MARINE RENEWABLE ENERGY AND ENVIRONMENTAL IMPACTS

ADVANCING CALIFORNIA'S GOALS

PREPARED FOR THE CALIFORNIA STATE LANDS COMMISSION

2013

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Storm Surf
Courtesy of James Fortman

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Use of Terms

The report uses a number of terms to describe types of MRE, and discusses three specific technology types. To ensure clarity, this report uses the following conventions:

- **MRE technology:** refers to all types of marine renewable energy including wave, tidal and current, and offshore wind technologies.
- **Marine Hydrokinetic (MHK) device or technology:** refers to technologies that generate energy from the movement of ocean waves, tides, and currents.
- **Wave Energy Converter (WEC):** refers only to devices or technologies that generate energy from the movement of ocean waves, including point absorbers, attenuators, overtopping devices, oscillating water columns, and oscillating wave surge converters.
- **Tidal or Current Energy Devices:** refers only to devices that generate energy from tidal flow including axial flow turbines, cross flow turbines, and reciprocating devices. Many of these devices can also be modified or used directly to generate energy from ocean currents.

In addition, the way CEQA defines the category "noise" requires additional language in this report for broader sound impacts. To ensure clarity, this report uses the following convention:

- **Noise:** refers to the impacts of sound from a project on humans and communities.
- **Acoustics:** refers to the impacts of sound from a project on marine species.

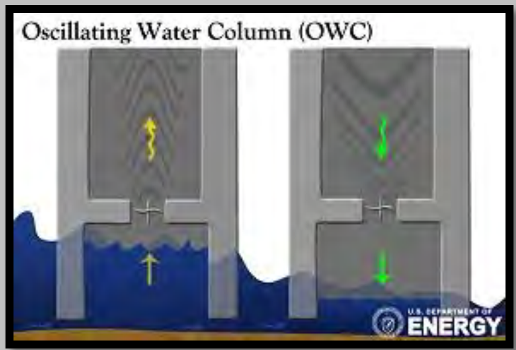
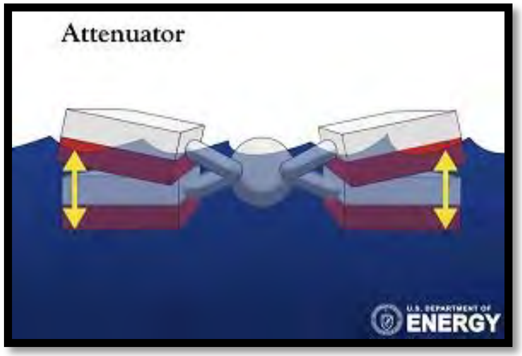
Acronyms

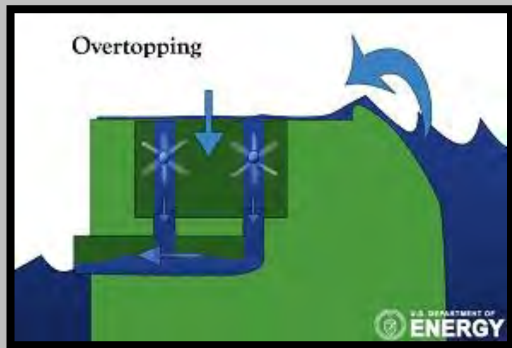
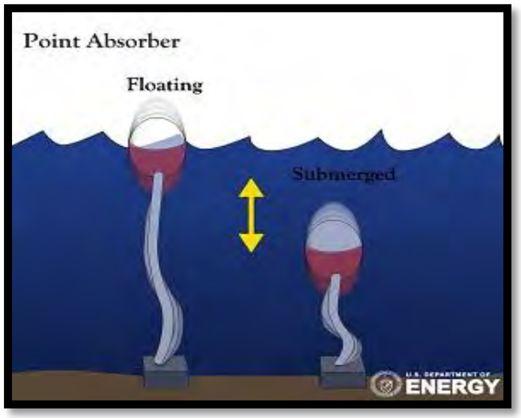
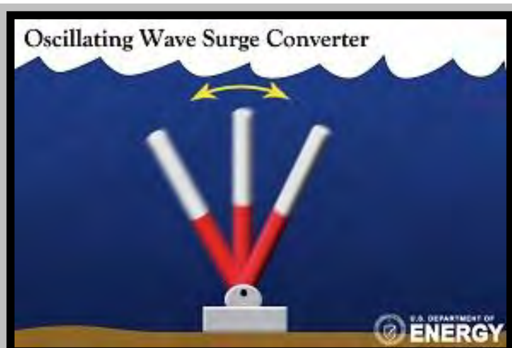
Acronym	Definition
AC	Alternating Current
BOEM	Bureau of Ocean Energy Management
CEQA	California Environmental Quality Act
CO_2	Carbon Dioxide
dB	Decibels
DOE	Department of Energy
DC	Direct Current
EPRI	Electric Power Research Institute
EMF	Electromagnetic Fields
EMEC	European Marine Energy Center
FAD	Fish Attracting Device
FERC	Federal Energy Regulatory Commission
g CO_2-e/kWh	Grams of CO_2 equivalent per kilowatt-hour
GHG	Greenhouse Gas
GW	Gigawatts
Hz	Hertz
kg	Kilogram(s)
kHz	Kilohertz
km	Kilometer(s)
kWh	Kilowatt-hour(s)
MHK	Marine Hydrokinetic
MRE	Marine Renewable Energy
MW	Megawatts
m	Meter(s)
m/s	Meter(s) per second
g/L	Micrograms per liter
T	Microteslas
mG	Milligauss
mm	Millimeter(s)
mV/cm	Millivolts per centimeter
nV/cm	Nanovolts per centimeter
OPT	Ocean Power Technology
OWET	Oregon Wave Energy Trust
OWCs	Oscillating Water Columns
OWSCs	Oscillating Wave Surge Converters
OCS	Outer Continental Shelf
PG&E	Pacific Gas and Electric
PNNL	Pacific Northwest National Laboratory
SARA	Scientific Application and Research Associates
SWRCB	State Water Resources Control Board
TWh	Terrawatt-hour(s)
V/m	Volts per meter
watts/m^2	Watts per meter squared
WECs	Wave Energy Converters

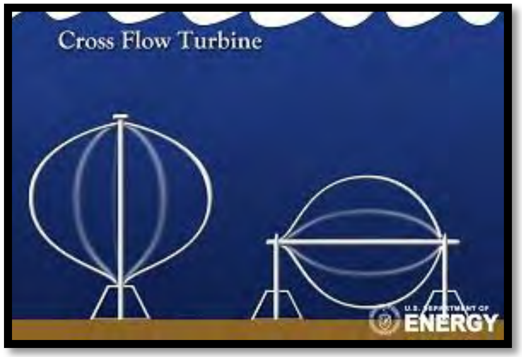
Summary Table

The following table summarizes the environmental impact of different Marine Renewable Energy (MRE) Technologies. The impacts listed here are of greatest concern for the specific technology discussed. This is *not* a comprehensive list of impacts.

Table S.1.1: Summary of Marine Renewable Energy Technologies and Their Environmental Impacts

Resource	Technology	Description	Likely Environmental Impacts*
Wave energy		OWCs are partially submerged structures that enclose a column of air above the surface of the water. Waves funneled into the structure cause the water column to rise and fall. As the water column moves, it acts as a piston, pressurizing and depressurizing the air column to spin a turbine.	• **Entrapment** of marine species for some device designs; • New **hard-substrate habitat** in either the intertidal zone or offshore; and • B**arotrauma impacts** to swim bladder fishes, pinnipeds and seabirds.
Wave Energy		Attenuators are long, linear devices with their principle axis parallel to incoming waves. The waves cause articulated components of the device to bend and drive generators.	• **Entanglement or collision**, especially for marine mammals.

Resource	Technology	Description	Likely Environmental Impacts*
Wave Energy		Overtopping devices are partially submerged structures with a design that funnels waves over the top of the structure into a reservoir; the water then runs back out to sea from the reservoir through a turbine.	• **Entrapment** and **impingement** of marine species; • **New hard-substrate habitat** either in the intertidal zone or offshore; and • **Public safety** concerns due to the device's exposed reservoir.
Wave Energy		Point absorbers look very similar to traditional buoys. They move on the surface of the water like a buoy, and their movement is used to generate energy.	• **Entanglement** of marine species; and • **New haul-out areas** for pinnipeds.
Wave Energy		Oscillating wave surge converters capture mechanical energy by using the relative motion between a float, flap, or membrane and a fixed reaction point.	• **Collision** with diving seabirds, marine mammals, and fish.

Resource	Technology	Description	Likely Environmental Impacts*
Tidal Energy	 	Both axial flow and cross flow turbines typically have two or three blades mounted on a shaft to form a rotor. The kinetic motion of the water current or tide creates lift on the blades, causing the rotor to turn, which drives a mechanical generator.	• Axial and cross flow turbines are expected to have similar environmental impacts; • Collision **with marine species**; and • Increased concentrations of pollutants **in nearby water bodies.**
Tidal Energy		Reciprocating devices use the flow of water to produce lift or drag of an oscillating part of the device. This oscillation produces mechanical energy that feeds into a power conversion system.	• **Collision** with marine species; and • **Increased concentrations of pollutants** in nearby water bodies.

Resource	Technology	Description	Likely Environmental Impacts*
Offshore Wind		Although similar to land-based wind turbines, offshore wind turbines are feasible because of innovation in engineering the foundation of the structure. The development of viable floating foundations will allow offshore wind turbines to move into deeper water.	• **Collision** with bats or seabirds; • **Artificial Lighting** changing animal behavior; and • **Man-made acoustics** associated with the turbine.

***** Most common or anticipated impacts; not necessarily a comprehensive list. Please see Section 5 for a thorough and descriptive list of general and device-specific impacts associated with MRE technologies with reference to the California Environmental Quality Act (CEQA).

1 Introduction

The development, planning, and permitting of emerging technologies presents a challenge to project proponents and resource managers, and marine renewable energy (MRE) is no exception. California has been considered for MRE project development for a number of reasons, including the high demand for electricity and the ambitious renewable portfolio standard policy of the State. The demand for energy is growing in California at 1.2% per year; currently, the State obtains less than 12% of its electricity from renewable sources.[1] California's Global Warming Solutions Act of 2006 sets portfolio standards requiring that carbon dioxide (CO_2) emissions be reduced to 1990 levels by 2020, and to 80% less than 1990 levels by 2050. In addition, Governor Brown signed Senate Bill X1-2 into law in April 2011, which requires that 33% of electricity sold to California consumers come from renewable sources by 2020, codifying Executive Order S-14-08 issued by Governor Schwarzenegger in 2008. MRE technologies are generally expected to produce far lower greenhouse gas (GHG) emissions over the lifespan of a project than traditional electricity sources. However, GHG emissions are very project and device-specific, and there is little research on the potential GHG emission from an MRE project. To determine the GHG emissions over the lifespan of a project, Oceanlinx, an oscillating water column (OWC) manufacturer, performed a life cycle assessment for their products, which considered the sourcing of the materials, the manufacturing of the OWC, maintenance, and recycling/end-of-life-cycle activities. The assessment found that the total GHG emissions produced during the life cycle of their products is fewer than 50 grams of CO_2 equivalent per kilowatt-hour (g CO_2-e/kWh); some products may even produce as few as 24 g CO_2-e/kWh.[2] In comparison, a coal-fired power plant produces almost 900 g CO_2-e/kWh during its life cycle, an oil-fired power plant produces just over 700 g CO_2-e/kWh, and a natural gas combined cycle produces just over 375 g CO_2-e/kWh.[2]

Wave, tidal, and offshore wind energy have the potential to meet a significant portion of California's renewable portfolio standards and energy demand. In addition, there are a number of factors that make MRE development more attractive relative to onshore renewable energy development including:

- Water is roughly 784 times denser than air, so smaller, slower tidal turbines can generate as much energy as a large wind turbines rotating much faster;
- Waves, tides, and currents are easier to predict than wind and solar energy, allowing for greater power reliability; and
- Offshore wind occurs with greater frequency and strength than onshore wind, and in some cases is known to coincide with peak demand of electricity resources.

These advantages have led to MRE development on the East Coast, Pacific Northwest, and Europe. Although MRE devices have been successfully deployed, and MRE developers have shown interest in California, no devices have been deployed in State waters to date. Approximately 14 MRE projects in State waters have requested a preliminary permit from the Federal Regulatory Energy Commission (FERC). The preliminary permit issued by FERC is an opportunity for applicants to research their sites and determine if they have the technological and financial capabilities to develop their projects. None of the projects has moved forward; all were either cancelled by FERC or the applicant. For a list of these projects, please see Appendix D. Issues that may have delayed MRE development in California include:

- Resource managers have difficulty acquiring and allocating funds for broad-scale research that would also inform project-specific environmental impacts and appropriate siting;

- State actions, such as designating renewable energy areas, may spark political controversy because these actions could be considered preferential treatment towards a specific type of technology (e.g. the area designated may be good for wave energy, but not tidal energy);
- Since field studies and data are scarce, especially regarding impacts to California species and habitats, resource managers may require extensive pre-project studies, resulting in permitting delays;
- Funding environmental studies to determine the environmental impacts of a project under the California Environmental Quality Act (CEQA) is costly for project proponents;
- The ocean is heavily used in California for activities ranging from commercial fishing to surfing to kelp-harvesting, creating the potential for space-use conflicts when siting MRE projects;
- The part of the coast with the most potential for wave energy production has limited transmission capacity;
- Local citizens express concern about impacts to their communities from MRE projects.[3]

The State of California has already taken a number of steps to move MRE forward in the state, including providing permitting guidance, funds for technology demonstration and deployment, and previous research on environmental effects of MRE technologies. Work completed or currently being done to advance MRE includes:

- The State of California signed a Memorandum of Understanding with the FERC to support the timely processing of applications for MRE projects;
- The Ocean Protection Council commissioned a report on Developing Wave Energy in California: Potential Ecological and Socio-Economic Effects;
- The Ocean Protection Council created Permitting Guidance for Ocean Renewable Energy Test and Pilot Projects;
- The California Energy Commission has dedicated approximately $130 million from 2012 to 2014 towards "technology demonstration and deployment" of new renewable energy technologies, including MRE technologies;
- The California Marine Renewable Energy Working Group serves as a central point of contact for project proponents to have a pre-project meeting and receive feedback from agencies on what they need to consider in their project design.

In addition to the work done by the State, MRE research has been funded by the Bureau of Ocean Energy Management, the State of Oregon, the Snohomish Public Utility District, the Cape Wind project, MRE project proponents, and governments in Europe. The studies funded and produced by these entities are cited throughout this report, and some in-progress studies relating to California are listed in the "Moving Forward" section.

This report builds upon the previous work done by the State and other entities by compiling and synthesizing information from MRE research and monitoring efforts to inform the reader of the environmental effects of these technologies. It then examines the applicability and limitations of that information in California, identifies critical data gaps, and recommends steps agencies and other stakeholders can take to facilitate the installation of MRE projects in California. Although available to all, the report's content will be most useful to resource managers at California State and local agencies, policymakers who are determining how to support the development of MRE technologies, project proponents who want to determine which aspects of their project affect environmental review, and researchers who are interested in filling data gaps in existing information. Additional research needs are identified in the "Research Needs" section, and brief summaries of research needs are in the environmental impacts section. This report should be used to answer general questions on the environmental impacts of specific technologies or infrastructure. It can also provide a starting point for a more detailed, project-specific analysis. The technologies covered are: wave energy devices, tidal energy devices, offshore wind turbines, and the infrastructure associated with all three types of devices.

Other ocean alternative energy systems not covered in this document include:

- **Ocean thermal energy conversion:** Ocean thermal energy conversion uses temperature differences between deep- and shallow-water to generate energy. This type of renewable energy is only viable in tropical areas and would not be effective in California;
- **Salinity gradient energy generation:** Salinity gradient technologies use salinity differences to force water through a membrane to generate energy. These technologies are generally sited at the mouths of rivers. Currently, they are prohibitively expensive to develop and use; and
- **Algae biofuel:** Algae production for biofuels falls into a different category of ocean-related energy and potential impacts than the kinetic types of energy considered in this report. This report focuses on extracting kinetic energy which creates electricity from the movement of wind, tides, and waves.

This report models its impact discussion after the requirements of the CEQA (Pub. Resources Code, §21000 et seq.), which requires California public agencies to consider the environmental impacts of the projects they fund or authorize. In accordance with the State CEQA Guidelines[i], agencies analyze potential impacts to a number of different resource "categories" (e.g., Air Quality, Biological Resources, Cultural Resources, etc.) and, in some cases, identify and evaluate alternatives to proposed projects. If the analysis identifies significant environmental impacts, agencies must then identify and require measures to reduce or avoid those impacts, if feasible.

The "categories" to be analyzed are outlined in Appendix G of the State CEQA Guidelines (Cal. Code Regs., tit 14 §1500 et seq.). Appendix G recommends resource categories for agencies to consider when assessing environmental impacts. However, Appendix G is geared towards projects occurring on land, rather than in the ocean. To adequately consider impacts to the marine environment, some Appendix G categories must be broadly interpreted.[ii] A table of Appendix G categories and their application to the marine environment is included below:

Table 1.1.1: CEQA Guidelines Appendix G Categories and Their Application to the Marine Environment

Appendix G Category	Application to the Marine Environment
Agriculture and Forestry	Aquaculture and Fisheries
Public Services	Coast Guard search and rescue operations, national defense/homeland security
Transportation/Traffic	Shipping lanes/vessel movement on the water
Land Use/Planning	Marine Protected Area Networks, shipping lanes, other spatial designations

[i] The State CEQA Guidelines are found in Title 14 of the California Code of Regulations, commencing with section 15000.
[ii] To see the CEQA Guidelines Appendix G checklist, please see Appendix C of this report.

To limit redundancy in this report, the following section includes a matrix, which outlines the CEQA categories impacted by each type of technology. This report is designed to be used like a reference book, where the reader can turn to the sections of interest. To get the most out of this report, use the matrix in the next section to find the appropriate sections to read for each technology. In addition to this introductory section, this report contains the following:

- **Section 2: Matrix** provides a "key" to which CEQA categories are impacted by each type of MRE technology.
- **Section 3: Offshore Energy Potential of California and Project Siting** describes which areas of California have the greatest concentration of offshore energy, including siting constraints for developers;
- **Section 4: Types of MRE Technologies** describes each type of technology and provides examples of commercial devices;
- **Section 5: Environmental Impacts of MRE** discusses the environmental effects caused by MRE projects, and the CEQA resource categories that are likely to be impacted by these effects;
- **Section 6: Research Needs** discusses the impacts of highest priority for future research and monitoring and which monitoring methods are preferred to determine those impacts. This section will also discuss in-progress federal research on environmental issues that can be applied to MRE projects
- **Section 7: Moving Forward** discusses the processes used in other states to effectively permit MRE projects and next steps for the State of California.

As the State moves forward, agencies coordinating and deciding on priority data needs, may help MRE applicants to engage in efficient project planning. Of the additional information needed, agencies should prioritize information that is applicable to many MRE technologies for funding and research opportunities through State and Federal programs. Prioritizing research to answer general questions will provide the greatest return on investment, and is less likely to create preferential treatment toward any single type of technology. Other states that have proven their ability to work through MRE project issues with a more coordinated and efficient planning strategy have an advantage over California for future development in this part of the green energy sector. With appropriate planning, siting, and project design, MRE can become a valuable and environmentally intelligent part of California's green energy mix.

2 Matrix

The following matrix shows CEQA categories that are expected to be impacted by various marine renewable energy (MRE) technologies. The matrix should be used to find the appropriate impact sections to reference in Section 5 for each type of MRE technology. The impacts in this report focus on the operational phase of a MRE project. The impacts of MRE construction in the marine environment are relatively well understood from other marine construction projects, and are not covered in this report.

Key:
X Impacts common to many MRE technologies
XX Technology-specific impacts

Table 2.1.1: Marine Renewable Energy Technologies and the CEQA Categories They Impact

CEQA Impact Category	Marine Renewable Energy Technologies							
	Oscillating Water Column	Attenuator	Overtopping Device	Point Absorber	Oscillating Wave Surge Converter	Axial Flow and Cross Flow Turbines	Reciprocating Device	Offshore Wind Turbine
Aesthetics	X	X	X	X	X	X	X	XX
Agriculture and Forestry	X	X	X	X	X	X	X	X
Biological Resources	XX	X	XX	X	XX	XX	X	XX
Cultural Resources	X	X	X	X	X	X	X	X
Geology/Soils	X	X	X	X	X	X	X	X
Hazards and Hazardous Materials	X	X	X	X	X	X	X	X
Hydrology/Water Quality	X	X	X	X	X	X	X	X
Land Use/Planning	X	X	X	X	X	X	X	X
Mineral Resources	X	X	X	X	X	X	X	X
Noise	X				X			X
Public Services	X	X	X	X	X	X	X	X
Recreation	X	X	X	X	X	X	X	X
Transportation/Traffic	X	X	X	X	X	X	X	X
Utilities/Service Systems	X	X	X	X	X	X	X	X

3 Offshore Energy Potential of California and Project Siting

Successfully siting a marine renewable energy (MRE) project is dependent on the energy resources and environmental characteristics at the site, in addition to the operational requirements of the technology. Siting is an important step in the process of MRE development along the coast in order to reduce and avoid environmental impacts associated with a project, while still accessing commercially viable offshore energy. Siting a project outside of critical habitat is a good way to avoid impacts to endangered species. In addition, poor siting creates environmental and operational problems that may not have been present otherwise. For example:

> One of the earliest commercial wind projects developed in the United States is located in Altamont Pass, California, and, due to poor site selection, causes the death of several thousand birds each year, including species protected by the federal Migratory Bird Treaty Act. This early mistake contributes to a perception that wind turbines are inherently hazardous to birds, despite evidence to the contrary. Tidal energy [and other marine renewable energy] development would be well-served by avoiding such costly mistakes.[4]

In addition to sites that create environmental and operational problems, some sites are simply not suitable for certain projects. Many technology designs require certain water depths or bathymetry for efficient functioning. These constraints vary across device designs, making generalizations for all MRE technologies difficult. For example, several wave energy converter (WEC) developers have stated that consistency of wave height and period are desirable, while others consider the height of incoming waves more important. Some WEC producers have tried to account for siting limitations by designing devices that may be adjusted to extract energy from the average wave height at a specific site, rather than searching for a site that would match the device perfectly. In addition, MRE developers in Oregon prefer soft-bottom habitat for project sites, because it enables them to use concrete blocks as anchors for their project.[5]

Although MRE devices vary in size and position in the water column, generally all projects will require an onshore electrical substation, or an underwater substation, underwater electrical cables, ground anchors, mooring lines, or foundations to be able to operate and transmit electricity to land-side users. Sites near existing substations and undersea power cables are considered desirable, both in terms of cost and potential environmental impact. Constructing new electrical infrastructure for a project is expensive. In 2008, the cost of using deep-water offshore construction vessels was over $100,000 per day, and the cost of shallow-water or nearshore vessels was $35,000 to $65,000 per day. Additionally, fuel costs for these vessels averaged $15,000-$25,000 per day.[6]

3.1 Wave Energy Siting

California has abundant wave energy resources. Theoretically, the total deep-water wave energy available in California is 293 terrawatt-hours (TWh) per year.[7] As waves move closer to shore, they lose energy due to contact and friction with the seafloor, meaning deeper-water has more wave power than shallow-water. As shown in Table 3.1.1, the Central California coast (from Cape Mendocino to Point Arguello) has the greatest amount of wave energy.[7] The annual wave energy estimates are divided into outer and inner shelf resources to show how much energy was lost in a region due to contact and friction with the seafloor. The outer shelf was considered the 200 meter (m) depth contour and the inner shelf was considered 50 m depth contour. Of the available wave energy in California, only some is technically recoverable by WECs. Figures 3.1.1 and 3.1.2 show the range of recoverable wave energy in Northern, Central, and Southern California for the outer and inner shelf, respectively.

Table 3.1.1: Total Annual Available Wave Energy in California by Region
(From *Mapping and Assessment of the United States Wave Energy Resource*; see endnote 7 for full reference)

Area	Wave Energy Along the Outer Shelf (more than 200 m depth)	Wave Energy Along the Inner Shelf (less than 50 m depth)
Northern California	65 TWh per year	45 TWh per year
Central California	185 TWh per year	148 TWh per year
Southern California	43 TWh per year	12 TWh per year

TWh Terawatt-hours

Figure 3.1.1: Amount of Total and Technically Recoverable Wave Energy on the Outer Shelf of California by Region
(From *Mapping and Assessment of the United States Wave Energy Resource*; see endnote 7 for full reference)

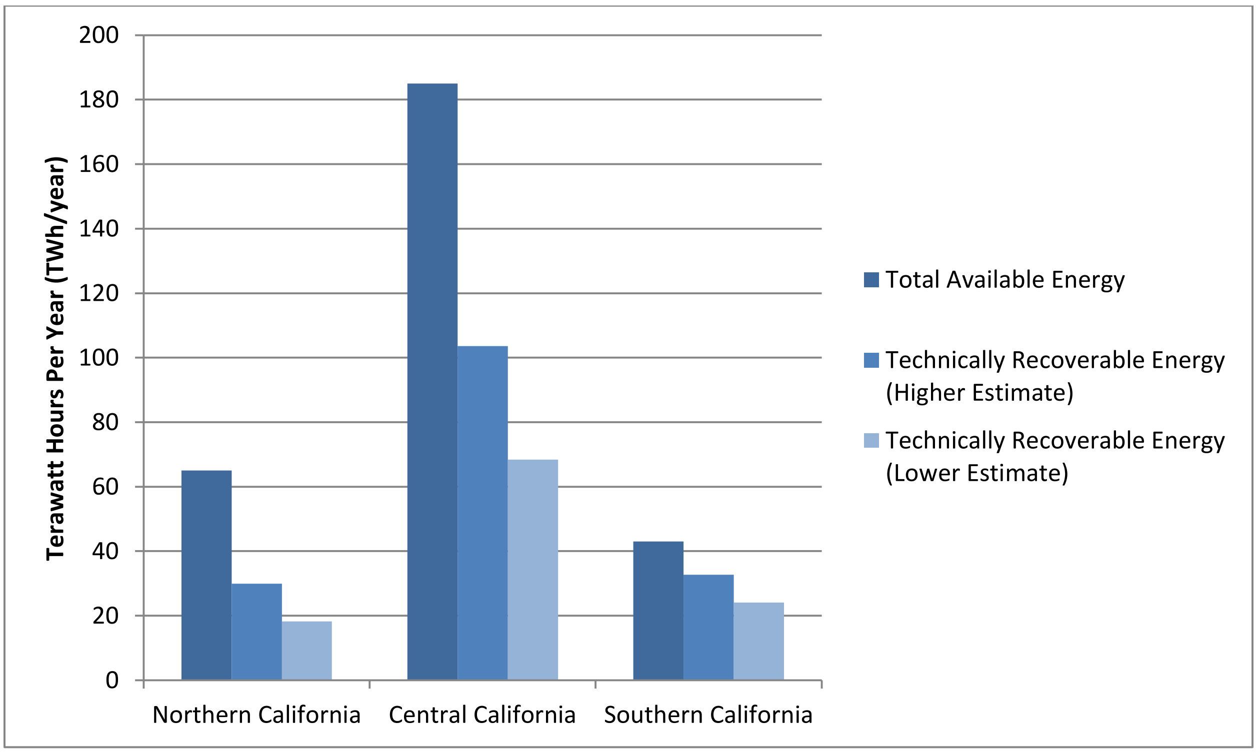
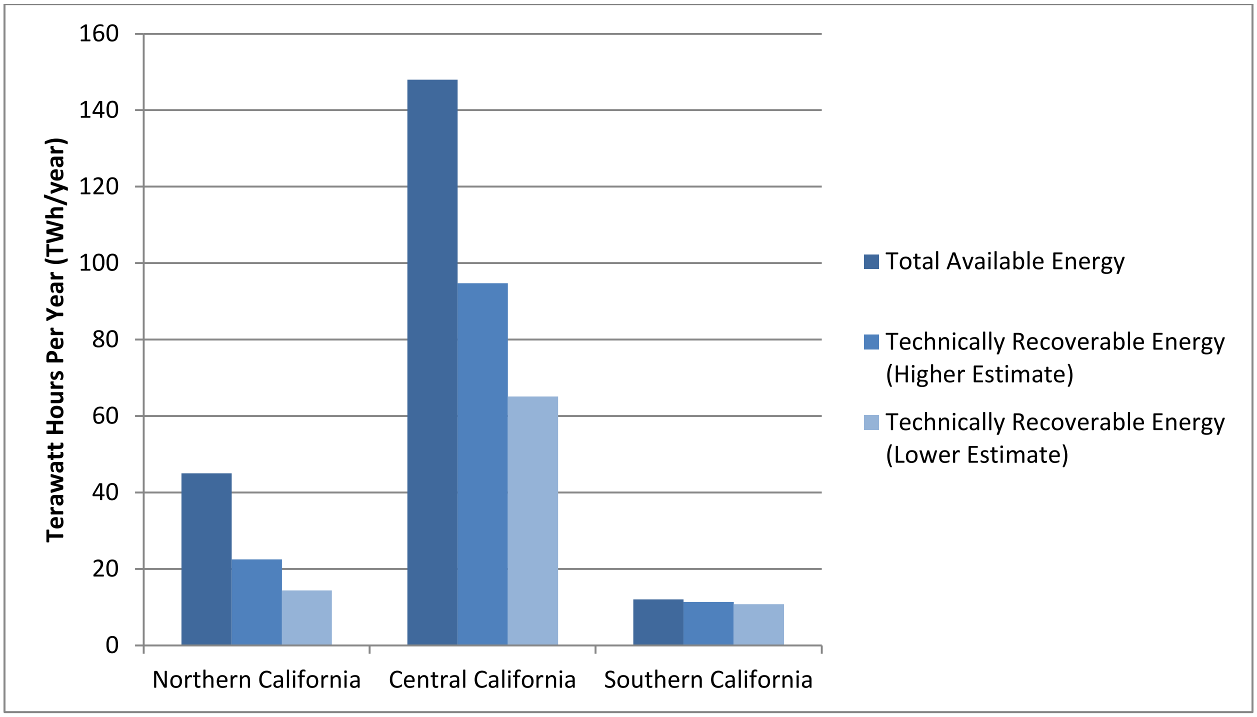


Figure 3.1.2: Amount of Total and Technically Recoverable Wave Energy on the Inner Shelf of California by Region

(From *Mapping and Assessment of the United States Wave Energy Resource*; see endnote 7 for full reference)



3.2 Tidal Energy Siting

In comparison to wave energy, tidal energy resources in California are more localized.[8] Researchers from the Georgia Tech Research Corporation evaluated theoretical tidal energy sites in the United States and found that the total theoretical tidal power resource in California is 204 megawatts (MW) and, of this, 178 MW is at the entrance to San Francisco Bay.[8] Generally, tidal turbines have minimum flow requirements ranging from 0.5 to 1 meter per second (m/s). Under these constraints, the minimum power density needed for turbine operation is 500 watts/m^2, which corresponds to a flow speed of approximately 1 m/s.[8] The Georgia Tech research team identified additional criteria for potential tidal energy sites including adequate depth for a small device (5 m) and a minimum surface area of 0.5 square kilometers (km^2).[8] Using a coarse-scale analysis, the team found three tidal energy "hotspots" in California that met the criteria: Golden Gate, Carquinez Strait, and the Humboldt Bay Entrance. The report stressed, however, that more potential sites for tidal energy could be discovered with a fine-scale analysis. Table 3.1.2 provides more information on tidal energy hotspots in California. For a table of all of the tidal energy locations that had a flow speed of 1 m/s in California, refer to Appendix B.

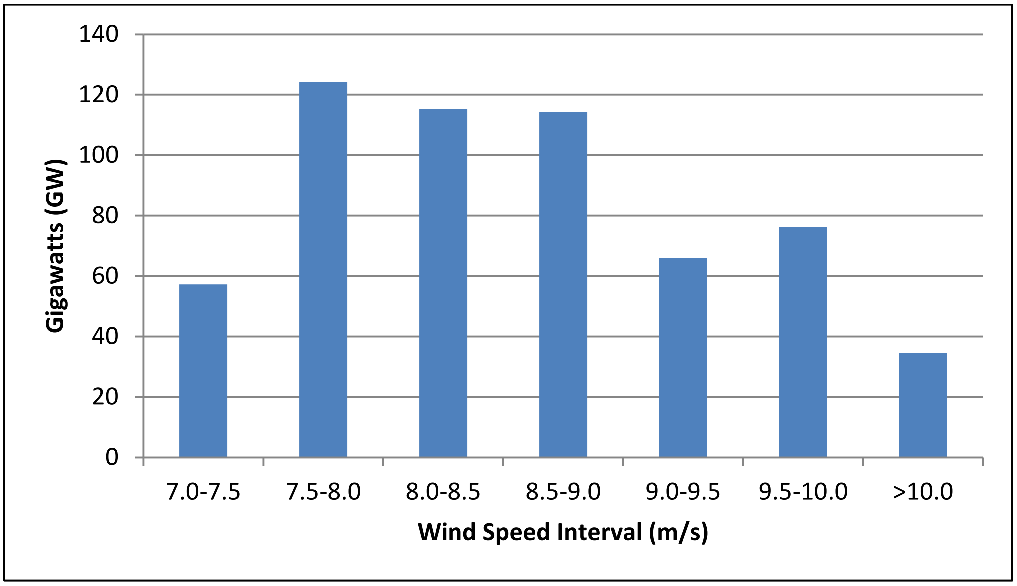
Table 3.1.2: Tidal Energy Hotspots in California

Location	Surface Area (in km^2)	Maximum Depth (m)	Mean Depth (m)	Kinetic Power Density (watts/m^2)
Golden Gate	<1	111	50	750
Carquinez Strait	12	36	19	914
Humboldt Bay Entrance	<1	11	9	941

3.3 Wind Energy Siting

The total offshore wind energy resource in California is roughly 588 gigawatts (GW) at 90 m from the surface.[9] The majority of California's offshore wind energy occurs at wind speeds between 7.5 and 9.0 m/s. Figure 3.1.3 presents a breakdown of California's offshore wind energy resource.

Figure 3.1.3: Offshore Wind Energy Potential in California by Wind Speed Interval[iii, 9]



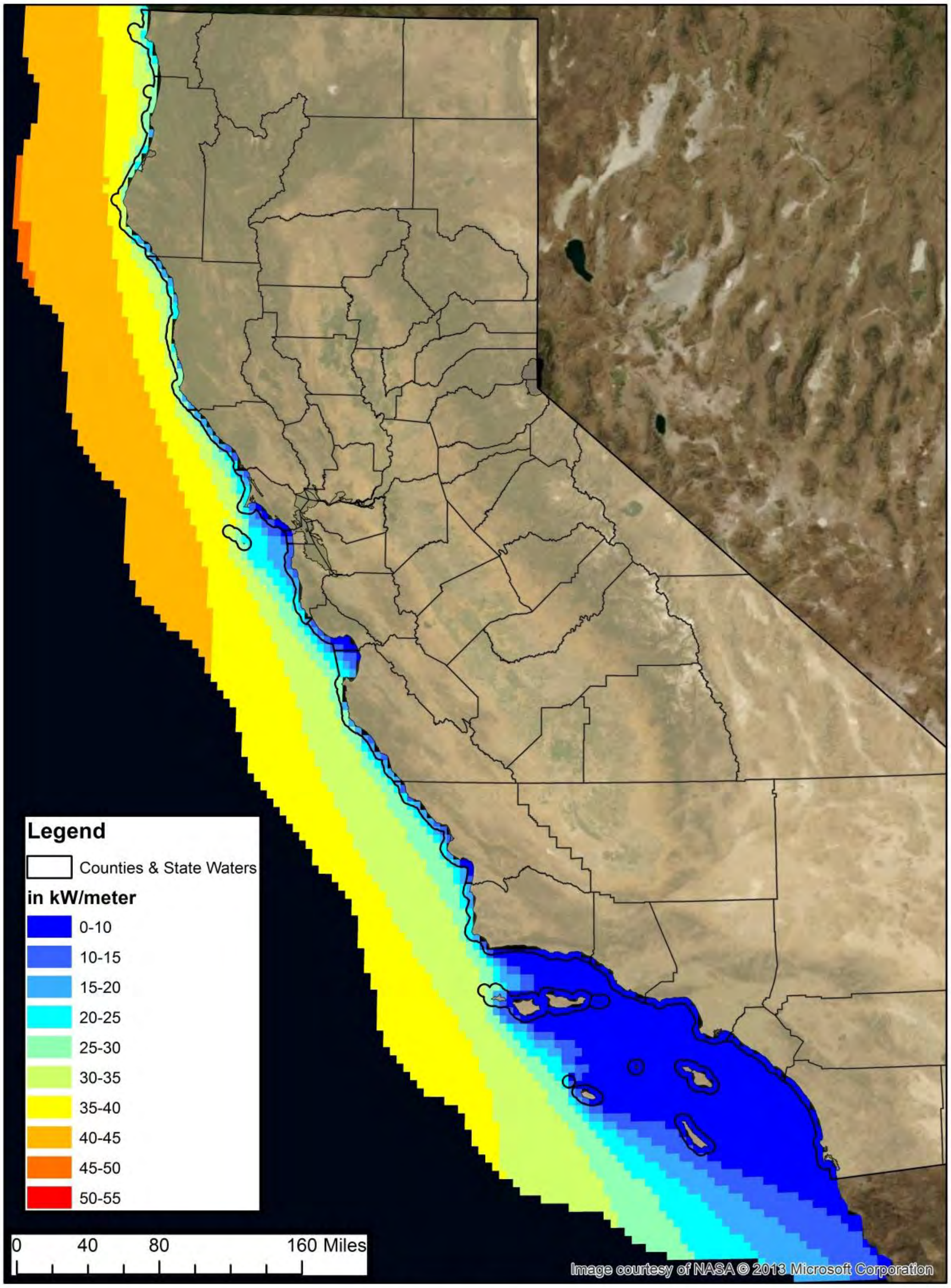
3.4 Tools for Siting

The coastal and ocean areas of California are heavily used in a wide variety of ways by many stakeholders, and provide important habitat for rare and commercially valuable species. In an effort to compile this information into a centralized database, the California Coastal Geospatial Working Group is creating a spatial data portal and viewer with information on human uses, natural habitat, and other spatial activities that occur on the coast of California and in the ocean offshore. This data portal could be used by project proponents to assess potential sites for MRE development and eliminate sites that are less ideal due to conflicting uses, as well as allow agency staff to view spatial data quickly and inform environmentally and socially sensitive siting. Additionally, after a site is selected, the information in the data portal could be used to inform a cumulative impacts analysis for the MRE project, as well as provide information about ongoing or planned projects in the area. The California Coastal Geoportal is expected to be publicly available by early fall of 2013.

Figures 3.1.4, 3.1.5, 3.1.6, 3.1.7, and 3.1.8 on the following pages are maps depicting offshore energy potential in California State and Federal waters. The data, which will be available in the above mentioned spatial data portal, were modeled on a coarse scale because most of these resource assessments were done on a national level for Federal agencies.

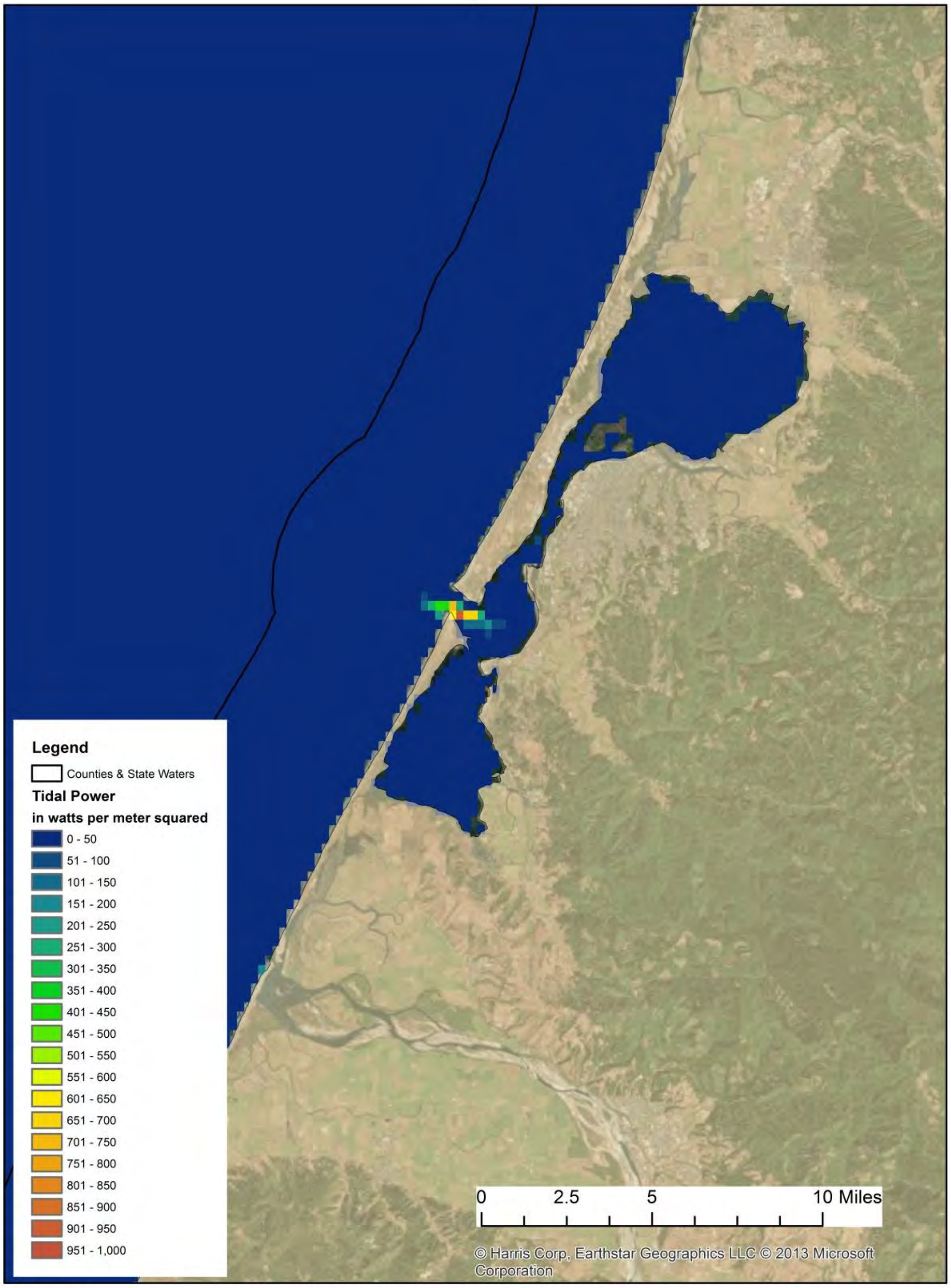
[iii] Offshore wind resources were assessed at 90 m above the surface and out to 50 nautical miles (nm) from shore.

Figure 3.1.4: Annual Wave Power Density in California



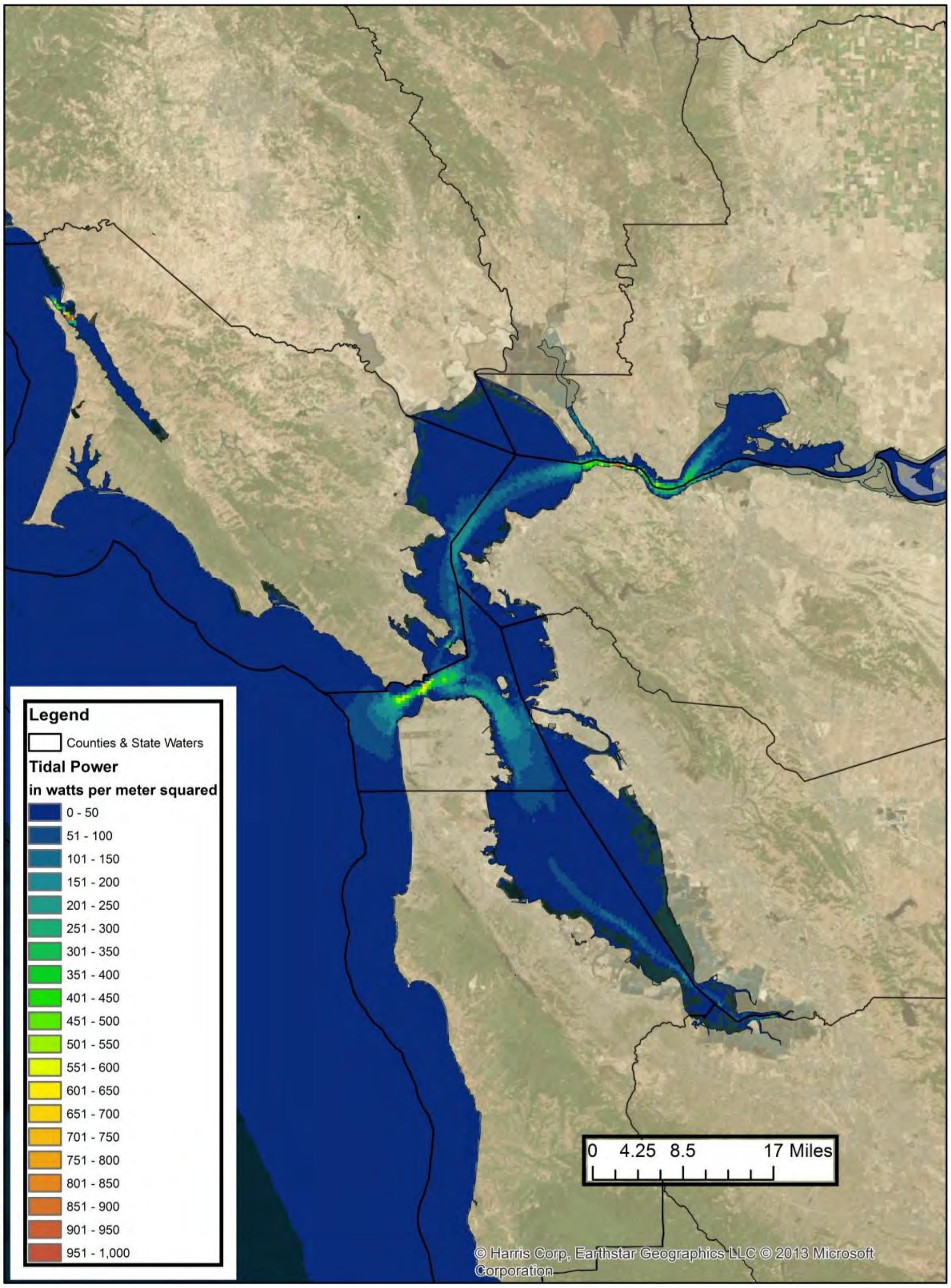
Data Sources: US Department of Energy (Wave Energy Data)
California State Lands Commission (County and State Waters Data)
Bing (Satellite imagery)

Figure 3.1.5: Humboldt Bay Tidal Power



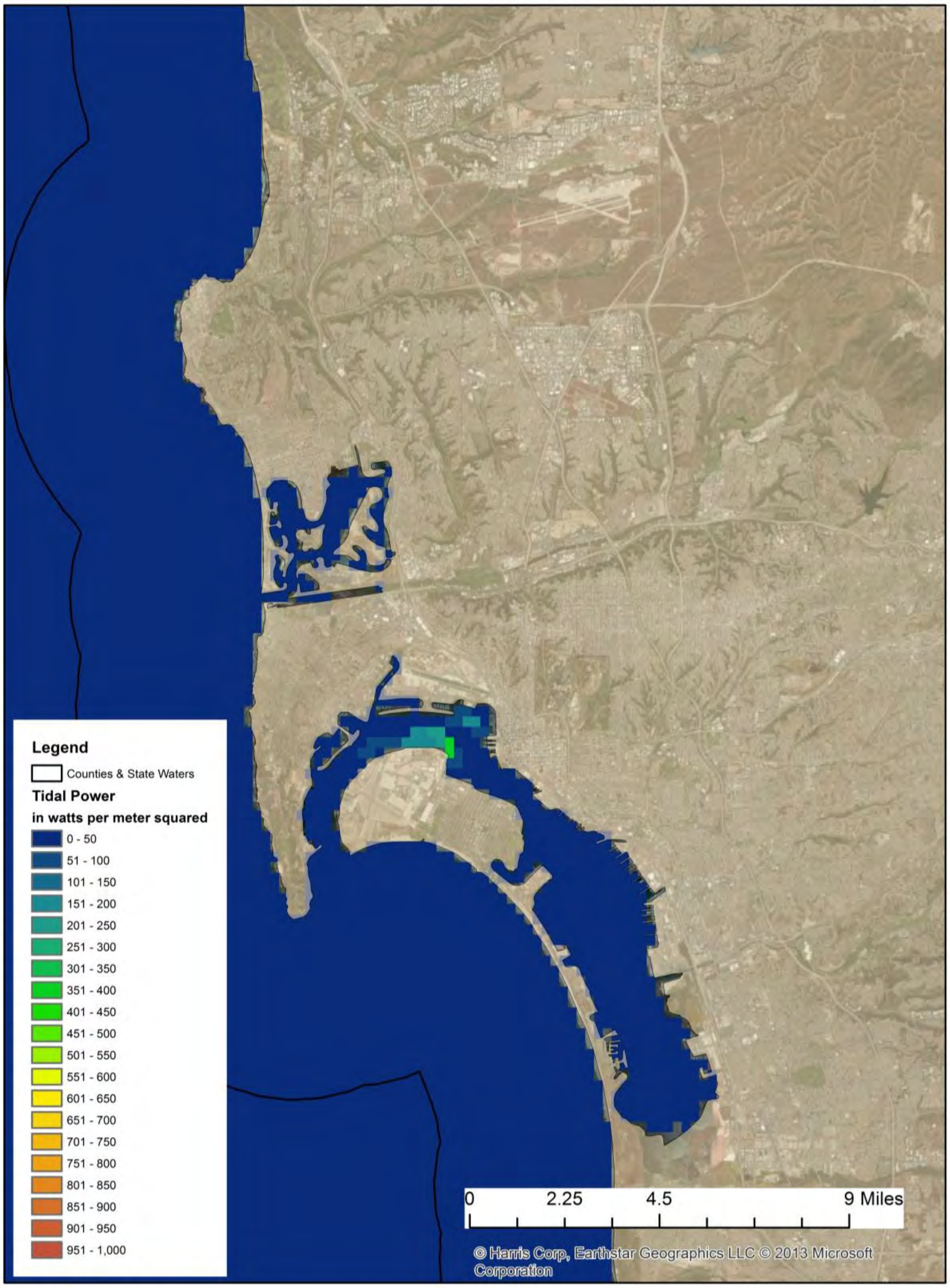
Data Sources:
Oak Ridge National Labratory and Georgia Institute of Technology (Tidal Energy Data)
California State Lands Commission (California Counties & State Waters)
Bing (Satellite Image)

Figure 3.1.6: San Francisco Bay Tidal Power



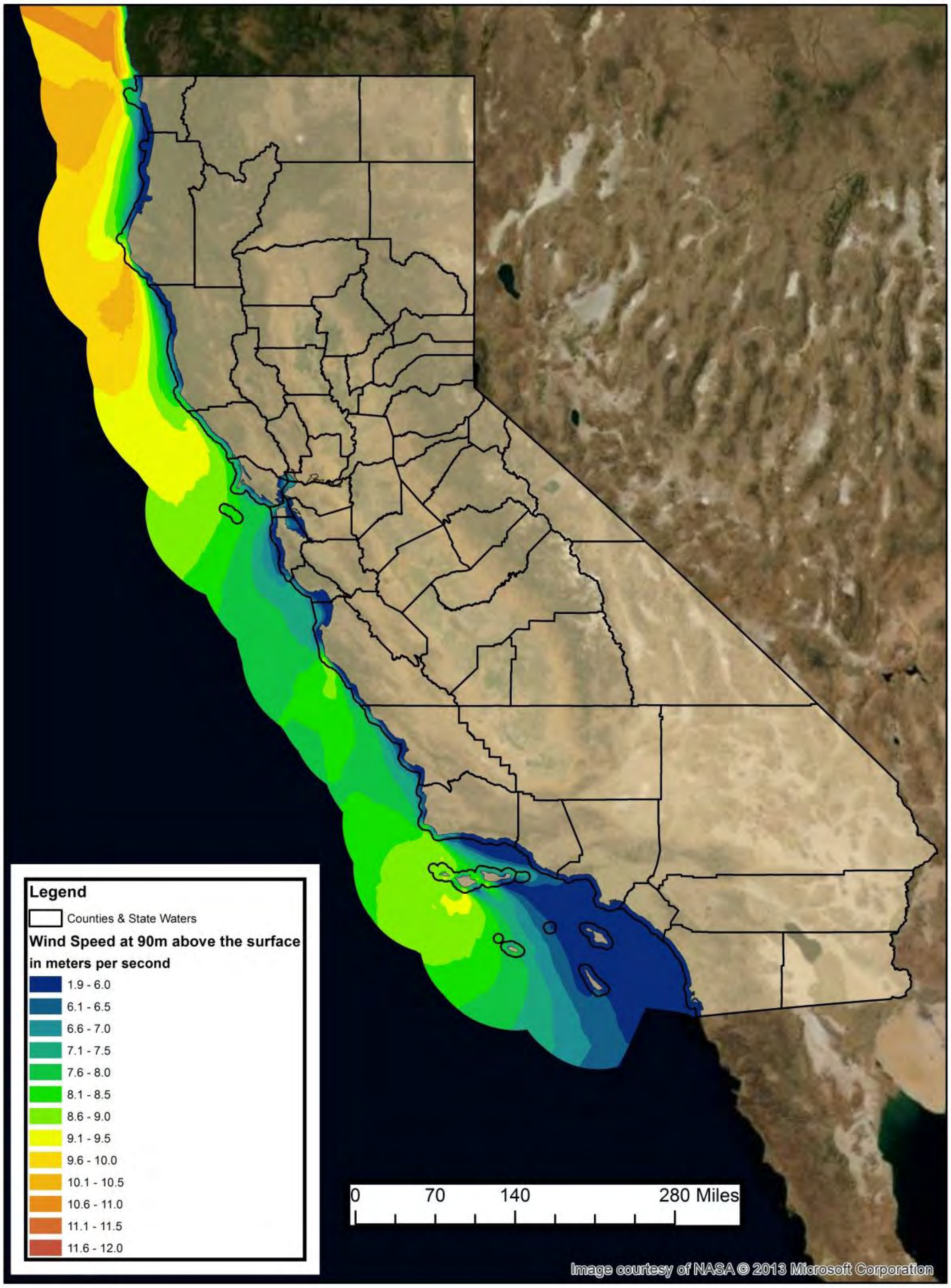
Data Sources:
Oak Ridge National Labratory and Georgia Institute of Technology (Tidal Energy Data)
California State Lands Commission (California Counties & State Waters)
Bing (Satellite Image)

Figure 3.1.7: San Diego Bay Tidal Power



Data Sources:
Oak Ridge National Labratory and Georgia Institute of Technology (Tidal Energy Data)
California State Lands Commission (California Counties & State Waters)
Bing (Satellite Image)

Figure 3.1.8: California Offshore Wind Speed at 90 Meters



Data Sources:
Bing (Satellite Image)
California State Lands Commission (Counties & State Waters)
National Renewable Energy Labratory (Offshore Wind Data)

4 Types of MRE Technologies

Marine Renewable Energy (MRE) technologies include both marine hydrokinetic (MHK) technologies and offshore wind turbines. MHK devices, which include wave energy converters and tidal energy converters, use the motion of water to generate energy. The U.S. Department of Energy (DOE) has separate programs for offshore wind and MHK technologies. An extensive list of MHK technologies in varying stages of development may be found on the DOE's Water Power Program Site,[iv] and information on offshore wind technologies may be found on the DOE's Wind Program Site.[v]

In addition to an explanation of the types of MRE technologies and how they generate energy, this section provides examples of current commercial devices to provide an idea of what MHK devices and offshore wind turbines look like in reality, rather than in a theoretical diagram, and shows how these devices can vary in design and appearance. The MRE devices selected for the "current commercial devices" sub-sections below were those technologies furthest along in the development and field testing process at the time of publication.

4.1 Wave Energy Converters

Wave Energy Converters (WECs) can be broken into five categories:

- Oscillating water columns (OWCs);
- Attenuators;
- Overtopping devices;
- Point absorbers; and
- Oscillating wave surge converters (OWSCs).

WECs can be designed to operate either far offshore or in nearshore areas. In comparison to offshore wind or tidal turbines, WECs are a less developed technology, and there is more uncertainty regarding their energy conversion efficiency, as well as their environmental impacts. A more detailed description of each type of WEC is provided below.

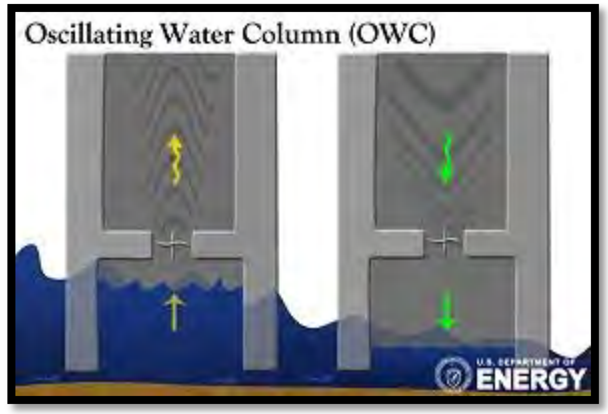
[iv] "Water Power Program: Marine and Hydrokinetic Technology Listings." *US Department of Energy*. US Department of Energy, 2012. Web. 15 Feb 2012. <http://www1.eere.energy.gov/water/hydrokinetic/listings.aspx?type=Tech>.

[v] "Wind Power Program." *US Department of Energy.* US Department of Energy 2013. Web. 2 May 2013. < http://www1.eere.energy.gov/wind/index.html>.

4.1.1 Oscillating Water Columns (OWCs)

Oscillating water columns (OWCs) are partially submerged structures that enclose a column of air above the surface of the water. Waves are funneled into the structure below the waterline, causing the water column to rise and fall. As the water column rises and falls, it acts as a piston, pressurizing and depressurizing the air column to spin a turbine. OWCs may be shore-based, nearshore, or float in deeper water[10].

Figure 4.1.1. Oscillating Water Column Diagram



Graphic Credit: US Department of Energy[10]

4.1.1.1 *Current Commercial Devices*

Figure 4.1.2. BlueWAVE by Oceanlinx

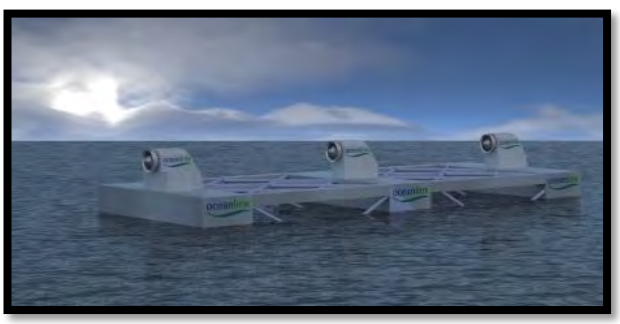


Photo Credit: Oceanlinx

- Company based in Australia
- An anchored floating design for deep-water (40-80 meters (m))
- Multiple OWCs clustered to a space-frame, reducing required electrical infrastructure
- Maximum power generation of 2.5 megawatts (MW) for the full scale design comprised of 6 OWCs
- Units deployed at test sites in Australia, with anticipated grid connection in 2013[11]

Figure 4.1.3. The LIMPET OWC by Voith Hydro Wavegen

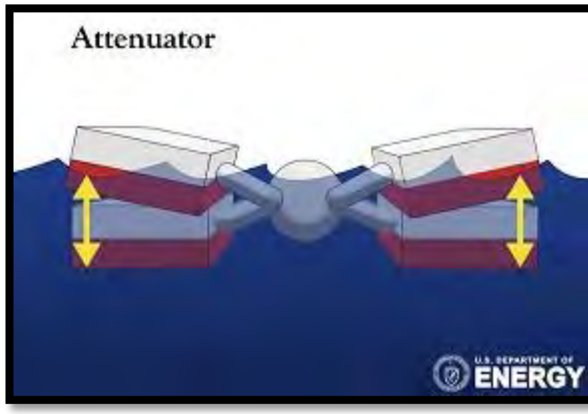
Photo Credit: Voith Hydro Wavegen

- Company based in Scotland
- Shore-based design
- Easy maintenance and transmission
- Maximum power generation at 500 kilowatts (kW) per unit
- Unit currently operating in Islay, Scotland[12]

4.1.2 Attenuators

Attenuators are typically moored to the seafloor at one end, and oriented with their principal axis parallel to the direction of the incoming waves, which cause articulated components of the attenuator to bend and drive generators.[10] The size of the devices can be substantial: for example, the Pelamis attenuator is 390-feet long, 11-feet wide, with about 7 feet above the surface of the water. [13]

Figure 4.1.4. Attenuator Diagram



Graphic Credit: US Department of Energy[10]

4.1.2.1 *Current Commercial Devices*

Figure 4.1.5. Wave Attenuator by Wavestar

Photo Credit: Wavestar A/S

- Company based in Denmark
- Uses a series of buoyant floats on lever arms that create energy as they rise and fall with the motion of the waves[14]
- Maximum power of 600 kilowatts (kW) generated by a unit deployed in Hanstholm, Denmark
- A 1:2 scale attenuator has been deployed in Hanstholm and has been connected to the grid since 2010[15]

Figure 4.1.6. Attenuator by Pelamis Wave Power

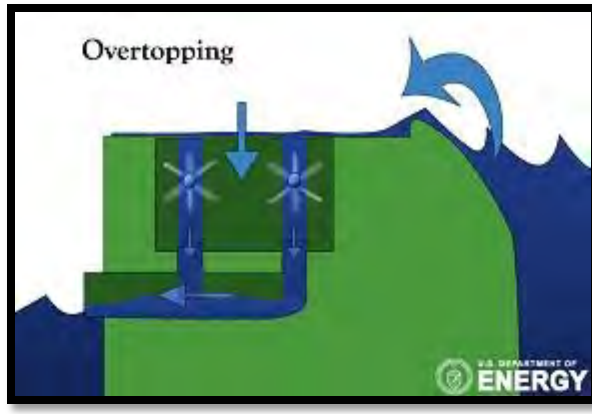
Photo Credit: Pelamis Wave Power

- Company based in Scotland
- Made up of five tubes linked by universal joints which allows flexing in two directions
- As waves pass down the machine, sections bend in the water and the movement is converted to electricity by hydraulic take-off systems[13]
- Maximum power generation of 750 kW per unit[16]
- Currently deployed in Portugal, Scotland, and the United Kingdom

4.1.3 Overtopping Devices

Overtopping devices consist of partially submerged structures with a design that funnels waves over the top of the structure into a reservoir; the water then runs back out to sea from the reservoir through a turbine.[10] Shore-based and floating models have been created for overtopping devices.[10]

Figure 4.1.7. Overtopping Device Diagram



Graphic Credit: US Department of Energy[10]

4.1.3.1 *Current Commercial Devices*

Figure 4.1.8. Overtopping Device by Wave Dragon

Photo Credit: Wave Dragon

- Company based in Denmark
- Allows ocean waves to overtop a ramp which deposits water into a reservoir above sea level and released through a number of turbines[17]
- Device is moored to the seafloor with gravity anchor blocks[17]
- Maximum power generation up to 11 megawatts (MW) per unit
- Device currently deployed and connected to the grid in Denmark

Figure 4.1.9. Sea-Wave Slot Cone Generator by Wave Energy AS

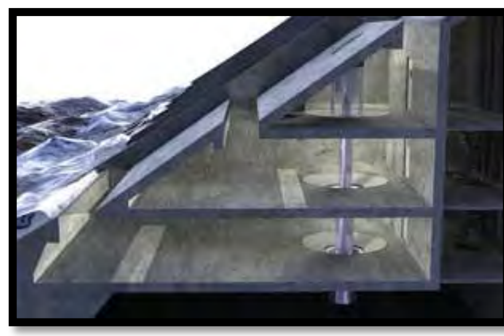


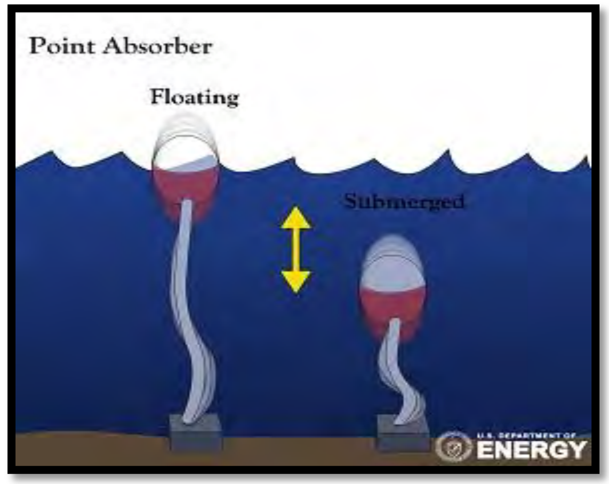
Photo Credit: Wave Energy AS

- Company based in Norway
- Shore-based design, utilizes three reservoirs stacked on top of one another[18]
- Water enters the reservoir as waves break over the slots, and flows through the turbine, creating electricity[18]
- Meant to be integrated with breakwater structures[18]
- Maximum power generation up to 200 kW
- A test project of this technology is underway in Norway[18]

4.1.4 Point Absorbers

Point absorbers are able to capture wave energy from all directions, and their size is small in comparison to the wavelength of a wave, which is the distance between the crests of two subsequent waves.[10] Point absorbers often look like large buoys, and can float on the surface of the ocean, or they can be completely submerged. When on the surface, these floating devices use the float's movement over the top of waves to create mechanical energy. When completely submerged, these devices, also known as submerged pressure differentials, move by inducing a pressure differential inside the device, which drives a fluid pump to create mechanical energy.[10]

Figure 4.1.10. Point Absorber Diagram



Graphic Credit: US Department of Energy[10]

4.1.4.1 *Current Commercial Devices*

Figure 4.1.11. Power Buoy by Ocean Power Technology (OPT)

Photo Credit: Ocean Power Technology Inc.

- Company based in the United States
- A portion of the PowerBuoy floats on the surface of the water[19]
- As the buoy moves with the waves, it creates mechanical motions within the device that are converted to electricity by a power take-off system and transported to shore via underwater power cables[19]
- The PowerBuoy 150 is approximately 115-feet long and 46-feet wide, and generates 150 kilowatts (kW) per device[19]
- Units have been deployed in Hawaii, New Jersey, and Scotland, with current projects underway in Oregon, New Jersey, Spain, and Australia[20]

Figure 4.1.12. CETO by Carnegie Wave Energy

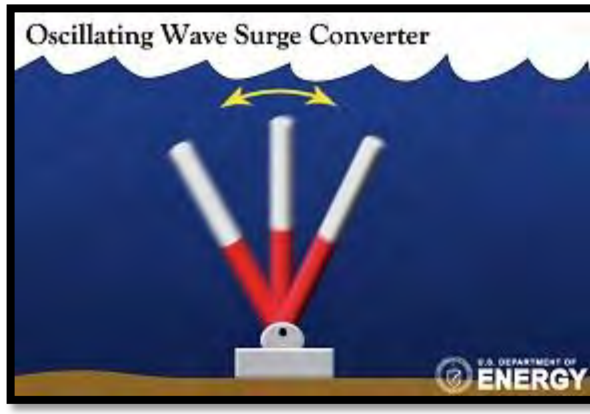
Photo Credit: Carnegie Wave Energy

- Company based in Australia
- CETO uses a submerged pressure differential to pump high pressure water to shore through a pipe system[21]
- The water is then run through a traditional hydroelectric turbine onshore, and then cycled back to the CETO device to be pumped again[21]
- Maximum power generation up to 240 kW per unit for the CETO 5 design (pictured above)[22]
- CETO prototypes have been deployed in Australia, with anticipated deployments in Bermuda, Canada, Ireland, and France[23]

4.1.5 Oscillating Wave Surge Converter (OWSC)

Oscillating Wave Surge Converter (OWSC) technology captures mechanical energy by using the relative motion between a float, flap or membrane, and a fixed reaction point. The float, flap or membrane oscillates along a given axis and mechanical energy is extracted from the motion of the oscillating part relative to its fixed reference.[10]

Figure 4.1.13. OWSC Diagram



Graphic Credit: US Department of Energy[10]

4.1.5.1 *Current Commercial Devices*

Figure 4.1.14. Oyster by Aquamarine Power

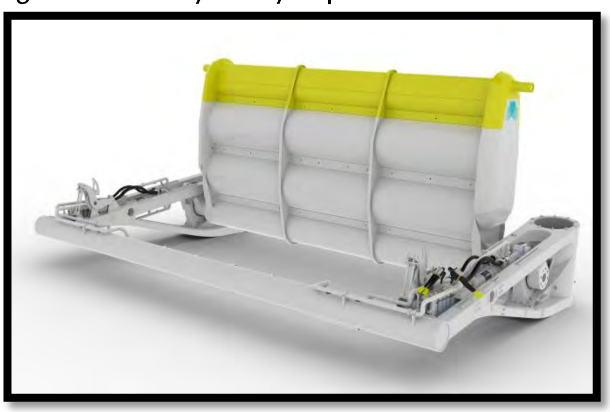


Photo Credit: Aquamarine Power

- Company based in Scotland
- The Oyster Device is a buoyant, hinged flap attached to the seabed in the nearshore area[24]
- Only the top (the yellow portion in the picture above) would be visible from the surface of the water[24]
- The movement of the flap drives two hydraulic pistons that push high pressure water onshore to drive a conventional hydroelectric turbine[24]
- Maximum power generation up to 800 kilowatts (kW) for the Oyster 800 unit[25]
- Units deployed at test sites in Scotland[26]

Figure 4.1.15. WaveRoller by AW Energy

Photo Credit: AW Energy

- Company based in Finland
- The WaveRoller is a fully submerged device that operates in nearshore areas and is anchored to the seafloor
- The back and forth movement of the wave surge moves the plate which produces kinetic energy collected by a piston pump, which is a closed hydraulic system[27]
- Maximum power generation between 500 kW and 1000 kW per unit[28]
- Units deployed at a test site in Portugal

4.2 Tidal Energy Converters

Tidal energy converters can be broken into three categories:

- Axial Flow Turbines;
- Cross Flow Turbines; and
- Reciprocating Devices.

Although research has been done to evaluate the environmental impacts of axial flow and cross flow turbines (referred to as tidal turbines), researchers have yet to differentiate between the impacts attributed to each.

Tidal Turbines

A review of the United States Department of Energy's hydrokinetic technology database reveals that tidal turbines are being pursued in a modular design that enables easy scaling to a variety of array sizes, including designs for river (often referred to as "in-stream"), tidal, and ocean current use. Cross flow turbines appear to be utilized more often for river-based power generation, but are sometimes used in tidal energy projects. On the other hand, axial flow turbines are used in river, tidal, and ocean current generation. Tidal and river generation appear to be the most thoroughly studied settings for axial flow and cross flow turbines. Although ocean current generation is theoretically possible, it has not been attempted, and there are no grid-connected technologies operating in the United States for ocean current energy generation.

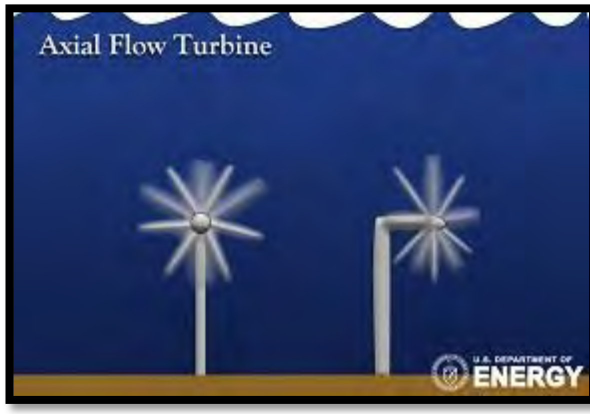
Tidal Reciprocating Devices

These devices appear very different from traditional tidal turbines because they use the lift, drag, or other forces created by tidal currents to generate energy. Some reciprocating devices are able to move and generate energy from weaker currents than traditional tidal turbines, and may allow for energy production in new areas. Reciprocating devices are very new, and since they generate energy differently than tidal turbines, they will be discussed separately.

4.2.1 Axial Flow Turbines

Axial flow turbines typically have two or three blades mounted on a horizontal shaft to form a rotor. The kinetic motion of the water current or tide creates lift on the blades, causing the rotor to turn, driving a mechanical generator; however, the turbine must be oriented in the direction of the flow. Axial flow turbines are available in shrouded and open rotor models.[10] Shrouded rotors have a structure that connects the tips of the rotor blades on the turbine; Figure 5.3.7, on page 5-35 of this report, shows a shrouded rotor of OpenHydro's axial turbine shows a shrouded rotor. The diagram of an axial flow turbine to the right shows and open rotor axial turbine.

Figure 4.2.1. Axial Flow Turbine Diagram



Graphic Credit: US Department of Energy[10]

4.2.1.1 *Current Commercial Devices*

Figure 4.2.2. SeaGen S by Marine Current Turbines

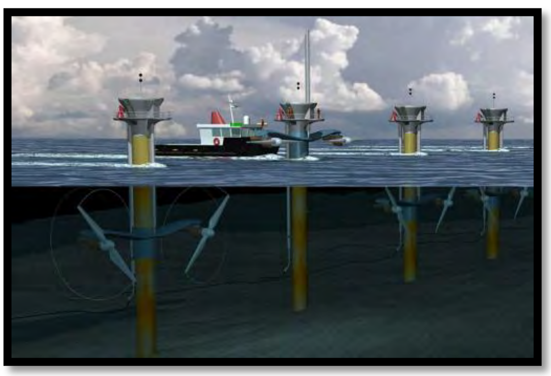


Photo Credit: Marine Current Turbines

- Company based in the United Kingdom
- Sea Gen S consists of two axial flow turbines mounted on a crossbeam which is attached to a monopole structure, allowing the crossbeam to be winched and raised above the water line[29]
- Maximum power generation of 2 Megawatts (MW) per unit for the SeaGen S Mk2[29]
- Units deployed for testing in Ireland[29]

Figure 4.2.3. Kinetic Hydropower System by Verdant Power

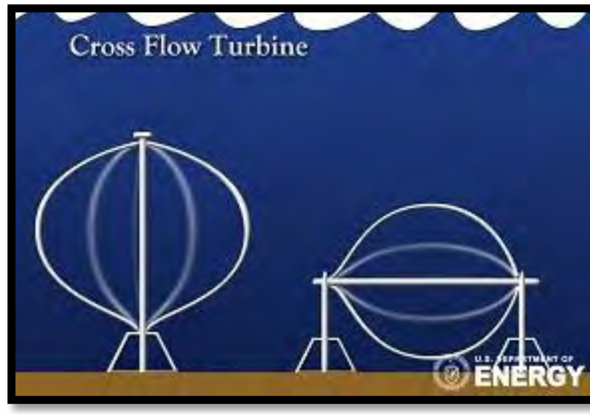
Photo Credit: Verdant Power

- Company based in the United States
- Verdant's Kinetic Hydropower System consists of modular axial flow turbines that can be arranged in a variety of arrays, making the technology scale-able[30]
- Power generation per unit is dependent on the diameter of the rotor (determined by water depth) and the size of the generator (determined by the diameter of the rotor and the water current)
- Currently has a tidal energy project in the East River of New York City[30]

4.2.2 Cross Flow Turbines

Cross flow turbines typically have two or three blades that are mounted on a shaft to form a rotor. The kinetic motion of the current creates lift on the blades causing the rotor to turn, driving a mechanical generator. These turbines can operate with flow from multiple directions without needing to change their orientation. This technology is available in both shrouded and open models.[10]

Figure 4.2.4. Cross Flow Turbine Diagram



Graphic Credit: US Department of Energy[10]

4.2.2.1 *Current Commercial Devices*

Figure 4.2.5. Power Generation System by New Energy Corporation

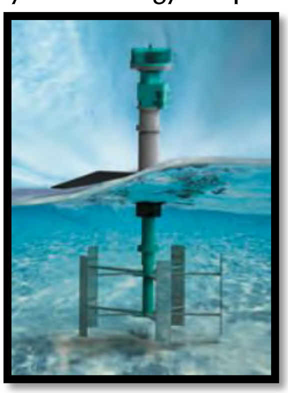


Photo Credit: New Energy Corporation

- Company based in Canada
- Available in 5, 10, and 25 kilowatt (kW) models; 125 and 250 kW systems are in development[31]
- Although referred to as a tidal turbine, most testing has been done in rivers and canals
- 5 and 25 kW models installed in various parts of Canada and Alaska

Figure 4.2.6. TidGen Power System by Ocean Renewable Power Company

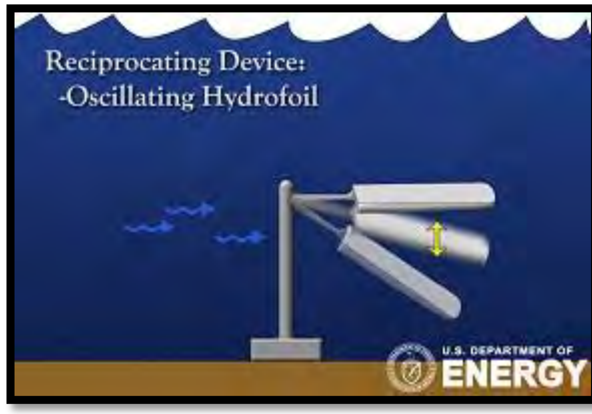
Photo Credit: Ocean Renewable Power Company

- Company based in the United States
- There are a number of different devices using this turbine technology
- At a scale appropriate for shallow tidal sites[32]
- Designed to be sited in water depths of 50 to 100 feet, and may be used at tidal or deep river sites[32]
- Maximum power generation up to 180 kW per unit[32]
- Units installed and connected to the grid in Maine[33]

4.2.3 Reciprocating Devices

Reciprocating devices use the flow of water to produce lift or drag of an oscillating part of the device transverse to the flow direction. This response from the machine can be induced by a vortex, or the Magnus effect[vi]. The graphic to the right shows an oscillating hydrofoil device, one type of reciprocating device. Oscillating hydrofoil devices are similar to an airplane wing; yaw control systems adjust their angle relative to the water stream, creating lift and drag forces. The lift and drag causes device oscillation, and mechanical energy from the oscillation feeds into a power conversion system.[10]

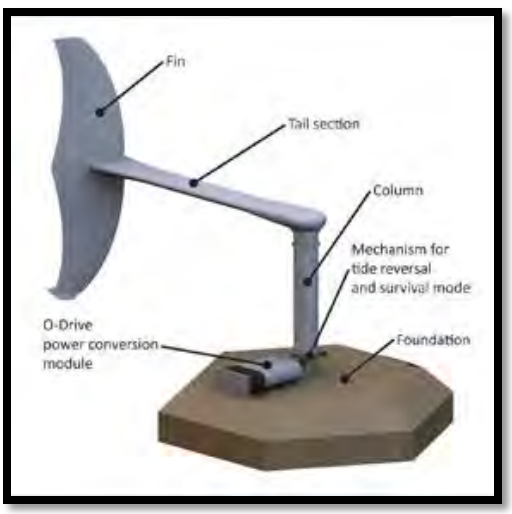
Figure 4.2.7. Reciprocating Device Diagram



Graphic Credit: US Department of Energy[10]

4.2.3.1 *Current Commercial Devices*

Figure 4.2.8. BioStream by BioPower Systems



Graphic Credit: BioPower System

- Company based in Australia
- An oscillating hydrofoil system[34]
- Designed for current speeds of 1 m/s or greater[34]
- Oncoming currents cause the fin to move in a side-to-side swimming motion used to create electricity[34]
- A 250 kW demonstration project is currently in development[34]

Figure 4.2.9. VIVACE Converter by Vortex Hydro Technology

Photo Credit: Vortex Hydro Technology

- Company based in the United States
- Uses the power of vortex induced vibration from water currents to induce the oscillation of a cylinder that is converted to electricity[35,36]
- Can produce energy in currents that are weaker than those presently considered for other tidal energy technologies[35]
- Power generation depends on the flow speed and size of the device

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[vi] A vortex is a region in seawater where the flow is mostly moves in a spinning motion about an imaginary axis. This spinning motion can be used to move reciprocating devices and generate energy. The Magnus effect is when an object spinning in a fluid creates a whirlpool of fluid around itself and experiences force perpendicular to its line of motion. This effect could be used to make a reciprocating device move and generate energy.

4.3 Offshore Wind Turbines

Offshore wind turbines emerged as a technology from land-based wind turbines, and are a more mature technology than tidal or wave energy devices. Offshore wind devices are similar to onshore turbines in terms of their visible components; the major difference between offshore and onshore turbines is in their foundation. The foundations of offshore wind turbines are undergoing innovation, especially in the development of floating foundations. Floating foundations allow siting of offshore wind turbines in deep-water. A diagram of floating offshore wind foundation designs is shown in figure 4.3.3. Some floating foundations, such as the foundation shown in figure 4.3.2, have been built and deployed. Offshore wind turbines are also becoming larger than land-based turbines because there are fewer constraints on equipment transportation, a limit to the size of land-based turbines.[39] The average rotor diameter of a land-based turbine is 114 m; in comparison, the largest offshore wind turbine example below has a rotor diameter of 164 m.[37,38] In 2010, most land-based turbines generated between 1.5-3 MW, while offshore wind turbines generated between 3 -5 MW.[38] Blade tip speeds of offshore machines are also generally higher (80 meters per second [m/s] or greater) because of lower aerodynamic noise concerns in the near-field environment.[39] Finally, economics favor minimizing the height of turbine towers offshore.[40]

4.3.1 Current Commercial Devices

Figure 4.3.1. Turbina Sapiens (SWT-6.0-154) by Siemens

Photo Credit: Siemens

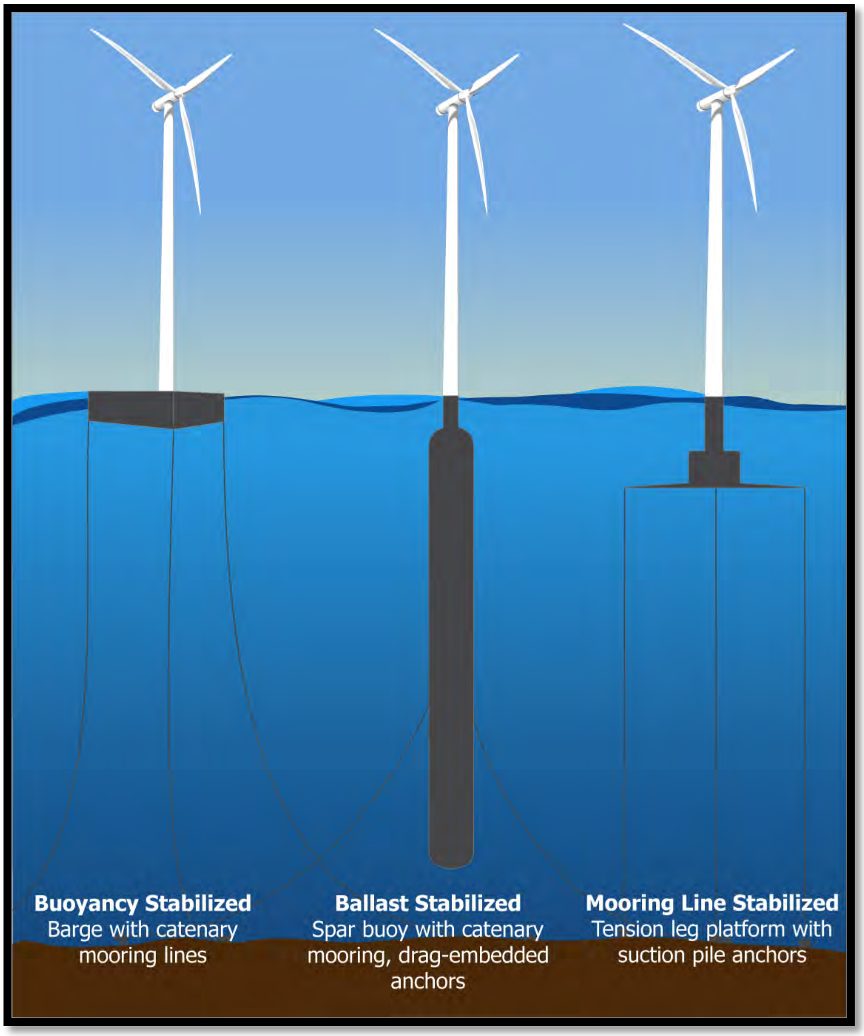
- Company based in Germany
- Built to be an offshore wind turbine (although the photo above is from a land-based installation)[41]
- Produces 6.0 megawatts (MW) of power at full capacity[41]
- Rotor diameters are available in 120 m and 154 m lengths[41]

Figure 4.3.2. V80-2 MW Gridstreamer Turbine by Vestas with WindFloat Foundation Technology by Principle Power

Photo Credit: Vestas Wind Systems

- Vestas is based in Denmark,[42] Principle Power is based in the United States[43]
- The WindFloat foundation can accommodate offshore wind turbines from 3 MW to 10 MW[44]
- Figure 4.3.2 shows a 2 MW with a rotor diameter of 80 m.[45]
- Vestas produces a larger offshore wind turbine, which generates up to 8 MW of power, with a rotor diameter of 164 m.[46]

Figure 4.3.3. Three Floating Wind Turbine Foundation Designs



Graphic Credit: Advanced Structures and Composite Center, University of Maine

5 Environmental Impacts of Marine Renewable Energy

Marine Renewable Energy (MRE) is a new and growing industry; currently, there are a broad range of technologies and designs being tested for their energy production feasibility and success. Since a broad range of designs exists, determining the environmental impacts of every MRE technology is not feasible for this report. Similarly, the broad scope of this report makes meaningfully assessing cumulative impact infeasible. Despite the broad range of impacts and project-specific considerations, though, some general patterns are evident; many devices affect the environment in similar ways and will produce similar impacts. These effects are outlined in this section. In addition, if a type of technology creates specific effects in the environment, a short description of specific effects and potential impacts for that technology is included.

5.1 Aesthetics

General Impacts

MRE devices, whether shore-based, nearshore or offshore, may have a significant effect on a scenic vista. Most MRE devices currently in development and testing have an above-water component. The impact may be mitigated to a less than significant level depending on the device used and the viewshed. Some specific device models, such as the Limpet OWC (shown in Figure 4.1.3), are noted for appearing less noticeable on the landscape.[47] In addition to considering the aesthetic impacts of a project from shore, aesthetic impacts should also be considered from the viewpoint of ocean users on cruise boats, whale watching vessels, and recreational vessels, for example. Offshore aesthetic impacts will be project specific, depending on the type of MRE device and the number of devices employed in the project area. Shipping lanes or other known vessel travel routes could be used as "receptor points" to determine aesthetic impacts to boaters, fishermen, and other ocean users.

Technology-Specific Impacts

5.1.1 Offshore Wind Turbines

Wind turbines have a large above-water profile in comparison to other types of MRE technologies. The large above-water profile of offshore wind turbines may lead to significant aesthetic impacts. Many residents on the California coast may express concerns that offshore wind turbines do not fit the aesthetic character of their community.

Cape Wind, a wind farm planned for construction in Massachusetts, produced the images shown in Figure 5.1.1, which demonstrate how visible their proposed wind farm would be from shore at various beaches in the area. Other MRE corporations have produced similar simulated photos for their projects. Photos such as these will be an essential tool when assessing the aesthetic impacts of offshore wind projects and performing stakeholder outreach.

Figure 5.1.1. Two Simulated Views of the Cape Wind Project in Massachusetts

Photo Credit: Cape Wind Project
Simulated view from Cotuit (5.6 miles away) [48]

Photo Credit: Cape Wind Project
Simulated view from Craigville (6.5 miles away)[48]

5.2 Agriculture and Forestry (Aquaculture and Commercial Fisheries)

A MRE project may impact aquaculture resources by reducing the kinetic energy available to areas with aquaculture operations. Since aquaculture involves growing marine species, some of the impacts described in the biological resources section may be applicable to aquaculture species as well.

A MRE project may impact commercial fisheries through siting and space-use conflicts. Siting MRE projects may remove productive areas from the fishing grounds, and may also increase fuel costs for fishermen if they have to travel around a device array to reach the fishing grounds.

In this section, impacts to aquaculture by reducing wave and tidal energy are discussed first, followed by a discussion of siting impacts on commercial fisheries.

5.3 Aquaculture

General Impacts

5.3.1 Reduction in Wave Energy

Changes caused by lower wave energy on water circulation, food availability, and pollutant concentrations in nearshore waters may all impact existing aquaculture operations on the California coast. Aquaculture species need a specific set of environmental conditions for their survival and quality as a commercial product. Negative changes, such as increased pollutant concentrations, near aquaculture operations may decrease the commercial value, food safety, or viability of the product. Pilot or demonstration projects are unlikely to reduce wave energy to the point that it would impact aquaculture; therefore, this impact is limited to commercial-scale projects.

5.3.2 Reduction in Tidal Energy

A reduction in tidal energy on the lee side of a tidal turbine may impact nearby aquaculture. Many areas that have viable tidal energy resources are located at confined entrances to large estuaries, such as the Golden Gate. Since viable locations for tidal energy resources are located near estuaries, most of the research on tidal energy reduction and subsequent impacts has focused on estuaries. Reducing tidal energy may change sediment deposition, depth of light penetration, and pollutant concentrations, which may impact aquaculture operations in the areas that are suitable for tidal energy production. Aquaculture species have biological requirements for environments where they can thrive, and changing tidal energy will alter the environmental conditions species experience at aquaculture operations, potentially impacting aquaculture production. Similar to a reduction in wave energy, pilot or demonstration tidal energy projects are unlikely to reduce tidal energy to the point that it would impact aquaculture operations; therefore, this impact is limited to commercial-scale projects.

Figure 5.2.1. Mussels Growing on Oyster Longlines in Humboldt Bay

Photo Credit: Confluence Environmental Company

5.4 Commercial Fishing

General Impacts

5.4.1 Siting Impacts

A socioeconomic study performed by Conoway *et al*. (2012) determined conflicting spatial uses on the outer continental shelf of the West Coast, and how those conflicts relate to MRE development. In California, the study focused on the north coast. On the north coast, commercial fishermen follow the fish from year to year, so the area fished is variable.[49] In addition, fishermen also require more space than the actual footprint of their gear to fish effectively, including additional space for deploying and bringing in gear, as well as maneuvering. Commercial fishermen state that the compatibility of offshore MRE with their activities is contingent upon the actual layout and footprint of the project relative to their activities, as siting MRE devices at a high density may prevent their ability to fish in certain areas. The issues associated with device density are very device-specific and project specific; there may be proposed projects where the fishing community favors a high density project with a smaller overall footprint, and vice versa. The footprint of an MRE project is often larger than the project itself due to associated infrastructure and the safety concerns of fishermen. Across user groups, most participants in the study felt that MRE projects would conflict most with commercial crabbing, and to some extent, with trawling.[49] The main point of conflict between crabbing and MRE projects is that crab gear could catch on mooring lines associated with a MRE project, or the device itself. An additional area of concern is over access to space; from a spatial standpoint the crab fishery is open-access[vii], and siting an MRE project may remove valuable crab grounds from the fishery. Overall, surface fishing operations such as salmon (*Oncorhynchus* spp) and albacore (*Thunnus alalunga*) fisheries will likely have fewer conflicts with MRE projects than bottom fishing operations because their vessels and gear tend to be more maneuverable. In addition, commercial fishermen also expressed a preference for a stationary MRE device that would be easier to see and navigate around, rather than a moored device.[49]

Future Research Needs

- Research on how wave farms may alter the structure of the water column, including variations in temperature and salinity.
- Research on how reducing wave energy or tidal energy may alter water circulation and water quality.
- Research on how well current wave energy or tidal energy reduction models predict the actual wave energy or tidal energy reduction of a project.
- Spatial information on commercial fishing activities currently taking place within State waters.
- Research on how existing MRE projects work to manage conflicts with commercial fishermen.

[vii] With the exception of Marine Protected Areas (MPAs), please see the Land Use/Planning Section for more details

5.5 Biological Resources

MRE projects may impact biological resources in a number of ways including:

- Reduction in wave and tidal energy;
- Addition of hard structures and mooring lines;
- Release of hazardous materials;
- Addition of electromagnetic fields (EMF); and
- Addition of acoustics in the project area

These impacts to biological resources are broadly discussed across MRE devices below, including technology specific impacts when appropriate.

General Impacts

5.5.1 Reduction in Wave Energy

5.5.1.1 *Habitat Disturbance and Species Responses*

Wave power strongly determines where marine species can live, and changing the wave power along a shoreline will impact species distribution. Marine species may respond in an exponential way to linear changes in wave power. For example, kelp along the Central California coast has been observed to show nonlinear increases and decreases in abundance based on the wave energy in the area.[50] In addition, reducing wave energy may change ecological community composition. As a result, species that are less robust may be able to live in areas that were previously too exposed for them. Reduction in wave power may also allow for the accumulation of fine sediments offshore in areas that previously contained coarser material, potentially altering habitat for benthic species and attracting species associated with a finer grain size.

In rocky intertidal and subtidal areas, a reduction in wave energy may influence vertical zonation patterns, as well as species distribution and abundance, along the shore. Intertidal areas exposed to greater wave power have higher zone elevations and larger zone widths than areas that experience less wave power.[50] Reducing wave energy may reduce the amount of wave-induced disturbance the nearshore environment experiences from the movement of large objects, such as driftwood and rocks. However, very few scientific studies have been done to determine how wave-induced disturbance varies across areas with different wave energy exposures.

Figure 5.3.1: Intertidal Zones on a Rocky Shoreline

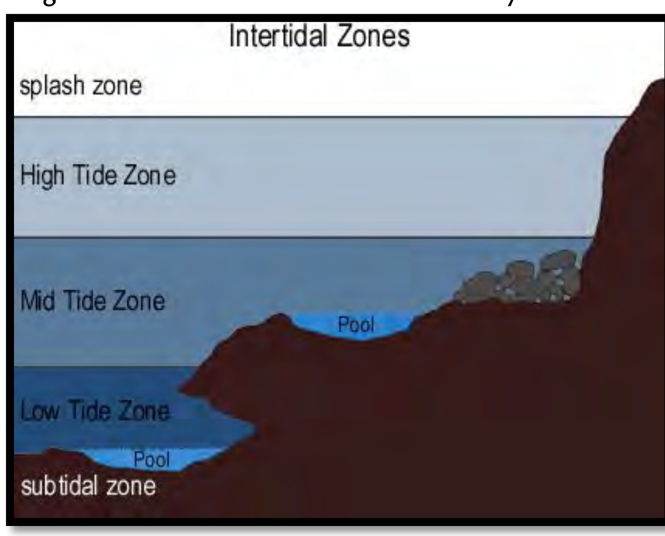


Photo Credit: beachapedia.org

At some rocky shore sites, sand is an important agent of disturbance. Sand can act as an abrasive that scours organisms with each passing wave, or can settle out of the water column and bury organisms on the surface of the rocks. Various rocky intertidal species have differing abilities to tolerate these processes, and the distribution of species both within and among sites can be influenced by sand. A reduction in wave power at a site may allow larger amounts of fine sediments to settle out of the water column, potentially exposing intertidal species to greater impacts from sand. Since a reduction in wave energy can also increase sand deposition on beaches, it can affect the shape of beaches and the structure of the natural community there. These changes could be important for some beach spawning fish, such as California grunion.[50]

5.5.1.2 *Wave Power, Food, Reproduction, and Settlement*

Waves cause water turbulence within the surf zone, which delivers nutrients and food, and removes waste substances from organisms. Generally, the delivery of food and nutrients in the water column increases with wave power, although oceanographic currents play a large role in the amount of food and nutrients available. The more food and nutrients organisms receive in the intertidal zone, the faster they grow. For many of these species, reproductive ability depends on body size, so a reduction in wave power may lower species reproduction. Reduced wave power may also affect a species' ability to spread to new areas by decreasing larval dispersal along the shore, and reducing undertow and rip currents, which are important for delivering larvae further offshore during the early stages of development.[50]

Wave Energy Converters (WECs) may affect the onshore settlement of intertidal species through larval transport and fish attraction. When larvae reach the shore, they need to encounter appropriate places to settle, and remain there long enough to metamorphize into juveniles. The higher the rate of water movement, the more larvae that come into contact with appropriate settling sites. Reducing wave energy may impact "recruitment limited" populations, or populations that depend on recruits, such as larvae, from outside of the population to occupy all of the habitat available. There is some evidence to suggest that some intertidal populations, such as mussels (*Mytilus californicus*) and algae along the California coast, are recruitment limited.[51] Cumulative impacts may occur if reduced wave energy were to coincide with other changes, such as increased coastal development, in the surrounding environment. For example, the larvae of many intertidal species on WECs may attract kelp-dwelling plaktivorous fish species to the area, potentially leading to increased predation and reducing the number of larvae reaching shore.[50]

5.5.2 Reduction in Tidal Energy

Placing tidal turbines in a channel may impact biological resources, primarily by changing the movement and deposition of sediment. Decreased tidal flow will lead to decreased suspended sediment and turbidity in some areas, increasing the depth of light penetration in the water column and the depth at which phytoplankton can grow.[52] Additional changes in sediment-associated nutrients may provide additional food for phytoplankton blooms. Reduced flushing may increase eutrophication and lead to hypoxia in a tidal channel or bay. If these conditions persist over time, species that can survive in hypoxic conditions may be favored, and eliminate those species that cannot.

5.5.3 Hard Structures and Mooring Lines

Mooring lines, anchors, seafloor foundations, and exposed hard surfaces are all used to secure and maintain MRE technologies. The presence of these structures in the marine environment may have a variety of environmental impacts during their construction, operation and decommissioning. Once constructed, these structures add hard exposed surfaces and hard substrate to the marine environment, as well as vertical structure in the water column that may act as an artificial reef with the potential to attract fish and other marine species. In addition, these structures may increase the risk of collision and entanglement for marine species, while providing roosting and haul-out sites for seabirds and pinnipeds.

5.5.3.1 *Fish Attractant*

Mooring lines, seabed foundations, anchors and even floating MHK technologies may act as fish attracting devices (FADs). Research has shown that fish are attracted to floating objects in otherwise unstructured pelagic habitats.[53] Fish are visually attracted to structures floating on the surface or in in the water column, coupled with additional olfactory and acoustic cues.[53] The spatial and physical complexity of a structure at both small and large scales also influences whether fish or other marine species are attracted to the structures. At a small scale, smooth surfaces are harder for invertebrates to colonize, which may initially reduce the number of fouling organisms present until the surface complexity is increased by the organisms themselves.[53] At a large scale, smooth, less complex structures are less attractive to fish; for example, wind turbine monopiles are not as attractive to fish as oil rigs with latticework.[53]

Different fish species may benefit from structures in the water column over their various life history stages. Some benefits include:

- Shelter from predators;
- Concentration of food supply;
- Spatial reference;
- Resting area after foraging;
- Meeting point for members of the same species;
- Shade;
- Point of reference for schooling behavior;
- Substitute environment;
- Cleaning station (meeting point for different fish species for parasite removal); and
- Substratum for egg deposition.[54]

However, fish that are attracted to such devices may experience recruitment failure. In the natural environment, fish would be attracted to drifting algae as it moves through the pelagic environment. Drifting algae in California attracts the larvae of kelp bass (*Paralabrax clathratus*), blacksmith (*Chromis punctipinnis*), and rockfish (*Sebastes* spp).[55] Drift algae are also used by invertebrates during early life history stages. Unlike drifting algae, MHK devices and the associated infrastructure do not float with ocean currents or winds. As a result, species attracted to an artificial structure may experience settling and recruitment failure because the structure does not travel through the environment in the same way as floating algae.[55]

5.5.3.2 *Artificial Reefs*

Man-made hard structures, such as seafloor foundations, placed in the marine environment may function as artificial reefs. Artificial reefs differ from FADs in that they provide habitat for reproduction, while FADs simply attract fish from other areas. The artificial reef effect may be especially pronounced in areas with soft-bottom habitat. MRE developers may prefer to locate their technologies on soft-bottom habitats for logistical reasons; soft-bottom habitats make fixing the device and burying the power cables running from the project to shore easier. However, placing foundations, monopiles, mooring lines, and anchors on soft-bottom habitat will convert the immediate area to a hard-bottom habitat. Although the actual space taken up by some foundations or anchors may be small, the species that prefer a hard substrate habitat may be attracted to these structures on soft-bottom habitat. As a result, the introduction of hard-substrate species into a soft-substrate habitat may give the project a larger footprint than the structure itself.[53]

In the academic community, there is debate about whether artificial reefs on soft bottom habitat have positive, negative, or negligible effects on fish populations. One argument is that the new habitat directly increases fish reproduction. A second argument is that artificial reefs attract fish from natural reefs, which creates space for greater reproductive success at natural reefs. A third argument is that, because artificial reefs concentrate prey fish species in one area, they allow for greater predation and population decline than at natural reefs.[53]

To determine whether a MRE project creates an artificial reef effect, and how this impacts marine species, the project should be monitored over multiple years. The community composition at a new underwater structure will change over time due to ecological succession, and long-term monitoring would capture these changes. Some artificial reef effects are fairly straightforward to predict, such as which species of fish are attracted to mooring lines, but how these direct changes impact higher trophic levels in the food web is more difficult to predict. Changes in ecological succession on artificial reefs may also be hard to determine when background signals, such as the

El Niño Southern Oscillation, have a significant impact on species abundance and distribution from year to year.[53] For example: MRE structures may create habitat for the benthic stage of jellyfish, which may increase pelagic-stage jellyfish populations. More jellyfish, in turn, may attract leatherback turtles to the project area, which could be impacted through entanglement or collision with project components. Long-term monitoring will determine the impacts of artificial reefs to high-trophic level marine species, such as leatherback sea turtles, in California State waters.

5.5.3.3 *Compaction and Displacement*

The construction/installation phase of a MRE project may alter benthic habitat due to the compression and compaction of sediment when placing hard structures and mooring lines on the seafloor. As a result, habitat loss and temporary displacement may occur for benthic species, including demersal fish and invertebrates, as well as infauna and non-mobile species. In addition, increased turbidity and sediment loading may occur as a result of the construction/installation phases, potentially affecting species that feed on the intertidal benthos. The sensitivity of these species, including vulnerability and recoverability, should be taken into consideration when assessing the potential impacts of adding hard structures and mooring lines associated with MRE projects in the marine environment.[56]

5.5.3.4 *Fouling Communities and Invasive Species*

Parts of a MRE project will be subject to colonization by fouling organisms. To prevent fouling, moving parts of a device will likely be covered with an antifouling compound to prevent the settlement of fouling organisms, which would increase the weight and drag of moving parts of the device. While antifouling compounds may impact the marine environment (Sections 5.3.5, 5.6.3, 5.7.4), the management of fouling organisms on unprotected or inadequately protected surfaces, may affect the surrounding benthic community. For example, the Reedsport wave energy project in Oregon includes planned maintenance involving divers scraping fouling organisms off of the mooring lines used to hold the WECs in place. Because WECs reduce wave energy as waves pass by them, shells and other organic material that had been scraped off the mooring lines may not be removed from the local area by wave power or currents. As a result, the presence of this organic material may change the physical and chemical characteristics of the surrounding habitat. Sediment size, angularity, and organic content are major determinants of habitat suitability for species burrowing in seafloor sediments, so the addition of shells and fouling species scraped from MHK infrastructure will change the burrowing community.[53]

In addition, the hard surfaces created by these projects may also support an increase in invasive species populations, potentially damaging diverse, native communities. Invasive species are often effective at colonizing disturbed sites, which gives them a competitive advantage over native species when colonizing an area that is disturbed during placement of foundations, anchors, mooring lines, and piles. The hard surfaces of MHK projects may provide good habitat for invasive species. In addition, MRE structures may act as stepping stones for a marine species requiring a hard substrate to expand their range. [53]

Figure 5.3.2. The Sea Squirt (*Didemnum vexillum*)

Photo Credit: Janna Nichols

A sea squirt (Didemnum vexillum) covering the underside of a dock, surrounding other species, including two anemones in the lower left of the photo.

For example, exotic species are found to selectively colonize oil and gas platforms offshore in Southern California. However, in this instance, the specific species studied also acted as a food source for native fishes.[53]

Figure 5.3.3. A Small Colony of *Watersipora subtorquata*

Photo Credit: Andrew N. Cohen, Center for Research on Aquatic Bioinvasions

Small colony of Watersipora subtorquata on hard substrate.

In California, there are a number of offshore invasive species of concern, including the sea squirt (*Didemnum vexillum*) and *Watersipora subtorquata*. The sea squirt was introduced to Washington State from Japan and has since been found in Oregon and California in San Francisco Bay, Elkhorn Slough, Woodley Island, Mission Bay, and Bodega Bay.The sea squirt changes its morphological variants based on whether the current in the area is high or low, making it highly adaptable to a wide variety of current strengths. This species can grow on hard substrates or spread out like a mat on the seafloor. Spreading out over the seafloor separates benthic species and their prey that burrow in the sand, and covers up the feeding tubes of burrowing species.[57] As a result, monitoring should be done to assess the presence of sea squirts on the infrastructure associated with MHK projects. *Watersipora subtorquata* is an invasive fouling organism of particular concern because it is resistant to copper-based antifouling paints. It starts its growth as a flat, roughly circular colony, but as it becomes larger, it grows outward from the substrate in lobes and frills, resembling a red head of lettuce.

As it grows, over 20 other fouling species use it as a substrate for their growth, facilitating the invasion of organisms that are not as copper-tolerant. *Watersipora* is currently established in San Francisco Bay, and is most common in lower intertidal and upper subtidal areas, although it can grow at depths of tens of meters.[58] It is often found on the sides of floating docks and could establish itself near the water line on MHK devices and their infrastructure. During the environmental review of an MRE project, the potential impact of invasive species settlement and expansion should be considered. To prevent the spread of invasive species, mitigation measures, such as cleaning vessels and equipment of fouling organisms, could be put in place to reduce the risk of invasive species becoming established at the project site.

Figure 5.3.4. A Large Colony of *Watersipora subtorquata*

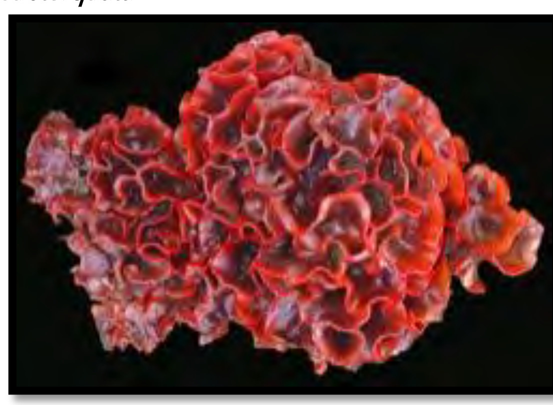


Photo Credit: California Academy of Sciences

Large colony of Watersipora subtorquata displaying lobes and frills in its growth.

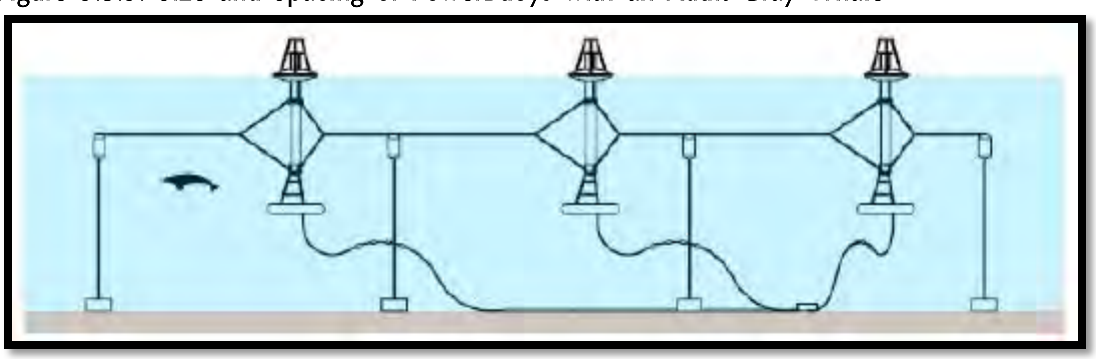
5.5.3.5 *Entanglement Risk*

The potential for species entanglement in the mooring lines of any MRE device is directly related to the amount of tension on the mooring lines and the rigidity of the power cables associated with the device. For a species to become entangled in a mooring line, the line must be slack rather than taut. "Slack" is relative in terms of the body weight of the animal encountering the mooring line; for example, a line that would be "taut" for a jellyfish may be "slack" for a sea lion because the sea lion weighs more and may run into the line with greater force. If an animal encounters a line that is "taut" it will collide with the line, rather than become entangled in it. Another concern is that mooring lines and anchors may entangle algal drift mats and fishing gear, especially crab pots, and could entangle marine species.[5] Mitigation measures proposed to solve this issue include regular diver surveys and removal of any derelict fishing gear present in the area.

Plankton species under 10 cm in diameter are at little risk for entanglement because they will move with the ocean currents around the mooring lines. Fish are not particularly vulnerable to entanglement or entrapment due to their size and behavior; however, entanglements have been documented for larger fish species, such as basking sharks, that have sufficient size and mass to become entangled in mooring lines.[61] Because sea turtles cannot swim backwards, they are inherently vulnerable to entanglement in loose lines that can wrap around their neck and shoulders. Leatherback turtles are especially vulnerable because of their large front flippers. [59,] However, the Bureau of Ocean Energy Management (BOEM) states that, due to sea turtles' slow and deliberate swimming and the small number of mooring lines used in MHK projects, sea turtles may avoid entanglement, making population level effects unlikely.[60]

Although there is broad documentation of pinnipeds and cetaceans becoming entangled in fishing gear, pinnipeds and small toothed whales are unlikely to experience significant entanglement or entrapment risks from MRE projects. These species small size relative to the infrastructure needed for MRE projects, as well as their behavior makes significant impacts unlikely. The mooring lines and cables used for MRE projects are thicker than fishing line, and the devices and their associated infrastructure are very large. For small toothed whales, the ability to actively use echolocation to avoid objects should minimize entanglement risk.[5]

Figure 5.3.5. Size and Spacing of PowerBuoys with an Adult Gray Whale



Graphic Credit: Reedsport OPT Wave Park. 2010. Draft License Application to the Federal Energy Regulatory Commission for FERC Project #12713. Reedsport OPT Wave Park, LLC.

Graphic depicts the relative size and spacing of OPT's PowerBuoy with an adult gray whale.

Baleen whales, on the other hand, are much larger than toothed whales, and are at risk for entanglement in mooring lines while feeding. When a feeding baleen whale encounters a line, the whale often responds by rolling, this may entangle the whale in the line. MRE projects are expected to have different impacts on baleen whales based on the arrangement of the devices and their mooring lines.[61] MRE projects designed with mooring cable possess the greatest risk of entanglement. Some mooring line setups resemble similar, but smaller double buoys on commercial crab pots, which pose a major threat to gray whales off the coast of Oregon.[5] Additionally, thin mooring cables are thought to be more dangerous to baleen whales than thick ones because they may cause lacerations and entanglements, although thick cables may still cause blunt-force trauma.[5] In addition, transmission cables or anchor lines that are buried less than 1 m in subsurface sediment may be unearthed by feeding gray whales along the California coast. As a result, developers should plan to bury cables more than 1 m deep in their project design.[5] Horizontal cables may be more likely to cause entanglement than vertical lines, particularly in specific parts of the water column; in this respect, even short tag lines attached to a buoy with a slack horizontal line pose a significant risk for entanglement. In sum, horizontal, long, floating devices present the highest risk of collision or entanglement for whales.

It should also be noted that cetaceans and pinnipeds may avoid a MRE device or project entirely due to the sounds it produces, therefore reducing the risk of entanglement.

Most of the uncertainty regarding entanglement risks to marine species is not necessarily related to the likelihood of exposure, but to the effect of exposure. Mitigation methods and techniques already exist to reduce the risk of entanglement by increasing the tension on mooring lines. If the maximum mass and speed of any animal encountering a line can be predicted, mooring line tensions can be raised to the point where entanglement may be completely avoided.[61]

5.5.3.6 *Collision Risk*

There is little risk of underwater collision for organisms less than 10 cm in diameter because they are unable to swim quickly relative to the speed of ocean currents, and therefore, will move with the flow of ocean currents around underwater infrastructure. However, jellyfish and other soft-bodied plankton may experience shredding or dismemberment when colliding with very thin structures, such as taut mooring lines.[62] As a result, this may impact higher trophic species, such as the leatherback sea turtle, which prey on jellyfish species, such as the sea nettle, by decreasing the their food source.[62]

Large marine species, such as whales, weigh a great deal less than most MRE devices; this means that despite their vulnerability to entanglement in mooring lines, whales are unlikely to become entangled in an MRE device itself. However, whales may collide with a device if they encounter it.[62] The likelihood of underwater collision increases with the size, mass, and swimming speed of the animal, as well as the color and acoustic output of the MRE device. The creation of new underwater habitat as a result of MRE development may also increase the probability of collision. For example, MRE devices that act as artificial reefs may attract more fish than the surrounding area, which may attract higher trophic species, such as marine mammals, and increase the risk of collision for marine mammals with underwater infrastructure.[63]

Seabirds may also be at risk of collision with MRE devices; however, risk is dependent on the bird's ability to avoid MRE structures. For example, due to their smaller above-water profile, MHK devices may represent a much smaller collision risk to seabirds than offshore wind devices. In addition, fixed underwater structures pose a minimal collision risk to seabirds, while the moving parts and mooring lines associated with MHK devices may be more difficult for seabirds to navigate when foraging underwater.[64] Birds that feed via pursuit diving have slow and controlled dive profiles, while plunge diving birds have a lower margin of avoidance with structures and are more likely to collide with a device.[64] Pursuit diving birds propel themselves underwater using their wings or feet, while plunge diving birds use the momentum of diving from a great height to combat their natural buoyancy to propel them into the water. California birds of greatest concern for collision with MRE devices are: sooty shearwaters, California brown pelicans, Brandt's cormorants, double-crested cormorants, pelagic cormorants, western gulls, California gulls, common murres, pigeon guillemots, and marbled murrelets.[50] These bird species are of particular concern due to their likelihood of interaction with MHK devices as a result of their location, life history, and physical characteristics. For a more in-depth discussion regarding birds in California and MHK technologies, please refer to the California Energy Commission and the Ocean Protection Council's 2008 report, *Developing Wave Energy in Coastal California: Potential Socio-Economic and*

Environmental Effects. For more information on the impacts of offshore wind turbines to seabirds, please refer to Section 5.3.12.

5.5.3.7 *Haul-Out and Roosting Sites*

Above-water exposed hard structures associated with MHK projects, such as radio telemetry towers and lines and meteorological instruments, can create new roosting sites for seabirds and haul-outs for pinnipeds.[5] New offshore roosting sites may expand the foraging range of coastal birds, since the structures provide a place to land. Birds of prey may also use the structures as a hunting area to target roosting birds.[65] Lighting associated with these structures may amplify this by attracting seabirds, however using different colors for lighting may reduce bird attraction. Roosting and lighting increases the risk of collision between seabirds and the exposed (above water) structures on a MRE device. Similarly, the availability of exposed hard structures for haul-out sites may attract to pinnipeds to MRE devices, increasing the risk of collision or entanglement.[5] In addition, if a MRE project acts as a fish attracting device or an artificial reef, pinnipeds and seabirds may associate the project with food, and increase their risk for collision or entanglement.

5.5.3.8 *Impacts Due to Avoidance*

MRE projects may also displace biological resources from important habitats. For example, both migrating and non-migrating whales may avoid a project area due to the placement of MRE devices and their acoustic output. For migrating whales, this may result in narrower migration routes against beaches or other barriers, which may increase their risk of predation by orcas. In addition, a MRE project could also reduce the ability for migrating and non-migrating whales to forage successfully by displacing them from important feeding habitats.[5]

Pinnipeds, on the other hand, are unlikely to avoid the area due to the presence of a MRE project. For example, pinnipeds have been shown to habituate to anthropogenic sound sources, such as acoustic deterrent devices at aquaculture sites[66], and may even be attracted to a MRE project due to an abundance of fish near hard structures and artificial reefs as a result of the project.

For seabirds, the low above-water profiles of MHK devices, in comparison to offshore wind turbines, will have minimal impacts to daily flight patterns.[64] However, the placement of MRE projects near important nesting sites and feeding grounds may impact seabirds with hatchlings if they have to travel further to forage. As a result, placing MRE projects in these areas may increase impacts on seabird populations.[64]

5.5.4 Release of Antifouling Compounds and Other Chemicals

MRE technologies utilize a variety of antifouling compounds and other chemicals that slowly release toxic compounds to prevent fouling organisms from becoming established. MRE technologies with moving or floating parts will likely require the use of antifouling paints to minimize drag and extra weight caused by fouling organisms. However, these compounds may have impacts on biological resources beyond the fouling community.

In addition, some MRE technologies may require a fluid to convert linear motion to rotary motion, which drives a generator. Freshwater or seawater is sometimes used, but most technologies currently use petroleum or vegetable-based hydraulic fluid.[73] Any release of hydraulic fluid or lubricant from a device would be accidental, but would impact biological resources that encounter the air-water interface, such as seabirds and marine mammals.

Most MRE technologies will also have potential organic or metal pollutants associated with the infrastructure used for electrical signals, and some installations may use sacrificial anodes to protect metal structures. The release of the metals associated with sacrificial anodes and other pollutants may also be toxic to biological resources. The substances used in antifouling coatings, sacrificial anodes, and hydraulic fluids are discussed below, along with their toxicity to marine life and their environmental impacts.

5.5.4.1 *Copper*

Copper is toxic to a wide range of marine organisms, from algae to crustaceans to fish in laboratory tests.[67] The U.S. Environmental Protection Agency's (USEPA) acute and chronic concentration standards for dissolved copper in saltwater is 4.8 micrograms per liter (g/L) and 3.1 g/L, respectively.[68] Acute concentration standards are for short-term events, and chronic concentration standards are for long term concentrations. In fish, copper binds to sites on the gills that play critical roles in taking up sodium ions, blocking sodium uptake, and leading to a decrease of sodium ions in fish plasma, which can be fatal.[67] High copper concentrations have also been shown to kill fish larvae, which have not yet developed livers to manage toxic substances. In clams (*Macoma balthica*), high copper concentrations can cause reproductive anomalies and change the sex ratio of males to females in the clam population. There have also been correlations of DNA damage in the bay mussel (*Mytilus edulis*) as a result of certain concentrations of copper.[67] It is difficult, however, to determine the effects of copper on marine organisms in field studies because sites that have heavy copper contamination are also heavily contaminated with a number of other toxic pollutants. As a result, measuring the potential impacts of copper alone is very challenging.

5.5.4.2 *Zinc*

Zinc is only moderately toxic to some marine organisms, while many can regulate tissue residues of zinc over wide ranges of existing zinc concentrations in water, food, and sediments. Fish are most tolerant of zinc concentrations, while phytoplankton and some larval crustaceans and mollusks are the most sensitive.[69] Zinc may bioaccumulate up the food chain in the marine environment, especially in oysters. Oysters naturally bioaccumulate zinc in high concentrations, which can continue to move up the food chain when they are eaten. Acutely lethal concentrations of zinc range from 100 to 50,000 g/L for marine species. [69]

5.5.4.3 *Aluminum*

Most research conducted on aluminum toxicity in fish species has focused on freshwater fish in acidic environments, such as those created by acid mine drainage, because lower pH water enhances aluminum toxicity and dissolution in water. In acidified lakes, aluminum reacts with proteins in the gills of fish and frog embryos, making respiration difficult, and birds that eat contaminated fish experience eggshell thinning and chicks with low birth weights.[70] In addition, dissolved aluminum has been shown to be fatal to crab larvae (*Cancer anthonyi*) at 10 parts per million (ppm) after a 7 day exposure, and to *Ctenodrilus serratus*, a polychaete worm, at concentrations of 0.48 ppm after a 4 day exposure.[71,72]

5.5.4.4 *Lubricants and Hydraulic Fluids*

Marine species that interact with the air-water interface, such as seabirds or marine mammals, are particularly vulnerable to a hydraulic fluid leaks or spills because these fluids are often oil-based and float on the surface of the water. Shorelines near the project area would also be vulnerable to hydraulic fluids washing onshore and species using shoreline, coastal wetland, and beach environments may be vulnerable to impacts from exposure to hydraulic fluids.[73] Some MHK projects have used biodegradable, vegetable-based hydraulic fluid formulas, which are less toxic to marine life than petroleum; however, leaks of any oil-based hydraulic fluid could lead to a loss of insulation for seabirds and sea otters.[73]

5.5.5 Electromagnetic Fields (EMF)

Light availability is limited in the marine environment, making vision limited in the underwater world. This impediment to underwater vision has put a strong selective pressure on marine organisms for well-developed senses of hearing, smell, taste, and in some species, the ability to sense magnetic fields or electrical fields.[74] A MRE device or the associated marine electrical cables and underwater electrical infrastructures (such as substations or transformers) may produce EMF. A MRE project may use one of two types of power cables currently used to transfer electricity to shore: direct current (DC) and alternating current (AC). [75] Currently, AC power transmission cables are the industry standard for offshore energy projects, but DC cables may be used more in the future as projects are sited further offshore. DC cable systems are able to carry power over long distances using only two cables and have lower power losses in comparison to AC cable systems, which require using three cables to transport electricity.[74]

Current industry practice uses conductive sheathing to block the electric field within the cables from the external environment.[74] When the direct electric field (E-field) is conducted by the covered sheathing, it leaves a magnetic field (B-field) in the surrounding water.[75] When a conductor (e.g.: seawater) moves through the magnetic field, it creates an induced electric field (I-field). Both the B-fields and I-fields generated by power cables have the potential to be sensed by and impact the behavior of a wide range of marine species.[74]

There is increasing evidence that both marine vertebrates and invertebrates can sense the earth's magnetic field and use the information for orientation and navigation. Marine species can detect changes in magnetic inclination and intensity, and use this ability to migrate. Sensing magnetic inclination is roughly equivalent to sensing the line of latitude anywhere on the globe. Marine species that can detect magnetic fields include mollusks, crustaceans, elasmobranchs, marine mammals, sea turtles, and anadromous fishes.[74,75] These species are thought to detect magnetic fields through a variety of senses, including:

- Magnetite detector: Some species are believed to have small crystals of magnetite, a magnetic mineral, in special receptors in their head. The crystals will align with the incident magnetic field and exert a rotation that modulates the ion channels of the cell.[74]
- Optical Pumping: Theoretical models are proposed for the effects of magnetic stimuli on pigments in the visual system of animals. Free electrons from excited visual pigments may interact with an ambient magnetic field and change information sent to the brain by the optic nerve. Experimental evidence exists for this phenomenon in birds, but is lacking in marine species.[74]

Unlike the sensory mechanisms listed above, some marine species can sense electrical fields directly (electrosensitivity). Chondrichthyans, which include the elasmobranch fishes (sharks and rays) and holocephali ratfishes, possess a unique sensory system known as the Ampullae of Lorenzini which detects electrical fields.[74] This sensory system is used to locate prey a few inches beneath the surface of the seafloor. These species may also be able to detect the presence of magnetic fields through their ability to sense electrical fields, or they may possess a currently unknown separate sensory system to detect magnetic fields. Some evidence of electroreception has also been reported for decapod crustaceans, including crabs, shrimp, and lobsters, and for groups of fishes, including lampreys, sturgeon, and some teleost (bony) fishes.[74] MRE projects can potentially change the intensity, inclination, and declination of the local geomagnetic field, and thus may have an effect on species' ability to sense changes in the properties of EMF. For background information on the geomagnetic field, refer to Appendix E. The following sections describe the potential impacts of EMF on biological resources by species group.

5.5.5.1 *Elasmobranchs*

Introduced EMF may impact the daily behaviors and life history functions of elasmobranchs. Many elasmobranchs, such as sharks and rays, are migratory species, and encounters with EMF created by underwater power cables may temporarily affect their migration routes. Many sharks and rays also have home ranges; therefore, resident populations close to submarine cables may be attracted, repelled, or unaffected by the presence of power cables. As a result, distributions and swimming behavior of elasmobranch populations may be affected.

EMF may also impact feeding and mating. The presence of an anthropogenic EMF may interfere with the natural electrical fields utilized by elasmobranchs to detect and locate prey. Experiments have shown that elasmobranchs attack unsheathed submarine electric cables with weak electrical current running through them; therefore, although cables used in MRE projects would be sheathed, elasmobranchs may show some kind of predatory response to the weak I-field produced by seawater or marine species moving through the magnetic field.[76] Available data suggests that elasmobranchs rely on low-frequency fields for prey detection and attack, but the success rate of feeding near strong electrical fields is unknown. Elasmobranchs also use their electrical sense to locate and detect members of their own species to mate; however, the impact of anthropogenic EMF on elasmobranch reproduction is unknown.[74]

5.5.5.2 *Other Fish Species*

Although it is known that other fish can detect magnetic fields, it is less understood how important this sense is for their ability to effectively migrate, travel their home range, or locate prey or other members of the same species. However, exposure to EMF has been shown to delay embryonic development in some fish.[76]

Most research on non-elasmobranch fish has focused on lampreys (order Petromyzontiforms*)* and salmonids (family Salmonidae*)*. Research suggests that salmonids may be influenced by anthropogenic *electric* fields, but are unlikely to be influenced by anthropogenic *magnetic* fields. Research conducted on salmon response to electrical fields found that their heart rate becomes elevated at E-field strengths of 0.007 to 0.07 volts per meter (V/m). The first response, shuddering of the gills and fins, occurs at E-field strengths of 0.5 to 7.5 V/m. Salmon start swimming towards electrically charged anodes between 0.025 V/m and 15 V/m. Harmful effects to salmon, such as electronarcosis[viii] or paralysis, from E-fields are observed at strengths of 15 V/m or more.[76]

Crystals of magnetite have been found in four species of Pacific salmon (*Oncorhynchus* spp.), though not in sockeye salmon (*O. nerka*). These crystals are believed to serve as a compass that orients salmon using the earth's magnetic field; however, research has concluded that, although salmon can detect B-fields, their behavior is likely governed by multiple stimuli, such as a celestial (sun and moon) compass and olfactory signals.[77] When salmon were exposed to an artificial magnetic field, there was no observable change to the horizontal or vertical movement of the salmon. In addition, research involving sockeye salmon suggests that this species relies on visual cues to locate its natal stream and olfactory cues to reach its natal spawning channel, as blocking any potential magnetic sense they have did not change their ability to migrate effectively.[76]

Green sturgeon (*Acipenser medirostris*), like elasmobranchs, can utilize electroreception to locate prey. In studies done on Sterlet sturgeon (*A. ruthenus*) and Russian sturgeon (*A. gueldenstaedtii*), the following behaviors were recorded:

- At 1.0 to 4.0 hertz (Hz) at 0.2 to 3.0 millivolts per centimeter (mV/cm), sturgeon responded by searching for the electricity source and foraging;
- At 50 Hz and 0.2 to 5.0 mV/cm, sturgeon responded by searching for the source of the electricity; and
- At 50 Hz at 0.6 mV/cm or greater, sturgeon responded by avoiding the electrical field.

5.5.5.3 *Cetaceans*

Currently, it is believed that cetaceans can sense the geomagnetic field and use it to form a magnetic map during migration, which allows them to direct themselves even in areas of low magnetic intensity and gradient.[76] Whether cetaceans utilize the field intensity or inclination angle of the geomagnetic field is unknown. In addition, it is unknown whether cetaceans solely rely on the geomagnetic field or if they use it in addition to input from other senses. The following species are sensitive to stranding (to a statistically significant degree) when the earth's B-field has a total intensity variation of less than 0.5 milligauss (mG): common dolphin (*Delphinus* spp.), Risso's

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[viii] Electronarcosis in fish is when a constant DC current prevents the fish's brain from communicating with the rest of its body, in essence the fish "goes to sleep." Fisheries managers use electronarcosis to keep fish relaxed while they take measurements and tissue samples, and implant radio tags. For a reader-friendly explanation of electronarcosis and how it is used, please see: http://fish-notes.blogspot.com/2010/03/electronarcosis-not-as-shocking-as-you.html

dolphin (*Grampus griseus*), Atlantic white-sided dolphin (*Lagenorhynchus acutus*), fin whale (*Balaenoptera physalus*), and long-finned pilot whale (*Globicephala melas*).[76] Live strandings of toothed and baleen whales have also correlated with local geomagnetic anomalies; there is some evidence that shifts in EMF due to submarine cables have been significantly correlated to whale strandings.[76] Cetaceans are likely to react to anthropogenic EMF, but the degree of their response (i.e., a trivial change in swim direction, a longer detour during their migration, or increased strandings) is unknown.[74]

5.5.5.4 *Sea Turtles*

Sea turtles (*Chelonioidea* spp.) are known to use their geomagnetic sense for orientation, navigation, and migration. In one research study, sea turtle hatchlings were taken from their hatching beaches and exposed to various magnetic inclination angles while swimming in a tank in a lab. When the hatchlings were exposed to an inclination angle that was present near the Caribbean, they would turn and swim north, which is the same response they have on their migration in the ocean. This demonstrates that sea turtles can distinguish between different magnetic inclination angles and perhaps derive an approximation of latitude. Lohmann and Lohmann (1994) theorize that because most nesting beaches are aligned north-south, and thus have a unique inclination angle associated with them, a turtle's ability to recognize specific inclination angles may explain how adult turtles find their natal beaches after years at sea.[78] The use of a geomagnetic sense may be especially important for hatchlings as they swim offshore. When juveniles or adults migrate to feeding or nesting grounds, they use the geomagnetic field to reach the general area, and another set of cues, most likely olfactory, to pinpoint the final destination.[74] An experiment performed with turtles in the Indian Ocean showed that adult turtles have unknown alternative mechanisms to find their nesting areas even with an impaired magnetic sense, although the routes they took were less direct. It also showed that a single exposure to a locally disturbed magnetic field may cause persistent effects on the turtles' magnetoreceptors well after the exposure.[74]

If sea turtles experience an altered magnetic field even 0.05 T off from the naturally occurring field, the change may affect their detection systems for a short period of time. Hatchlings will be most vulnerable to the effects of local changes to the geomagnetic field because they attempt to leave the beach at night when other cues that turtles use to navigate (i.e. daylight) are not available.[ix] For juveniles and adults, local changes to the geomagnetic field may cause a minor deviation from the direct route to their destination.

5.5.5.5 *Invertebrates*

Invertebrates are known to have a magnetic sense, but how they use it is unknown.[74] However, in studies done on sea urchin larvae exposed to a DC magnetic field, sea urchin larvae experienced delayed miotic cycles, slower growth, and greater incidence of exogastrulation, a developmental deformity in which the primitive gut begins to form outside of the sea urchin embryo rather than inside of it.[79] Spiny lobster (*Panulirus argus*) has been shown to use the earth's magnetic field to orient itself; however, no detrimental effects due to anthropogenic EMF have been observed in spiny lobster.[76] Additional studies have been done on the blue mussel (*Mytilus edulis*), the North Sea prawn (*Crangon crangon*), and round crab (*Rhithropanopeus harrisii*), where these species were exposed to a static magnetic field for several weeks. No differences in survival between the experimental and control groups of these species were detected.[76] However, some biochemical parameters of the blue mussels changed when exposed to magnetic fields; for example, the exposed mussels experienced a 20% decrease in hydration and a 15% decrease in amine nitrogen values (amino acids), regardless of the strength of the magnetic field.[76]

Based on fishing information, Dungeness crab (*Metacarcinus magister*) is widely believed to be sensitive to EMF; however, scientific publications are lacking. Chemical reactions during galvanic

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[ix] Hatchlings use the position of light to find their way to the ocean from the beach at night, and once they are in the water they use the direction of the waves and the geomagnetic field to orient themselves.

corrosion of metals can also produce EMF. As a result, crab fisherman must coat their traps in a substance that will not corrode to be successful, since Dungeness crabs are known to avoid corroding crab pots. To learn more about Dungeness crabs and EMF, refer to the Pacific Northwest National Laboratory's (PNNL) study on the behavioral responses of Dungeness crabs to EMF that began in 2012.[80]

A field study conducted on a DC power transmission cable running from Sweden to Poland found that, after one year, there was no statistically significant difference in the abundance and composition of benthic species (larger than one millimeter across) from before the installation of the cable. This indicates that post-larval benthic species recovered from the disturbance of burying the cable, and did not appear to be impacted by its electromagnetic field.[81]

5.5.6 Acoustics

Hard structures associated with MRE projects will add acoustics to the marine environment through the sounds of the device moving, the sounds of waves hitting the device, and the sounds associated with maintenance vessel traffic. The additional acoustics in the marine environment may impact biological resources. In water, sound travels at an average speed of 1500 meters per second (m/s), which is more than four times faster than sound travels in air. Generally, marine species are able to perceive sound between 7 Hz and 180 kHz,[82] and use sound for a variety of life history functions, including communication, individual recognition, predator avoidance, prey capture, orientation, navigation, mate selection, and mother-offspring bonding.[83] In general, on quiet days, ambient sound in the ocean is dominated by anthropogenic activities, such as vessel traffic; on stormy days, non-anthropogenic sources, such as waves hitting hard surfaces, dominate.[84]

5.5.6.1 *Fish*

Sound plays a major role in the lives of fish for important life history functions, including feeding, schooling, and reproduction.[84] As a result, fish have developed sensory mechanisms to detect, localize, and interpret sound. While fish use their inner ear for sound detection and balance, the lateral line system allows fish to sense the movement of water. In addition, the swim bladder increases a species' sensitivity to sound depending on if it is in close proximity or mechanically connected to the inner ear. Available scientific data indicate that most fish species are able to detect sounds to 1 kilohertz (kHz), with some species capable of detecting sounds around 3 to 4 kHz; however, some fish species, like the American shad (*Alosa sapidissima*), have been shown to detect sounds up to 180 kHz.[85] Damage to the sensory cells of the inner ear have been documented in fish exposed to loud sounds, but unlike humans, fish can regenerate these sensory cells, suggesting that sensory impairment may only be temporary.[5] Additionally, some fish may avoid areas with intense sound, while others may show an initial startle response and then become acclimated to the added noise. Sounds that do not immediately cause a startle response may nonetheless still affect predator-prey interactions, feeding, spawning, and migration behavior.[84] To gain a full understanding of the effects of sound on fish, it may be necessary to measure or estimate particle motion in addition to sound pressure, since both measurements have been shown to play an important role in the detection of an acoustic signal for many fish species.[86,87]

5.5.6.2 *Seabirds*

Diving seabirds, including plunge-divers and pursuit-divers, may also be affected by underwater sounds. Whether underwater sounds created by MRE devices would alter the behavior of seabirds is unknown; however, the underwater sounds created by MRE devices and their associated infrastructure may also keep seabirds out of the area, thus preventing them from colliding with hard surfaces or mooring lines.[84]

5.5.6.3 *Marine Mammals*

Marine mammals have excellent underwater hearing abilities and rely on sound for important life history functions, including communication, feeding, reproduction, and predator-prey avoidance. The species most likely to hear and interact with MRE devices are pinnipeds and cetaceans. Most pinnipeds can hear frequencies (up to 75 kHz, with auditory thresholds as low as 60 decibels (dB).[82] Pinnipeds may be attracted to the structures associated with MHK devices because they offer areas to haul-out and may attract prey species. Along the California coast, California sea lions and harbor seals are considered the most likely species to interact with MRE devices; however, whether the sounds from the device will change their behavior is unknown.[84] Cetaceans, on the other hand, can hear at low-, mid-, and high-frequencies up to 180 kHz, depending on the species, with sound pressure levels as low as 30 dB.[82] The sounds produced by an MRE device may deter whales from the project area; however, if they do not, cetaceans may be at risk of collision with the device. In this case, acoustic deterrence devices may prove useful.

Monitoring the acoustic output of a MRE device would prove useful when determining the potential impacts to marine mammals. Breakwaters may potentially be used as a proxy for determining acoustic and wave reduction impacts caused by placing MRE devices offshore. Additionally, some studies have been done on the acoustic output of offshore wind turbines, which may be applicable when evaluating the sounds produced by other MRE devices. For more information on impacts to biological resources from offshore wind turbine acoustics, please refer to section 5.3.12.

Future Research Needs

- Research on how well current wave energy or tidal energy reduction models predict the actual wave energy or tidal energy reduction of a project.
- Research on how wave farms may alter the structure of the water column, including variations in temperature and salinity.
- Research on how wave-induced disturbance varies across areas with different wave energy exposures.
- Research on how reducing wave energy or tidal energy impacts water circulation and water quality.
- Research on the ecosystem impacts of artificial reefs to resident and migratory fishes in areas with soft-bottom habitat.
- Research on how static hard structures impact near-field habitat and sediment characteristics.
- Research on the impacts of static hard structures, especially mooring lines, on sea turtles, cetaceans, pinnipeds, mustelids, and marine birds.
- Research to determine which mooring designs reduce the risk of entanglement.
- Research on how moving underwater structures interact with and impact sea turtles, cetaceans, pinnipeds, mustelids, and marine birds.
- Research on which species are most vulnerable to collision or other negative interactions with moving underwater structures.
- Research on how EMF impacts ecosystem interactions.
- Research on how EMF impacts benthic invertebrates, especially Dungeness crab.
- Research on how EMF impacts resident and migratory fishes; rockfish species and salmon should be prioritized.
- Research on how EMF impacts elasmobranchs, especially lab studies showing how elasmobranchs respond to EMF in underwater cables.
- Information on how EMF impacts juvenile and adult turtle species found in California.
- Research on how sounds and vibrations from MRE devices impact marine organisms.

Technology-specific impacts

5.5.7 Oscillating Water Column

OWCs sited in intertidal areas can create the functional equivalent of rocky intertidal habitat, potentially replacing existing sandy or muddy intertidal habitat. This change in habitat may alter species assemblages present at the site. Many artificial hard structures have been placed in intertidal areas, such as riprap and seawalls, which can be used as a model when determining the impacts of siting an intertidal OWC. In addition, siting an intertidal OWC may impact sediment transport along the shore, which may also impact biological resources. The physical structure of an OWC may entrap marine species, such as fish, sea turtles, marine mammals, jellyfish, and plankton, as waves wash into the device's tank. The size of the organism and their ability to escape the tank with the next wave depends on the design of the device. The large and relatively rapid changes in air pressure that occur within an OWC may also have impacts for entrapped swim bladder fishes and higher-order vertebrates, such as pursuit-diving seabirds and pinnipeds.[61]

Figure 5.3.6. The OE Buoy (OWC) by Ocean Energy Limited

Photo Credit: Ocean Energy Limited

Future Research Needs

- Research on pressure changes near or in OWCs.
- Research on the rate of entrapment for OWCs and potential impacts to marine species.

5.5.8 Overtopping Device

The mechanism by which overtopping devices generate energy makes them very likely to entrap and entrain marine life. Marine species may be washed into the reservoir with the waves and may also be exposed to the turbine. This may cause significant impacts depending upon where the device is sited. Any sufficiently large animal that is exposed to the turbine may suffer injury or mortality; however, some devices have been designed with screens that prevent the entrapment of larger species. In addition, entrapment may affect the performance of the equipment; for example, dense jellyfish blooms near an overtopping device may clog and damage the device.

Species that spend time in the upper part of the water column are most likely to be affected by overtopping devices, and are more at risk to being washed into the device's tank. For example, federally threatened populations of Steelhead trout, live at the surface of the water column, and are therefore at risk to be entrained and killed by overtopping devices.[88]

Overtopping devices sited in intertidal areas may also create the functional equivalent of rocky intertidal habitat. This new habitat may replace sandy or muddy intertidal habitat and alter species assemblages present at the site. Many artificial hard structures have been placed in intertidal areas, such as riprap and seawalls, and these structures can be used as a model when determining the impacts of siting an intertidal overtopping device. Some overtopping devices have even been designed to be incorporated into artificial structures, such as seawalls and jetties, and could be included in projects that occur along the coast.

Future Research Needs

- Research on the rate of entrapment and impingement, and potential impacts to marine species.

5.5.9 Oscillating Wave Surge Converter

OWSCs act as large pumps in the ocean to create electricity. Because many designs involve large plates or structures oscillating underwater, they may create a high risk of collision with marine species. Most of these devices are designed to be sited in the nearshore area, and many of the plates extend from the seafloor to the surface of the water when completely upright, so species in all parts of the nearshore water column may be affected. In addition, an OWSC may not be visible at the sea surface due to movement, increasing the risk of seabird collision. Seabirds are more likely to collide with a moving device that is not visible from the air than with a stationary, visible structure. The risk and degree of injury caused by a collision with an OWSC depends upon the weight and speed of the device, as well as the weight and speed of the species colliding with the device. The heavier and faster both the device and the species are, the more likely a collision and injury will occur.[62]

Future Research Needs

- Research on how cetaceans, pinnipeds, seabirds and fish interact with moving underwater structures.

5.5.10 Axial Flow and Cross Flow Turbines

Collision with marine species is a concern for axial flow and cross flow turbines. The PNNL and Sandia Laboratory modeled the severity of a strike by an axial flow turbine on a male southern resident killer whale in Puget Sound. The modeling results found that, under the most severe scenario, the whale's tissues could bruise.[89] The study also looked at the potential for broken bones, but found that the pressure and force exerted by the turbine blade was clearly insufficient to break the whale's jaw.[89]

Tidal turbines may also cause a variety of impacts to migratory fish species. Some species may use the area on the lee side of the turbines to rest during their migration since the current is weakened due to the removal of energy by the turbine; however, evidence from European Marine Energy Center (Figure 5.3.7) and the Verdant Tidal Power Project in New York's East River shows that fish are generally absent from tidal project areas during strong tidal currents when the turbine is in operation. It is unknown if fish are only absent due to the strong currents or due to the turbine's rotation.[90] The lack of fish present during turbine operation decreases the likelihood of collision and entrapment by the device.

Figure 5.3.7. European Marine Energy Center (EMEC) Analysis of Fish Collision with the OpenHydro Tidal Turbine[90]

EMEC OPENHYDRO TURBINE SCREEN SHOTS, JULY 15, 2009

Left: Screenshot at 6:00 a.m.; tidal velocity = 1.8 m/s. The turbine is rotating; no pelagic species are present. *Right*: Screenshot at 10:30 a.m.; tidal velocity has reduced and is approaching 1.2 m/s. Fish are observed beginning to arrive from the downstream side of the turbine in small numbers. The numbers of fish observed slowly begins to increase throughout the following hour as the flow stops.

Left: 11:14 a.m.; tidal velocity has reduced to 0.5 m/s. Large numbers of pelagic fish (pollock) can be observed actively feeding downstream of the turbine. The fish appear to stay downstream while feeding on debris and particulate matter in the water flow. Fish are not observed upstream of the turbine. The turbine is currently stationary. *Right*: 7:03 p.m. - tide has turned and velocity is recorded at 1.5 m/s. Turbine is rotating and no fish are observed during this state of the tide.

Source: Sue Barr, OpenHydro, memo November 2010.

Very little information is available regarding bird collision with axial flow turbines. Generally, most birds will not dive deep enough in the water column to encounter a turbine, but some deep diving birds, such as common murres, can dive to depths of 330 feet. For comparison, the deepest part of San Francisco Bay is 370 feet, and as a result, a turbine sited in San Francisco Bay would be within diving range of common murres and other deep diving birds. Additionally, it would be important to determine whether endangered or threatened seabirds may encounter an axial flow turbine based on their diving depth and guild.

Tidal turbines may also impact biological resources through a process called cavitation, which occurs behind tidal turbines in the water column. Cavitation occurs when the water pressure behind a device drops dramatically, causing small bubbles of water vapor to form, and travel to areas of higher pressure and then collapse. The collapse of cavitation bubbles sends shock waves through the water column, and can potentially harm marine species.[91] Cavitation is also undesirable for the device itself, reducing its efficiency and damaging device structures.[91] Although cavitation could cause serious impacts to biological resources, marine species may avoid the area due to the noise created by the collapse of water vapor bubbles. In addition, device developers have a financial incentive to ensure that cavitation does not occur, and to ensure the safety and efficiency of their device and associated equipment.[91]

Future Research Needs

- Research on how cetaceans, pinnipeds, seabirds, and fish interact with moving underwater structures.

5.5.11 Reciprocating Devices

Reciprocating devices may impact biological resources through a process called cavitation, which occurs behind reciprocating devices in the water column. Cavitation occurs when the water pressure behind a device drops dramatically, causing small bubbles of water vapor to form, and travel to areas of higher pressure and then collapse. The collapse of cavitation bubbles sends shock waves through the water column, and can potentially harm marine species.[91] Cavitation is also undesirable for the device itself, reducing its efficiency and damaging device structures.[91] Although cavitation could cause serious impacts to biological resources, marine species may avoid the area because of the noise created by the collapse of water vapor bubbles. In addition, device developers have a financial incentive to ensure that cavitation does not occur, and to ensure the safety and efficiency of their device and associated equipment.[91]

Future Research Needs

- Research on how cetaceans, pinnipeds, seabirds, and fish interact with moving underwater structures.
- Research on the effectiveness of using axial flow or cross flow turbines as a substitute when determining the environmental impacts of a reciprocating device.

5.5.12 Offshore Wind Turbines

Offshore wind turbines may impact marine birds and bats due to interactions with turbine blades. Impacts to birds due to collision vary based upon the type of bird and its flight pattern. A German study found that half of migratory bird flights are at heights that coincide with those of turbine rotor blades.[92] Birds at greatest risk for collision are wading birds and gulls, as they generally make daily migrations from their inland nesting sites to their coastal feeding grounds. Large birds such as swans and geese tend to be less maneuverable, and may be at greater risk of colliding with the turbine blades.[92] Additional birds at risk in California include pelicans, murres, murrelets, and shearwaters. Although there is a great deal of concern about the effects of offshore wind farms on seabirds, reductions in avian abundance caused by offshore wind development appears to be due to avoidance of the area rather than due to collision mortality.[93]

Bats are also at risk for collision with wind turbines. Hoary bats (*Lasiurus cinereus*) migrate across coastal areas and to offshore islands and may come into contact with offshore wind turbines.[94] Although bats and birds are often treated similarly in impact analyses, it is important to note that bats behave very differently than birds. Migrating bats are attracted to the structure of wind turbines and will actively investigate wind farms, a tendency which has not been demonstrated in birds. Bats, unlike birds, are also prone to depressurization injuries; however, it is still unclear whether bat mortalities due to wind turbines is caused by barotrauma, collision or some other interaction with the turbine.[92]

In addition to collision impacts, the foundations of offshore wind turbines will vibrate as the turbine operates, creating acoustics in the marine environment. In 2003, research was conducted in British Columbia on the behavioral responses of harbor porpoise and harbor seals to playback sounds of a 2 MW wind power generator. When exposed to wind turbine sounds, harbor porpoises significantly altered their surface and breathing patterns within 60 feet of the sound source. In addition, the number echolocation clicks emitted significantly increased in the presence of playback recordings, with echolocation clicks observed 19.6% of the time in comparison to 8.4% of the time when turbine sounds were not present. While schooling, a behavior interpreted as a fright response, has been observed in harbor porpoises in the presence of pingers associated with gill nets, this behavior was not observed in response to the playback sounds of wind turbines, and avoidance of the area was less intensive.[95]

In the presence of playback recordings of wind turbines, harbor seals significantly increased their surfacing distance from the sound source from 239 m to 284 m;[95] however, evidence from aquaculture operations have shown that harbor seals habituate to even highly aversive sounds. In addition, the low-frequency sounds produced by wind turbines may mask the low-frequency sounds produced by male harbor seals during the mating season, and therefore may negatively impact harbor seal reproduction.

The continued presence of harbor porpoises and harbor seals in close proximity to shipping lanes suggest that these species may become habituated to high sound energy levels, similar to those created by offshore wind turbines.[95] Since most information on the acoustic impacts of wind turbines comes from wind farms with 2-3 MW devices, continued monitoring is needed as more powerful and louder devices are installed.

Future Research Needs

- Research on the spatial distribution of seabirds, especially nesting sites.
- Research on how the movement of turbine blades affects bats and birds.
- Research on how static structures, such as monopiles, affect nearshore habitat.
- Research on how lighting associated with offshore wind farms affects bats and birds.

5.6 Cultural Resources and Tribal Uses

General Impacts

5.6.1 Cultural Sites

Siting MRE projects in areas with shipwrecks and other submerged cultural sites may cause impacts to cultural resources, and the best way to avoid impacts to cultural resources is to select a location without cultural sites nearby. Geophysical or bathymetric surveys could be used to identify unknown shipwrecks beyond the surf zone, and known locations of shipwrecks could be approximated by querying the California State Lands Commission's shipwrecks database. Surveys for cultural resources should occur prior to construction and ideally during project design.

5.6.2 Tribes and Tribal Communities

Projects located both nearshore and offshore may impact cultural resources and traditional activities of importance to California tribes and tribal communities. Since most MRE devices will require a buffer zone for safety, a MRE project may impact the ability for tribes and tribal communities to engage in subsistence gathering, access traditional foods, and engage in religious and spiritual activities. Consultation with tribal groups should occur as early as possible in the design and planning phase of a project to ensure appropriate siting of MRE devices. Tribal groups may need extra time to bring issues or documents to their governing bodies before responding to requests for information or providing comment on a project. Tribal groups may also have a deliberative political process which requires additional time for decision making. Building extra time into the planning process will facilitate better government to government consultation. The California Native American Heritage Commission is a resource to determine appropriate tribes and tribal communities to contact regarding a project.

Future Research Needs

- Spatial information on known locations of cultural resources.
- Research on how existing MRE projects work to manage conflicts with tribal groups.

5.7 Geology/Soils

General Impacts

5.7.1 Reduction in Wave Energy

Extracting energy from incoming waves may interfere with sediment transport in nearshore and shoreline areas. Waves control the morphology of beaches above and below the water level, as well as the sand barriers and spits at the mouths of estuaries and bays.[50] Beaches are able to respond and adjust to existing wave power and changes in wave power, making them effective methods of coastal defense. The most likely impact from a decrease in wave power would be changes in the profile of the beach.[50] The magnitude of longshore currents (currents that move parallel to shore) and sand-transport rates depend on wave height, and may be reduced by the presence of a WEC.[50] As a result, reduced sediment transport may reduce how often estuarine and lagoonal inlets along the coast become closed to the ocean.[50] Changes in wave refraction and shoaling would affect the angles at which the waves break on the beaches, also altering the nearshore currents and sand-transport rates. This may potentially produce significant shoreline changes, with erosion focused along some stretches of beach, and accumulation of eroded transported sand widening other stretches of beach.[5]

5.7.2 Reduction in Tidal Energy

Tidal turbines are expected to reduce current velocities both upstream and downstream of the devices and can lead to significant changes in sediment deposition patterns. Some sediment that is transported back and forth within the estuary daily with the tides would settle out of the water column because the tides would no longer have the energy to keep them suspended. Modeling done for Severen Estuary in Great Britain found that areas furthest away from the tidal turbine would experience the greatest decrease in suspended sediment. The model predicted that the largest decrease in suspended sediments occurred 6.21 miles downstream of the array, where less tidal energy existed at baseline conditions. [52] Because tidal turbines need to be located in areas of very high energy, the amount of suspended sediment would be greatest near the turbines.

Figure 5.7.1. New Energy Corporation's EnCurrent System in the Yukon Territory

Photo Credit: New Energy Corporation

5.7.3 Hard Structures and Mooring Lines

Building a seafloor foundation or anchoring mooring lines for a MRE project will disturb seafloor sediments and, potentially, benthic communities; however, previous research on the physical disturbance caused by burying electrical cables in soft-bottom habitat determined that there was no statistical difference between the abundance or composition of benthic communities before and a year after cable burial.[81] MRE developers in Oregon appear to prefer soft-substrate areas for development, and most of the research on changes in seafloor sediments focuses on soft-bottom habitats.

Placing a hard structure on the seafloor may also cause scour around the structure due to the changes in ocean currents and waves around the structure. Scouring may undermine the anchors or foundation of an MRE device. Information already exists for the littoral (sand transport) cells along the California coast, so it may be possible to model the potential for and intensity of scouring around hard structures before siting a project. In addition, if a large renewable energy device breaks loose of its moorings during a severe storm event, it may cause additional scouring as it moves along the bottom of the seafloor.[5] Project applicants should describe how they will prevent or avoid scouring, and provide a contingency plan in case the amount of scouring that occurs is excessive and the anchoring system or foundation requires modification.

Future Research Needs

- Research on how wave energy removal impacts seafloor sediment and shoreline sediment characteristics.
- Research on how tidal energy removal impacts seafloor sediment and shoreline sediment characteristics.
- Research on how static structures, such as monopiles, impact near-field habitat and sediment characteristics.

Technology-Specific Impacts

5.7.4 Oscillating Water Columns

Siting an OWC along the shore will change longshore sediment transport. Areas upcoast of the device will accumulate sediment, while areas downcoast of the device will erode. Generally, sand transport in California moves from north to south, with several exceptions.[96] For shore-based OWCs, potential impacts to the coastline could be approximated by considering the impacts of other coastal armoring.

Future Research Needs

- Research on how existing coastal armoring impacts sediment transport, and how sediment transport impacts may differ for OWCs.

5.7.5 Overtopping Devices

Siting an overtopping device along the shore will change longshore sediment transport. Sediment will accumulate upcoast of the device, and will erode downcoast of the device. Generally, sand transport in California moves from north to south, with several exceptions.[96] For shore-based overtopping devices, potential impacts to the coastline could be approximated by considering the impacts of other coastal armoring.

Future Research Needs

- Research on how existing coastal armoring impacts sediment transport, and how sediment transport impacts may differ for overtopping devices.

5.8 Hazards and Hazardous Materials

General Impacts

5.8.1 Reduction in Tidal Energy

The reduced flushing and movement of fine sediments may change the public's exposure to sediment-associated toxins, such as mercury. Reduced movement of fine sediments may allow more mercury to accumulate in the bottom sediments. When the sediments are disturbed, the mercury becomes methylated by microbes, and becomes available for uptake by marine species. San Francisco Bay is one area with enough tidal energy to be considered for an MHK project in California, which is currently listed for mercury impairment under the Clean Water Act. As a result, regulators should consider the impacts of a tidal project on mercury movement and settlement in San Francisco Bay, and other potential project areas, before approving a project.

5.8.2 Physical Hazards

MRE devices may cause hazards to navigators and the public due to the size of the devices. Larger projects may site multiple devices in the water at a density that would make navigating a vessel through the project area hazardous. For safety, MRE projects may exclude other uses related to boating and vessel travel in the area. If a collision between a vessel and a MRE device were to occur, vessel fuel or other hazardous chemicals could be released into the environment. In addition, shore-based or nearshore devices may be hazardous to the public due to their large size and dynamic movement. These devices will likely exclude other public uses, such as swimming and surfing, close to the project area.

5.8.3 Release of Antifouling Compounds and other Chemicals

The use of antifouling compounds, hydraulic fluids, and sacrificial anodes may expose the public and the environment to hazardous materials. A decrease in wave or current power on the lee side of a MRE device may prevent the natural dispersal of toxins from the area, leading to accumulation in the sediments and in marine life. The public may also potentially be exposed to these toxins from the consumption of fish or shellfish harvested from the area with reduced wave or current power. In addition, the public may be exposed to hydraulic fluids if a leak or spill was to occur and the fluid becomes a film on top of the water, potentially washing to shore.

Future Research Needs

- Research on how reducing tidal energy may alter water circulation and water quality.
- Research on how well current wave energy or tidal energy reduction models predict the actual wave energy or tidal energy reduction of a project.
- Research on how applicable hazardous materials impact nearby sediments.
- Spatial information on areas that are currently polluted and may require alternative antifouling coatings.

5.9 Hydrology/Water Quality

General Impacts

5.9.1 Reduction in Wave Energy

A reduction in wave height and wave power may result in less vertical mixing of the water column in the surf zone; reduced mixing may, in turn, result in water column stratification, a rise in sea surface temperatures, lowered surface salinity and increased retention of contaminants within the top layer of the water column.[5,50] High-energy surf is important for the mixing and dilution of pollutants that reach the nearshore, and also creates seaward rip currents that move the pollutants offshore. Reducing these high-energy conditions may increase the length of time pollutants stay in the nearshore area.

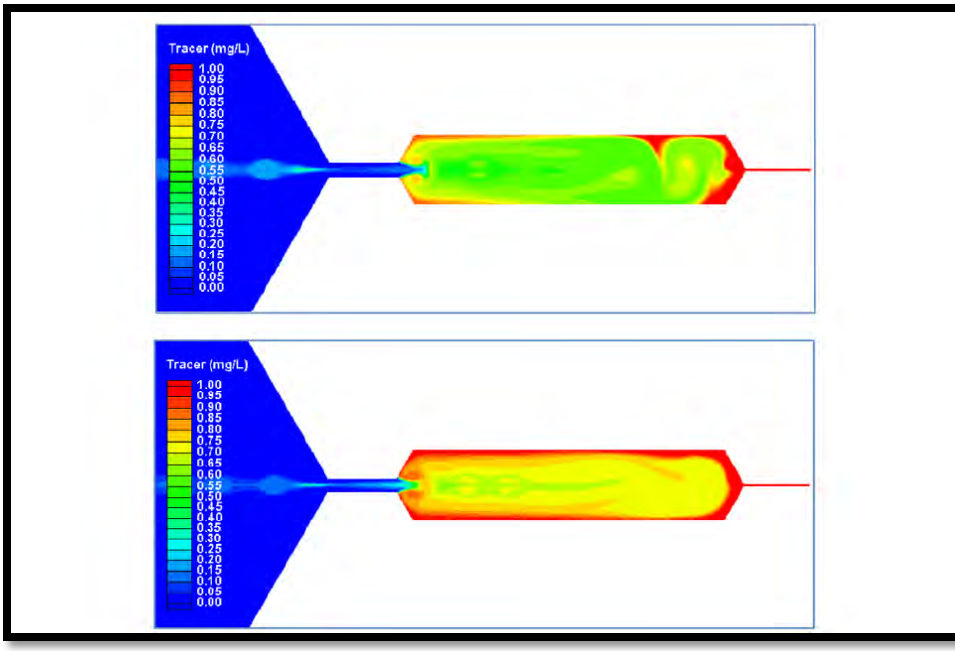
The presence of WECs may impact turbidity in nearby waters. Less turbidity on the shore side of the device will allow for a larger zone where light is present in the water column. More light in the water column will allow for greater algae growth, which may have additional indirect effects on the ecological systems of the project area.

5.9.2 Reduction in Tidal Energy

Theoretical models done by the PNNL can provide guidance regarding the changes in tidal current speeds and flushing when a tidal turbine is placed in a channel. The model was run for two scenarios, one with no turbine and one with 11,400 turbines in the model channel.[97] This is a much larger number of turbines than would be proposed for a tidal power project, and the natural configuration of real-world bays and channels is very different than that of the PNNL model; therefore, the results of the modeling should be considered only for general guidance. The model is useful for understanding the relationships between different natural processes, such as tidal flushing and pollutant residence time, when flow is reduced.

The model showed a reduction in tidal current from 4.3 m/s to 3.8 m/s, with the largest change occurring in the channel. [97] The PNNL team also modeled tidal amplitude, and found that the maximum amplitude decreased from 1.97 m for no turbines to 1.72 m with turbines, with the greatest change in amplitude at the end of the bay.[97] Finally, the PNNL team modeled the flushing of a tracer, a substance used to model and track chemical movement, in the bay. Please see Figure 5.9.1 for a diagram of the tracer model results. In the no turbine scenario, the tracer was flushed out in 45.4 days, which increased to 75.9 days with turbines.[97]

Figure 5.9.1. The Concentration of a Tracer in the Bay After 20 Days Without and With Turbines[97]



If a bay is already having difficulty flushing out toxins or nutrients, then regulators should consider the additional impacts of flushing when considering a tidal turbine project. Although the volume change was only reduced by 13% in this model, the flushing time for the tracer was increased by 67%.[97] The flushing time increases almost exponentially in comparison with reduction in flow; however, the flushing time appears to be more dependent upon the number of turbines than on the volume of the tidal change. In addition, reduced flushing is correlated with increased incidence of eutrophication, hypoxia, and fisheries failure.[97] When determining environmental impacts, managers could assume that pollutant residence time in a bay depends on the number of turbines in the water, which has an exponential relationship to flow reduction.

The fine sediments that settle out of the water column with the addition of tidal turbines will have implications for the fate and transport of sediment-associated metals, nutrients, and pathogens in the water column. For example, modeling performed by Kadiri *et al.* (2012) showed that there was a reduction in fecal indicator bacteria up to 15.5 miles downstream of a tidal turbine array, which is much further than their results for changes in suspended sediment. This indicates that bacteria are moving in the estuary through means other than the association with fine sediment, and the changes to movement of bacteria should be assessed separately from changes in suspended sediment.[52]

5.9.3 Tsunami Impacts

One specific requirement in CEQA under Hydrology and Water Quality is that agencies consider whether a project will be inundated by a tsunami, seiche, or 100-year flood. The technologies discussed within this document, whether they are floating and are secured with mooring lines or stand on seafloor foundations or pilings, are at risk from inundation by a tsunami. Tsunamis occur when a great body of water is displaced, usually by a landslide or an earthquake. In the open ocean, tsunami waves are small, but they become taller and larger as they encounter the shallow water along the coast. Since all of these MRE technologies must be secured to the seafloor to keep them in place, they will either be separated from their moorings during a tsunami event and continue to float in the ocean or they will remain connected to their moorings and become inundated. If a MRE device becomes separated from its moorings, the device may pose an additional safety hazard as components of the project are washed onto the coast. Many commercial-scale MRE devices are very large, and could cause significant damage to coastal structures if they are swept into the coast by a tsunami event. However, MRE technologies located further offshore, such as WECs and offshore wind turbines, are more likely to encounter smaller tsunami waves, and will be less likely to experience impacts from tsunami inundation. It is likely that regardless of which way the MRE structure responds to a tsunami, it will sustain damage from the event.

5.9.4 Release of Antifouling Compounds and Other Chemicals

Copper leaching is a well-known water quality problem in California. Copper leaching from antifouling compounds on vessels in areas of poor circulation in Southern California has caused water bodies to be listed on the State Water Resources Control Board's (SWRCB) 303(d) list. The list names bodies of water in California that do not meet the requirements of the Clean Water Act. The SWRCB must develop and implement plans to reduce the concentrations of pollutants in listed water bodies.[98] Since MRE projects may reduce wave, tidal, and current power, and thus circulation, they may contribute to water quality violations if a substantial amount of toxic metals are released into the water column from submerged infrastructure.

Although many of the water bodies on the list have unknown sources of heavy metals, adding additional sources through antifouling coatings and sacrificial anodes may prevent attainment of listed water bodies. Please see Appendix A for the marine water bodies listed in California due to pollution from copper and zinc; aluminum is not currently listed as a pollutant for marine water bodies on the SWRCB 303(d) list.

Alternative antifouling coatings may be preferable for projects proposed near or in an area of poor water quality due to antifouling or sacrificial anode metals. One product currently being used on U.S. Coast Guard vessels produces hydrogen peroxide in the presence of sunlight, and may be combined with up to 5% copper.[73] In comparison, traditional copper-based antifouling compounds contain 40-75% copper. Another option is a non-biocidal foul release coating, which prevents the adhesion of fouling organisms by providing a low-friction, ultra-smooth surface. These coatings do not prevent the establishment of fouling organisms, but make it easy to clean the organisms off by reducing their adhesion to the coated surface.[73]

Future Research Needs

- Research on how reducing wave energy impacts water circulation and water quality.
- Research on how reducing tidal energy impacts water circulation and water quality.
- Research on how well current wave energy or tidal energy reduction models predict the actual wave energy or tidal energy reduction of a project.

5.10 Land Use/Planning

General Impacts

CEQA requires that agencies consider whether a proposed project would conflict with existing general plans, local coastal plans, and other ordinances. As a result, proposed MRE project siting must consider California's network of Marine Protected Areas (MPAs), spatial fisheries management plans, such as groundfish conservation areas, and National Marine Sanctuaries (NMS), in addition to the location of shipping lanes and entrances to ports and harbors.

California's network of MPAs is an existing spatial plan within State waters that prohibits all activities that are not specifically allowed in the regulations. When the MPA regulations were drafted, MRE development was not considered among the allowable activities within an MPA. Therefore the construction and operation of a MRE project may conflict with an existing spatial plan if sited within a MPA.

Groundfish conservation areas are a Federal spatial plan managed by the Pacific Fishery Management Council. The groundfish conservation areas are one tool in a suite of management options to manage the 90 species of groundfish[x] that occur off the west coast.[99] Some of these groundfish conservation areas are also groundfish marine reserves, where no fishing activity is allowed to take place. These reserves are used to meet a number of fishery management objectives including stock rebuilding, enhancing long-term biological productivity, and assisting long-term economic production.[100] Since the Pacific Fishery Management Council may only regulate fishing activity, the groundfish conservation areas and groundfish marine reserves do not prohibit other types of activities, such as depositing dredged material or siting MRE projects. [100] Therefore, although MRE projects may be sited within a groundfish conservation area, if significant impacts to groundfish species are expected to occur, the MRE project may conflict with the objectives of the conservation area.

NMS are spatial areas that are designated by the Secretary of Commerce to protect areas of the marine environment with national significance. California has four NMS: the Channel Islands NMS, the Monterey Bay NMS, the Gulf of the Farallones NMS, and the Cordell Bank NMS.[101] Regulations for NMS differ by sanctuary; for example, some NMS prohibit oil and gas exploration and alteration of the seafloor.[102] Siting an MRE project with seafloor components in a NMS where alteration of the seafloor is prohibited may conflict with the existing NMS spatial plan, creating impacts to land use/planning.

The U.S. Coast Guard designates shipping lanes for vessels traveling to and from large ports, which are not likely to be compatible with MRE sites due to significant shipping traffic in the area. As a result, MRE projects sited in or near shipping lanes, and entrances to ports and harbors, may face restrictions or a more complicated permitting and leasing process.[103] For more information on the impacts of MRE siting near shipping lanes, please see Section 5.13.

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[x] The category of "groundfish" includes demersal fish such as rockfish, flatfish, roundfish, sharks and skates, and other demersal species.

5.11 Mineral Resources

General Impacts

A MRE project could potentially be sited in an area with existing mineral resources. Due to safety concerns, a MRE project may restrict uses related to extracting mineral resources from the project area. This could result in a loss of a known mineral resource of value to the people of California during the lifetime of the MRE project.

5.12 Noise

General Impacts

The amount of noise a MRE device makes has to do with its construction and components; devices that generate more power are not necessarily noisier. A commercial-scale MRE project may create a substantial increase in ambient noise levels above the levels existing without the project. Waves breaking on hard structures may create additional noise in the project vicinity than the natural condition of waves breaking on sandy beaches. Increased noise levels may only become significant to nearby communities if a large number of MRE devices are present. Noise generated by a pilot or demonstration project is not likely to be significant.

Figure 5.10.1. Aquamarine Power's Oyster in Operation

Image Credit: Aquamarine Power
The Oyster OWSC in operation

5.13 Public Services

General Impacts

Full-scale MRE projects may result in impacts to public services; however, pilot or demonstration projects are not expected to create significant impacts to public services due to their small size and power generating capacity.

As noted in Section 5.8, Hazards and Hazardous Materials, an array of MRE devices in the water may create new navigational hazards for vessels. As a result, additional navigational hazards may increase the need for Coast Guard and search and rescue services offshore. In addition, MRE projects may create an additional need for homeland security protection. The U. S. Department of Homeland Security has a sector devoted to protecting the energy sector. Presidential Policy Directive 21 identifies the energy sector as uniquely critical because it enables all other critical infrastructure sectors in the U. S. to function.[104] As MRE arrays are developed, they will require homeland security protection, like other power generation sources. Protecting new, offshore power generation sources may require additional resources from the Department of Homeland Security. As a result, a number of offshore MRE projects may increase the need for protection and may impact public services

5.14 Recreation

General Impacts

5.14.1 Siting Impacts

Not all MRE projects or devices will impact recreation. Some devices will be located too deep in the water column to impact recreation, while those located offshore are anticipated to have minimal impact. In addition, many MRE arrays will be sited with devices in a high enough density to eliminate the feasibility or safety of sailing vessels transiting through the area. As a result, siting a MRE project near shore may reduce areas for sailing, as well as other recreational opportunities, such as surfing, swimming, and diving, due to the safety dangers posed by their hard structures, moving parts, and size.

5.14.2 Electromagnetic Fields

Submarine power cables may impact recreationally valuable species, such as tuna and Dungeness crab (*Metacarcinus magister*), and thus impact recreational activities. Recreational fishing may be impacted near the cables, and if EMF causes significant changes in some species (i.e. salmon) migration behavior, recreational fishing upstream may be impacted as well.

Future Research Needs

- Spatial information on recreational activities currently taking place within State waters along the California coast
- Research on the impacts of EMF on recreationally valuable species.

5.15 Transportation/Traffic

General Impacts

MRE projects will change the way vessel traffic moves on the water. MRE devices and their infrastructure may create a navigational hazard for vessels, and therefore some vessels will be required to travel around an array of MRE devices rather than through the array. As mentioned in Section 5.8, Land Use/Planning, MRE projects should consider the location of shipping lanes, as well as the entrances to ports and harbors, when siting a project. Commercial shipping interests generally do not perceive a conflict between MRE development and their activities, as long as the shipping lanes remain unchanged. The shipping industry also uses lanes for towing to and from port using tugboats. These "tug lanes" are negotiated with crab fishermen to ensure that crab pots are not present in the lane. Although the shipping industry would like MRE projects to be sited away from tug lanes, they are willing to re-negotiate the location of the tug lanes with crab fishermen, if necessary. Outside of commercial shipping interests, the additional vessels used to service a MRE project may increase boat traffic and cause congestion near the project site and near the port used for maintenance.

5.16 Utilities/Service Systems

General Impacts

The addition of a commercial scale MRE project is likely to require the installation of additional electrical transmission infrastructure, and may require additional construction by electric utilities to accommodate the electricity generated from the project. Impacts to electric utilities are unlikely during the pilot and demonstration phase of a project.

6 Research Needs

While future research needs have been briefly mentioned throughout this report, this section summarizes what research needs still exist, and provides information on MRE research currently underway. Pacific Energy Ventures produced a report to prioritize the most important information and monitoring for MRE projects; the report was broken down into priorities for wave, tidal and offshore wind energy. In general, they found that:

- Impacts of electromagnetic fields (EMF) to elasmobranchs were high priority for all three types of energy;
- Impacts of static devices to near-field habitat, ecosystem interactions, and cetaceans were high priority for two out of three MRE technologies (wave energy and offshore wind); and
- Impacts of moving devices to cetaceans were high priority for two out of three MRE devices (wave energy and tidal energy).

Table 6.1.1 summarizes the research needs identified in this report, in combination with those mentioned in Pacific Energy Ventures' report. For more detail regarding monitoring and research priorities, please see the West Coast Environmental Protocols Framework by Pacific Energy Ventures, cited in the "Further Readings" section.

Table 6.1.1. Summary of Research Needs Identified in this Report

Research Need	Impact Category/Applicable Technology
How wave farms alter the structure of the water column, including variations in temperature and salinity	• Aquaculture and Fisheries • Biological Resources • All wave energy devices
How reducing wave energy or tidal energy may alter water circulation and water quality	• Aquaculture and Fisheries • Biological Resources • Hazards and Hazardous Materials • Hydrology and Water Quality • All wave and tidal energy devices
Spatial information on commercial fishing activities currently taking place within State waters	• Aquaculture and Fisheries • All MRE devices
How existing MRE projects work to manage conflicts with commercial fishermen	• Aquaculture and Fisheries • All MRE devices
Research on how well current wave energy or tidal energy reduction models predict the actual wave or tidal energy reduction of a project	• Aquaculture and Fisheries • Biological Resources • Hazards and Hazardous Materials • Hydrology and Water Quality • All wave and tidal energy devices
How wave-induced disturbance varies across areas with different wave energy exposures	• Biological Resources • Wave energy devices
Ecosystem impacts of artificial reefs to resident and migratory fishes in areas with soft-bottom habitat	• Biological Resources • All MRE devices
How static, hard structures impact near-field habitat and sediment characteristics	• Biological Resources • Geology/Soils • All MRE devices
How static, hard structures, especially mooring lines, impact sea turtles, cetaceans, pinnipeds, mustelids, and marine birds	• Biological Resources • All MRE devices

Research Need	Impact Category/Applicable Technology
Determine which mooring line designs reduce the risk of entanglement	• Biological Resources • All wave energy devices
How moving underwater structures interact with and impacts sea turtles, cetaceans, pinnipeds, mustelids, and marine birds	• Biological Resources • All tidal energy devices • Overtopping devices • OWSCs • Attenuators • Point Absorbers
Which species are most vulnerable to collision or other negative interactions with moving underwater structures	• Biological Resources • All tidal energy devices • Overtopping devices • OWSCs • Attenuators • Point Absorbers
How EMF impacts ecosystem interactions, benthic invertebrates, resident and migratory fishes, elasmobranchs, and juvenile and adult turtle species	• Biological Resources • Recreation • All MRE devices
How sounds and vibrations from MRE devices impact marine organisms	• Biological Resources • All MRE devices
How pressure changes in or near OWCs and the impacts of rapid pressure change on marine species	• Biological Resources • OWCs
The rate of entrapment or impingement in MRE devices and potential impacts to marine species	• Biological Resources • OWCs • Overtopping Devices
The effectiveness of using axial flow or cross flow turbines as a substitute when determining environmental impacts of a reciprocating device	• All resource categories • Reciprocating devices
The spatial distribution of seabirds, especially nesting sites	• Biological Resources • Offshore wind turbines
How the movement of wind turbine blades and lighting associated with offshore wind farms affect bats and birds	• Biological Resources • Offshore wind turbines
Spatial information on known locations of cultural resources	• Cultural Resources • All MRE devices
Research on how existing MRE projects work to manage conflicts with tribal groups	• Cultural Resources • All MRE devices
How wave and tidal energy removal impacts seafloor and shoreline sediment characteristics	• Geology/Soils • All MRE devices
How existing coastal armoring impacts sediment transport, and how shore-based sediment transport impacts differ	• Geology/Soils • OWCs • Overtopping devices
How hazardous materials associated with MRE projects impact nearby sediments	• Hazards and Hazardous Materials • All MRE devices
Spatial information on areas that are currently polluted and may require alternative antifouling coatings	• Hazards and Hazardous Materials • All MRE devices
Spatial information on recreational activities currently taking place within State waters along the California coast	• Recreation • All MRE devices

The Bureau of Ocean Energy Management (BOEM), a Federal agency with leasing authority over Federal waters, has committed to performing ongoing research of the Outer Continental Shelf (OCS) to inform their leasing decisions. BOEM is interested in funding research to inform MRE development on the OCS. Selected studies of potential use for the State include:

Table 6.1.2. Ongoing BOEM-funded Studies for MRE

Name	Study Number	Final Report Due
Inventory and Analysis of Coastal and Submerged Archeological Site Occurrence on the Pacific OCS	PC-11-01	August 2013
Nocturnal Surveys for Ashy Storm-Petrels and Xantus's Murrelets at Offshore Oil Production Platforms, Southern California	PC-12-04	September 2014
Renewable Energy *in situ* Power Cable Observation	PC-11-03	2015
Survey of Benthic Communities Near Potential Renewable Energy Sites Offshore the Pacific Northwest[xi]	PC-10-07	March 2014
Characterizing and Quantifying Sea Lion and Seal Use of Offshore Manmade Structures off California	PC-12-06	2014
Seabird and Marine Mammal Surveys off the Northern California, Oregon and Washington Coasts	PC-10-05	2013
Developing and Applying a Vulnerability Index for Scaling the Possible Adverse Effects of Offshore Renewable Energy Projects on Seabirds of the Pacific OCS	PC-12-01	Unknown
Department of Interior (DOI) Partnership: Distinguishing between Human and Natural Causes of Changes in Nearshore Ecosystems Using Long-term Data from DOI Monitoring Programs	PC-11-02	2013
Oregon Marine Renewable Energy Science Conference	PC-12-x11	2013
Renewable Energy Visual Evaluations	PC-10-08	September 2013

Research on environmental impacts and MRE is advancing rapidly. A number of online resources, such as the Tethys database, are designed to keep up with advances in research; these online resources are listed in the "Further Readings" section.

[xi] Includes northern California

7 Moving Forward

In the future, shifting to a more proactive approach towards MRE projects and potential environmental impacts will benefit the public, the State, and project proponents. Efforts by the State of Oregon exemplify an effective approach to collaboratively developing MRE. The State of Oregon chose to become a leader in MRE development through designating wave energy as an emerging industry, and recommending an investment of Oregon State Lottery funds in wave energy production incentives and investments. Some of these funds were used to form a public-private partnership called the Oregon Wave Energy Trust (OWET), which promoted the responsible development of ocean energy in Oregon. OWET has acted as a connector for all stakeholders involved in wave energy development and brought a wave energy developer to the State by offering a $200,000 matching grant for permitting and planning expenses to the developer. OWET went on to promote stakeholder outreach, develop a regulatory map and determine uncertainties, and conduct initial environmental research.

Oregon's proactive work on MRE development provided benefits to the public by adding a new source of green energy to the State's energy mix and engaging members of the public early in the process to educate them about the project and receive input. Oregon's approach was also valuable for the project proponent by determining exactly where there was uncertainty in the project design so research could be conducted to reduce such uncertainties. Finally, Oregon's approach provided value to the State by producing environmental data that can be used when determining the impacts of future MRE projects.

Taking a proactive approach towards MRE development, like the work done by Oregon, will enable more intelligent siting and the potential for fewer environmental impacts from MRE technology. Agencies should prioritize future research needs by addressing data gaps that can be broadly applied to many MRE technologies. Prioritizing research to answer general questions will provide the greatest return on investment, and is less likely to create preferential treatment toward any single type of technology. With some planning and research, MRE has the potential to be an environmentally responsible, local, electricity source for the State of California.

8 Further Readings

Electromagnetic Fields

Normandeau, Exponent, T. Tricas, and A. Gill. 2011. *Effects of EMFs from Undersea Power Cables on Elasmobranchs and Other Marine Species.* U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Pacific OCS Region, Camarillo, CA. OCS Study BOEMRE 2011-09. Available at: http://www.gomr.boemre.gov/PI/PDFImages/ESPIS/4/5115.pdf

Data Gaps and Monitoring Protocols

Pacific Energy Ventures. 2012. *West Coast Environmental Protocols Framework: Baseline and Monitoring Studies.* BOEM Contract Number: M10PC00092. Available at: http://www.oceanrenewableenergy.com/sites/default/files/file_uploads/Environmental%20Protocols%20Framework_FINAL%20REPORT.pdf

Web Resources

Cape Wind Final Environmental Impact Statement: The Final EIS for the United States' first offshore wind farm in Massachusetts. The EIS may include studies or analyses of interest. Web address: http://www.boem.gov/Renewable-Energy-Program/Studies/Cape-Wind-FEIS.aspx

Ocean Renewable Energy: A website run by Pacific Energy Ventures, a firm that has done consulting work with BOEM and the Oregon Wave Energy Trust. The site is periodically updated to synthesize new information on environmental impacts of wave energy; the site also includes a list of sources. Web address: http://www.oceanrenewableenergy.com/content/west-coast-wave

Snohomish Public Utility District's FERC Application: Application to place an OpenHydro tidal turbine in Admiralty Inlet, Puget Sound. Application includes modeling and studies of interest, including: an environmental report, an orca collision analysis, and benthic habitat monitoring plan, a derelict gear monitoring plan, and detection of tidal turbine noise. Web address: http://www.snopud.com/PowerSupply/tidal/aifinalapp.ashx?p=2030

Tethys: An online database of academic and government research regarding marine renewable energy. Tethys is managed by the US Department of Energy's Wind and Water Power Program. Web address: http://mhk.pnnl.gov/wiki/index.php/Browse_Knowledge_Base

9 Glossary

Alternating Current One of two types of power cables used to power electricity from an offshore energy project to shore. Alternating current cable systems require three cables to transport electricity, and are the current industry standard.

Ampullae of Lorenzini A sensory system unique to elasmobranch fishes (sharks and rays) and holocephali ratfishes that detects electrical fields and is used to locate prey just below the seafloor.

Anadromous Fish A species that spends most of its life in the sea and returns to freshwater to spawn (i.e., salmon, shad, smelt, striped bass, and sturgeon).

Attenuator A long, linear wave energy converter with its principle axis parallel to incoming waves, which cause articulated components of the device to bend and activate a hydraulic system connected to an electric generator.

Axial Flow Turbine A tidal energy device oriented in the direction of the water current or tide, and typically has two or three blades mounted on a horizontal shaft to form a rotor. The kinetic motion of the water current or tide creates lift on the blades and causes the rotor to turn, which drives a mechanical generator.

California Environmental Quality Act (Pub. Resources Code,§21000 et seq.) Requires California public agencies to consider the environmental impacts of the projects they fund or authorize. In accordance with both CEQA and the State CEQA Guidelines (Cal. Code Regs., tit. 14, §15000 et seq.), agencies analyze potential impacts to a number of different resource "categories" (e.g., Air Quality, Biological Resources, Cultural Resources, etc.) and, in some cases, identify and evaluate alternatives to proposed projects. If the analysis identifies significant environmental impacts, agencies must then identify and require measures to reduce or avoid those impacts, if feasible.

Carbon Dioxide Equivalent (CO_2-e) A term referring to the amount of greenhouse gasses released by an activity. If an activity releases methane, the methane's ability to trap heat would be converted into the amount of carbon dioxide required to trap the same amount of heat. The amount of greenhouse gasses released would then be expressed in carbon dioxide equivalent.

Cavitation Occurs when the water pressure behind a turbine drops dramatically, causing small bubbles of water vapor to form, travel to areas of higher pressure, and collapse. The collapse of cavitation bubbles sends shock waves through the water column and can harm marine species.

Cetacean A collective term for marine mammals commonly known as whales, dolphins, and porpoises in the order Cetacea.

Cross Flow Turbine A tidal energy device that can capture energy from water currents and tides from multiple directions, and typically has two or three blades mounted on a horizontal shaft to form a rotor. The kinetic motion of the water current or tide creates lift on the blades and causes the rotor to turn, which drives a mechanical generator.

Crustacean A collective term for a large group of arthopods, which includes animals such as crabs, lobsters, crayfish, shrimp, krill, and barnacles.

Direct Current One of two types of power cables used to power electricity from an offshore energy project to shore. Direct current cable systems are able to carry power over long distances using only two cables, and have lower power losses in comparison to an alternating current cable system, which requires three cables to transport electricity.

Elasmobranchs A collective term for sharks, skates, and rays.

Electromagnetic Field A property of space caused by the mutual interaction of electric fields (stationary charges) and magnetic fields (moving charges or currents) that may be found around MRE devices and power cables.

Eutrophication The enrichment of an ecosystem with chemical nutrients, typically compounds containing nitrogen and/or phosphorus.

Fouling (biofouling) The accumulation of microorganisms, plants, algae, or animals on surfaces in contact with the water, including ships and underwater structures.

Hypoxia The condition in which dissolved oxygen is below the level necessary to sustain most animal life in an area.

Kinetic Energy The energy of motion.

Littoral Zone The shallow area of seafloor closest to land that lies between the highest high and lowest low tides.

Marine Hydrokinetic Device or Technology Refers to technologies that generate energy from the movement of ocean waves, tides, and currents.

Marine Renewable Energy Technology Refers to all types of marine renewable energy including wave, tidal and current, and offshore wind technologies.

Marine Protected Area Discrete geographic marine or estuarine areas seaward of the mean high tide line or the mouth of a coastal river, including any area of intertidal or subtidal terrain, together with its overlying water and associated flora and fauna, that have been designated by law or administrative action to protect or conserve marine life and habitat.

Mustelids A collective term for members of the family Mustelidae (commonly referred to as the weasel family), which includes sea otters.

Offshore Wind Turbine A marine renewable energy device that generates electricity from offshore wind.

Oscillating Water Column A partially submerged wave energy converter that encloses a column of air above the surface of the water. The waves are funneled into the structure below the waterline, causing the water column to rise and fall, which acts as a piston, pressurizing and depressurizing the air column to spin a turbine.

Oscillating Wave Surge Converter A wave energy converter that captures mechanical energy by using the relative motion between a float, flap, or membrane and a fixed reaction point.

Overtopping Device A partially submerged wave energy converter with a design that funnels waves over the top of the structure into a reservoir; the water then runs back out to sea from the reservoir through a turbine.

Phytoplankton Single- celled algae that form the base of the marine food web.

Pinniped A collective term for marine mammals comprising the families Odobenidae (i.e., walruses), Otariidae (i.e., sea lions, fur seals), and Phocidae (i.e., true seals).

Point Absorber A wave energy converter that moves on the surface of the water like a buoy, and its movement is used to generate energy.

Reciprocating Device A tidal energy device that uses the flow of water to produce lift or drag of an oscillating part of the device, which produces mechanical energy that feeds into a power conversion system.

Sacrificial Anodes Highly active metals attached to objects, such as vessels or underwater structures, to prevent the object from corroding.

State Waters Territorial waters subject to state jurisdiction extending from the mean high tide line to three nautical miles offshore.

Tidal Energy Converter Refers only to devices that generate energy from tidal flow including axial flow turbines, cross flow turbines, and reciprocating devices. Many of these devices can also be modified or used directly to generate energy from ocean currents.

Wave Energy Converter Refers only to devices or technologies that generate energy from the movement of ocean waves, including point absorbers, attenuators, overtopping devices, oscillating water columns, and oscillating wave surge converters.

10 Appendix A: Impaired Marine Water Bodies due to Copper & Zinc

Water Body Name	Pollutant	Estimated Size Affected	Unit	Water Body Type	Potential Sources
Stege Marsh	Copper	29.2108	Acres	Estuary	Source Unknown
Calleguas Creek Reach 1 (was Mugu Lagoon on 1998 303(d) list)	Copper	343.791	Acres	Estuary	Point Source
Los Angeles Harbor - Fish Harbor	Copper	91	Acres	Bay & Harbor	Source Unknown
Los Angeles/Long Beach Inner Harbor	Copper	3003	Acres	Bay & Harbor	Source Unknown
Los Cerritos Channel	Copper	30.5	Acres	Wetland, Tidal	Nonpoint Source
Bolsa Chica State Beach	Copper	2.64146	Miles	Coastal & Bay Shoreline	Source Unknown
Huntington Harbour	Copper	220.90351	Acres	Bay & Harbor	Source Unknown
Newport Bay, Lower (entire lower bay, including Rhine Channel, Turning Basin and South Lido Channel to east end of H-J Moorings)	Copper	767	Acres	Bay & Harbor	Source Unknown
Newport Bay, Upper (Ecological Reserve)	Copper	652.915	Acres	Estuary	Source Unknown
Rhine Channel	Copper	20	Acres	Bay & Harbor	Source Unknown
Dana Point Harbor	Copper	119.465	Acres	Bay & Harbor	Marinas and Recreational Boating
Mission Bay at Quivira Basin	Copper	65	Acres	Bay & Harbor	Unknown Nonpoint Source
Oceanside Harbor	Copper	52.21	Acres	Bay & Harbor	Unknown Nonpoint Source
San Diego Bay Shoreline, Chula Vista Marina	Copper	0.407938	Miles	Coastal & Bay Shoreline	Source Unknown
San Diego Bay Shoreline, at Americas Cup Harbor	Copper	88	Acres	Bay & Harbor	Source Unknown
San Diego Bay Shoreline, at Coronado Cays	Copper	47	Acres	Bay & Harbor	Source Unknown
San Diego Bay Shoreline, at Glorietta Bay	Copper	52	Acres	Bay & Harbor	Source Unknown
San Diego Bay Shoreline, at Harbor Island (East Basin)	Copper	73	Acres	Bay & Harbor	Source Unknown
San Diego Bay Shoreline, at Harbor Island (West Basin)	Copper	131.947	Acres	Bay & Harbor	Source Unknown

San Diego Bay Shoreline, at Marriott Marina	Copper	24	Acres	Bay & Harbor	Source Unknown
San Diego Bay Shoreline, between Sampson and 28th Streets	Copper	53	Acres	Bay & Harbor	Point Source
Oakland Inner Harbor (Pacific Dry-dock Yard 1 Site, part of SF Bay, Lower)	Copper (sediment)	1.77713	Acres	Bay & Harbor	Source Unknown
Los Angeles Harbor - Consolidated Slip	Copper (sediment)	36	Acres	Bay & Harbor	Nonpoint Source
Marina del Rey Harbor - Back Basins	Copper (sediment)	390.91	Acres	Bay & Harbor	Nonpoint Source
San Diego Bay, Shelter Island Yacht Basin	Copper, Dissolved	154	Acres	Bay & Harbor	Point Source
Stege Marsh	Zinc	29.2108	Acres	Estuary	Source Unknown
Calleguas Creek Reach 1 (was Mugu Lagoon on 1998 303(d) list)	Zinc	343.791	Acres	Estuary	Source Unknown
Los Angeles Harbor - Fish Harbor	Zinc	91	Acres	Bay & Harbor	Source Unknown
Los Angeles/Long Beach Inner Harbor	Zinc	3003	Acres	Bay & Harbor	Source Unknown
Los Cerritos Channel	Zinc	30.5	Acres	Wetland, Tidal	Nonpoint Source
Rhine Channel	Zinc	20	Acres	Bay & Harbor	Source Unknown
Dana Point Harbor	Zinc	119.465	Acres	Bay & Harbor	Source Unknown
San Diego Bay Shoreline, between Sampson and 28th Streets	Zinc	53	Acres	Bay & Harbor	Unknown Nonpoint Source
Mission Creek	Zinc (sediment)	8.45275	Acres	Estuary	Industrial Point Sources
Oakland Inner Harbor (Pacific Dry-dock Yard 1 Site, part of SF Bay, Lower)	Zinc (sediment)	1.77713	Acres	Bay & Harbor	Source Unknown
San Leandro Bay (part of SF Bay, Lower)	Zinc (sediment)	588.324	Acres	Bay & Harbor	Source Unknown
Colorado Lagoon	Zinc (sediment)	13.23	Acres	Wetland, Tidal	Nonpoint Source
Dominguez Channel Estuary (unlined portion below Vermont Ave)	Zinc (sediment)	140	Acres	Estuary	Point Source
Los Angeles Harbor - Consolidated Slip	Zinc (sediment)	36	Acres	Bay & Harbor	Nonpoint Source
Marina del Rey Harbor - Back Basins	Zinc (sediment)	390.91	Acres	Bay & Harbor	Nonpoint Source

11 Appendix B: Theoretical Tidal Energy Resources in California

Location	Width (m)	Maximum Depth (m)	Mean Depth (m)	Maximum Power (MW)
San Diego Bay	1124	3.9	3.0	3
Tomales Bay	673	1.6	1.5	3
Heckman Island	439	7.9	7.8	6
Humboldt Bay	663	7.9	7.8	14
San Francisco Bay Entrance	3943	51.3	30.7	178

12 Appendix C: CEQA Environmental Checklist

CEQA Environmental Checklist

PROJECT DESCRIPTION AND BACKGROUND

Project Title:	
Lead agency name and address:	
Contact person and phone number:	
Project Location:	
Project sponsor's name and address:	
General plan description:	
Zoning:	
Description of project: (Describe the whole action involved, including but not limited to later phases of the project, and any secondary, support, or off-site features necessary for its implementation.)	
Surrounding land uses and setting; briefly describe the project's surroundings:	
Other public agencies whose approval is required (e.g. permits, financial approval, or participation agreements):	

ENVIRONMENTAL FACTORS POTENTIALLY AFFECTED:

The environmental factors checked below would be potentially affected by this project. Please see the checklist beginning on page 3 for additional information.

☐	Aesthetics	☐	Agriculture and Forestry	☐	Air Quality
☐	Biological Resources	☐	Cultural Resources	☐	Geology/Soils
☐	Greenhouse Gas Emissions	☐	Hazards and Hazardous Materials	☐	Hydrology/Water Quality
☐	Land Use/Planning	☐	Mineral Resources	☐	Noise
☐	Population/Housing	☐	Public Services	☐	Recreation
☐	Transportation/Traffic	☐	Utilities/Service Systems	☐	Mandatory Findings of Significance

DETERMINATION:

On the basis of this initial evaluation:

☐	I find that the proposed project COULD NOT have a significant effect on the environment, and a NEGATIVE DECLARATION will be prepared.
☐	I find that although the proposed project could have a significant effect on the environment, there will not be a significant effect in this case because revisions in the project have been made by or agreed to by the project proponent. A MITIGATED NEGATIVE DECLARATION will be prepared.
☐	I find that the proposed project MAY have a significant effect on the environment, and an ENVIRONMENTAL IMPACT REPORT is required.
☐	I find that the proposed project MAY have a "potentially significant impact" or "potentially significant unless mitigated" impact on the environment, but at least one effect 1) has been adequately analyzed in an earlier document pursuant to applicable legal standards, and 2) has been addressed by mitigation measures based on the earlier analysis as described on attached sheets. An ENVIRONMENTAL IMPACT REPORT is required, but it must analyze only the effects that remain to be addressed.
☐	I find that although the proposed project could have a significant effect on the environment, because all potentially significant effects (a) have been analyzed adequately in an earlier EIR or NEGATIVE DECLARATION pursuant to applicable standards, and (b) have been avoided or mitigated pursuant to that earlier EIR or NEGATIVE DECLARATION, including revisions or mitigation measures that are imposed upon the proposed project, nothing further is required

Signature:	**Date:**
Printed Name:	**For:**

CEQA Environmental Checklist

Dist.-Co.-Rte.	P.M/P.M.	E.A.

This checklist identifies physical, biological, social and economic factors that might be affected by the proposed project. In many cases, background studies performed in connection with the projects indicate no impacts. A NO IMPACT answer in the last column reflects this determination. Where there is a need for clarifying discussion, the discussion is included either following the applicable section of the checklist or is within the body of the environmental document itself. The words "significant" and "significance" used throughout the following checklist are related to CEQA, not NEPA, impacts. The questions in this form are intended to encourage the thoughtful assessment of impacts and do not represent thresholds of significance.

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
I. AESTHETICS: Would the project:				
a) Have a substantial adverse effect on a scenic vista	☐	☐	☐	☐
b) Substantially damage scenic resources, including, but not limited to, trees, rock outcroppings, and historic buildings within a state scenic highway	☐	☐	☐	☐
c) Substantially degrade the existing visual character or quality of the site and its surroundings?	☐	☐	☐	☐
d) Create a new source of substantial light or glare which would adversely affect day or nighttime views in the area?	☐	☐	☐	☐
II. AGRICULTURE AND FOREST RESOURCES: In determining whether impacts to agricultural resources are significant environmental effects, lead agencies may refer to the California Agricultural Land Evaluation and Site Assessment Model (1997) prepared by the California Dept. of Conservation as an optional model to use in assessing impacts on agriculture and farmland. In determining whether impacts to forest resources, including timberland, are significant environmental effects, lead agencies may refer to information compiled by the California Department of Forestry and Fire Protection regarding the state's inventory of forest land, including the Forest and Range Assessment Project and the Forest Legacy Assessment Project; and the forest carbon measurement methodology provided in Forest Protocols adopted by the California Air Resources Board. Would the project:				
a) Convert Prime Farmland, Unique Farmland, or Farmland of Statewide Importance (Farmland), as shown on the maps prepared pursuant to the Farmland Mapping and Monitoring Program of the California Resources Agency, to non-agricultural use?	☐	☐	☐	☐
b) Conflict with existing zoning for agricultural use, or a Williamson Act contract?	☐	☐	☐	☐

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
c) Conflict with existing zoning for, or cause rezoning of, forest land (as defined in Public Resources Code section 12220(g)), timberland (as defined by Public Resources Code section 4526), or timberland zoned Timberland Production (as defined by Government Code section 51104(g))?	☐	☐	☐	☐
d) Result in the loss of forest land or conversion of forest land to non-forest use?	☐	☐	☐	☐
e) Involve other changes in the existing environment which, due to their location or nature, could result in conversion of Farmland, to non-agricultural use or conversion of forest land to non-forest use?	☐	☐	☐	☐
	☐	☐	☐	☐
III. AIR QUALITY: Where available, the significance criteria established by the applicable air quality management or air pollution control district may be relied upon to make the following determinations. Would the project:				
a) Conflict with or obstruct implementation of the applicable air quality plan?	☐	☐	☐	☐
b) Violate any air quality standard or contribute substantially to an existing or projected air quality violation?	☐	☐	☐	☐
c) Result in a cumulatively considerable net increase of any criteria pollutant for which the project region is non- attainment under an applicable federal or state ambient air quality standard (including releasing emissions which exceed quantitative thresholds for ozone precursors)?	☐	☐	☐	☐
d) Expose sensitive receptors to substantial pollutant concentrations?	☐	☐	☐	☐
e) Create objectionable odors affecting a substantial number of people?	☐	☐	☐	☐
IV. BIOLOGICAL RESOURCES: Would the project:				
a) Have a substantial adverse effect, either directly or through habitat modifications, on any species identified as a candidate, sensitive, or special status species in local or regional plans, policies, or regulations, or by the California Department of Fish and Game or U.S. Fish and Wildlife Service?	☐	☐	☐	☐
b) Have a substantial adverse effect on any riparian habitat or other sensitive natural community identified in local or regional plans, policies, regulations or by the California Department of Fish and Game or US Fish and Wildlife Service?	☐	☐	☐	☐

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
c) Have a substantial adverse effect on federally protected wetlands as defined by Section 404 of the Clean Water Act (including, but not limited to, marsh, vernal pool, coastal, etc.) through direct removal, filling, hydrological interruption, or other means?	☐	☐	☐	☐
d) Interfere substantially with the movement of any native resident or migratory fish or wildlife species or with established native resident or migratory wildlife corridors, or impede the use of native wildlife nursery sites?	☐	☐	☐	☐
e) Conflict with any local policies or ordinances protecting biological resources, such as a tree preservation policy or ordinance?	☐	☐	☐	☐
f) Conflict with the provisions of an adopted Habitat Conservation Plan, Natural Community Conservation Plan, or other approved local, regional, or state habitat conservation plan?	☐	☐	☐	☐

V. CULTURAL RESOURCES: Would the project:

a) Cause a substantial adverse change in the significance of a historical resource as defined in §15064.5?	☐	☐	☐	☐
b) Cause a substantial adverse change in the significance of an archaeological resource pursuant to §15064.5?	☐	☐	☐	☐
c) Directly or indirectly destroy a unique paleontological resource or site or unique geologic feature?	☐	☐	☐	☐
d) Disturb any human remains, including those interred outside of formal cemeteries?	☐	☐	☐	☐

VI. GEOLOGY AND SOILS: Would the project:

a) Expose people or structures to potential substantial adverse effects, including the risk of loss, injury, or death involving:	☐	☐	☐	☐
i) Rupture of a known earthquake fault, as delineated on the most recent Alquist-Priolo Earthquake Fault Zoning Map issued by the State Geologist for the area or based on other substantial evidence of a known fault? Refer to Division of Mines and Geology Special Publication 42?	☐	☐	☐	☐
ii) Strong seismic ground shaking?	☐	☐	☐	☐
iii) Seismic-related ground failure, including liquefaction?	☐	☐	☐	☐

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
iv) Landslides?	☐	☐	☐	☐
b) Result in substantial soil erosion or the loss of topsoil?	☐	☐	☐	☐
c) Be located on a geologic unit or soil that is unstable, or that would become unstable as a result of the project, and potentially result in on- or off-site landslide, lateral spreading, subsidence, liquefaction or collapse?	☐	☐	☐	☐
d) Be located on expansive soil, as defined in Table 18-1-B of the Uniform Building Code (1994), creating substantial risks to life or property?	☐	☐	☐	☐
e) Have soils incapable of adequately supporting the use of septic tanks or alternative waste water disposal systems where sewers are not available for the disposal of waste water?	☐	☐	☐	☐

VII. GREENHOUSE GAS EMISSIONS: Would the project:

a) Generate greenhouse gas emissions, either directly or indirectly, that may have a significant impact on the environment?

b) Conflict with an applicable plan, policy or regulation adopted for the purpose of reducing the emissions of greenhouse gases?

An assessment of the greenhouse gas emissions and climate change is included in the body of environmental document. While Caltrans has included this good faith effort in order to provide the public and decision-makers as much information as possible about the project, it is Caltrans determination that in the absence of further regulatory or scientific information related to GHG emissions and CEQA significance, it is too speculative to make a significance determination regarding the project's direct and indirect impact with respect to climate change. Caltrans does remain firmly committed to implementing measures to help reduce the potential effects of the project. These measures are outlined in the body of the environmental document.

VIII. HAZARDS AND HAZARDOUS MATERIALS: Would the project:

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
a) Create a significant hazard to the public or the environment through the routine transport, use, or disposal of hazardous materials?	☐	☐	☐	☐
b) Create a significant hazard to the public or the environment through reasonably foreseeable upset and accident conditions involving the release of hazardous materials into the environment?	☐	☐	☐	☐
c) Emit hazardous emissions or handle hazardous or acutely hazardous materials, substances, or waste within one-quarter mile of an existing or proposed school?	☐	☐	☐	☐

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
d) Be located on a site which is included on a list of hazardous materials sites compiled pursuant to Government Code Section 65962.5 and, as a result, would it create a significant hazard to the public or the environment?	☐	☐	☐	☐
e) For a project located within an airport land use plan or, where such a plan has not been adopted, within two miles of a public airport or public use airport, would the project result in a safety hazard for people residing or working in the project area?	☐	☐	☐	☐
f) For a project within the vicinity of a private airstrip, would the project result in a safety hazard for people residing or working in the project area?	☐	☐	☐	☐
g) Impair implementation of or physically interfere with an adopted emergency response plan or emergency evacuation plan?	☐	☐	☐	☐
h) Expose people or structures to a significant risk of loss, injury or death involving wildland fires, including where wildlands are adjacent to urbanized areas or where residences are intermixed with wildlands?	☐	☐	☐	☐

IX. HYDROLOGY AND WATER QUALITY: Would the project:

a) Violate any water quality standards or waste discharge requirements?	☐	☐	☐	☐
b) Substantially deplete groundwater supplies or interfere substantially with groundwater recharge such that there would be a net deficit in aquifer volume or a lowering of the local groundwater table level (e.g., the production rate of pre-existing nearby wells would drop to a level which would not support existing land uses or planned uses for which permits have been granted)?	☐	☐	☐	☐
c) Substantially alter the existing drainage pattern of the site or area, including through the alteration of the course of a stream or river, in a manner which would result in substantial erosion or siltation on- or off-site?	☐	☐	☐	☐
d) Substantially alter the existing drainage pattern of the site or area, including through the alteration of the course of a stream or river, or substantially increase the rate or amount of surface runoff in a manner which would result in flooding on- or off-site?	☐	☐	☐	☐
e) Create or contribute runoff water which would exceed the capacity of existing or planned stormwater drainage systems or provide substantial additional sources of polluted runoff?	☐	☐	☐	☐
f) Otherwise substantially degrade water quality?	☐	☐	☐	☐

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
g) Place housing within a 100-year flood hazard area as mapped on a federal Flood Hazard Boundary or Flood Insurance Rate Map or other flood hazard delineation map?	☐	☐	☐	☐
h) Place within a 100-year flood hazard area structures which would impede or redirect flood flows?	☐	☐	☐	☐
i) Expose people or structures to a significant risk of loss, injury or death involving flooding, including flooding as a result of the failure of a levee or dam?	☐	☐	☐	☐
j) Inundation by seiche, tsunami, or mudflow	☐	☐	☐	☐

X. LAND USE AND PLANNING: Would the project:

a) Physically divide an established community?	☐	☐	☐	☐
b)Conflict with any applicable land use plan, policy, or regulation of an agency with jurisdiction over the project (including, but not limited to the general plan, specific plan, local coastal program, or zoning ordinance) adopted for the purpose of avoiding or mitigating an environmental effect?	☐	☐	☐	☐
c) Conflict with any applicable habitat conservation plan or natural community conservation plan?	☐	☐	☐	☐

XI. MINERAL RESOURCES: Would the project:

a) Result in the loss of availability of a known mineral resource that would be of value to the region and the residents of the state?	☐	☐	☐	☐
b) Result in the loss of availability of a locally-important mineral resource recovery site delineated on a local general plan, specific plan or other land use plan?	☐	☐	☐	☐

XII. NOISE: Would the project result in:

a) Exposure of persons to or generation of noise levels in excess of standards established in the local general plan or noise ordinance, or applicable standards of other agencies?	☐	☐	☐	☐
b) Exposure of persons to or generation of excessive groundborne vibration or groundborne noise levels?	☐	☐	☐	☐
c) A substantial permanent increase in ambient noise levels in the project vicinity above levels existing without the project?	☐	☐	☐	☐

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
d) A substantial temporary or periodic increase in ambient noise levels in the project vicinity above levels existing without the project?	☐	☐	☐	☐
e) For a project located within an airport land use plan or, where such a plan has not been adopted, within two miles of a public airport or public use airport, would the project expose people residing or working in the project area to excessive noise levels?	☐	☐	☐	☐
) For a project within the vicinity of a private airstrip, would the project expose people residing or working in the project area to excessive noise levels?	☐	☐	☐	☐

XIII. POPULATION AND HOUSING: Would the project:

a) Induce substantial population growth in an area, either directly (for example, by proposing new homes and businesses) or indirectly (for example, through extension of roads or other infrastructure)?	☐	☐	☐	☐
b) Displace substantial numbers of existing housing, necessitating the construction of replacement housing elsewhere?	☐	☐	☐	☐
c) Displace substantial numbers of people, necessitating the construction of replacement housing elsewhere?	☐	☐	☐	☐

XIV. PUBLIC SERVICES:

a) Would the project result in substantial adverse physical impacts associated with the provision of new or physically altered governmental facilities, need for new or physically altered governmental facilities, the construction of which could cause significant environmental impacts, in order to maintain acceptable service ratios, response times or other performance objectives for any of the public services:	☐	☐	☐	☐
Fire protection?	☐	☐	☐	☐
Police protection?	☐	☐	☐	☐
Schools?	☐	☐	☐	☐
Parks?	☐	☐	☐	☐
Other public facilities?	☐	☐	☐	☐

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
XV. RECREATION:				
a) Would the project increase the use of existing neighborhood and regional parks or other recreational facilities such that substantial physical deterioration of the facility would occur or be accelerated?	☐	☐	☐	☐
b) Does the project include recreational facilities or require the construction or expansion of recreational facilities which might have an adverse physical effect on the environment?	☐	☐	☐	☐
XVI. TRANSPORTATION/TRAFFIC: Would the project:				
a) Conflict with an applicable plan, ordinance or policy establishing measures of effectiveness for the performance of the circulation system, taking into account all modes of transportation including mass transit and non-motorized travel and relevant components of the circulation system, including but not limited to intersections, streets, highways and freeways, pedestrian and bicycle paths, and mass transit?	☐	☐	☐	☐
b) Conflict with an applicable congestion management program, including, but not limited to level of service standards and travel demand measures, or other standards established by the county congestion management agency for designated roads or highways?	☐	☐	☐	☐
c) Result in a change in air traffic patterns, including either an increase in traffic levels or a change in location that results in substantial safety risks?	☐	☐	☐	☐
d) Substantially increase hazards due to a design feature (e.g., sharp curves or dangerous intersections) or incompatible uses (e.g., farm equipment)?	☐	☐	☐	☐
e) Result in inadequate emergency access?	☐	☐	☐	☐
f) Conflict with adopted policies, plans or programs regarding public transit, bicycle, or pedestrian facilities, or otherwise decrease the performance or safety of such facilities?	☐	☐	☐	☐
XVII. UTILITIES AND SERVICE SYSTEMS: Would the project:				
a) Exceed wastewater treatment requirements of the applicable Regional Water Quality Control Board?	☐	☐	☐	☐
b) Require or result in the construction of new water or wastewater treatment facilities or expansion of existing facilities, the construction of which could cause significant environmental effects?	☐	☐	☐	☐

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
c) Require or result in the construction of new storm water drainage facilities or expansion of existing facilities, the construction of which could cause significant environmental effects?	☐	☐	☐	☐
d) Have sufficient water supplies available to serve the project from existing entitlements and resources, or are new or expanded entitlements needed?	☐	☐	☐	☐
e) Result in a determination by the wastewater treatment provider which serves or may serve the project that it has adequate capacity to serve the project's projected demand in addition to the provider's existing commitments?	☐	☐	☐	☐
f) Be served by a landfill with sufficient permitted capacity to accommodate the project's solid waste disposal needs?	☐	☐	☐	☐
g) Comply with federal, state, and local statutes and regulations related to solid waste?	☐	☐	☐	☐

XVIII. MANDATORY FINDINGS OF SIGNIFICANCE

	Potentially Significant Impact	Less Than Significant with Mitigation	Less Than Significant Impact	No Impact
a) Does the project have the potential to degrade the quality of the environment, substantially reduce the habitat of a fish or wildlife species, cause a fish or wildlife population to drop below self-sustaining levels, threaten to eliminate a plant or animal community, substantially reduce the number or restrict the range of a rare or endangered plant or animal or eliminate important examples of the major periods of California history or prehistory?	☐	☐	☐	☐
b) Does the project have impacts that are individually limited, but cumulatively considerable? ("Cumulatively considerable" means that the incremental effects of a project are considerable when viewed in connection with the effects of past projects, the effects of other current projects, and the effects of probable future projects)?	☐	☐	☐	☐
c) Does the project have environmental effects which will cause substantial adverse effects on human beings, either directly or indirectly?	☐	☐	☐	☐

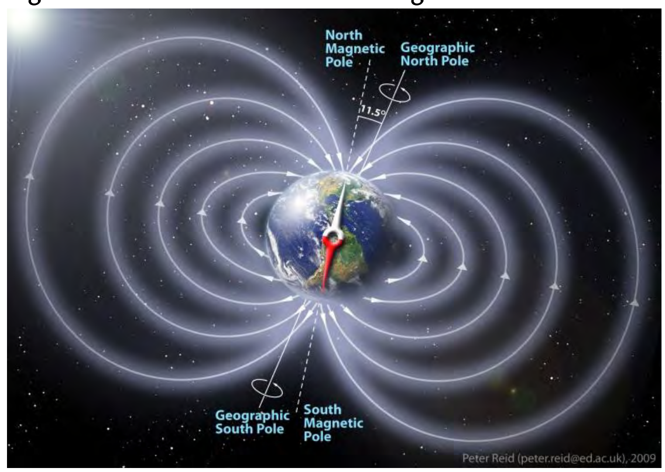
13 Appendix D: Former FERC Licenses for MRE Projects in California State Waters

Developer	Project	Year
Golden Gate Energy	San Francisco Bay Tidal Energy Project	2005
California Wave Energy Partners	Centerville OPT Wave Energy Park	2007
Chevron California Renewable Energy	Pelamis Project (near Fort Bragg)	2007
Pacific Gas & Electric (PG&E)	North Coast WaveConnect (Humboldt)	2008
PG&E	North Coast WaveConnect (Mendocino)	2008
PG&E	Central Coast Wave Connect	2009
Sonoma County Water Agency	Del Mar Landing Project	2009
Sonoma County Water Agency	Fort Ross South Project	2009
Sonoma County Water Agency	Fort Ross North Project	2009
Scientific Application and Research Associates (SARA)	SWAVE Catalina Green Wave Energy Project	2009
JD Products LLC	San Onofre	2010
Golden Gate Energy	San Francisco Bay Tidal Project (II)	2010
Greenwave Energy Solutions	Mendocino Wave Park	2011
Greenwave Energy Solutions	San Luis Obispo Wave Park	2011

14 Appendix E: The Geomagnetic Field and MRE Development

The earth produces a natural magnetic field, referred to as the geomagnetic field, which marine organisms use to navigate while migrating, as well as orient themselves in the marine environment. The magnetic field resembles that of a bar magnet running down the center of the planet. The magnetic field lines emerge from the southern half of the planet and re-enter the earth in the northern half. The intensity of the earth's magnetic field is greatest near the poles and weakest near the equator. There are also magnetic variations across the ocean floor due to varying amounts of magnetic minerals in the seafloor. Basalt, an iron-rich volcanic rock that makes up much of the seafloor, contains a strongly magnetic mineral called magnetite which can distort local compass readings.

Figure 14.1.1: The Earth's Geomagnetic Field



Graphic Credit: Peter Reid

Graphic of the earth's magnetic field. The field enters the earth at the magnetic north pole, and exits at the south pole.

The inclination of the magnetic field is the angle at which the magnetic field lines intersect the earth's surface at a specific location. The angle of inclination is 0 at the equator, 90 at the Magnetic North Pole, and -90 at the Magnetic South Pole, and varies in between, depending on latitude. Declination at a particular location on the earth's surface measures the angle, in degrees, between magnetic north on a compass and true north. Declination is positive when magnetic north is east of true north, and is negative when magnetic north is west of true north.

MRE projects can potentially change local intensity, inclination, and declination, and thus may have an effect on species' ability to sense changes in the properties of magnetic fields.

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