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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 Marine and Hydrokinetic Devices

Reference Models #1, #2 and #3

AE Copping
SH Geerlofs

November 2011

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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.

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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 ([10], [8], [13], [11], [15]). 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 ([7], [14]). The success of the MHK industry in the U.S. depends on a favorable comparison of COE with that of other renewable energy sources ([12]).

Pacific Northwest National Laboratory (PNNL) has been tasked to develop the COE contribution from studies and regulatory processes necessary to site and permit MHK devices. 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. Cost estimates for projects using each of the three major technologies (tidal, wave, and river energy capture) have been developed at the pilot scale, and for small and large commercial arrays. 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 reference sites and devices. Cost estimates were reviewed by agency staff, researchers, and consultants familiar with environmental permitting processes.

The goals of the environmental siting and permitting cost requirement portion of the Reference Model project are to:

1. Determine information needs, study requirements, and costs for each reference model for 1) scoping; 2) baseline; 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 flow of studies, permitting pathways, to smooth pathway to siting and permitting.
4. Create and apply 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 presents the results of the first two goals for Reference Models #1, #2, and #3. Engagement with the appropriate regulatory agencies is ongoing (Goal 3); comparisons of reference model sites to potential and developed MHK sites will follow (Goal 4). These first Reference Models are described in Table 1, along with the waterbody and aquatic receptors of concern.

Table 1. Description of Three Reference Models

Reference Model	Technology	Water Body	Aquatic Receptors
#1 Tidal	Unducted double-bladed tidal device, gravity mounted, non-surface piercing	Generic version of Tacoma Narrows, Puget Sound, Washington	Marine animals and habitats likely to be found in a fjord-like temperate estuary like Puget Sound
#2 Riverine	Cross-flow turbine with 3 blades, 2 rotors, mounted on barge	Generic version of Scotlandville Bend, Mississippi River, Louisiana	Freshwater animals and habitats likely to be found in a developed river like the Mississippi
#3 Wave	Point absorber buoy, surface float, subsurface reaction plate, anchored to bottom	Generic version of coastal northern California	Marine animals and habitats likely to be found on an open temperate coastline

2.0 Methods

Environmental studies contribute a significant component of overall COE for both pilot and 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.

2.1 Regulatory Drivers

Reference models are designed to be generic; they provide a benchmark of expected costs for each potential study likely to be encountered during the licensing process. PNNL has constructed and applied a series of logic models, or decision cascades, which illustrate how site characteristics and regulatory concerns drive selection and inclusion of individual studies during licensing (Figure 1). These logic models are being used to develop a web-based interface to guide users through a menu of studies and associated costs. In real-world permitting processes, some of the studies described for pilot and commercial scale processes may not be required, as determined by the unique siting and regulatory characteristics of the project.

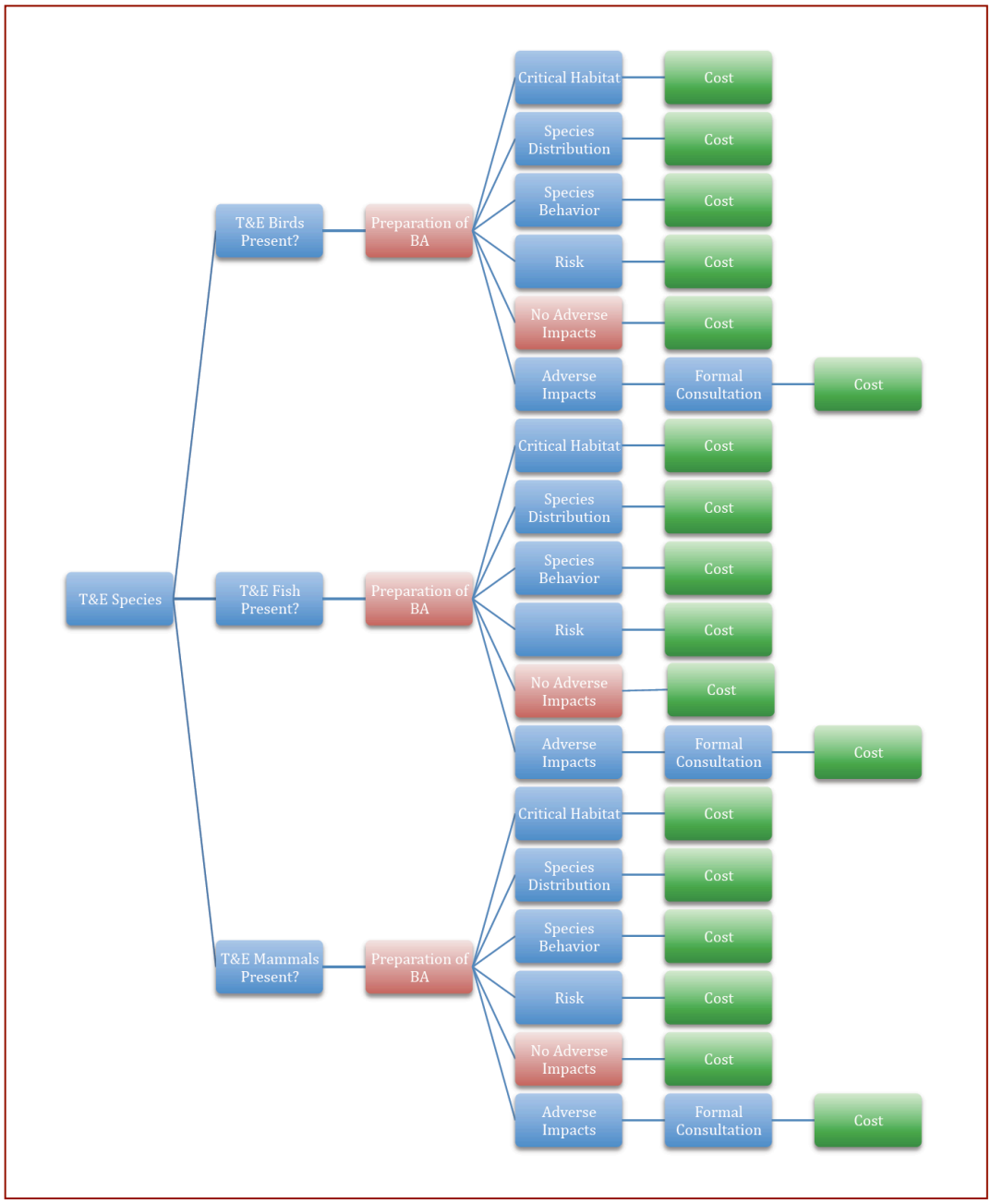

Figure 1. Example of a logic model for the tidal power reference model site. This example illustrates the decision pathway for determining studies and associated costs needed to address threatened and endangered species (T&E Species). Blue and red boxes indicate decision points in the logic process, green boxes identify points where costs could be incurred.

The logic models and all environmental studies and related costing information were parsed into four stages: 1) Siting and Scoping; 2) Pre-installation Assessment; 3) Post-installation Monitoring; and 4) NEPA and administrative process. The description of each step and the categories of investigations are further described below.

Each of these development stages has costs associated with it; while the specific technology and site will have a major influence on the costs for any project, there are many commonalities driven by regulatory requirements and information needs across projects. PNNL researchers derived cost ranges from the best available information on existing and planned MHK projects, consulted with developers and the consultants supporting them, and relied on best professional judgment of researchers and natural resource management agency staff. Costs for each of the studies and processes have been developed for pilot projects using real-world data; from this, costs were extrapolated for small (10-50 device) and large (> 50 devices) commercial development arrays. While the size of a pilot project differs from one technology and location to another, in general pilot projects include 1 to 10 devices, total less than 5MW generation capacity, and can be deployed for up to 5 years ([10]). To date there are only a small number of pilot projects under development in the U.S., and fewer in the water. PNNL researchers developed a set of scaling rules to extrapolate from pilot project costs to those of small commercial scale and to large scale commercial. Costing information developed for the early stage of pilot projects rely on information from ongoing expenditures from U.S. projects. Post-installation monitoring costs are more speculative as no monitoring programs have been fully implemented to date.

Each of the stages includes the need to document and carry out processes associated with meeting regulatory requirements. These includes 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 almost all of the siting and permitting processes that drive costs are included under the broad umbrella of the National Environmental Policy Act (NEPA)[1].

2.2 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.

2.3 Pre-installation Studies, Analysis and Documentation

After choosing a site, working with local stakeholders, and determining the requirements in conjunction with government agency staff, each developer must design and carry out the necessary studies, analyse and interpret the data, and document the process under the existing regulatory authorities. Pre-installation studies (also frequently referred to as baseline assessment) for wave, tidal, and river projects will differ somewhat, and site-specific and technology-specific differences will have an influence; however, in almost all cases, the environmental areas listed in Table 2 will be required by federal and state statutes. Sample collection and analysis, data analysis and interpretation, quality

assurance and quality control, and documentation for regulatory purposes are needed for each study. At this stage, developers will also carry out more detailed resource assessment studies and surveys to inform micrositing.

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	Aquatic animals under threat of extinction	Endangered Species Act [3]
Marine mammals	Concern and special societal value afforded to specific groups of animals	Marine Mammal Protection Act [5]
Migratory birds	Birds that migrate across regions and continents and considered at risk	Migratory Bird Treat Act [6] (international treaty)
Important fish and shellfish populations	Fish populations of commercial, recreational, or cultural importance	Magnuson Stevens Fishery Conservation, Management Act [4] (protects critical habitats and fish populations)
Habitats	Need to assess quantity and quality of habitat, due to important role in supporting aquatic species	Magnuson Stevens Fishery Conservation and Management Act, other federal and state regulations
Water Quality	Cumulative degradation of water quality (DO, nutrients, human benefits), changes in sediment transport (affecting habitats shoreforms)	Clean Water Act [2] and state equivalents

Closely associated with environmental assessment is the examination of potential conflicts with other uses; the two ubiquitous uses that U.S. regulation require be examined for all development in marine areas include navigation and historic preservation; the FERC licensing process also requires that recreational resources are assessed. PNNL researchers included costs for investigations in these three areas in the COE estimates.

2.4 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 energy converters or turbines (nearfield), focusing on the potential for animals colliding with devices or becoming entangled in mooring lines. As the size of wave,

tidal, or riverine hydrokinetic farms grow, 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 and effects on marine populations and communities. While site- and technology-specific differences will drive the details of such studies, in general there is likely to be a common set of requirements (Table 3). As for pre-installation studies, sample collection and analysis, data analysis 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 wave, tidal and riverine project development.

Target of Study	Project Scale	Type of Study	Reason for the Study
Aquatic mammals	Pilot and Commercial	Nearfield monitoring	Strike, 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 coming off tidal turbines	Change in acoustics over time: damage, harassment of aquatic 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 total estimated costs for the first three reference models are presented in tables 4, 5 and 6, for pilot and commercial scale tidal, wave and riverine reference sites used for the Department of Energy reference model project. These sites are: Puget Sound tidal, U.S. west coast wave, and Mississippi instream hydrokinetic. Complete tables that show detailed costing information for each reference model, phase, information need, and study are shown in the Appendices.

Table 4. Reference Model 1 (Puget Sound Tidal) Cost Estimates

Information Need	Pilot		Small Scale Commercial		Large Scale Commercial	
	Low	High	Low	High	Low	High
Siting & Scoping	$125,000	$280,000	$215,000	$370,000	$225,000	$390,000
Pre-Installation Studies	$790,000	$2,510,000	$1,160,000	$3,540,000	$1,345,000	$4,085,000
Post-Installation	$470,000	$870,000	$5,665,000	$13,935,000	$5,665,000	$13,935,000
NEPA & Process	$730,000	$830,000	$910,000	$1,430,000	$1,110,000	$1,680,000
Total	$2,115,000	$4,490,000	$7,950,000	$19,275,000	$8,345,000	$20,090,000

Table 5. Reference Model 2 (Mississippi Riverine) Cost Estimate

Information Need	Pilot		Small Scale Commercial		Large Scale Commercial	
	Low	High	Low	High	Low	High
Siting & Scoping	$85,000	$105,000	$152,000	$190,000	$162,000	$200,000
Pre-Installation Studies	$170,000	$410,000	$450,000	$1,065,000	$550,000	$1,305,000
Post-Installation	$100,000	$155,000	$1,100,000	$2,105,000	$1,100,000	$2,105,000
NEPA & Process	$70,000	$125,000	$140,000	$275,000	$140,000	$275,000
Total	$425,000	$795,000	$1,842,000	$3,635,000	$1,952,000	$3,885,000

Table 6. Reference Model 3 (West Coast Wave) Cost Estimate

Information Need	Pilot		Small Scale Commercial		Large Scale Commercial	
	Low	High	Low	High	Low	High
Siting & Scoping	$240,000	$430,000	$330,000	$520,000	$330,000	$520,000

Pre-Installation Studies	$1,218,000	$2,047,000	$1,985,000	$3,715,000	$1,798,000	$3,767,000
Post-Installation	$475,000	$945,000	$7,235,000	$17,445,000	$7,235,000	$17,445,000
NEPA & Process	$725,000	$1,125,000	$905,000	$1,725,000	$1,105,000	$1,975,000
Total	$2,658,000	$4,547,000	$10,455,000	$23,405,000	$10,468,000	$23,707,000

Costs shown here summarize **total** costs expected at pilot and each commercial phase. As described more fully below, commercial costs were extrapolated from pilot costs 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. Commercial costs were initially calculated as incremental costs above those incurred in the pilot; in tables 4, 5, and 6, we add pilot and additional commercial costs to produce a total cost for both small scale and large-scale commercial phases.

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 7); 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 8. 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 cetaceans were found in an estuary, the marine mammal surveys costs would be greatly reduced; 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 projects, costs may be higher.

Table 7. Environmental studies that are likely to be required for each reference model stage.

Siting and Scoping	Pre-Installation Studies	Post-Installation Monitoring	NEPA Process [1]
Preliminary resource assessment—feasibility	Detailed resource assessment	Marine mammal	NEPA document preparation
Environmental scoping	Seabed survey, mapping and bottom composition	Fish	Monitoring and study plans
Community outreach	Marine mammals	Benthos	
Regulatory outreach	Fish and invertebrates	Seabirds	
	Seabirds	Acoustic characterization monitoring	
	Turtles		
	Water quality		
	Habitat		
	Cultural resources		
	Navigation		

Table 8. Examples Of Pilot Scale Study Assumptions—Pre-Installation (Baseline) Studies for Fish, Aquatic Mammals, Seabirds, and Turtles.

Information Need	Specific Studies	Key Assumptions
Aquatic mammals	Baseline—distribution, speciation, and behavioral analysis: acoustic monitoring, shore-based observation, literature review.	Costs will vary between sites—for example, Puget Sound tidal will focus data collection on endangered Southern Resident Killer Whales, while west coast wave will focus on migratory species, such as gray whales. One year of observation and acoustic monitoring.
Fish and invertebrates	Baseline—distribution, speciation, and behavioral analysis: Split-beam hydroacoustics, grab samples for invertebrates, trawls, traps, and other sampling methods	Costs vary by site, technology, regulatory drivers, and stakeholder interests. ESA listed and commercially valuable species will drive studies. Depending on regulatory and stakeholder needs, multi-year pre-installation monitoring will be required by agencies; 1) Telemetry receivers to detect tagged ESA-listed species 2) Grab sampling to assess benthic inverts; 3) Trapping to assess crab; 4) Trawling to assess demersal fish and benthic invertebrates.
Birds	Baseline—distribution, speciation, behavioral analysis: observation, literature review and synthesis.	May not be necessary for a tidal power project that does not pierce the surface. For tidal power, deep diving birds are the primary concern. For wave power projects, surveys and observations could be carried out concurrently with marine mammal research. Estimated one year of survey, 12-24 surveys.
Turtles	Baseline—distribution, speciation, and behavioral analysis of T&E turtles in project area	One year of surveys. Low cost option: surveys done in conjunction with marine mammal and seabird boat surveys, no additional equipment charges; high cost option: surveys done from small aircraft.

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.

3.1.1.1 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. To date, no monitoring programs have been approved or initiated at the reference sites characterized here; costs were estimated based on professional judgment. Yearly monitoring costs were estimated and extended to the proposed 5-year term of a FERC pilot license.

3.1.1.2 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.

3.1.1.3 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

Cost estimates for permitting and siting at a small (10 to 50 devices) and large (greater than 50 devices) commercial scale were extrapolated from costs determined for pilot-scale projects. Translating costs from pilot to commercial scale followed a number of assumptions.

3.2.1 Assumptions for Scaling Pilot Project Costs to Commercial Scale

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 behavioural 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.

3.2.2 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	Example
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 that are 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 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.

3.2.3 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 reduce sharply 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.

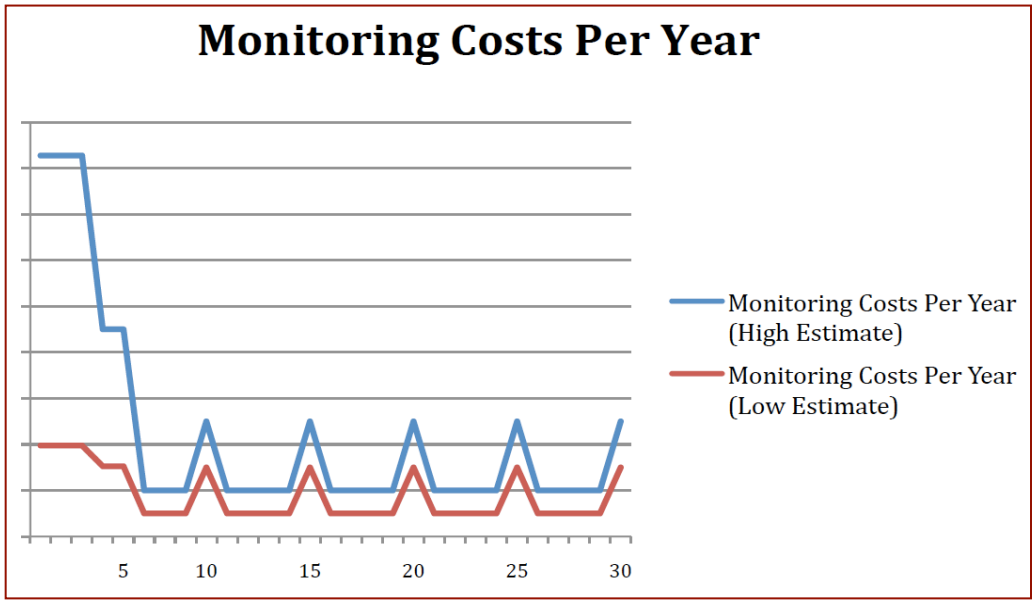

Figure 2. Hypothetical cost profile for monitoring costs over a thirty-year license term for a commercial-scale tidal farm. Costing figures are not shown, as data are preliminary.

The process we have 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 generic nature of the Department of Energy reference model requires that we consider the degree to which these costs are representative of tidal, wave and river sites throughout the country. 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 boat-based observer assessments of marine mammals and sea turtles along an open coastline will reduce days of shiptime; 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 is still expected. With a limited number of U.S. 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 each MHK technology type 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, we will revisit the logic models, further refining the list of studies and associated costs for each stage of development. Similarly the scaling rules (Table VIII) 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.

3.3 Cost Differences Among MHK Technologies

Differences in waterbody characteristics, MHK technologies, and animals and habitats present in tidal, river and wave sites account for differences in costs among the estimates for siting and permitting for the three reference models. In the real world, even greater differences are likely because permitting requirements and siting complexities are unique to each proposed MHK site.

3.4 Tidal sites (Reference Model #1)

These sites are generally small in geographic size, requiring limited seabed surveys. However, these sites tend to be located at waterbody constrictions, often encompassing the major ingress and egress pathways for marine life to pass from one estuarine basin to another. This heightened sensitivity to interaction with marine mammals, fish and other highly valued organisms may drive up pre-installation studies and post-installation monitoring costs. Spinning tidal turbine blades and acoustic noise from rotors may pose risk to marine animals from strike and acoustic masking, and may require extensive post-installation monitoring to verify and inform risk assumptions. Non-surface piercing turbines provide relatively limited risk to most seabirds, so that bird surveys may be limited. Tidal sites generally are within fairly well studied bodies of water, so that some environmental data may be available for scoping and pre-installation assessment.

3.5 Riverine sites (Reference Model #2)

Rivers that are suitable for MHK energy development are often large industrialized stretches that are impacted by other anthropogenic activities. Animals and plants living in these areas may be considered to be less sensitive than those in marine water, with the exception of animals that are under special protection (such as the U.S. Endangered Species Act). Working in rivers is easier and less costly than working in marine waters; as a result survey and study costs can be expected to be lower. In addition, environmental sensitivities may be lower in Louisiana (generic location for the river reference model) than in Washington State (tidal reference model) and California (wave reference model), resulting in lower costs for public process and many permitting activities.

3.6 Wave sites (Reference Model #3)

Wave sites appropriate for power generation are most commonly found in coastal areas, encompassing large expanses of ocean. Work in the open ocean is costly, and may require that large areas be surveyed for migratory species, habitat quality and seabed variations. In addition, coastal sites are likely to support commercial and recreational fisheries and other ocean uses, requiring more extensive environmental scoping and outreach. Seabirds and sea turtles, as well as marine mammals and large fish become important marine receptors of concern for pre-installation studies. However, most wave sites have sea room for passage of migratory animals, and may not require a high level of year round monitoring of marine mammals, fish and turtles. Open coastal areas are less likely to have extensive environmental data sets available, driving pre-installation survey costs higher.

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 importantly, the process of determining appropriate studies to meet regulatory needs can assist the process of standardizing a pathway to getting MHK projects in the water and expanding towards commercial production of power. PNNL staff will continue to refine the costs estimates established to date, adding examples of tidal and wave sites and technologies, under the Department of Energy reference model project. In addition, we will work with the regulatory agencies to refine the specific studies proposed here, working towards a process that is mutually acceptable to developers, regulators and stakeholders.

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Appendix A—Costing Tables

REFERENCE MODELS #1 - #3 SUMMARY COSTING TABLES

Tidal

Information Need	Pilot Low	Pilot High	Small Scale Commercial Low	Small Scale Commercial High	Large Scale Commercial Low	Large Scale Commercial High
Siting & Scoping	$125,000	$280,000	$215,000	$370,000	$225,000	$390,000
Pre-Installation Studies	$790,000	$2,510,000	$1,160,000	$3,540,000	$1,345,000	$4,085,000
Post-Installation	$470,000	$870,000	$5,665,000	$13,935,000	$5,665,000	$13,935,000
NEPA & Process	$730,000	$830,000	$910,000	$1,430,000	$1,110,000	$1,680,000
Total	$2,115,000	$4,490,000	$7,950,000	$19,275,000	$8,345,000	$20,090,000

River

Information Need	Pilot Low	Pilot High	Small Scale Commercial Low	Small Scale Commercial High	Large Scale Commercial Low	Large Scale Commercial High
Siting & Scoping	$85,000	$105,000	$152,000	$190,000	$162,000	$200,000
Pre-Installation Studies	$170,000	$410,000	$450,000	$1,065,000	$550,000	$1,305,000
Post-Installation	$100,000	$155,000	$1,100,000	$2,105,000	$1,100,000	$2,105,000
NEPA & Process	$70,000	$125,000	$140,000	$275,000	$140,000	$275,000
Total	$425,000	$795,000	$1,842,000	$3,635,000	$1,952,000	$3,885,000

Wave

Information Need	Pilot Low	Pilot High	Small Scale Commercial Low	Small Scale Commercial High	Large Scale Commercial Low	Large Scale Commercial High
Siting & Scoping	$240,000	$430,000	$330,000	$520,000	$330,000	$520,000
Pre-Installation Studies	$1,218,000	$2,047,000	$1,985,000	$3,715,000	$1,798,000	$3,767,000
Post-Installation	$475,000	$945,000	$7,235,000	$17,445,000	$7,235,000	$17,445,000
NEPA & Process	$725,000	$1,125,000	$905,000	$1,725,000	$1,105,000	$1,975,000
Total	$2,658,000	$4,547,000	$10,455,000	$23,405,000	$10,468,000	$23,707,000

Tidal Reference Model #1

Pilot - Siting and Scoping

Information Need	Specific Studies	Low Cost	High Cost	Key Assumptions
Preliminary Resource Assessment—Feasibility	Desktop feasibility—resource intensity and theoretical resource	40,000	50,000	Key information developer would use to select site and file preliminary permit. Costs may be lower if existing regional model (such as PNNL—FVCOM) is used.
Environmental Scoping	Desktop study—review existing information	25,000	50,000	Used for preliminary NEPA scoping and to identify key information needs for baseline.
Community Outreach	Targeted information delivery, community meetings, workshops	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. Would feed inform NEPA process.
Regulatory Outreach	Policy and regulatory analysis, reach out to regulators for future NEPA process	10,000	100,000	Figures based on real-world experience with early adopter projects. Costs would likely be significantly lower for future subsequent projects.
Total		**125,000**	**280,000**	

Pilot - Pre-Installation Studies

Information Need	Specific Studies	Low Cost	High Cost	Key Assumptions
Detailed Resource Assessment	ADCPs, ADVs and ECMs to characterize flow and turbulence at the site.	225,000	275,000	10 days ship time—4 days ship mounted survey and two three-month deployments with turnaround (30k). Engineering and instrumentation (150-180k). Data management, analysis, and reporting (45k)
Seabed Survey, Mapping and Bottom Composition	Side-scan survey of site area, ROV survey at site, optional survey of bottom composition below seabed	100,000	300,000	Side-scan survey and ROV to identify bottom features, shipwrecks, cables, any munitions, derelict fishing gear or other anomalies that could cause siting hazards or be of concern during environmental permitting (230 k) GIS site map (20k). Subsurface seabed composition to inform foundation and anchor design (100-150k)
Marine Mammals	Baseline—distribution, speciation, and behavioral analysis: Acoustic monitoring, shore-based observation, literature review.	150,000	620,000	Low-end reflects actual costs in Admiralty Inlet; High end assumes that not all developers would have access to similar research resources and is based on costing data from HT Harvey. Collecting marine mammal baseline data at a cost that can be supported by a limited pilot project budget is an emerging area of research.
Fish and Invertebrates	Baseline—distribution, speciation, and behavioral analysis: Split-beam hydroacoustics, grab samples for invertebrates, trawls, traps, and other sampling methods	150,000	765,000	Low-end reflects actual costs in Admiralty Inlet; High end assumes that not all developers would have access to similar research resources and is based on costing data from HT Harvey. Collecting fisheries baseline data at spatial and temporal scales useful for project siting and environmental review is an emerging area of research.
Seabirds	Baseline—distribution, speciation, behavioral analysis: Observation, literature review and synthesis.	0	50,000	May not be necessary for a tidal power project that does not pierce the surface. Deep diving birds are the primary concern. If necessary, surveys and observations would be carried out concurrently with marine mammal research. Existing data in Puget Sound may be sufficient.
Water Quality	Baseline—CTD deployed during resource assessment; water quality model coupled to hydrodynamic model to indicate relative water quality effects.	110,000	200,000	Two three-month seabed deployment of CTD concurrent with resource assessment. Water quality modeling requires existence of coupled hydrodynamic/water quality model.
Habitat	From seabed survey, development of habitat maps and potential nearshore survey	20,000	25,000	May not have to do nearshore survey if directional drilling avoids habitat effects.
Cultural Resources	Three phases: Inventory, testing, data recovery	15,000	195,000	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	AIS transponder, risk assessment	5,000	10,000	AIS transponder near project to record ship tracks; data used in Coast Guard consultation.
Recreation	Recreation overview and initial impact assessment	15,000	70,000	Focus on fishing, sea kayaking, sail and power boat passage, scuba, shore-based use and viewshed. 3-9 month study, interviews, site visit, meetings with developer and staff, summary of existing data, summary report.
Total		**790,000**	**2,510,000**	

Pilot - Post-Installation Monitoring

Information Need	Specific Studies	Low Cost	High Cost	Key Assumptions
Marine Mammal	Monitoring—blade 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, hydrophones, active acoustics (100-250k). Operating costs are recurring yearly (50-75k). Tremendous uncertainty here—costs could be much higher depending on agency needs.
Fish	Monitoring—blade 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.
Benthos	Periodic survey and sampling to determine effects	60,000	100,000	**(costs are for one year of monitoring—multiple years may be required)** ROV surveys, six surveys over three years.
Turbine Performance	Velocity, vibration, temperature, stress	70,000	75,000	**(costs are for one year of monitoring—multiple years may be required)** Not an environmental cost, but may be integrated into environmental monitoring platform and provides context for environmental measurements.
Acoustic Characterization Monitoring	Noise coming off turbines	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. 1 week of ship time, then one person/month for analysis.
Total		**470,000**	**870,000**	

Pilot - Nepa and Process

Information Need	Specific Studies	Low Cost	High Cost	
NEPA Document Preparation	Consulting firm Contract	650,000	750,000	Agency consultation, Biological Assessment, MMPA permits, 404 water quality permit, CZMA, drafts and final EIS, draft and final license agreement.
Monitoring and Study Plans	Consultants or research partners	80,000	80,000	Separate plans for(1) marin mammals and (2) fish, invertebrates and water quality. Assumes several interations to satisfy agency concerns.
Total		**730,000**	**830,000**	

Pilot - Total

	Pilot	
Information Need	Low	High

Siting & Scoping	$125,000	$280,000
Pre-Installation Studies	$790,000	$2,510,000
Post-Installation	$470,000	$870,000
NEPA & Process	$730,000	$830,000
Total	**$2,115,000**	**$4,490,000**

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 $25k-$50k provides most of the necessary information, will 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	100,000	**Continuing Cost, Incremental Increase**—Pilot costs: $50k-$80k: Outreach budget may increase for commercial scale, based on the difference in length of permitting process—anticipated at 1.5 years for a pilot, 4 years for a commercial project in WA state waters (Pacific Energy Ventures 2010). 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	30,000	0	30,000	0	**Continuing Cost, Incremental Increase**—Pilot costs: $10k-100k: For a small-scale and large-scale commercial project, costs are likely similar to pilot on the high end, but low end of the range would likely increase, based on larger potential footprint and expected level of regulatory concern.
Total		**90,000**	**90,000**	**100,000**	**110,000**	

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	ADCPs, ADVs and ECMs to characterize flow and turbulence at the site.	50,000	75,000	75,000	125,000	**Incremental Increase**—Pilot Costs: $225k-$275k: Cost scaling is a factor of site size. Additional ship 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	80,000	200,000	80,000	200,000	**Additive Study**—Would not be likely in pilot-scale, detailed hydrodynamic modeling would be more useful at commercial scale.
Seabed Survey, Mapping and Bottom Composition	Side-scan survey of site area, ROV survey at site, optional survey of bottom composition below seabed	0	0	50,000	100,000	(Small Commercial) **Covered in Pilot**—Pilot Costs: $100-$300k (Large Commercial) **Incremental Increase**—Larger project footprint would necessitate additional ship time and potentially additional ROV survey to facilitate siting.
Marine Mammals	Baseline Health— 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: $150k-$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	Baseline Health— 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: $150k-$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.
Seabirds	Baseline Health— Population analysis, food availability and preference, reproduction—compare to existing data (assuming availability)	50,000	100,000	50,000	100,000	**Additive Study**—Pilot Costs: $0k-$50k. 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	Baseline—CTD deployed during resource assessment; water quality model coupled to hydrodynamic model to indicate relative water quality effects.	0	0	10,000	50,000	(Small Commercial) **Covered in Pilot**—footprint similar to pilot scale costs expected to be similar as well. (Large Commercial) **Incremental Cost**—increased spatial and temporal scale for modeling—would extend boundaries further for water quality modeling and require longer time-scale runs. Also requires additional calibration samples.
Habitat	From seabed survey, development of habitat maps and potential nearshore survey	5,000	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 turbine 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 (potentially the entire basin). May require additional surveys and data collection, such as LIDAR.
Cultural Resources	Three phases: Inventory, testing, data recovery	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	AIS transponder, risk assessment	0	0	10,000	20,000	(Small Commercial) **Covered in Pilot**—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		**370,000**	**1,030,000**	**555,000**	**1,575,000**	

C - Post Installation Studies and 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 Mammal	Nearfield Monitoring—blade 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.
Fish	Nearfield Monitoring—blade 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.
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.
Acoustic Characterization Monitoring	Noise coming off turbines	5,000	5,000	5,000	5,000	**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—would likely continue for life of project for the purposes of both environmental and performance monitoring.
Ecosystem Effects Seabird	Assess changes to pre-installation population analysis, fitness, food availability and preference, reproduction—compare to existing data (assuming availability)	100,000	300,000	100,000	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	Assess changes to pre-installation population analysis, fitness, food availability and preference, reproduction—compare to existing data (assuming availability)	100,000	300,000	100,000	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)	100,000	300,000	100,000	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		**395,000**	**1,655,000**	**395,000**	**1,655,000**	**(Per year)**
30-year total		**5,195,000**	**13,065,000**	**5,195,000**	**13,065,000**	**(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	100,000	500,000	300,000	750,000	**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	80,000	100,000	80,000	100,000	**Incremental Increase**—Study plans from pilot project will inform preparation of commercial scale document. But costing of ecosystem-type monitoring studies and additional scope of studies due to longer process, higher potential for environmental risk, and greater agency scrutiny will require additional study plan preparation.
Total		**180,000**	**600,000**	**380,000**	**850,000**	

Commercial - Tidal 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		90,000	90,000	100,000	110,000	**Preliminary Permit, scoping, and lead up to DLA**
Pre-Installation Studies		370,000	1,030,000	555,000	1,575,000	**From final license agreement through baseline data collection phase**
Post-Installation		5,195,000	13,065,000	5,195,000	13,065,000	**Over the course of the 30 year license**
NEPA and Process		180,000	600,000	380,000	850,000	**Over the course of the FERC licensing process, Preliminary permit to FLA**
Total		5,835,000	14,785,000	6,230,000	15,600,000	(additional costs above those incurred in pilot)

River Reference Model #2

Pilot - Siting and Scoping

Information Need	Specific Studies	Low Cost	High Cost	Key Assumptions
Preliminary Resource Assessment—Feasibility	Desktop feasibility— resource intensity and theoretical resource	20,000	25,000	Key information developer would use to select site and file preliminary permit.
Environmental Scoping	Desktop study—review existing information on key species and habitats as well as competing uses.	10,000	10,000	Records searches and contacting resource agencies, universities, etc. for data sufficient. For competing uses, contact Corps of Engineers and resource agencies.
Community Outreach	Targeted information delivery, identify existing groups and policy structures, and carry out focus groups and workshops.	50,000	60,000	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	5,000	10,000	May not be a need to carry out policy analysis, such information may already exist
Total		**85,000**	**105,000**	

Pilot - Pre-Installation Studies

Information Need	Specific Studies	Low Cost	High Cost	Key Assumptions
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.	50,000	100,000	Water velocities would likely be characterized by a boat-mounted ADCP and, for finer-scale informatin, a bottom-mounted ADCP. This would be done to support power production goals (optimize siting). Low estimates assume 4-ADCPs and tide gauges for two weeks, high estimates assumes one month.
River Bottom Survey and Mapping	Assess suitability of riverbed for anchoring floating barge platforms. Also identify bottom anomalies or other features of interest for benthic habitat characterization.	20,000	75,000	Cost for field work + equipment; includes 2 days to survey project site and cable route.
Fish and Invertebrates	Baseline—Site-specific studies of fish presence in the area to focus operational monitoring	40,000	50,000	Netting and electrofishing during 4 seasons to determine species list and relative abundance.
Water Quality	Water quality meter point casts from boat; contaminants analysis in lab	0	0	Based on Free Flow study plan, no noted water quality studies in pre-installation-water quality monitoring included below.
Habitat	Riverbed habitat surveys conducted during the river bottom mapping surveys listed above. Additional surveys of river bank and land-based infrastructure	10,000	20,000	Shoreline surveys for rare, threatened and endangered plants and animals. Cost is minimal if terrestrial footprint of pilot project is small.
Ambient Noise	Characterize ambient noise. Literature review and survey of expected projected related noise and EMF.	10,000	10,000	Assumes existing information on device noise profile and EMF.
Cultural Resources	Three phases: Inventory, testing, data recovery. And assessment of traditional cultural properties.	10,000	60,000	Low estimate is for historic properties inventory only. Ans assessment of traditional cultural properties. 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	Assess navigational use of project area and potential effects caused by project operation. Also assess effects to navigation if project is damaged by debris.	10,000	15,000	Paper studies and simple models to ascertain competing uses. New field studies not needed.
Recreation	Recreation overview and initial impact assessment	20,000	80,000	Focus on boat and shore based fishing, powerboat navigations and access, shore-based use in viewshed. 3-9 month study, interviews, site visit, meetings with developer and staff, summary of existing data, summary report.
Total		**170,000**	**410,000**	

Pilot - Post Installation Monitoring

Information Need	Specific Studies	Low Cost	High Cost	Key Assumptions
Fish and Diving Birds	Active acoustic monitoring for presence of fish and diving birds in project area and their interactions with the pilot project	25,000	80,000	**(costs are for one year of monitoring—multiple years may be required)** Purchase of a DIDSON or similar device for long-term use. Costs would be lower if device is rented for a week or two. Costs would be higher if interactions are studied for multiple arrays/locations. Studies of endangered pallid sturgeon probably not needed because of minimal interaction with raft-mounted rotor, but other, common species (freshwater drum, Alabama shad) would be studied.

Water Quality Monitoring	Routine water quality monitoring at project site, comparison with control sites	10,000	10,000	**(costs are for one year of monitoring—multiple years may be required)** Estimate also includes costs for temporary use of construction containment measures to ensure that oils and other hazardous chemicals are not spilled during project installation
River Bed Habitat	Monitor shoreline erosion and sedimentations from construction and operations	5,000	5,000	**costs are for one year of monitoring—multiple years may be required)**
Noise and EMF Characterization Monitoring	Noise coming off turbines and EMF coming of device and cable	20,000	20,000	**(costs are for one year of monitoring—multiple years may be required)**
Navigation	Develop signage and lighting scheme to warn boaters of project presence—monitor safety and compliance	40,000	40,000	Up front costs for signage and lights and education activities.
Total		**100,000**	**155,000**	

Pilot - Nepa and Process

Information Need	Specific Studies	Low Cost	High Cost	Key Assumptions
NEPA Document Preparation	Consulting firm contract	50,000	75,000	Like an EA (rather than a full EIS). Costs for NEPA could vary widely, but likely to be relatively low for this site because (1) few environmental issues, (2) less public concern about impacts, and (3) small cost for public meetings in rural Louisiana.
Monitoring and Study Plans	Consultants or research partners	20,000	50,000	Study plans to address identified agency needs: Navigation, EMF, Acoustics, pre-installation, and monitoring.
Total		**70,000**	**125,000**	

Pilot - Total

	Pilot	
Information Need	Low	High
Siting & Scoping	$85,000	$105,000
Pre-Installation Studies	$170,000	$410,000
Post-Installation	$100,000	$155,000
NEPA & Process	$70,000	$125,000
Total	**$425,000**	**$795,000**

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	60,000	60,000	70,000	**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**	**85,000**	**77,000**	**95,000**	

Commercial - Pre-Installation Studies

		Small Scale Commercial	Small Scale Commercial	Large Scale Commercial	Large Scale Commercial	

Information Need	Specific Studies	(Low Estimate)	(High Estimate)	(Low Estimate)	(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.
River Bottom Survey, Mapping and Bottom Composition	Assess suitability of riverbed for anchoring floating barge platforms. Also identify bottom anomalies or other features of interest for benthic habitat characterization.	0	0	20,000	75,000	(Small Commercial) **Covered in Pilot—**Pilot Costs: $20K-75K (Large Commercial) **Incremental Increase—**Larger project footprint would necessitate additional ship time and potentially additional ROV survey to facilitate siting.
Fish and Invertebrates	Baseline Health— Population analysis, food availability and preference, reproduction—compare to existing data (assuming availability)	40,000	50,000	40,000	50,000	**Additive Study—**Pilot Costs: $40k-$50k. 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
Water Quality and Sediment Transport Modeling	Baseline—CTD casts and sediment traps; water quality model coupled to hydrodynamic model to indicate relative water quality effects and sediment transport	20,000	40,000	40,000	60,000	**Additive Study**—Arrays may raise concerns for sediment transport processes and effects on river habitat and infrastructure. 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	Riverbed habitat surveys conducted during the river bottom mapping surveys listed above. Additional surveys of river bank and land-based infrastructure	5,000	10,000	20,000	80,000	(Small commercial) **Incremental Increase—**Pilot costs $10k-$20k. 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 turbine 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 (potentially the entire basin). May require
Cultural Resources	Three phases: Inventory, testing, data recovery. And assessment of traditional cultural properties.	5,000	10,000	15,000	50,000	**Incremental Increase**—Pilot costs $10k-$60k. Increasing the area of potential effect offshore would increase the likelihood that submerged cultural
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	5,000	10,000	(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		**280,000**	**655,000**	**380,000**	**895,000**	

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
Fish and Diving Birds	Nearfield Monitoring— Active acoustic monitoring for presence of fish and diving birds in turbine nearfield and their interactions with the pilot project.	10,000	80,000	10,000	80,000	**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.
Water Quality Monitoring	Routine water quality monitoring at project site, comparison with control sites	10,000	10,000	10,000	10,000	**Continuing Costs:** Monitoring at the pilot scale (if applicable) will have established water quality effects, if monitoring was carried out at the pilot scale, costs for small commercial-scale monitoring at the nearfield will be smaller or constant. Costs are per year, potentially recurring for the term of the license.
River Bed Monitoring —Farfield Changes	Survey and sampling to determine effects on safety and stability of river infrastructure due to sediment loss or loss of energy	40,000	80,000	40,000	80,000	**Additive Study:** Monitoring at the pilot scale (if applicable) will have established effects at the nearfield; At commercial scale, monitoring may be required to investigate energy removal effects and changes in sediment transfer downstream of site. Effects on river infrastructure (locks, piers, dams, etc.) may be a concern.

						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.
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.
Total		120,000	230,000	120,000	230,000	**(Per Year)**
30-year total		**1,000,000**	**1,950,000**	**1,000,000**	**1,950,000**	**(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**	

Riverine 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	85,000	77,000	95,000	**Preliminary Permit, scoping, and lead up to DLA**
Pre-Installation Studies		280,000	655,000	380,000	895,000	**From final license agreement through baseline data collection phase**
Post-Installation		1,000,000	1,950,000	1,000,000	1,950,000	**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		**1,417,000**	**2,840,000**	**1,527,000**	**3,090,000**	**(additional costs above those incurred in pilot)**

Wave Reference Model #3

Pilot - Siting and Scoping

Information Need	Specific Studies	Low Cost	High Cost	Key Assumptions
Resource Assessment—Maximum Available Power	Assessment of waves heights, lengths, periods over seasons	90,000	90,000	Access to NCEP-NOPP Wavewach III 30-yr hindcast dataset. 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	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	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. 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 survey at site, compile data and create georeferenced site maps.	110,000	110,000	Cost for field work + equipment; includes 2 days to survey project site and cable route ($47 k). Mapping assumes lab work, data enter, analysis, and report writing ($62 K)
Marine Mammals	Baseline—distribution, speciation, and behavioral analysis: acoustic monitoring, vessel-based observation, and literature review.	485,000	620,000	1 year study. Large vessel for gray whale surveys in spring and winter; small vessel surveys for 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.
Fish and Invertebrates	Baseline—distribution, speciation, and behavioral analysis: Telemetery 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	Baseline—distribution, speciation, and behavioral analysis: small boat surveys and line transects	37,000	150,000	1 year of surveys; Low: assumes 6 surveys done in conjunction with marine mammal surveys, 6 done independently. High: assumes 24 surveys/year done independently.
Turtles	Baseline—distribution, speciation, and behavioral analysis of T&E turtles in project area	12,000	38,000	1 year of surveys. Low: surveys done in conjunction with marine mammal and seabird boat surveys, no equipment charges; High- surveys done from small aircraft
Water Quality	Water quality meter point casts from boat; contaminants analysis in lab	40,000	54,000	Low estimate is if paired with fish and invertebrate studies (no boat charges); High is to conduct separate water quality measurements.
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	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	AIS transponder near project to record ship tracks; data used in Coast Guard consultation.
Recreation	Recreation overview and initial impact assessment	20,000	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		**1,218,000**	**2,047,000**	

Pilot - Post Installation Studies

Information Need	Specific Studies	Low Cost	High Cost	Key Assumptions
Marine Mammals and Turtles	Monitoring—Strike, entanglement, 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, hydrophones, active acoustics (100-250k). Operating costs are recurring yearly and include surveys of lines for entanglement (50-75k). Tremendous uncertainty here—costs could be much higher depending on agency needs.
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	Monitoring—Strike, aggregation effects, avoidance effects.	75,000	150,000	(costs are for one year of monitoring—multiple years may be required) Vessel surveys to assess bird behavior, camera packages. Tremendous uncertainty here—costs could be much higher depending on agency needs.
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) ROV or diver surveys, six surveys over three years.
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		475,000	945,000	

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**	

Pilot - Total

	Pilot	
Information Need	Low	High
Siting & Scoping	$240,000	$430,000
Pre-Installation Studies	$1,218,000	$2,047,000
Post-Installation	$475,000	$945,000
NEPA & Process	$725,000	$1,125,000
Total	**$2,658,000**	**$4,547,000**

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 $50k-$100k provides most of the necessary information, will 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	50,000	80,000	**Continuing Cost, Incremental Increase**—Pilot costs: $50k-$80k: Outreach budget may double for commercial scale, based on the difference in length of permitting process—anticipated at 1.5 years for a pilot, 5years for a commercial project. 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	30,000	0	30,000	0	**Continuing Cost, Incremental Increase**—Pilot costs: $50k-160k: For a small-scale and large-scale commercial project, costs are likely similar to pilot on the high end, but low end of the range would likely increase, based on larger potential footprint and expected level of regulatory concern.
Total		**90,000**	**90,000**	**90,000**	**90,000**	

C - 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—Hydrodynamic Modeling of Maximum extractable Power	Consider array effects and insert hypothetic MHK device into wave model developed for preliminary assessment.	80,000	200,000	80,000	200,000	**Additive Study**—Would not be likely in pilot-scale, detailed hydrodynamic modeling would be more useful at commercial scale.
Seabed Survey, Mapping and Bottom Composition	Side-scan survey of site area, ROV survey at site, optional survey of bottom composition below seabed	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	Baseline Condition—Population analysis, food availability and preference, reproduction—compare to existing data (assuming availability)	122,000	223,000	30,000	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	Baseline Condition—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.

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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.
Turtles	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: $12k-$38k. 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
Water Quality/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	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	AIS transponder, risk assessment	0	0	10,000	20,000	(Small Commercial) **Covered in Pilot**—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		**767,000**	**1,668,000**	**580,000**	**1,720,000**	

Commercial - Post-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**
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.

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	500,000	**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	500,000	**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	500,000	**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		**720,000**	**2,400,000**	**720,000**	**2,400,000**	**(Per Year)**
30 Year Total		**6.76 M**	**16.50 M**	**6.76 M**	**16.50 M**	**(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	100,000	500,000	300,000	750,000	**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	80,000	100,000	80,000	100,000	**Incremental Increase—Study plans from pilot project will inform preparation of commercial scale document. But costing of ecosystem-type monitoring studies and additional scope of studies due to longer process, higher potential for environmental risk, and greater agency scrutiny will require Additive Study plan preparation.**
Total		**180,000**	**600,000**	**380,000**	**850,000**	

Commercial - Wave 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		90,000	90,000	90,000	90,000	**Preliminary Permit, scoping, and lead up to DLA**
Pre-Installation Studies		767,000	1,668,000	580,000	1,720,000	**From final license agreement through baseline data collection phase**
Post-Installation		6,760,000	16,500,000	6,760,000	16,500,000	**Over the course of the 30 year license**
NEPA and Process		180,000	600,000	380,000	850,000	**Over the course of the FERC licensing process, Preliminary permit to FLA**
Total		**7,797,000**	**18,858,000**	**7,685,000**	**19,160,000**	**(additional costs above those incurred in pilot)**

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