Applying Risk Science and Stakeholder Engagement to Overcome Environmental Barriers to Marine and Hydrokinetic Energy Projects

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Abstract

The production of electricity from the moving waters of the ocean has the potential to be a viable addition to the portfolio of renewable energy sources worldwide. The marine and hydrokinetic (MHK) industry faces many hurdles, including technology development, challenges of offshore deployments, and financing; however, the barrier most commonly identified by industry, regulators, and stakeholders is the uncertainty surrounding potential environmental effects of devices placed in the water and the permitting processes associated with real or potential impacts.

Regulatory processes are not well positioned to judge the severity of harm due to turbines or wave generators. Risks from MHK devices to endangered or protected animals in coastal waters and rivers, as well as the habitats that support them, are poorly understood. This uncertainty raises concerns about catastrophic interactions between spinning turbine blades or slack mooring lines and marine mammals, birds and fish.

In order to accelerate the deployment of tidal and wave devices, there is a need to evaluate the extensive list of potential interactions that may cause harm to marine organisms and ecosystems, to set priorities for regulatory triggers, and to direct future research. Identifying the risk of MHK technology components on specific marine organisms and ecosystem components can separate perceived from real risk-relevant interactions. Scientists from Pacific Northwest National Laboratory (PNNL) are developing an Environmental Risk Evaluation System (ERES) to assess environmental effects associated with MHK technologies and projects through a systematic analytical process, with specific input from key stakeholder groups.

The array of stakeholders interested in the development of MHK is broad, segmenting into those whose involvement is essential for the success of the MHK project, those who are influential, and those who are interested. PNNL and their partners have engaged these groups, gaining valuable information, gathering pertinent feedback on the efficacy of the process, and providing a level of ownership for the risk evaluation process that will encourage adoption of the outcome to inform future MHK siting and permitting decisions.

The ERES development process provides the scientific structure to support risk characterization, comparison of tradeoffs, and risk-informed decision-making by project and technology developers, regulatory agencies, and other interested stakeholders. The PNNL team will determine the range and severity of environmental effects of MHK development, leading to the development of mitigation strategies where residual risk remains.

I. INTRODUCTION

The production of electricity from kinetic ocean energy has the potential to be a reliable and viable renewable energy source worldwide. Estimates for energy production from marine and hydrokinetic (MHK) energy in the U.S. alone are comparable to those for conventional hydropower, approximately 33,000 MW [1]. While deployment of pilot and commercial-scale MHK devices in the European Union, Canada and Asia is moving forward, MHK is still a nascent industry in the U.S. The MHK industry worldwide faces many challenges, including device technology development, grid connection and integration, mooring systems design, as well as the need to attract public and private financing. Perhaps the greatest barrier, however, as identified by industry, regulators, and stakeholders, is the challenges of siting and permitting MHK installations [2, 3].

Optimum siting of MHK installations consist of maximizing the ocean resource (wave, tidal or ocean current) from which energy can be extracted, while minimizing conflicts with existing ocean uses and minimizing environmental impacts to the marine organisms and the marine environment. Although there does not appear to be a strong belief among regulatory agency

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staff or stakeholders that MHK devices are likely to cause wide spread harm to marine animals, habitats or the overall marine ecosystem [4], there are so few data available worldwide that directly addressing the interactions of sensitive marine receptors with MHK devices that threats to marine resources cannot be ruled out to the satisfaction of statutory mandates or stakeholders. This overwhelming lack of certainty prevents the smooth transition from MHK project planning to deployments across the U.S. and is seen to be a major impediment to getting devices in the water, and learning more about the direct and indirect effects of devices and systems.

Laboratory and field research can help fill data gaps in our understanding of potential MHK effects on marine systems, but the overwhelming gaps in data require that we focus our financial and scientific resources on the most important effects. This focus requires evaluating the extensive list of potential interactions that may cause harm to marine organisms and ecosystems in a systematic manner, setting priorities to inform regulatory actions, and determining the highest priority risks for each type of MHK technology in ocean areas where MHK development is likely. Identifying the risk of MHK technology components to specific marine organisms and ecosystem components can separate perceived from real risk-relevant interactions.

II. OPTIMUM SITING OF MARINE AND HYDROKINETIC DEVICES

When choosing a site for pilot or commercial scale deployment of MHK devices, a project developer must consider 1) the available tidal or wave resource; 2) the marine environmental resources that may be affected by the construction and operation; 3) infrastructure costs such as transmission distance to shore and the availability of nearby electrical grid interconnects; 4) the proximity to ports and industries with manufacturing and deployment capabilities; and 5) the availability of human resources with capabilities in marine industries including offshore deployment, operations and maintenance. Once an area is chosen, detailed siting and permitting requirements become a process that will eliminate areas and array configurations from consideration. Presuming that the proposed deployment area has been strategically chosen by the developer, the skill with which the developer negotiates the final siting and permitting processes will determine whether a productive outcome (i.e. deployment of a pilot or full scale MHK installation) will result. Successful deployments will add to our knowledge of potential environmental effects of MHK devices on marine organisms and the marine environment, as well as provide much needed device operational data. Failure to successfully negotiate the siting and permitting process will result in a non-productive outcome, where permitting costs become prohibitive or the site becomes impossible to permit at any cost. Non-productive outcomes result in no new MHK devices in the water, no new data on power generation potential, and no increase in knowledge about interactions of MHK devices in the marine environment.

III. SITING AND PERMITTING CONSTRAINTS

Siting and permitting requirements for MHK devices are established by laws and regulations that limit development in the ocean in order to protect marine resources, to enable coherent use of the oceans and shorelines by multiple users, and to ensure resiliency to coastal hazards. These processes were not designed with marine energy production in mind, but to address other activities such as shipping, commercial fishing, oil and gas exploration, coastal development and recreation [5]. Licensing processes for MHK installation and operation are being adapted from those created for conventional hydropower installations [6]. The regulatory agencies that oversee the regulations being applied to MHK development are many and varied, and include those at the federal, state and local level.

Regulatory processes are not well suited to judging the severity of harm due to turbines or wave generators in ocean or estuarine areas; the closest equivalent systems are conventional hydropower dams and turbines. Risks from MHK devices to endangered or protected animals in coastal waters, as well as the habitats that support them, are not well understood, raising concerns about catastrophic interactions between spinning turbine blades or slack mooring lines and marine mammals, birds, and fish. The potential risk to marine ecosystems from energy removal or synergies with other human activities are even less well known.

In addition, a broad range of stakeholders have concerns and aversions to a new industry entering the oceans that range from concern about harm to marine animals, to competition for shoreline and ocean space with more established uses such as fishing and recreation, to suspicion about new and unknown machines being deployed in their ocean backyard.

IV. WORKING WITH STAKEHOLDERS

Engagement of stakeholders at the outset to establish new conditions for use of coastal and ocean areas has been shown to smooth the way for future uses [7,8]. Pacific Northwest National Laboratory (PNNL) scientists developed a framework to examine the range of stakeholders with an interest in MHK development, interviewing significant numbers of these stakeholders to understand their perspectives [9]. In addition to gaining understanding of perceived risks and concerns from the stakeholder groups and establishing pathways for communication of science-based information, the output of the stakeholder framework allowed for organized and efficient input to the risk evaluation system under development. Input to the risk evaluation system by stakeholders is discussed below.

To develop the stakeholder framework, PNNL scientists carried out a modified Delphi process [9], whereby each contact provides additional contacts and reasons for approaching additional interested parties [10]. Careful listening was needed to understand the relationship individual or groups of stakeholders have to MHK energy development. The outcome of that process was a parsing of stakeholders into three groups:

- an essential group without whose involvement the industry cannot progress (essential);
- influential stakeholders who may have an impact on the outcome of a technology, siting or permitting processes, or who have influence over essential players (influential); and
- stakeholders interested in the outcome of the MHK industry due to place-based interests or concerns (interested).

Stakeholders were classified by the sectors they represent and were later assigned as being *essential*, *influential*, or *interested*. Table 2 shows examples of the stakeholders with whom we interacted, parsing them into the three groups. Many groups of stakeholders may progress from being interested to influential, or from influential to essential at various stages of industry development.

Members of each stakeholder group had to be approached differently, with respect for their starting position, knowledge base, and level of commitment to the desired outcome. In order to gain trust and maintain positive relationships, major messages and information delivered to each group must remain consistent, but needed to be tailored to the interests and needs of the group. Although parsing of stakeholders into these groups based on their relationships to or influences on the MHK industry is affected by political processes and influences, the investigators avoided direct political involvement or discussion.

Table 1. Stakeholder groupings, based on relationship to MHK industry development

Group	Stakeholder Sector	Representative Stakeholders	Comments
Essential	MHK Industry in the United States	OPT, Verdant, ORPC, HydroGreen, etc.	Strongest interest in moving MHK development forward
	Regulators	FERC, BOEM (MMS), NOAA Fisheries, USFWS, state regulatory agencies	Need to come to consensus on regulatory needs, assist regulators in determining acceptable risks
	Federal funding agencies	DOE, BOEM (MMS), NOAA	R&D investment for pilot deployment and environmental studies is needed immediately
Influential	Federal and state resource management agencies	NOAA, USFWS, state resource agencies	Agencies will supply information to allow regulators to understand acceptable levels of risk
	Native American Tribes		Treaty Tribes have legal rights to protect marine resources and harvest rights, can be highly influential
	Regional governance bodies	West Coast Governors' Agreement on Ocean Health	
	International MHK Industry, regulators	Open Hydro, Clean Current, MCT, etc., United Kingdom and European Union regulatory bodies	Can provide examples and track record for industry, regulators, other stakeholders
	Public and private utilities		Utilities become essential players as the industry gets closer to generating power
	Private investors		Private investment becomes essential as devices are proven effective
Interested	Place-based NGOs Interested public	People for Puget Sound Marine Resources Committees	Often express concern over "industrialization of ocean." Concerns are generally highly linked to locations, place-based. Can be very open to education on importance of industry, renewables. Can also become very influential and litigious.

DOE = U.S. Department of Energy; FERC = Federal Energy Regulatory Commission; BOEM = Bureau of Ocean Energy Management; MMS = Minerals Management Service; MCT = Marine Current Turbines; NGO = nongovernmental organization; NOAA = National Oceanic and Atmospheric Administration; OPT = Ocean Power Technologies, Inc.; ORPC = Ocean Renewable Power Corporation; USFWS = U.S. Fish and Wildlife Service.

V. DETERMINING RISKS OF MHK DEVELOPMENT

Scientists at PNNL have been developing an Environmental Risk Evaluation System (ERES) to assess environmental effects associated with MHK technologies and projects through a systematic analytical process, with specific input from key stakeholder groups. Drawing on the conceptual frameworks and analytical tools developed for determining risks in other industrial applications [11,12]. the PNNL team is developing a new set of protocols and tools for examining risk in MHK systems, with an emphasis on the operational phase of projects. The ERES team has adopted the definitions of stressors and receptors to explain the interaction of MHK devices in the marine environment: stressors are those portions or systems of MHK devices, anchors and connectors that may cause harm to marine organisms or the marine environment; receptors are those parts of the marine ecosystem that could be affected by MHK-related stressors [13]. By examining the broad range of interactions between specific stressors and marine receptors, PNNL will determine the factors that pose the most significant risks to the environment, allowing for the development of practical mitigation strategies [14]. The outcome of the process will also help direct efficient and proportional monitoring of operational MHK devices after deployment. The steps and input points for informing ERES are shown in Fig. 1.

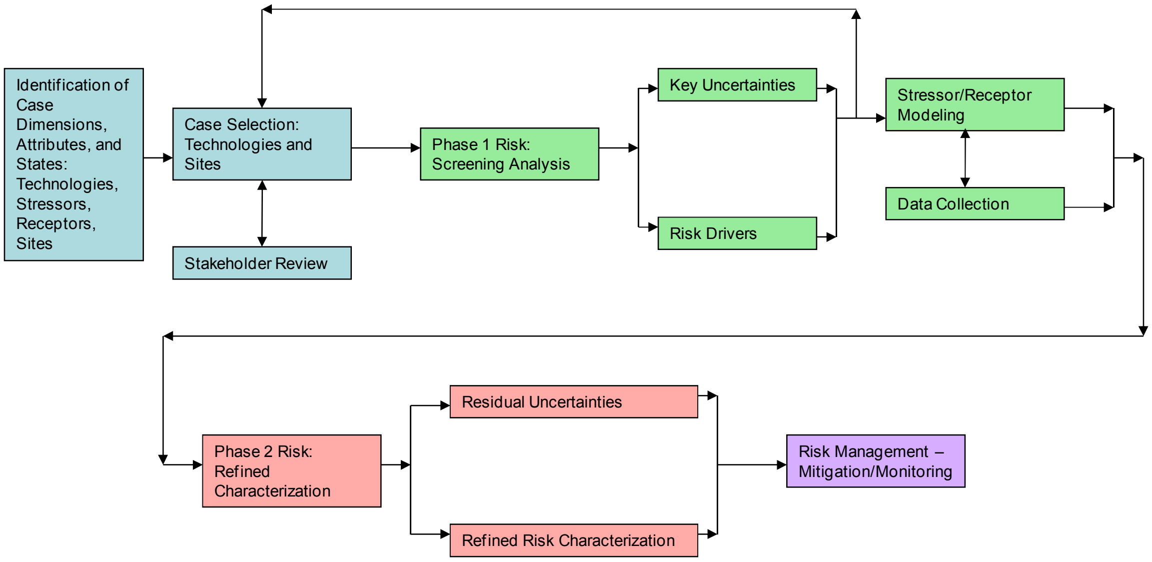

Figure 1. Risk-informed decision process showing inputs, feedback loops and outcomes. for managing risk, including mitigation and ongoing monitoring action.

In Figure 1, the first three (blue) boxes identify and prioritize specific case studies, with input from stakeholders. The next five (green) boxes lay out the screening process and help to direct data collection efforts, leading to more finely resolved definitions of environmental effects. The next three (red) boxes represent the detailed risk modeling that will characterize risk and remaining uncertainties. The outcome (purple box) will be used to choose appropriate actions.

ERES development involves deconstructing MHK energy generation into four risk dimensions: MHK technology, site characteristics, waterbody features, and environmental receptors. Each dimension is comprised of risk-relevant attributes. For example, “maximum rotational speed of the device” in an attribute of the “MHK Technology” dimension. In most cases a number of attribute states are possible. In the same example, four possible states for the attribute are 10-15 rotations per minute (RPMs), 15-20 RPM, 20-30 RPM, and greater than 30 RPM. Waterbody attributes may address the tidal prism, estuarine flushing rate, or prevailing wave regime. Site characteristic attributes may include bottom sediment type and slope. Receptor attributes may include the presence of cetaceans, foraging fish and birds in the project area, and sensitive nearshore habitats. Table 2 gives a snapshot of the dimensions, attributes, and states that will be used in a tidal MHK development project.

Table 2. Subset of a tidal turbine case for risk assessment, using ERES, for a tidal turbine case. The red circles indicate the states of each attribute, chosen to reflect the particular case.

Dimension	Attribute	State1	State2	State3	State4
MHK Technology	Max device speed (RPM)	[✓ 10-15]	15-20	20-30	>30
MHK Technology	Generation direction	One way	[✓ Two way]	---	---
MHK Technology	Turbine swept area (m2)	[✓ 20-60]	60-100	100-200	200-500
Waterbody Feature	Estuarine	Fjord	Mixed	[✓ Partially mixed]	Salt wedge
Receptors	Endangered salmonids	[✓ Yes]	No	---	---

ERES will be populated with features of MHK projects selected for their diverse representation of technology type, technology configuration, and geographic location. A risk case examined by ERES would consist of anywhere from 20 to 100 risk attributes, contributing information to the models developed to predict risk for that case. During the development stages of ERES, PNNL scientists are screening for risk-relevent attributes as they relate to specific receptors. As specific stressor-receptor interactions are shown to be risk-relevant, models will be developed to predict risk under a variety of operational modes. Risk will be assigned to attributes using relevant information from peer-reviewed articles or technical reports, baseline assessment, monitoring, and modeling data, as well as expert opinion.

A preliminary list of priority stressors has been identified for the operational phase of MHK projects. In many cases these stressors are of concern due to the high uncertainty and lack of data available to determine their impacts on receptors of interest. The receptors of interest include those for which regulatory endpoints exist, such as threatened and endangered species where "no take" (mortality, injury or harassment) or very limited take is allowed. Primary stressors include electromagnetic fields (EMF), acoustic outputs, blade strike, and attraction to/avoidance of devices. Table 3 summarizes these stressors as they will be investigated by ERES, as well as the data inputs needed to better resolve the uncertainty associated with the stressor/receptors interactions. As an example, certain fish and invertebrate species are known to use magnetic fields to navigate and to hunt for prey, notably sharks, rays and lobster [15]; EMF from devices may mask or confuse the animals' ability to forage, avoid predators, or reproduce. The risk from EMF exposure from tidal and wave devises is likely to have certain similarities (e.g. electric cable leakage) as well as differences (tidal turbines may produce significant EMF as they rotate, while wave devices produce little).

Table 3. Priority MHK stressors under investigation through ERES.

Stressor	Technology Type	Receptor of Concern	Probable Effect	Methods to Resolve Uncertainty
EMF	Tidal: cables and rotor Wave: cables	Fish, esp. sharks, rays Lobster Sea turtles Marine mammals	Changes in behavior, could result in inability to avoid predators; interruption of feeding, reproduction.	Laboratory studies to determine exposure/response curves. Acoustic and video imaging in field. Measurement of EMF from cables and devices.
Acoustics	Tidal: rotor and generator noise Wave: mooring line strum, surface float displacement, generator noise	Marine mammals, some fish: interruption of communication, navigation	Changes in migration behavior.	Laboratory studies to determine exposure/response curves. Acoustic and video imaging in field. Acoustic mapping of output from devices.
Blade strike	Tidal rotor	Marine mammals, fish, diving birds, sea turtles	Injury or death from strike, effects on larval fish from impingement, entrainment.	Probabilistic risk assessment for encounter, acoustic and video imaging.nearfield
Attraction to/ Avoidance of devices	Wave surface floats Tidal gravity bases	Fish, sea birds, sea turtles	Aggregation and possible increase in predation. Changes in migratory, feeding behavior.	Acoustic and video imaging in field, observations.

Once the most risk-relevant stressor-receptor interactions have been identified across wave and tidal MHK cases, in-depth risk modeling will be carried out. Deterministic models will include detailed hydrodynamic models to examine circulation spatially and temporally in the vicinity of proposed MHK installations. Probabilistic models will be used to understand interactions such as collision risk for marine mammals, turtles and fish with tidal turbines. More complex models such as hydrodynamic models or models based on geographic information system (GIS) platforms will remain outside the ERES and be available as linked models. Tools that are locally available (embedded within ERES) will perform simpler analyses based on spreadsheet functionality and other features, including tools to conduct sensitivity/what-if analyses, and Monte Carlo simulation. Results from ERES will include risk data sheets that list scenarios, impact severities, and measure(s) of uncertainty. As much as possible, ERES results will be spatially specific, linked to GPS and latitude-longitude coordinates. Visualization and animation tools are also under development for ERES and will be used to communicate risk results, including cumulative distribution functions and risk contour maps.

PNNL and team partners have engaged the essential, influential and (to a lesser extent) interested stakeholder groups, gaining valuable information, gathering pertinent feedback on the efficacy of the ERES process, and promoting a level of ownership for the risk evaluation process that will encourage adoption of the outcome to inform future MHK siting and permitting decisions.

VI. CONCLUSIONS

The challenges of developing, deploying, and operating electrical energy generating technologies in the highest energy areas of the ocean are significant, as is the outlook for gaining public and private sector financing to develop prototypes, pilot projects and commercial scale arrays. Unless barriers to placing the first few pilot devices and commercial arrays in the water are removed, the industry will struggle to survive. By taking into account the regulatory and stakeholder needs for information and providing assurances that MHK devices will not impart irrevocable harm to the marine environment and other uses of the oceans, MHK developers can smooth the path towards deployment and commercial generation of renewable ocean energy. Similarly the limited financial resources available to project developers can be targeted towards the most efficient siting and permitting processes if there is consensus on the highest risk interactions between MHK devices and marine resources. Public funds directed towards research and development for improving MHK systems and determining risks to the environment can be brought together with private investment to develop, deploy and mitigate effects of MHK arrays to solve the nation's energy needs if all parties participate openly in determining and addressing risks.

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