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PNNL - 23412

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

The Contribution of Environmental Siting and Permitting Requirements to the Cost of Energy for Wave Energy Devices

Reference Model #5

AE Copping
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LA Hanna

June 2014

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Richland, Washington 99352

Summary

Responsible deployment of marine and hydrokinetic (MHK) devices in estuaries, coastal areas, and major rivers requires that biological resources and ecosystems be protected through siting and permitting (consenting) processes. Scoping appropriate deployment locations, collecting pre-installation (baseline) and post-installation data all add to the cost of developing MHK projects, and hence to the cost of energy. Under the direction of the U.S. Department of Energy, Pacific Northwest National Laboratory scientists have developed logic models that describe studies and processes for environmental siting and permitting. Each study and environmental permitting process has been assigned a cost derived from existing and proposed tidal, wave, and riverine MHK projects. Costs have been developed at the pilot scale and for commercial arrays for a surge wave energy converter.

Acknowledgments

We appreciate the assistance of the engineers and scientists from Sandia National Laboratories, National Renewable Energy Laboratory, Oak Ridge National Laboratory, Advanced Research Laboratory at Penn State University and ReVision for their input and assistance in determining the designs that will affect the marine environment. We would also like to thank Brian Polagye from the University of Washington NNMREC and Glenn Cada from Oak Ridge National Laboratory for their thoughtful input on the reference model studies and costs.

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1.0 Introduction

Responsible deployment of marine and hydrokinetic (MHK) energy devices in estuaries, coastal areas, and rivers requires that biological resources and ecosystems be protected through siting and permitting processes (Bohlert et al. 2008, Dehlsen Associates 2012). Scoping appropriate deployment locations, collecting environmental baseline data, post-installation monitoring information, and mitigating for impacts add to the cost of developing each MHK installation, and hence to the cost of energy (COE) generated. The success of the MHK industry in the U.S. depends on a favorable comparison of COE with that of other renewable energy sources (Polagye et al. 2011).

As provided for the first four reference models (tidal, riverine, wave, and ocean current), Pacific Northwest National Laboratory (PNNL) has undertaken the task of determining the preliminary costs for the major categories of environmental and site specific studies that can be expected to be needed for reference model # 5, described in Table 1 below. PNNL's approach develops logic models that describe the expected studies for siting and permitting MHK devices, driven by the siting and regulatory processes that require those studies. Each study and environmental permitting process has been assigned a cost derived from data from existing and proposed MHK projects, scaling factors, projections for future post-installation monitoring costs, and expert opinion.. A range of costs is presented for each type of study and regulatory requirement to reflect the significant uncertainty that results from the generic nature of the reference model site and device. Cost estimates were reviewed by agency staff, researchers, and consultants familiar with environmental permitting processes.

Table 1.Description of Refence Model #5

Reference Model	Technology	Water Body	Marine Receptors of Importance
# 5 Surge Wave Energy Converter (WEC)	Surge WEC. Single large flap (25m wide, 16m high, 1m thickness), mounted on a floating structure (43m long, 29.5m wide, and 18m high), as shown in Figure 1. The power generator located on device. Device secured with tension leg moorings to seafloor, and embedment anchors.	Located in the offshore environment (~50 meter depth) off the coast of Northern California.	Migratory organisms including marine mammals and fish, nearshore habitat and changes in sediment processes.

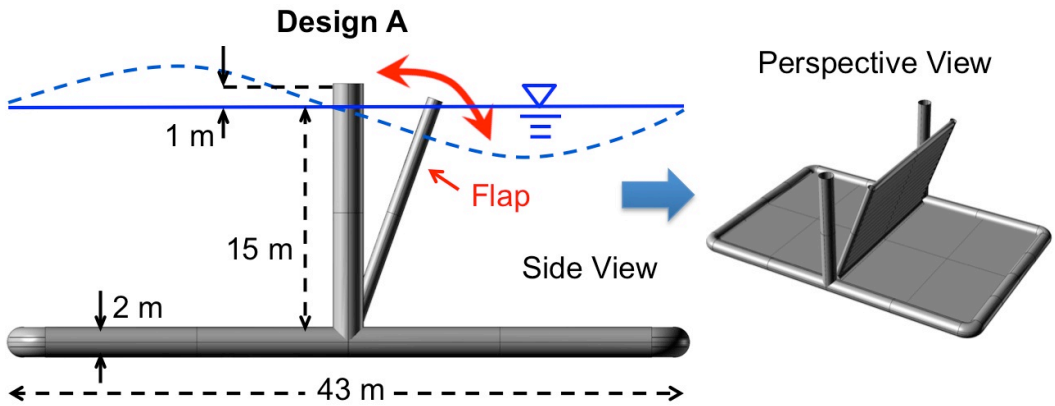

Figure 1. Conceptual design of Reference Model 5, surge WEC (courtesy of Yi-Hsiang Yu, NREL).

The goals for costing the contribution to the cost of energy (COE) from siting and permitting include:

1. Determine information needs, study requirements, and costs for each reference model for 1) scoping; 2) pre-installation; and 3) monitoring and mitigation phases, in order to assign costs to each.
2. Organize costs by major regulatory drivers—determine which regulations (and required studies) are highest cost drivers.
3. Engage regulatory agencies in the flow of studies, permitting pathways, to smooth pathway to siting and permitting.
4. Create logic-model to allow comparison of real world sites to reference model sites and determine total contribution of siting and permitting costs to COE.

This report addresses the first two goals; funding was not available to address goals #3 and #4.

2.0 Methods

Environmental studies may contribute a significant component of overall COE for pilot projects, and a lesser proportion for commercial scale MHK projects. In addition to the studies themselves, there is a need to account for the costs of data analysis and interpretation, and the documentation associated with the regulatory processes. Further costs are also derived from the collection of site-specific information that will assist MHK developers with choosing specific sites for development. Based on the need to account for these costs, PNNL researchers developed a set of logic models that are driven by regulatory requirements, as well as processes for collecting data that support the needs of the project developer.

The process for costing the siting and permitting contribution for COE was divided into three phases for reference model #5: 1) siting and scoping; 2) pre-installation information collection; and 3) post-installation monitoring. Costs for developing NEPA and other regulatory processes and deliverables are in addition to costs for the three phases and were developed independent of the three phases.

While the specific sites and technologies will have a major influence on the costs for any project, there are many commonalities driven by regulatory requirements and information needs across projects. For the first three reference models (RM#1, RM#2, and RM#3), PNNL researchers derived cost ranges from the best available information from existing and planned MHK projects by consulting with developers and the consultants supporting them; we also relied on the best professional judgment of researchers and natural resource management agency staff. For reference model #5 (Surge WEC), the basis for costs of environmental studies and processes were developed through extrapolation from the previous three models. While the Surge WEC model differs considerably from RM#3 (point absorber WEC) in its size, mooring, and operation, there are commonalities between the potential interactions of animals with the two devices. The impact of anchors and mooring lines on marine habitats in RM#5 is somewhat analogous to the lines and anchors proposed for RM#3 (wave). Due to the similar ocean space occupied by RM#5, the NEPA processes and study costs can be extrapolated using PNNL staff knowledge of other nearshore MHK projects and in consultation with experts in the area (Polagye et al. 2011).

Costs for each of the RM#5 studies and processes have been developed for pilot and commercial projects, as described. While the size of a pilot project differs from one technology and location to another, we have assumed that the RM#5 pilot project consists of one device, totaling less than 5MW generation capacity, and could be deployed for up to 5 years. The scaling rules used in RM#1-4 were applied to RM#5 to generate a range of costs for both small and large commercial scale projects (10 and 100 devices, respectively).

Each stage of study development (scoping and siting; pre-installation assessment; post-installation monitoring) requires documentation and adherence to processes designed to meet regulatory requirements. These include conducting public meetings, filing necessary permitting paperwork, and performing periodic checks with government agencies. Each of these processes has a cost associated with it, and has been accounted for in our costing estimates. It is assumed that many of the siting and permitting processes that drive costs are included under the broad umbrella of the *National Environmental Policy Act of 1969* (NEPA). Other regulatory drivers include: *Endangered Species Act of 1973, Clean Water Act of 1977, Marine Mammal Protection Act of 1972 As Amended, Magnuson-Stevens Fishery Conservation and Management Act*, and the *Migratory Bird Treaty Act of 1918*, as well as state and local regulatory requirements.

2.1 Siting and Scoping

Once a site has been identified that shows promise for development of tidal, wave or riverine energy, a developer will undertake feasibility investigations of the power resource potential and other information to support siting devices in specific locations. At that point, a scoping process is undertaken to identify the environmental issues of concern and to determine if there are conflicting uses for the site. Linking to ongoing ambient monitoring programs near to the proposed site will help assemble existing information. Necessary components of the scoping process include community outreach to ensure that stakeholders have a voice in determining environmental and competing use issues and to gain the trust of local leaders and the public. At the same time, project developers must work with regulatory agencies to determine what requirements they will need to meet for environmental assessment and post-installation monitoring. Each of these studies and processes has a cost associated with it that has been derived from the range of investments made by developers in the U.S.

2.2 Pre-installation Studies, Analysis and Documentation

Pre-installation studies (also frequently referred to as baseline assessments) for specific wave energy projects or other similar ocean energy projects located in the offshore environment, will have site and technology-specific differences and a range of siting and permitting needs. These studies will be used to establish a baseline of environmental quality against which post-installation monitoring results can be compared to determine whether the MHK installation has had an effect. In almost all cases, the environmental areas listed in Table 2 will be required by federal and state statutes. Environmental sample collection, observation, and analysis; data management and interpretation; quality assurance and quality control; and documentation for regulatory purposes, will be needed for each study.

Table 2. Pre-installation and Environmental Concerns that are Likely to Require Studies and Analysis to meet Regulatory Needs

Environmental Concern	Elements of Concern/Studies Needed	U.S. Regulatory Driver
Species under special protection	Marine animals under threat of extinction	Endangered Species Act *(Endangered Species Act of 1973)*
Marine Mammals	Concern and special societal value afforded to specific groups of animals	Marine Mammal Protection Act *(Marine Mammal Protection Act of 1972 as Amended)*
Migratory Birds	Birds that migrate across regions and continents and are considered to be at risk	Migratory Bird Treaty Act (international treaty) *(Migratory Bird Treaty Act of 1918)*
Important fish and shellfish populations	Fish populations of commercial, recreational, or cultural importance	Magnuson-Stevens Fishery Conservation, Management Act (protects critical habitats and fish populations) *(Magnuson-Stevens Fishery Conservation and Management Act)*
Habitats	Need to assess quantity and quality of habitat, due to important role in supporting marine species	Magnuson Stevens Fishery Conservation, Management Act, other federal and state regulations *(Magnuson-Stevens Fishery Conservation and Management Act)*
Water Quality	Cumulative degradation of water quality (DO, nutrients, human benefits), changes in sediment transport (affecting habitats shoreforms)	Clean Water Act and state equivalents *(Clean Water Act of 1977)*

2.3 Post-installation Studies, Analysis and Documentation

Post-installation monitoring studies should be derived from the findings of pre-installation studies and other published information from relevant field and laboratory studies. For small (pilot) projects, most concerns are likely to focus close to the wave device (nearfield), focusing on the potential for animals colliding with the device or a disruption of nearfield benthic habitat. As the size of the installment grows, regulations are likely to require that studies include those focused further from the devices (farfield), including assessments of biological processes such as food web effects, effects on marine populations and communities, and altered large scale sediment processes/effects on drift cells. While site- and technology-specific differences will drive the details of such studies, there is likely to be a certain common set of requirements (Table 3). As for pre-installation studies, sample collection, observation, and analysis; data management and interpretation; quality assurance and quality control; and documentation for regulatory purposes, have all been costed for post-installation monitoring.

Table 3. Post-installation Monitoring Studies for Nearshore Surge WEC Project Development

Target of Study	Project Scale	Type of Study	Reason for the Study
Marine Animals	Pilot and Commercial	Nearfield monitoring	Entrapment, entanglement, aggregation effects, avoidance effects.
Fish, pelagic invertebrates	Pilot and Commercial	Nearfield monitoring	
Migratory birds, diving birds, seabirds	Pilot and Commercial	Nearfield monitoring	
Sea turtles	Pilot and Commercial	Nearfield monitoring	
Benthic invertebrates	Pilot and Commercial	Underwater survey	Periodic survey and sampling to determine effects
Acoustics of the device	Pilot and Commercial	Noise generated by WEC	Change in acoustics over time: damage, harassment of marine mammals, sea turtles, fish, diving birds.
Seabirds	Commercial	Ecosystem effects	Changes to pre-installation population status, fitness, food availability and preference, reproductive success
Marine mammals	Commercial	Ecosystem effects	
Fish, pelagic invertebrates	Commercial	Ecosystem effects	
Sea turtles	Commercial	Ecosystem effects	

3.0 Results

The overall costs for environmental studies and associated processes required for RM#5 are summarized in Table 4. Detailed spreadsheets, references, standardized protocols, and in-depth explanation of costing is available for all parts of the environmental costing process for RM#5 (Appendix A). It should be noted that the costs listed here are not intended to make recommendations about what

studies should be carried out or how much they should cost, rather they reflect cost data representative of projects carried out to date and professional judgment about how the costs associated with RM#5 may differ. Real world costs may be significantly lower or higher depending on site characteristics, regulatory concerns, and stakeholder dynamics. Costs are also expected to be reduced over time. Numbers here represent a conservative estimate, and are not intended to inform study plan negotiations between developers and regulatory agencies.

Table 4. Nearshore Surge WEC summary tables

	Pilot		**Small Scale Commercial**		**Large Scale Commercial**	
Information Need	Low	High	Low	High	Low	High
Siting & Scoping	$240,000	$430,000	67,000	105,000	77,000	105,000
Pre-Installation Studies	$846,000	$1,583,000	770,000	1,555,000	595,000	1,615,000
Post-Installation	$320,000	$610,000	780,000	2,460,000	780,000	1,860,000
NEPA & Process	$725,000	$1,125,000	70,000	150,000	70,000	150,000
Total	**$2,131,000**	**$3,748,000**	**1,907,000**	**3,760,000**	**1,742,000**	**3,820,000**

Costs shown here summarize **total** costs expected at the pilot phase and each commercial phase. Small and large scale commercial costs have been calculated under the assumption that information collected during permitting at the pilot phase would be used for permitting in the commercial phase as well, thereby achieving cost savings; these costs were calculated as incrementally adding to those of the Pilot scale.

3.1 Pilot Project Costs

Using data from representative pilot project study plans, the studies that are likely to be required were derived for each reference model stage (Table 5); costs were then estimated for each study. The required studies and associated costs were based on assumptions derived from project experience and expert opinion; examples of the studies and the assumptions driving these costs are shown in Table 6. Cost ranges were used to represent the breadth of studies that may be required, depending on the specific animals and habitats encountered, as well as the range of materials, personnel, and equipment available. For example, if no endangered small cetaceans (i.e., dolphins, porpoises, killer whales) were found near the project site, the marine mammal surveys costs would be reduced to focus only on the presence of large cetaceans (i.e., the great whales); if a university partner or non-profit was capable of carrying out the work, costs might be less than employing a private firm. Conversely, if new instrumentation must be developed and tested expressly for the project, costs may be higher.

Table 5. Environmental Studies that are Likely to be Required for each Refence Model Stage

Siting and Scoping	**Pre-Installation Studies**	**Post-Installation Studies**	**NEPA Process**
Preliminary resource assessment-feasibility	Detailed resource assessment	Marine mammal	NEPA document preparation
Environmental scoping	Seabed survey, mapping	Fish	Monitoring and study

	and bottom composition		plans
Community outreach	Marine mammals	Benthos	
Regulatory outreach	Fish and invertebrates	Seabirds	
	Seabirds	Acoustic characterization monitoring	
	Turtles		
	Water quality		
	Habitat		
	Cultural resources		
	Navigation		

Table 6. Examples of Pilot Scale Study Assumptions — Pre-installation (Baseline) Studies for Fish, Marine mammals, Seabirds, and Turtles

Information Need	Specific Studies	Key Assumptions
Marine mammals	Baseline-distribution, species identification, and behavioral analysis: acoustic monitoring, literature review.	Data collection and monitoring focused on migratory marine mammals that use the offshore environment as a migratory corridor; as well as endangered mammals such as the Humpback whale and the Stellar sea lion.
Fish and Invertebrates	Baseline-distribution, species identification, and behavioral analysis: Split-beam hydroacoustics, grab samples for invertebrates, trawls, traps, and other sampling methods.	ESA listed and commercially valuable species will drive the studies, including highly migratory species that transit through this area such as ESA listed salmonids and Green sturgeon. Monitoring sediment processes and benthic habitat in the offshore and potentially nearshore environment may also be needed to evaluate the nearfield and farfield environmental effects of the Surge WEC.
Birds	Baseline-distribution, species identification, and behavioral analysis: observation, literature review and synthesis.	Although this device has minimal surface expression, monitoring will be needed to ensure the safety of coastal migratory and ESA listed birds such as the marbled murrelet, brown pelican and arctic tern, which may be present in the project area.
Turtles	Baseline-distribution, species identification, and behavioral analysis of T&E turtles in project area.	1 year of surveys completed with marine mammals surveys. While it is unlikely that Leatherback and Green sea turtles will migrate this far north, monitoring may need to be completed on a seasonal basis.

3.1.1 Uncertainties in Cost Estimates for Pilot Projects

There are several uncertainties in the cost estimates for pilot projects that cannot be quantified at this time. These are:

- **Monitoring Costs**. Costs for post-installation monitoring are less accurate than those for pre-installation studies because pre-installation studies that have been carried out at existing pilot projects were used to inform the costs, providing a level of confidence in the information, while no such estimates exist for post-installation monitoring. Costs were estimated based on professional judgment and published studies. Yearly monitoring costs were estimated and extended to the proposed 5-year term of a FERC pilot license.

- **Mitigation Costs.** Mitigation costs have not been factored into the cost estimates, although mitigation for impacts to marine animals, habitats or ecosystem processes is likely to be required for most MHK projects. These costs could be added to post-installation monitoring costs, but we cannot accurately estimate the magnitude of those costs at this time.

- **Uncertainty of Costs for Regulatory Requirements.** There is considerable uncertainty associated with the costs for complying with NEPA and other U.S. federal and state regulatory mandates; meeting these mandates will require concentrated effort at each stage of MHK projects. The magnitude of these costs are dependent on the length of time these process require; while some applicable laws and regulations have established timelines for processing permits, these timelines are often exceeded to achieve alignment between the parties involved.

3.2 Commercial Scale Costs

The scaling rules used in RM#1-4 were applied to RM#5 to extrapolate the small and large scale commercial project costs from those of the pilot project.

Costs estimates assume that a pilot permitting process, associated studies, and short-term deployment have already taken place in the project area prior to development at the commercial scale. Cost estimates for commercial scale are for **additional costs** beyond the pilot study. If a developer does not follow the pilot process but goes directly to a commercial scale project (which is allowed under the FERC process), an estimate of the commercial costs for environmental siting and permitting can be derived by summing the pilot and commercial estimates.

- Pre-installation environmental studies carried out at the pilot scale focus on population and behavioral assessments to measure potential **direct** effects to species of concern (e.g. fish, seabirds, sea turtles, marine mammals), in order to establish a baseline for post-installation monitoring. Information gathered from these pilot studies will inform the commercial scale and studies **may not** have to be repeated; supplemental baseline information may be needed as the project footprint increases.

- At commercial scale, additional pre-installation studies may focus on understanding **ecosystem effects** from arrays. These would be **additional studies** beyond those carried out at the pilot scale.

- The threshold between a small and large commercial array cannot be viewed as absolute, and must be determined on a site-specific basis. We have chosen thresholds appropriate for the reference sites we are working at, based on overall guidance of the DOE reference model project.

3.2.1 Scaling Rules

In addition to the assumptions that lead from pilot to commercial scale cost estimates, PNNL developed a set of "scaling rules" (Table 9) to allow for consistent comparison between changes in study costs from pilot to commercial scale; this consistency allows for relative comparison, which is useful considering the uncertainty in cost estimates.

Table 9. Rules for scaling environmental study costs from pilot to commercial scale projects.

Scaling Rule	Explanation	Examples
Covered in pilot	Information need was covered under the pilot project licensing process. Additional funds are likely not needed for studies at the commercial scale.	Desktop studies for initial determination of economic and environmental feasibility. This information would carry over directly into commercial scale.
Continuing costs	Recurring costs that continue from pilot into commercial scale permitting processes.	Nearfield monitoring studies may continue from pilot to commercial scale, though the expectation is that pilot nearfield monitoring studies may answer many of the questions required for commercial installation, so commercial costs may be at a lower level.
Incremental increase	Additional costs associated with larger footprint of a commercial-scale project. Cost increase likely to be marginal, incremental, and linear.	Resource assessment—larger project footprint may require procurement and deployment of additional ADCPs, ADVs, or other instruments, incrementally higher equipment costs and additional ship days above what would be expected for a pilot-scale project.
Multiplicative cost increase	Significant study cost increases as scale of project goes from pilot to commercial, and regulators require greater understanding of system or basin effects. Cost increase likely to be more than double the cost at the pilot scale and may increase in a non-linear fashion.	Habitat surveys and mapping may be expected to have a multiplicative cost increase if there is a large increase in footprint from pilot to commercial scale, or if a farfield habitat baseline is required.
Additional study	Larger scale projects may require studies, in addition to those required for a pilot project.	Farfield or ecosystem monitoring— Pre-installation studies that characterize valued species (fish, birds, marine mammals) will need to be at the basin-scale. If effects of a commercial project are considered to extend beyond the nearfield, or if regulators require "Before After Control Impact" (BACI)- style monitoring in the post-installation phase, completely new studies may be required.

Siting and scoping costs at commercial scale will increase incrementally over pilot scale costs, as the footprint of the MHK farm increases. However these costs will remain a relatively small fraction of total costs.

Pilot scale pre-installation studies may satisfy many of the regulatory needs at the commercial scale. However commercial scale projects may raise new questions about farfield or ecosystem effects, and as a result, additive studies may be necessary to assess baseline health on species of concern. Detailed hydrodynamic modeling may also be needed to inform array siting and to understand potential water quality and sediment transport effects. Finally, habitat mapping costs could increase multiplicatively when device numbers cross a threshold where farfield effects might be expected; this could lead to regulatory requirements for habitat mapping and assessment of a much larger area than that immediately adjacent to the array and associated infrastructure.

As with the pilot-scale assessment, there is considerable uncertainty in costs associated with post-installation monitoring for commercial developments. Some of the post-installation studies carried out at the pilot scale are likely to continue. However, information collected during monitoring of pilot devices may satisfy a number of regulatory questions, particularly the risk of direct effects of devices on animals (such as blade strike). As with pre-installation studies, increases in post-installation monitoring costs may be related to additional studies to understand farfield or ecosystem effects resulting from large arrays of devices.

3.2.2 Profile of Post Installation Monitoring Costs

Until sufficient data exist to anticipate interactions of MHK devices with marine animals and habitats, extensive monitoring is likely to be required during the initial years of deployment at the commercial scale, resulting in front-loading of costs in the first five years. These costs are expected to be sharply reduced to an annual baseline level, with periodic increases in activity to validate the trends seen in the first five years, and to address new questions or concerns as they arise. Figure 2 shows a hypothetical cost profile over the course of a thirty-year license term for a tidal power project.

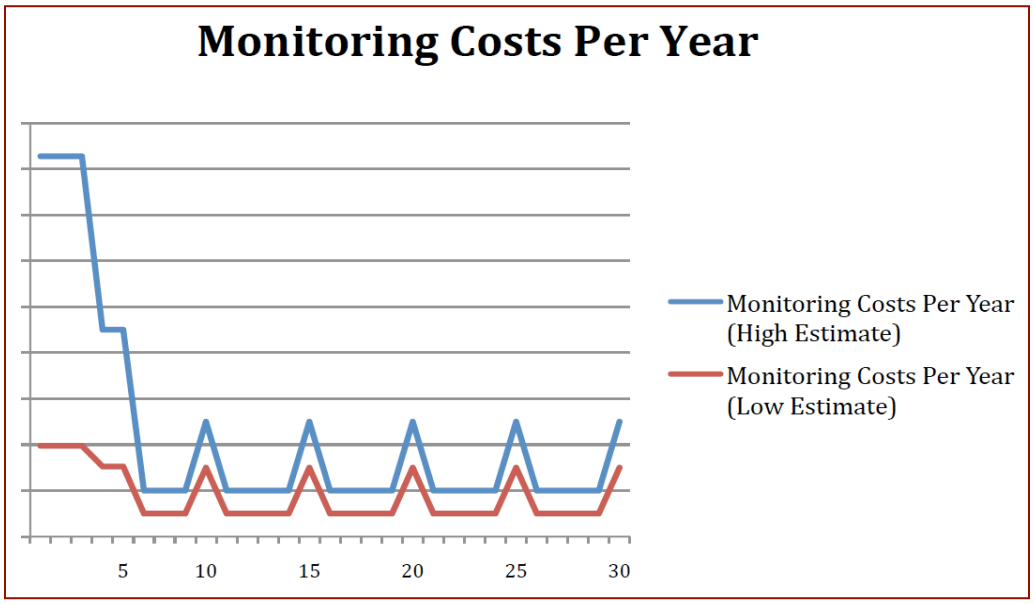

Figure 2. Hypothetical cost profile for monitoring costs over a thirty-year license term for a commercial-scale tidal farm. Costing figures are not shown, as data are preliminary.

3.3 Potential for Cost Savings and Refined Estimates

The process PNNL used to estimate costs of environmental studies and permitting relied heavily on information from developers, researchers and consultants involved in facilitating deployment of MHK devices in the U.S. The variability of cost estimates shown for environmental studies and permitting are large, as reflected by the cost ranges (low estimate, high estimate) shown, and represent preliminary answers that require more investigation before they can be seen as reliable contributors to the COE. Each major study has been costed independently; in reality there may be considerable cost savings if baseline and monitoring studies for various organisms are combined. For example, combining shore-based observer assessments of marine mammals and sea birds will reduce the costs of monitoring; similarly, acoustic monitoring for aquatic mammals and fish can be conducted during the same cruise, using an array of acoustic imaging devices and hydrophones. Where possible, these potential efficiencies were captured in low cost estimates and described in the assumptions, but considerable variability can still be expected. With a limited number of U.S. MHK projects approaching deployment, there have been limited sources of cost data available during this study. Future iterations of this process will help hone the costs of studies and permitting, as well as determine the proportionate contributions to the COE.

The cost ranges shown for the offshore surge WEC technology reflect choices among the studies, as indicated by the logic models. As we learn more about the conditions found at proposed MHK sites, the potential effects of these devices on marine animals, habitats and ecosystem processes, and the studies required to understand and address these effects, the logic models could be revisited, with further refinement of the list of studies and associated costs for each stage of development. Similarly the scaling

rules (Table 9) will be further refined and applied to commercial scale studies. Once sufficient study and costing data become available at the commercial scale, the scaling rules should become unnecessary and will be replaced with estimates of realistic costs.

3.4 Cost Differences among MHK Technologies

Factors such as waterbody characteristics, MHK technologies, and the marine animals and habitats indigenous to the site will be reflected in differences among permitting and siting costs for MHK projects in the U.S. As more MHK sites are chosen for development, additional permitting requirements and siting complexities may arise causing even greater divergence in permitting and siting costs.

Offshore surge WEC (RM #5) is located in the offshore marine environment in approximately 50 meters of water. Extensive pre- and post- installation monitoring will be needed to better understand the interaction between this device and migratory marine mammals, fish and reptiles; endangered species like the Humpback whale, Stellar sea lion, Chinook salmon and Green sturgeon will inhabit this environment during migration and for feeding. The sediment processes within the offshore and nearshore environment may also be at risk, and may require modeling and monitoring efforts to examine how the reduction of wave energy will affect sediment processes, subtidal habitats and shore forms. RM#5 may also require sea bird studies particularly for marbled murrelet, brown pelican and the arctic tern.

4.0 Conclusions

Estimating costs of environmental studies and permitting provides input to the COE, and also serves other purposes. These estimates may assist developers in determining upfront and ongoing costs of developing projects, as well as planning linked studies from pre-installation assessment to post installation monitoring, and developing mitigation strategies. Probably most important, the process of determining appropriate studies to meet regulatory needs can assist the standardization of a pathway for installing MHK projects in the water and expanding towards commercial production of power.

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Appendix A —Costing Tables

Summary Table of Reference Model # 5 (Nearshore Surge WEC)

Information Need	Pilot Low	Pilot High
Siting & Scoping	$240,000	$430,000
Pre-Installation Studies	$846,000	$1,583,000
Post-Installation	$320,000	$610,000
NEPA & Process	$725,000	$1,125,000
Total	**$2,131,000**	**$3,748,000**

Pilot Costs

Pilot - Siting and Scoping

Information Need	Specific Studies	Low Cost	High Cost	Key Assumptions
Preliminary Resource Assessment—Feasibility	Assessment of waves heights, lengths, periods over seasons	90,000	90,000	NCEP-NOPP Wavewach III 30-yr hindcast dataset would be ideal for the analysis, but there is no wave watch data within 5 miles from shore. Will require characterization of inshore wave climate 1) obtain wave climate parameters; 2) construct wave spectra (and calibrated spectral shape coefficients if data available); 3) calculated wave power density and estimate wave energy flux; 4) report
Environmental Scoping	Desktop study—review existing information on key species and habitats as well as competing uses.	50,000	100,000	Used for preliminary NEPA scoping and to identify key information needs for pre-installation studies.
Community Outreach	Targeted information delivery, community meetings, workshops and visual impact study	50,000	80,000	Development of materials and information to address anticipated stakeholder concerns and frame the value of the project to the community, attending or hosting 3-4 meetings with existing organizations, potential focus groups.

				Would inform NEPA process.
Regulatory Outreach	Policy and regulatory analysis, reach out to regulators for future NEPA process	50,000	160,000	Low: 6 meetings total with agency personnel (FERC, USFWS, NMFS, CDFG, FERC); High: 18 meetings total with agency personnel; Assumes all meetings are local and no travel costs
Total		**240,000**	**430,000**	

Pilot - Pre-Installation Studies

Information Need	Specific Studies	Low Cost	High Cost	Key Assumptions
Seabed Survey and Mapping	Side-scan survey of site area, ROV or diver survey at site, compile data and create	110,000	110,000	Cost for field work + equipment; includes 2 days to survey project site and cable route ($47 k). Also assumes cost for diver hazard pay. Mapping assumes lab work, data enter, analysis, and report writing ($62 K)
Marine Mammals	Baseline—distribution, species identification, and behavioral analysis: acoustic monitoring, shore-based observation, and literature review.	50,000	100,000	1 year study. Shore based observers for gray whale surveys in spring and winter; resident gray and humpbacks in summer and fall; acoustic monitoring with autonomous recorders for other species (i.e., dolphins and porpoises)- includes boat time to set and retrieve recorders. High end includes small plane surveys.
Fish and Invertebrates	Baseline—distribution, species identification, and behavioral analysis: Telemetry and tagging for sturgeon, grab samples for invertebrates, trapping for crabs, trawling for fish.	469,000	765,000	2 years of pre-installation monitoring as required by agencies; 1) Telemetry receivers to detect tagged ESA-listed sturgeon; 2) Grab sampling to assess benthic inverts; 3) Trapping to assess Dungeness crab; 4) Trawling to assess demersal fish and benthic invertebrates.

Seabirds/Shorebirds	Baseline—distribution, species identification, and behavioral analysis: shore based surveys and beach transects	20,000	40,000	1 year of shore based surveys.
Turtles	Baseline—distribution, species identification, and behavioral analysis of T&E turtles in project area. Shore based surveys.	12,000	38,000	1 year of surveys. Low: shore based surveys; High- surveys done from small aircraft
Sediment Transport/Water Quality	Baseline—CTD point casts; sediment transport modeling to indicate changes in sediment transport.	100000	220000	Nearshore WEC devices may raise concerns for sediment transport processes and effects to shoreforms. Sediment transport modeling may be required, and validation sampling. CTD casts and sediment traps may also be required.
Habitat	Benthic surveys covered in seabed analysis above. Nearshore surveys conducted by plant ecologists	20,000	20,000	Botanical surveys, dune surveys. 1 week (5 d), assumes no new transmission line. Does not include wetland delineation.
Cultural Resources	Three phases: Inventory, testing, data recovery. And assessment of traditional cultural properties.	15,000	195,000	Low estimate is for historic properties inventory only. High estimate reflects testing and data recovery that would only be necessary if sites are found that cannot be avoided. Estimates are for shoreline sites only; seabed survey would identify submerged cultural resources that could be avoided through siting.
Navigation	Establish vessel traffic baseline, risk assessment.	10,000	15,000	Surveys or interviews of commercial mariners, fishers and recreational boaters.

Recreation	Recreation overview and initial impact assessment	40,000	80,000	Focus on boat and shore based fishing, sail and powerboat navigation and access, surfing, shore-based use in viewshed. 3-9 month study, interviews, site visit, meetings with developer and staff, summary of existing data, summary report.
Total		**846,000**	**1,583,000**	

Pilot - Post Installation Monitoring

Information Need	Specific Studies	Low Cost	High Cost	Key Assumptions
Marine Mammals and Turtles	Monitoring—Strike, aggregation effects, avoidance effects. Continuation of baseline assessment.	50,000	100,000	**(costs are for one year of monitoring—multiple years may be required).** Shore based observers for gray whale surveys in spring and winter; resident gray and humpbacks in summer and fall; acoustic monitoring with autonomous recorders for other species (i.e., dolphins and porpoises)-includes boat time to set and retrieve recorders. High end includes small plane surveys. Fish cameras might see marine mammals.
Fish	Monitoring—Strike, aggregation effects, avoidance effects.	150,000	325,000	**costs are for one year of monitoring—multiple years may be required)** Equipment costs includes lights and camera package, tagging, active acoustics (100-250k). Operating costs are recurring yearly (50-75k). Tremendous uncertainty here—costs could be much higher depending on agency needs.
Seabirds/Shorebirds	Monitoring—Strike, aggregation effects, avoidance effects. Continuation of baseline assessment.	20,000	40,000	**(costs are for one year of monitoring—multiple years may be required)** Shore based observation and survey.

Benthos	Periodic survey and sampling to determine effects on benthic organisms and community	60,000	100,000	**(costs are for one year of monitoring—** multiple years may be required) Diver and boat surveys, 3-4 survey days per year**.**
Acoustic Characterization Monitoring	Noise coming off WECs	40,000	45,000	**(costs are for one year of monitoring—multiple years may be required)** Initial investment of 40k, then 5k recurring per year.
Total		**320,000**	**610,000**	

Pilot - NEPA and Process

Information Need	Specific Studies	Low Cost	High Cost	Key Assumptions
NEPA Document Preparation	Consulting firm contract	600,000	1,000,000	Agency consultation, Biological Assessment, MMPA permits, 404 water quality permit, CZMA, draft and final EIS, draft and final license agreement.
Monitoring and Study Plans	Consultants or research partners	125,000	125,000	Separate study plans prepared for 1) marine mammals & sea turtles, 2) fish, invertebrates, & water quality, 3) seabirds. Assumes several iterations for each study plan needed to satisfy agency concerns.
Total		**725,000**	**1,125,000**	

Commercial Costs

Commercial - Siting and Scoping

Information Need	Specific Studies	Small Scale Commercial (Low Estimate)	Small Scale Commercial (High Estimate)	Large Scale Commercial (Low Estimate)	Large Scale Commercial (High Estimate)	Scaling Rules—Scaling up from pilot
Preliminary Resource Assessment —Feasibility	Desktop feasibility—max flow rate, cross sectional area, length of channel: Theoretical resource	0	0	0	0	**Covered in Pilot**—Study at pilot scale directly applicable to small- and large-scale commercial.
Environmental Scoping	Desktop study—review existing information	10,000	10,000	10,000	10,000	**Incremental Increase**—Pilot study $10k provides most of the necessary information, may need to be updated for the commercial process.
Community Outreach (Note: Community outreach continues through all project phases)	Targeted information delivery, community meetings, workshops	50,000	80,000	60,000	80,000	**Continuing Cost, Incremental Increase—**Pilot costs: $50k-$60: Outreach budget may increase for commercial scale, based on the difference in length of permitting process—anticipated at 1.5 years for a pilot, 5.5 years for a commercial project following FERC's ILP process waters. Longer process will required more in-depth outreach, more public meetings, greater need for facilitated stakeholder interactions. Potential for broader stakeholder group.
Regulatory Outreach	Policy and regulatory analysis, reach out to regulators for future NEPA process	7,000	15,000	7,000	15,000	**Continuing Cost, Incremental Increase—**Pilot costs: $5k-10k: For a small-scale and large-scale commercial project, additional outreach would be needed beyond the pilot and costs would likely increase, based on larger potential footprint and expected level of regulatory concern.
Total		**67,000**	**105,000**	**77,000**	**105,000**	

Commercial - Pre-Installation Studies

Information Need	Specific Studies	Small Scale Commercial (Low Estimate)	Small Scale Commercial (High Estimate)	Large Scale Commercial (Low Estimate)	Large Scale Commercial (High Estimate)	Scaling Rules—Scaling up from pilot
Detailed Resource Assessment	Boat-mounted ADCP to survey general area. Once a particular site is chosen, bottom-mounted ADCP may be used to obtain more precise data for device placement.	25,000	50,000	35,000	75,000	**Incremental Increase**—Pilot Costs: $50k-$100k: Cost scaling is a factor of site size. Additional boat time and equipment is needed for larger site surveys.
Hydrodynamic Modeling—Maximum Available and Extractable Power (model would also be used in water quality tasks)	Modeling natural hydrodynamic conditions at the site as well as wake effects of proposed arrays	60,000	120,000	80,000	120,000	**Additive Study**—Would not be likely in pilot-scale, detailed hydrodynamic modeling would be more useful at commercial scale.
sea Bottom Survey, Mapping and Bottom Composition	Assess suitability ofseabed for anchoring floating barge platforms. Also identify bottom anomalies or other features of interest for benthic habitat characterization.	0	0	50,000	100,000	(Small Commercial) **Covered in Pilot**—Pilot Costs: $110k (Large Commercial) **Incremental Increase**—Larger project footprint would necessitate additional ship time and potentially additional ROV survey to facilitate siting.

Marine Mammals and sea turtles	Baseline Condition—Population analysis, food availability and preference, reproduction—compare to existing data (assuming availability)	150,000	240,000	40,000	100,000	**Additive Study—**Pilot Costs: $485k-$620k. Baseline at pilot scale collected population, distribution, and behavior to assess direct effects. Pilot scale information will be applicable to commercial scale, but additional studies needed to assess system-wide effects on habitat and food supply due to operation of arrays. Could be used in potential BACI-like monitoring studies, if required.
Fish and Invertebrates	Baseline Health—Population analysis, food availability and preference, reproduction—compare to existing data (assuming availability)	250,000	370,000	30,000	100,000	**Additive Study—**Pilot Costs: $469k-$765k. Baseline at pilot scale collected population, distribution, and behavior to assess direct effects. Pilot scale information will be applicable to commercial scale, but additional studies needed to assess system-wide effects on habitat and food supply due to operation of arrays. Could be used in potential BACI-like monitoring studies, if required.
Seabirds	Baseline Condition—Population analysis, food availability and preference, reproduction—compare to existing data (assuming availability)	30,000	100,000	30,000	100,000	**Additive Study—**Pilot Costs: $37k-$150k. Baseline at pilot scale collected population, distribution, and behavior to assess direct effects. Pilot scale information will be applicable to commercial scale, but additional studies needed to assess system-wide effects on habitat and food supply due to operation of arrays. Could be used in potential BACI-like monitoring studies, if required.
Water Quality and Sediment Transport Modeling	Baseline—CTD point casts; sediment transport modeling to indicate changes in sediment transport.	100,000	220,000	100,000	220,000	**Additive Study—**WEC arrays may raise concerns for sediment transport processes and effects to shoreforms. Sediment transport modeling may be required at both small- and large-scale commercial, and validation sampling. CTD casts and sediment traps

						may also be required.
Habitat	From seabed survey conducted in pilot, development of habitat maps and nearshore survey	30,000	50,000	80,000	375,000	(Small commercial) **Incremental Increase**—Small increase in costs to factor in studies habitat mapping for a slightly larger project footprint. At the small commercial scale, you still do not expect far field effects on habitat from turbine operation. (large commercial) **Multiplicative Increase**—when WEC numbers cross a threshold where you would begin to expect far field effects, habitat assessment and mapping would likely be required for a larger area. May require additional surveys and data collection, such as LIDAR.
Cultural Resources	Three phases: Inventory, testing, data recovery. And assessment of traditional cultural properties.	0	30,000	15,000	30,000	**Incremental Increase**—Increasing the area of potential effect offshore would increase the likelihood that submerged cultural resources would be found requiring documentation or mitigation. This estimate assumes that the nearshore footprint of the cable landing is the same at all project phases. If nearshore or shore-based footprint were to grow, costs would also grow.
Navigation	Assess navigational use of project area and potential effects caused by project operation. Also assess effects to navigation if project is damaged by debris.	0	0	10,000	20,000	(Small Commercial) **Covered in Pilot**—Pilot costs $10k-15k. Small commercial, similar footprint to pilot-scale, pilot studies would be applicable. (large Commercial) **Incremental Increase**—larger footprint than pilot and small commercial may require additional studies or data processing.

Recreation	Additional assessment costs above pilot for more precision, focus groups or panel evaluations, survey based evaluations, descriptive use information study, evaluation of changes to recreational resource	125,000	375,000	125,000	375,000	**Additive Studies—**Larger project area, greater potential risk to recreational opportunities, may require more detailed and intensive studies to understand potential effect on recreational resources and mitigation strategies
Total		**770,000**	**1,555,000**	**595,000**	**1,615,000**	

Commercial - Post-Installation Monitoring

Information Need	Specific Studies	Small Scale Commercial (Low Estimate)	Small Scale Commercial (High Estimate)	Large Scale Commercial (Low Estimate)	Large Scale Commercial (High Estimate)	Scaling Rules—Scaling up from pilot
Marine Mammals and Turtles	Nearfield Monitoring—Strike, entanglement, aggregation effects, avoidance effects.	30,000	325,000	30,000	325,000	**Continuing Costs:** Monitoring at the pilot scale will have established effects at the nearfield; costs for small commercial nearfield monitoring will be lower or remain at the same level per year. At the low end of range, periodic surveys expected. At the high end, continuation of nearfield visual and acoustic monitoring (farfield monitoring is an additive study costed below under "Ecosystem Effects"). Costs are per year—potentially recurring for 2-3 years at high costs, and continuing at a lower level of effort and cost for the term of the license.

Fish	Nearfield Monitoring—Strike, aggregation effects, avoidance effects.	30,000	325,000	30,000	325,000	**Continuing Costs:** Monitoring at the pilot scale will have established effects at the nearfield; costs for small commercial nearfield monitoring will be lower or remain at the same level per year. At the low end of range, periodic surveys expected. At the high end, continuation of nearfield visual and acoustic monitoring (farfield monitoring is an additive study costed below under "Ecosystem Effects"). Costs are per year—potentially recurring for 2-3 years at high costs, and continuing at a lower level of effort and cost for the term of the license.
Seabirds	Nearfield Monitoring—Strike, aggregation effects, avoidance effects.	30,000	150,000	30,000	150,000	**Continuing Costs:** Monitoring at the pilot scale will have established effects at the nearfield; costs for small commercial nearfield monitoring will be lower or remain at the same level per year. At the low end of range, periodic surveys expected. At the high end, continuation of nearfield visual and acoustic monitoring (farfield monitoring is an additive study costed below under "Ecosystem Effects"). Costs are per year—potentially recurring for 2-3 years at high costs, and continuing at a lower level of effort and cost for the term of the license.
Benthos	Periodic survey and sampling to determine effects	30,000	100,000	30,000	100,000	**Continuing Costs:** Monitoring at the pilot scale (if applicable) will have established effects at the nearfield; if monitoring was carried out at the pilot scale, costs for small

						commercial at the nearfield will be smaller or constant and may also include sampling and surveys of the farfield. At the low end of range, periodic nearfiled surveys expected. At the high end, additional sampling may be required in the farfield. Costs are per year—potentially recurring for 2-3 and continuing at a lower level of effort and cost for the term of the license.
Noise and EMF Characterization Monitoring	Noise coming off turbines and EMF off turbines and cables.	20,000	20,000	20,000	20,000	**Continuing Cost:** Assuming initial investment and deployment of monitoring technology at pilot scale, costs would be only for the recurring data collection and analysis. Costs are per year—potentially recurring for 2-3 years at high costs, and continuing at a lower level of effort and cost for the term of the license.
Navigation	Develop signage and lighting scheme to warn boaters of project presence—monitor safety and compliance	40,000	40,000	40,000	40,000	**Continuing Costs, Incremental Increase**—Larger project footprint may require purchase and installation of additional signage and lighting, as well as compliance monitoring. Upfront cost, with compliance monitoring continuing for term of license.

Ecosystem Effects Seabird	Assess changes to pre-installation population analysis, fitness, food availability and preference, reproduction—compare to existing data (assuming availability)	200,000	500,000	200,000	300,000	**Additive Study—**If there is regulatory concern that the scale of a project is likely to result in food chain or ecosystem effects on species of concern, monitoring may be required to assess changes based on pre-installation baseline studies. Studies may not be required for small-scale commercial deployments. If Before After Control Impact (BACI)-type studies are required for large commercial deployments, cost could be very high and have tremendous effects on project feasibility. Costs are per year—potentially recurring for 3-5 years at high costs, and continuing at a reduced effort and cost for the term of the license. Costs may increase periodically (approximately every five years) for additional survey effort or equipment replacement.
Ecosystem Effects Marine Mammals and Turtles	Assess changes to pre-installation population analysis, fitness, food availability and preference, reproduction—compare to existing data (assuming availability)	200,000	500,000	200,000	300,000	**Additive Study—**If there is regulatory concern that the scale of a project is likely to result in food chain or ecosystem effects on species of concern, monitoring may be required to assess changes based on pre-installation baseline studies. Studies may not be required for small-scale commercial deployments. If Before After Control Impact (BACI)-type studies are required for large commercial deployments, cost could be very high and have tremendous effects on project feasibility. Costs are per year—potentially recurring for 3-5 years at high cost, and continuing at a reduced effort and cost for the term of the license. Costs may increase periodically (approximately every five years) for additional survey effort or equipment replacement.

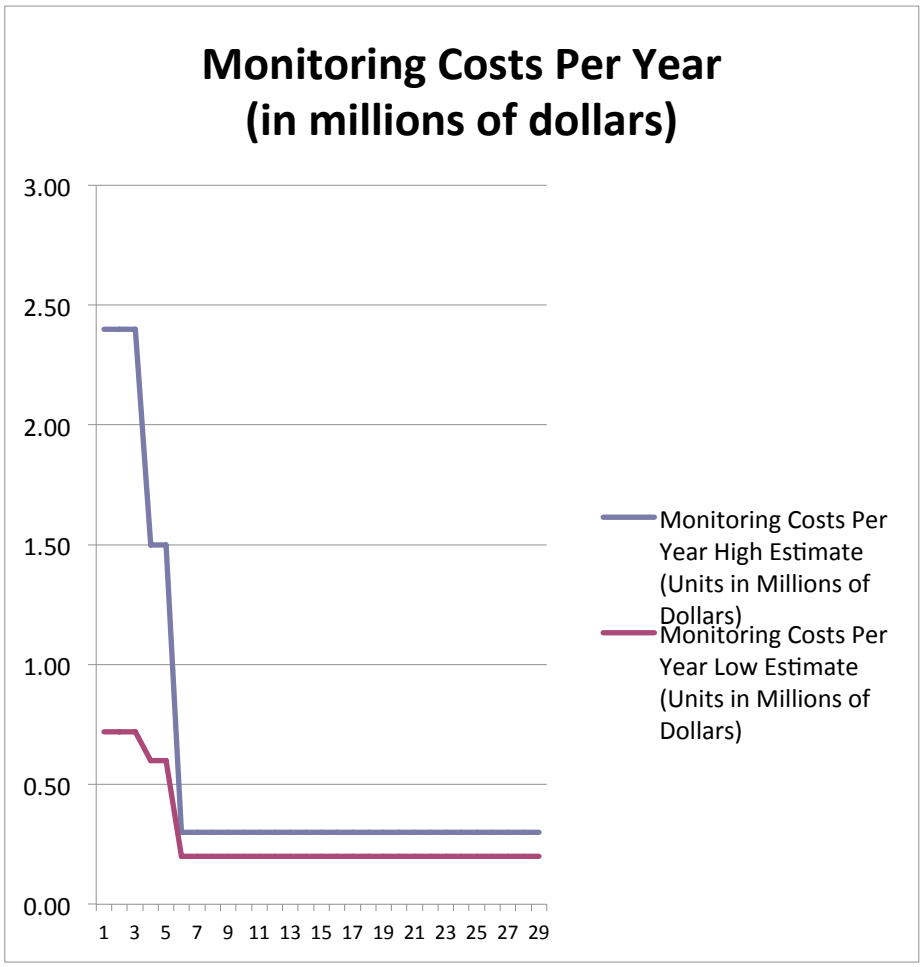
Ecosystem Effects Fish	Assess changes to pre-installation population analysis, fitness, food availability and preference, reproduction—compare to existing data (assuming availability)	200,000	500,000	200,000	300,000	**Additive Study—**If there is regulatory concern that the scale of a project is likely to result in food chain or ecosystem effects on species of concern, monitoring may be required to assess changes based on pre-installation baseline studies. Studies may not be required for small-scale commercial deployments. If Before After Control Impact (BACI)-type studies are required for large commercial deployments, cost could be very high and have tremendous effects on project feasibility. Costs are per year—potentially recurring for 3-5 years at high costs, and continuing at a reduced effort and cost for the term of the license. Costs may increase periodically (approximately every five years) for additional survey effort or equipment replacement.
Total		780,000	2,460,000	780,000	1,860,000	**(Per Year)**
30-year total		7,750,000	14,580,000	7,750,000	14,580,000	**(Based on cost profile illustrated in chart below)**

Commercial - NEPA and Process

Information Need	Specific Studies	Small Scale Commercial (Low Estimate)	Small Scale Commercial (High Estimate)	Large Scale Commercial (Low Estimate)	Large Scale Commercial (High Estimate)	Scaling Rules—Scaling up from pilot
NEPA Document Preparation	Consulting firm contract	50,000	100,000	50,000	100,000	**Incremental Increase—** NEPA document from pilot project will inform preparation of commercial scale document. But longer process, higher potential for environmental effects, and greater agency scrutiny will likely require additional work.
Monitoring and Study Plans	Consultants or research partners	20,000	50,000	20,000	50,000	**Incremental Increase—** Study plans from pilot project will inform preparation of commercial scale document. Higher potential for environmental risk, and greater agency scrutiny will require additional study plan preparation.
Total		**70,000**	**150,000**	**70,000**	**150,000**	

Surge Totals

Information Need	Specific Studies	Small Scale Commercial (Low Estimate)	Small Scale Commercial (High Estimate)	Large Scale Commercial (Low Estimate)	Large Scale Commercial (High Estimate)	Notes
Siting and Scoping		67,000	105,000	77,000	105,000	**Preliminary Permit, scoping, and lead up to DLA**
Pre-Installation Studies		770,000	1,555,000	595,000	1,615,000	**From final license agreement through baseline data collection phase**
Post-Installation		7,750,000	14,580,000	7,750,000	14,580,000	**Over the course of the 30 year license**
NEPA and Process		70,000	150,000	70,000	150,000	**Over the course of the FERC licensing process, Preliminary permit to FLA**
Total		**8,657,000**	**16,390,000**	**8,492,000**	**16,450,000**	**(additional costs above those incurred in pilot)**



Monitoring Costs Per Year High Estimate (Units in Millions of Dollars)	Monitoring Costs Per Year Low Estimate (Units in Millions of Dollars)
1.860	0.78
1.860	0.78
1.860	0.78
0.9	0.305
0.9	0.305
0.3	0.2
0.3	0.2
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