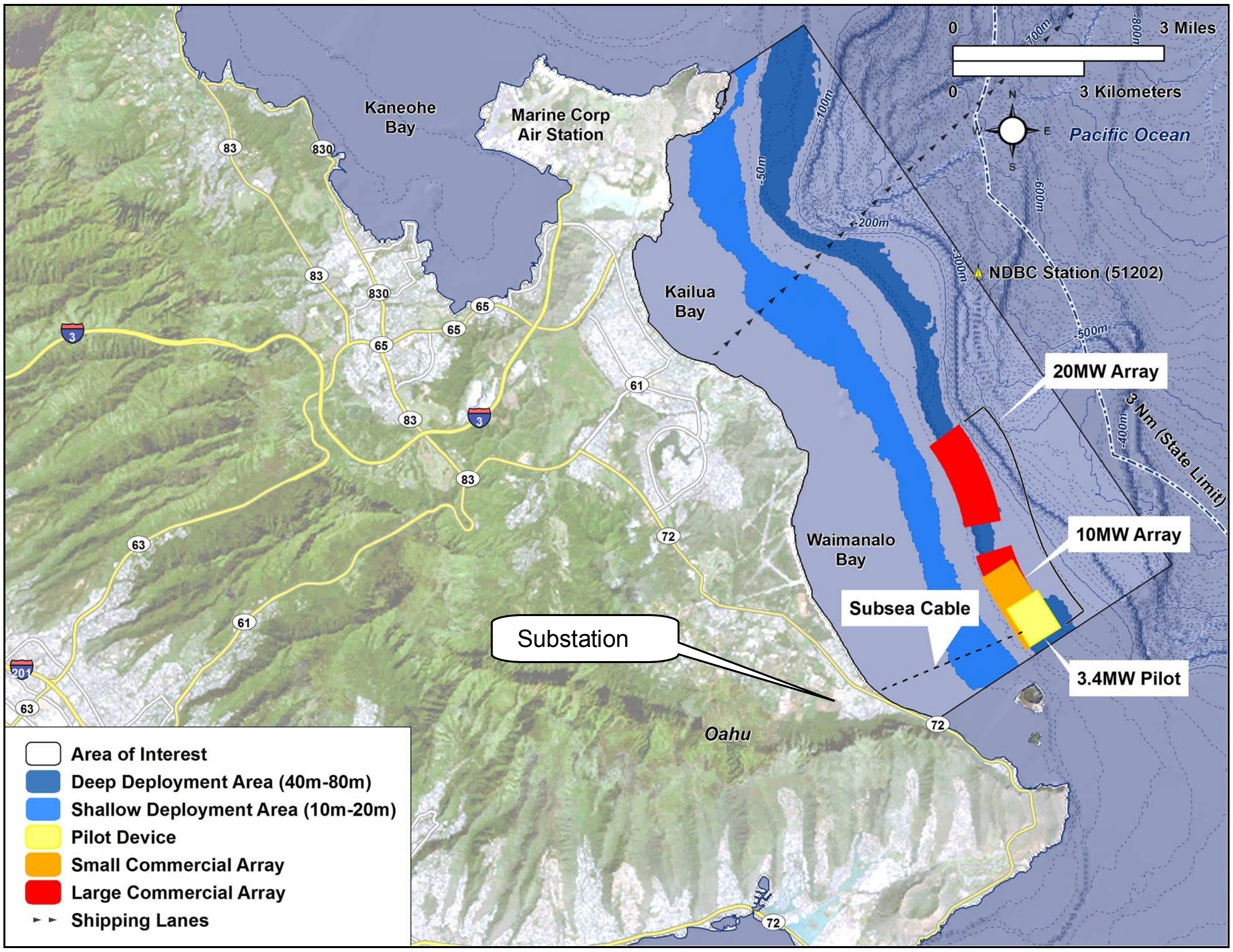

Figure 49 - Wave Dragon Scenario Options (Hawaii)

12.6 Scenario 16-18: California - Wave Dragon

Project			
Site	California		
Scale	Pilot	Sm. Comm.	Lg. Comm.
Technology	Wave Dragon		
Scenario Index	16	17	18
Device			
Rated Electrical Power	7,300kW		
Capacity Factor	30%		
Average Electrical Output	2,190 kW		
Device Type	Overtopping Device		
Foundation Type	Catenary Moored		
Total Weight	33,000 tons		
Device Length	170m		
Device Width	300m		
Hydraulic Fluid Volume	None		
Operational Considerations			
Installation/Decommissioning time	1 summer	1 summer	2 summers
Planned operational interventions per year	1	3	9
Project life	20 years	20 years	20 years
Site/Array			
Seabed composition	Sand / Mud		
Average Power density (kW/m)	30 kW/m		
Average Distance to shore	6.4 km		
Water Depth	70m		
Array Length - km (parallel to shoreline)	0.82	1.1	9.1
Array Width - km	0.82	0.82	0.82
Array Surface Area – km^2	0.7	0.9	7.4
Average Linear Array Density	36.6%	54.5%	23.2%
Cumulative Hydraulic Fluid Volume (m^3)	None	None	None
Array Performance			
Number of devices	1	2	7
Average electrical power (MW)	2.2	4.4	15
Rated electrical power (MW)	7.3	14.6	51
Annual Energy Delivered to Grid (MWh/year)	19,200	38,400	134,300
Average # of Households	1,685	3,369	11,792
Displaced CO2 (tons)	11,520	23,040	80,580

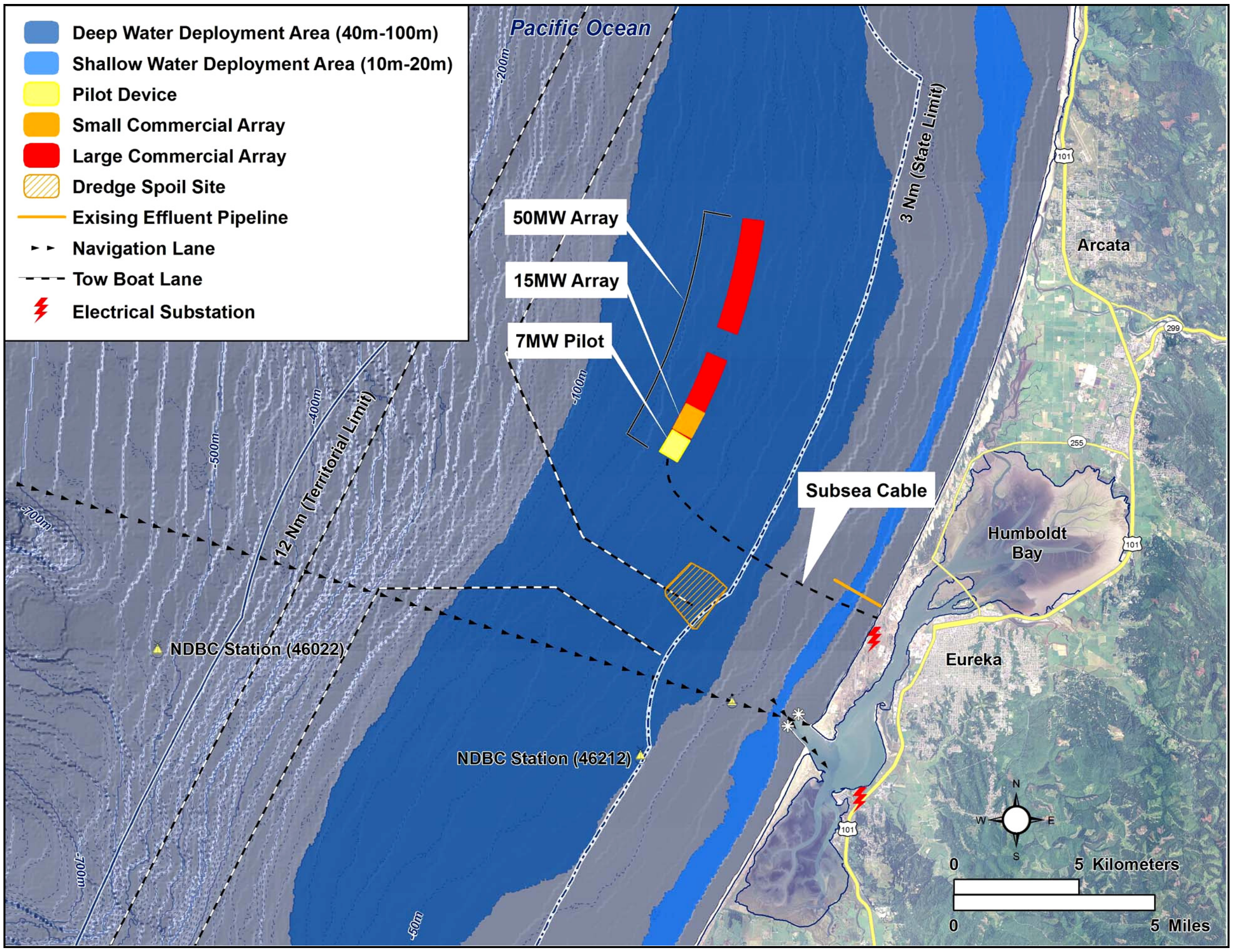

Figure 50 - Wave Dragon Scenario Options (California)

12.7 Scenario 19-21: Hawaii - Oyster II

Project			
Site	Hawaii		
Scale	Pilot	Sm. Comm.	Lg. Comm.
Technology	Oyster II		
Scenario Index	19	20	21
Device			
Rated Electrical Power	320kW		
Capacity Factor	30%		
Average Electrical Output	96 kW		
Device Type	Bottom Mounted Hinged Flap		
Foundation Type	Tension Anchors		
Total Weight	450 tons		
Device Length	estimated 20m		
Device Width	26 m		
Hydraulic Fluid Volume	None		
Marine Operational Considerations			
Installation/Decommissioning time	1 summer	1 summer	2 summers
Planned operational interventions per year	0	6	12
Project life	20 years	20 years	20 years
Site/Array			
Seabed composition	Sand/Limestone		
Average Power density (kW/m)	6.5 kW/m		
Average Distance to shore	2.5 km		
Water Depth	13m		
Array Length (parallel to shoreline)	0.026	1.6	3.2
Array Width	0.1	0.1	0.1
Array Surface Area – km^2	0.0	0.2	0.3
Average Linear Array Density	100.0%	50.0%	50.0%
Cumulative Hydraulic Fluid Volume (m^3)	None	None	None
Array Performance			
Number of devices	1	31	62
Average electrical power (MW)	0.1	3.0	6.0
Rated electrical power (MW)	0.32	9.9	19.8
Annual Energy Delivered to Grid (MWh/year)	800	26,100	52,100
Average # of Households	74	2,289	4,578
Displaced CO2 (tons)	480	15,660	31,260

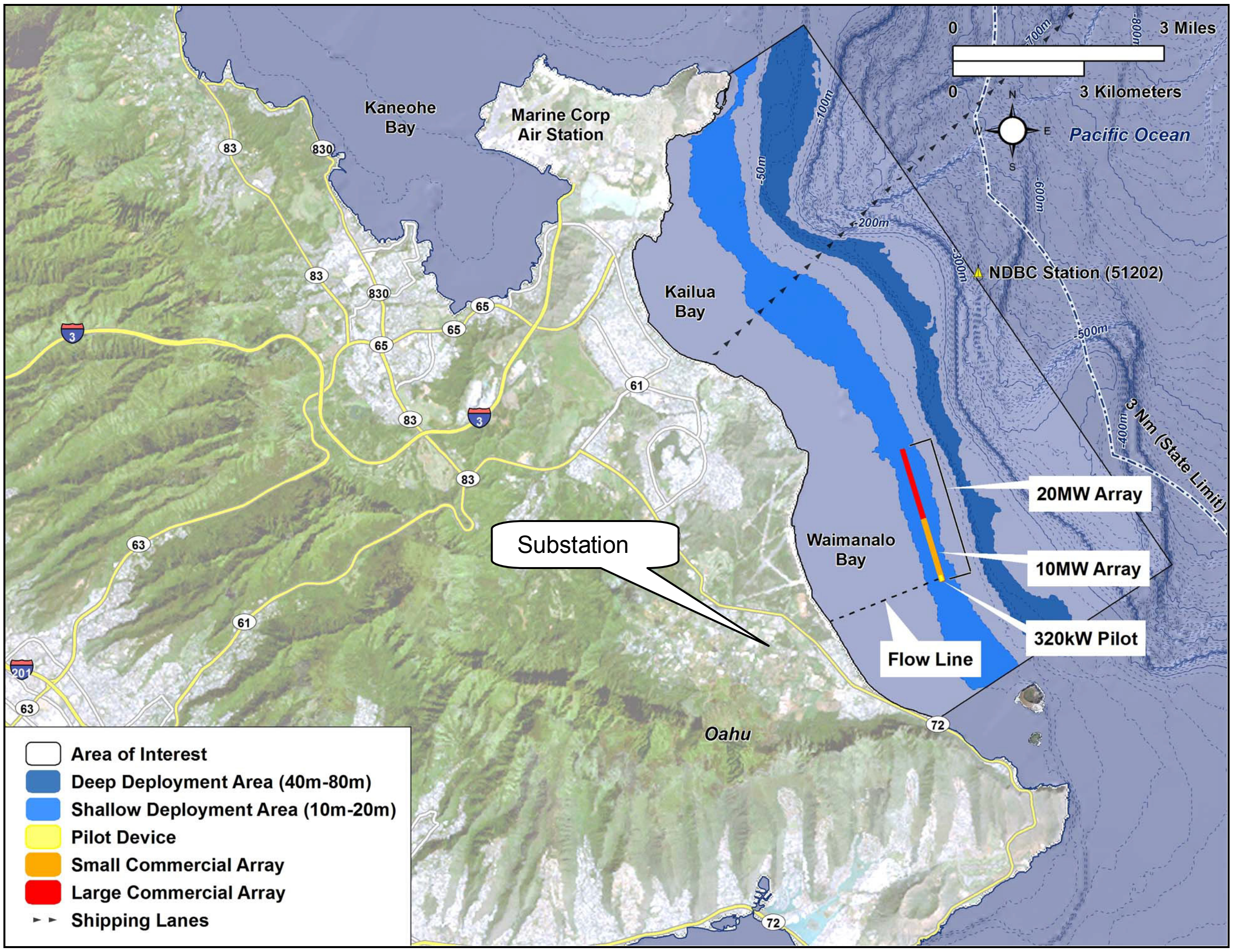

Figure 51 - Oyster II Scenario Options (Hawaii)

12.8 Scenario 22-24: California - Oyster II

Project			
Site	California		
Scale	Pilot	Sm. Comm.	Lg. Comm.
Technology	Oyster II		
Scenario Index	22	23	24
Device			
Rated Electrical Power	1460kW		
Capacity Factor	30%		
Average Electrical Output	438 kW		
Device Type	Bottom Mounted Hinged Flap		
Foundation Type	Tension Anchors		
Total Weight	450 tons		
Device Length	estimated 20m		
Device Width	26 m		
Hydraulic Fluid Volume	None		
Marine Operational Considerations			
Installation/Decommissioning time	1 summer	1 summer	2 summers
Planned operational interventions per year	0	1	3
Project life	20 years	20 years	20 years
Site/Array			
Seabed composition	Sand		
Average Power density (kW/m)	25 kW/m		
Average Distance to shore	1.2 km		
Water Depth	13m		
Array Length (parallel to shoreline)	0.026	0.4	0.7
Array Width	0.1	0.1	0.1
Array Surface Area – km^2	0.0	0.0	0.1
Average Linear Array Density	100.0%	50.0%	50.0%
Cumulative Hydraulic Fluid Volume (m^3)	None	None	None
Array Performance			
Number of devices	1	7	14
Average electrical power (MW)	0.4	3.1	6.1
Rated electrical power (MW)	1.46	10.2	20.4
Annual Energy Delivered to Grid (MWh/year)	3,800	26,900	53,700
Average # of Households	337	2,358	4,717
Displaced CO2 (tons)	2,280	16,140	32,220

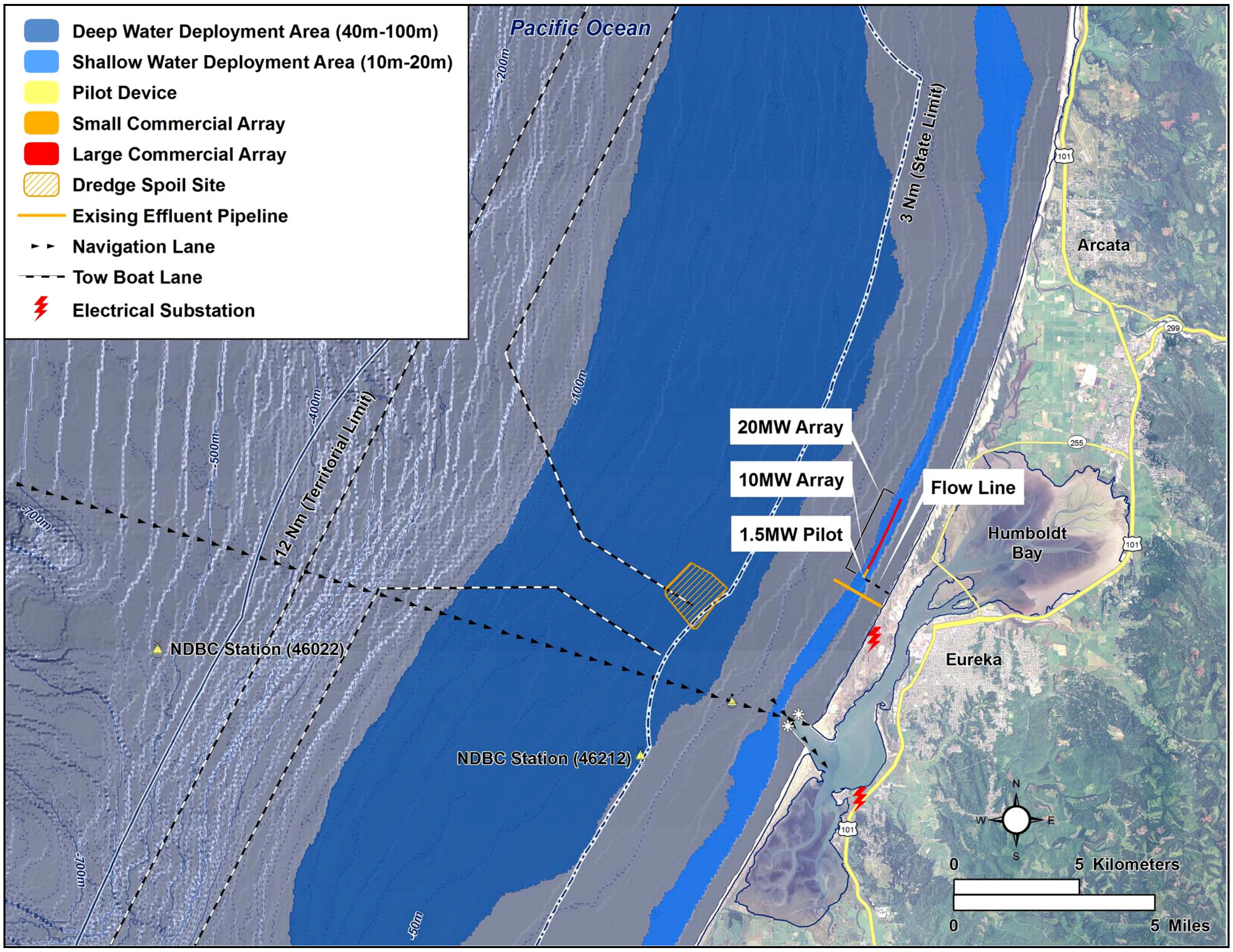

Figure 52 - Oyster II Scenario Options

13. Conclusions

This project has established baseline scenarios for wave power conversion at two sites in California and Hawaii. The two sites were chosen on the basis that they are representative of many other sites that have the potential to be developed commercially in the US. The scenarios capture variations in technical approaches and deployment scales and characterize some environmental effects, while also providing some guidance to navigation demarcation. The primary purpose of these scenarios is to provide illustrative examples of the key attributes of potential future developments. This in turn should provide all stakeholders with an improved understanding of the potential effects of these emerging technologies and focus all stakeholders on the critical issues that need to be addressed by future studies.

A few of the key findings from this scenario-based analysis include:

- Because the wave energy resource is, in most cases, uniform over a broad deployment region, it should be possible in most cases to accommodate conflicting uses, except at very large scales, where the available area restricts accommodating competing uses.
- Wave energy array downstream effects from the conversion of wave energy are likely small for most deep water technologies. Effects lessen as a function of distance to shore. With near-shore devices, the proximity to the affected area (beach) may create localized wave energy reductions. These local variations from such a deployment are not well-understood at present, and it is recommended to address this study through further modeling of the wave energy conversion process. For all devices, the percentage impact is larger during small waves than during large waves. Large winter waves are responsible for the majority of the sediment movements along the shorelines.
- The type of technology used has a major impact on the required array deployment area. In general, smaller deep water devices have a larger array footprint because of the required inter-device spacing. Shallow water devices can be deployed in very dense arrays, since they are fixed to the seabed. It remains unclear at which point very dense arrays become unsuitable because they have a high local wave energy conversion impact.
- Potential environmental effects are likely dominated by deployment scale, operational activities and infrastructure components such as subsea cables and mooring configurations.
- The range of technical approaches being considered for wave power conversion is very wide at present. This is very typical for technologies and markets that continue to be in an immature stage of development.

These scenarios demonstrate the promise of wave energy, but also point to a number of unresolved questions which require experience that can only be gained from in-water testing at smaller array deployment scales. Efforts by the Department of Energy and other agencies to promote device deployment and demonstration are of great benefit to this emerging industry and should be expanded. Further, it was beyond the scope of the present study to involve a wide range of stakeholders in the scenario-development process. Such stakeholder engagement could be used to further reduce uncertainties in the siting process. This engagement would also serve as an educational tool to stakeholders, which in turn would insure that duration and cost of the siting process could be minimized.

Finally, there are a number of key areas of research that could serve the industry as a whole, including;

- Quantification and compilation of electromagnetic field data near subsea cables;
- Quantification and compilation of noise-sources from construction and operation activities;
- Determination and compilation of species threshold studies for electromagnetic and acoustic impacts;
- Assessment of the impacts of navigation lighting on birds and determination of best practices;
- Detailed modeling of wave energy reduction in the wave shadow of wave energy plants and determination of thresholds levels of conversion.

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