PNNL-19990

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

Preliminary Screening Analysis for the Environmental Risk Evaluation System

Task 2.1.1: Evaluating Effects of Stressors – Fiscal Year 2010 Progress Report

Environmental Effects of Marine and Hydrokinetic Energy

RM Anderson
AE Copping
FB Van Cleve

November 2010

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161
ph: (800) 553-6847
fax: (703) 605-6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

This document was printed on recycled paper.
(9/2003)

PNNL-19990

Preliminary Screening Analysis for the Environmental Risk Evaluation System

Task 2.1.1: Evaluating Effects of Stressors – Fiscal Year 2010 Progress Report

Environmental Effects of Marine and Hydrokinetic Energy

RM Anderson
AE Copping
FB Van Cleve

November 2010

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

Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

Possible environmental effects of marine and hydrokinetic (MHK) energy development are not well understood, and yet regulatory agencies are required to make decisions in spite of substantial uncertainty about environmental impacts and their long-term effects. An understanding of risk associated with likely interactions between MHK installations and aquatic receptors, including animals, habitats, and ecosystems, can help reduce the level of uncertainty and focus regulatory actions and scientific studies on interactions of most concern. As a first step in developing the Pacific Northwest National Laboratory (PNNL) Environmental Risk Evaluation System (ERES), PNNL scientists conducted a preliminary risk screening analysis on three initial MHK cases—a tidal project in Puget Sound using OpenHydro turbines, a wave project off the coast of Oregon using Ocean Power Technologies point attenuator buoys, and a riverine current project in the Mississippi River using Free Flow Power Corporation turbines.

Through an iterative process, the screening analysis revealed that top-tier stressors in all three cases were the effects of the dynamic physical presence of the device (e.g., strike), accidents, and effects of the static physical presence of the device (e.g., habitat alteration). Receptor interactions with these stressors at the four highest tiers of risk were dominated by marine mammals (cetaceans and pinnipeds) and birds (diving and non-diving); only the riverine case (Free Flow) included different receptors in the third tier (fish) and the fourth tier (benthic invertebrates). Although this screening analysis provides a preliminary analysis of vulnerability of environmental receptors to stressors associated with MHK installations, probability analysis, especially of risk associated with chemical toxicity and accidents such as oil spills or lost gear, will be necessary to further understand high-priority risks. Subject matter expert review of this process and results is required and is planned for the first quarter of FY11. Once expert review is finalized, the screening analysis phase of ERES will be complete.

Project Overview

Energy generated from the world's oceans and rivers offers the potential to make substantial contributions to the domestic and global renewable energy supply. The U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) Wind and Water Power Program supports the emerging marine and hydrokinetic (MHK) energy industry. As part of an emerging industry, MHK project developers face challenges related to siting, permitting, construction, and operation of pilot- and commercial-scale facilities, as well as the need to develop robust technologies, secure financing, and gain public acceptance.

In many cases, little is known about the potential effects of MHK energy generation on the aquatic environment from a small number of devices or a large-scale commercial array. Nor do we understand potential effects that may occur after years or decades of operation. This lack of knowledge affects the solvency of the industry, the actions of regulatory agencies, the opinions and concerns of stakeholder groups, and the commitment of energy project developers and investors.

To unravel and address the complexity of environmental issues associated with MHK energy, Pacific Northwest National Laboratory (PNNL) is developing a program of research and development that draws on the knowledge of the industry, regulators, and stakeholders and builds on investments made by the EERE Wind and Water Power Program. The PNNL program of research and development—together with complementary efforts of other national laboratories, national marine renewable energy centers, universities, and industry—supports DOE's market acceleration activities through focused research and development on environmental effects and siting issues.

Research areas addressed include

- **Categorizing and evaluating effects of stressors** – Information on the environmental risks from MHK devices, including data obtained from in situ testing and laboratory experiments (see other tasks below) will be compiled in a knowledge management system known as Tethys to facilitate the creation, annotation, and exchange of information on environmental effects of MHK technologies. Tethys will support the Environmental Risk Evaluation System (ERES) that can be used by developers, regulators, and other stakeholders to assess relative risks associated with MHK technologies, site characteristics, waterbody characteristics, and receptors (i.e., habitat, marine mammals, and fish). Development of Tethys and the ERES will require focused input from various stakeholders to ensure accuracy and alignment with other needs.
- **Effects on physical systems** – Computational numerical modeling will be used to understand the effects of energy removal on water bodies from the short- and long-term operation of MHK devices and arrays. Initially, PNNL's three-dimensional coastal circulation and transport model of Puget Sound will be adapted to test and optimize simulated tidal technologies that resemble those currently in proposal, laboratory trial, or pilot study test stages. This task includes assessing changes to the physical environment (currents, waves, sediments, and water quality) and the potential effects of these changes on the aquatic food webs) resulting from operation of MHK devices at both pilot- and commercial-scale in river and ocean settings.
- **Effects on aquatic organisms** – Testing protocols and laboratory exposure experiments will be developed and implemented to evaluate the potential for adverse effects from operation of MHK devices in the aquatic environment. Initial studies will focus on electromagnetic field effects, noise

associated with construction and operation of MHK devices, and assessment of the potential risk of physical interaction of aquatic organisms with devices. A variety of fish species and invertebrates will be used as test animals, chosen due to their proximity to and potential susceptibility to MHK devices.

- **Permitting and planning** – Structured stakeholder communication and outreach activities will provide critical information to the project team to support execution of other project tasks. Input from MHK technology and project developers, regulators and natural resource management agencies, environmental groups, and other stakeholder groups will be used to develop the user interface of Tethys, populate the database, define the risk attributes of the ERES, and communicate results of numerical modeling and laboratory studies of exposure of test animals to MHK stressors. This task will also include activities to promote consideration of renewable ocean energy in national and local Coastal and Marine Spatial Planning activities.

The team for the Environmental Effects of Marine and Hydrokinetic Energy Development project is made up of staff, faculty, and students from

- Pacific Northwest National Laboratory
  - Marine Sciences Laboratory (Sequim and Seattle, Washington)
  - Risk and Decision Sciences (Richland, Washington)
  - Knowledge Systems (Richland, Washington)
- Oak Ridge National Laboratory (Oak Ridge, Tennessee)
- Sandia National Laboratories (Albuquerque, New Mexico; Carlsbad, California)
- Oregon State University, Northwest National Marine Renewable Energy Center (Newport, Oregon)
- University of Washington, Northwest National Marine Renewable Energy Center (Seattle, Washington)
- Pacific Energy Ventures (Portland, Oregon).

Acronyms and Abbreviations

DOE	U.S. Department of Energy
EERE	DOE Office of Energy Efficiency and Renewable Energy
EMF	electromagnetic field
ERES	Environmental Risk Evaluation System
ESA	*Endangered Species Act of 1973*
FF	Free Flow Power Corporation
MHK	marine and hydrokinetic
MMPA	*Marine Mammal Protection Act of 1972 As Amended*
MTBA	*Migratory Bird Treaty Act of 1918*
OH	OpenHydro
OPT	Ocean Power Technologies
PNNL	Pacific Northwest National Laboratory
S–R	stressor–receptor
T&E	threatened and endangered

Contents

Figure

Tables

1.0 Introduction

Responsible deployment of marine and hydrokinetic (MHK) energy devices in the marine and riverine waters of the United States requires that all appropriate regulatory requirements be met and that stakeholder concerns be taken into account. However, the regulatory pathways and stakeholder concerns have not been fully developed and addressed in accord with the needs and potential impacts of the emerging MHK industry. Pacific Northwest National Laboratory (PNNL) has been tasked by the U.S. Department of Energy (DOE) to help set priorities for focused regulatory scrutiny and to recommend the most pertinent and useful studies that support that scrutiny.

A key step in setting regulatory priorities is the assignment of risk to interactions between MHK installations and aquatic receptors, including animals, habitats, and ecosystems in the marine waters and rivers where MHK development is feasible. The conceptual process for setting priorities for MHK effects on environmental receptors was outlined in *Identification and Prioritization of Analysis Cases for Marine and Hydrokinetic Energy Risk Screening* (Anderson et al. 2010). Figure 1 shows the risk assessment process developed by PNNL. The initial steps in the process carried out during FY10 consisted of a case selection process (first three boxes) and screening analysis (next five boxes). This report details the process through preliminary screening analysis on an initial three cases chosen for FY10. Additional steps are needed to complete the screening analysis, including additional review of the process and outcomes with outside subject matter experts, which will be completed in late 2010 (first quarter of FY11).

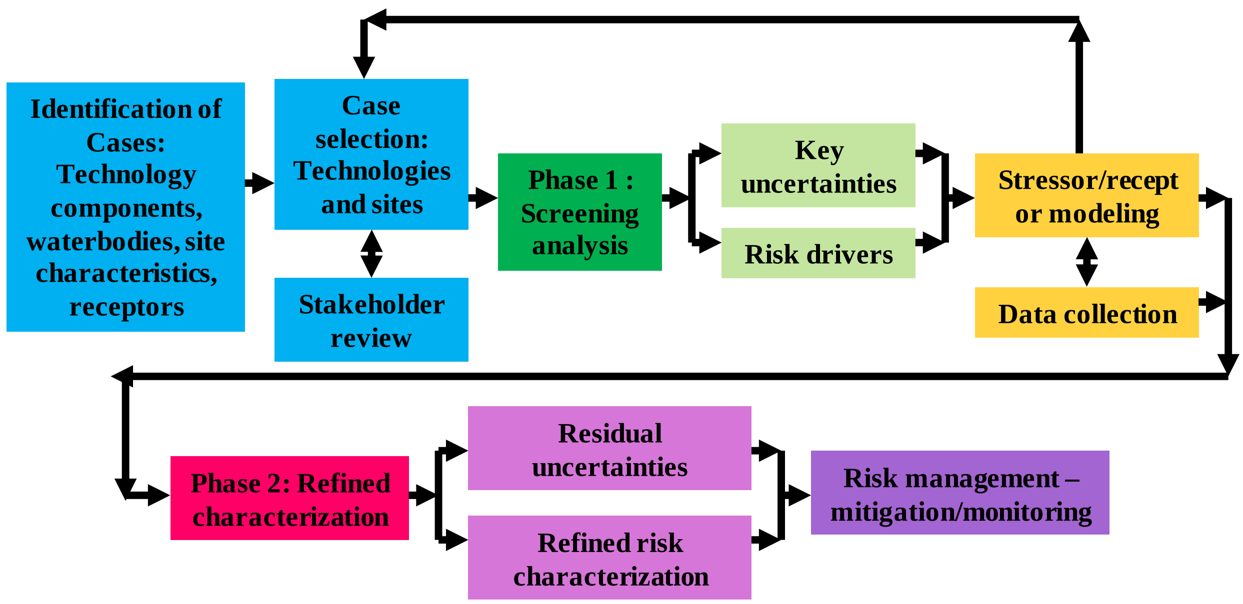

Figure 1. Risk-informed analytical process.

In this report, the methods used to conduct the preliminary screening analysis are detailed in Section 2. Results of the analysis are presented in Section 3 and discussed in Section 4. Section 5 presents a summary of next steps in the risk assessment. The single source cited in the text is listed in Section 6. An appendix provides additional details on the risk ranking process used in this analysis.

2.0 Methods

The methods for case identification and screening analyses are divided into four parts, which are detailed in this section. Additional backup materials can be viewed in the Appendix. The four steps are

- identification of initial cases
- identification of risk stressors and receptors
- description of impact scenarios
- ranking of highest-priority risks for each case.

2.1 Identification of Initial Cases

A case study approach is used to identify the risks associated with installation, operation, maintenance, and decommissioning of MHK devices. The cases that will make up the study will be drawn from proposed MHK projects, favoring those that are moving through the permitting and development process. The first cases identified for screening analysis in FY10 were identified from among several possible projects, using criteria that have been discussed with members of the DOE Water Power Team, other national laboratories, MHK project developers, regulators, environmental organizations, and other stakeholders (Table 1).

Table 1. Criteria for choosing MHK projects as cases for initial screening analysis during FY10. The criteria are listed in sequential order. Cases that received *Yes* or *Sufficient* for a criterion were passed on to the next criterion for consideration. Cases that received *No* or *Insufficient* for certain criteria were removed from consideration for FY10 but will be reconsidered at a later date.

Criterion	Explanation of Criterion
1. Real/Readiness	Project is expected to be in the water within 2 years; both the technology and the project are ready.
2. Developer Willingness	Developer is willing to share technology and project data.
3. Diverse Representation	The case helps span the analytical space: a. technology type (tidal, wave, riverine) b. technology configuration (e.g. axial flow, horizontal flow) c. climatic zone (temperate, tropical, sub-arctic)
4. National Interest	For example, the project has received DOE funding.
5. Available Data	Environmental effects data are available.

The following three cases were identified during FY10 for screening analysis:

- Tidal (OH) – The project is under development by Snohomish County Public Utility District No. 1, using the Open Centre turbine (OpenHydro) in Admiralty Inlet, Puget Sound, Washington. The case is described as a ducted, axial flow technology in a temperate, estuarine water body with bidirectional water flow. Protected Southern Resident killer whales are one of the key receptors of concern. Other important receptors include endangered pinnipeds (Steller sea lions), endangered fish (Chinook salmon), endangered diving birds (marbled murrelet), endangered rockfish, water quality in the Puget Sound basin, and alteration of nearshore habitats.
- Riverine (FF) – The technology developer Free Flow Power Corporation (FF) is developing a project using its turbine at Scotlandville Bend, just outside Baton Rouge, Louisiana, in the Mississippi River. The case is described as a ducted, axial flow turbine in a relatively shallow riverine system with unidirectional water flow. Endangered pallid sturgeons are one of the receptors of concern; others include endangered paddlefish, migrating diving birds, and changes in sedimentation patterns.
- Wave (OPT) – The technology developer Ocean Power Technologies (OPT) is developing a project using its PowerBuoy technology off the Pacific coast near Reedsport, Oregon. The case is described as a point-absorber wave energy converter deployed on a surface buoy in a continental shelf temperate ocean site. Migrating grey whales, endangered pinnipeds (Steller sea lions), endangered fish (Chinook salmon), endangered diving birds (marbled murrelet), endangered rockfish, and changes in sedimentation patterns are key receptors of concern.

2.2 Identification of Risk Stressors and Receptors

The screening analysis depends on the interaction between stressors and receptors at a site. Although each MHK technology differs in its components, configuration, and outputs, there are commonalities among them; eight stressors can be recognized for each technology (Table 2).

Receptors (animals and habitats) at MHK project sites differ by waterbody types, basin geometry, and geographic location; however, six major receptors can be identified for all waterbodies (Table 3).

2.3 Description of Impact Scenarios

The purpose of collecting case information from proposed MHK projects is to understand the collective risk posed by an MHK system (i.e., the device, moorings, anchors, surface floats, and cables) deployed in a specific body of water that supports a specific set of aquatic animals, habitats, and ecosystems. The smallest unit of risk calculation for this analysis is the interaction between stressors (the MHK device, moorings, and other infrastructure) and receptors (the animals and habitats). By analyzing multiple cases, PNNL researchers will develop a robust knowledge base of stressor–receptor interactions. The collection of all risk-relevant stressor–receptor pairs at a location constitutes an impact scenario that a project developer might encounter when assessing the regulatory and study needs before deployment or operation of an MHK installation. With variations in technology or siting, there may be more than one likely impact scenario for an MHK project; discussion between the project developer and regulators can help to determine the most appropriate studies that will support the interpretation of risk at the project site.

Table 2. Stressors associated with MHK technology.

Stressor	Explanation of Stressor
Physical presence of device (static)	Animals may be attracted to or avoid the device, altering ability to forage, rest, reproduce, and migrate. Habitats may be altered due to presence of the device.
Physical presence of device (dynamic)	Moving blades may threaten animals due to strike, impingement, or entrainment.
Noise	Acoustic output may disturb animals, interfering with communication, navigation.
Electromagnetic fields (EMFs)	EMFs may cause disturbance to animals, interfering with foraging and predator avoidance, or have other unknown effects.
Chemical leaching	Toxicity to animals
Energy removal	Changes in water transport due to removal of energy from waterbody, resulting in changes in sediment transport affecting nearshore and subtidal habitats
Changes in flow regime	Changes in water transport and flow regime, including deterioration of water quality and changes in base of food webs
Accidents	Accidents may include collision with surface vessels resulting in loose surface floats entangling animals, causing damage on beaches and intertidal areas, or spills of petroleum or other harmful chemicals. Also loss of surface floats and gear due to storms.

Table 3. Environmental receptors vulnerable to MHK technology.

Receptor Group	Members of the Receptor Group
Aquatic mammals	Marine mammals (cetaceans, pinnipeds), freshwater mammals
Birds	Diving and non-diving
Reptiles	Aquatic reptiles such as sea turtles
Fish	Resident and migratory
Invertebrates	Benthic macroinvertebrates
Nearfield habitat	Habitats in proximity to the MHK device that may be affected
Farfield	Habitats within the waterbody, distant from the MHK device, that may be affected

2.4 Ranking Highest-Priority Risks for Each Case

Assigning relative risk to each interaction between the stressors (MHK systems, including the device, moorings, and other infrastructure) and receptors (aquatic animals, habitats, and others) is the essence of the screening analysis step. The process is outlined here. Further details on the analysis steps and risk factors, as well as tables of intermediate analysis steps, are contained in the Appendix.

For each of the three initial cases, a list of risk-relevant stressor–receptor (S–R) pairs was compiled. Each S–R pair was evaluated against a set of seven biophysical factors to determine the vulnerability of the receptor to the stressor. This evaluation resulted in a list of ranked S–R pairs within each case. At this point, many of the S–R pair ranks will be tied, indicating that, with the current information, these S–R pairs are equally vulnerable. As further data or information become available, these ranks will be better clarified.

For all high-risk S–R pairs, a second set of regulatory risk factors was applied, resulting in a ranking of S–R pairs for each case. These ranks represent the vulnerability and level of regulatory protection applied to the receptors.

Resulting ties in rank were then subjected to two additional risk factor screenings—first as a measurement of the population strategy (*K* versus *r strategists*[1]) of the receptor, then against a set of "values" risk factors. The final rankings of S–R pairs represent the highest risks for vulnerability and level of protection for the receptors for each case. Additional steps are needed to determine the probability of occurrence for each of the ranked risks. For example, the rankings could change if an S–R pair demonstrating a high level of vulnerability exhibited a very low probability of occurrence.

In carrying out the S-R pair analysis, a sentinel species was chosen for each receptor group in order to examine interactions in the most realistic manner possible. For example, Southern Resident killer whales were chosen to represent the threatened and endangered cetacean for the Tidal (OH) case, while the sentinel threatened and endangered migratory fish for the Wave (OPT) case was Chinook salmon. For the purpose of describing the impact scenario, each sentinel species was used to represent the overall receptor group.

3.0 Preliminary Screening Analysis Results for Initial Three Cases

After the risk ranking process detailed in the previous section and the Appendix was conducted, four levels of risk were identified for each case (Table 4). The S–R risks within a color band in Table 4 (red, orange, yellow, green) represent risk ranks that are essentially tied for vulnerability of the receptor and degree of protection given that receptor by regulatory and legislative mandates. These tied risk ranks must be further elucidated through examination of the probability of the occurrence of each S–R interaction.

Top-tier stressors in all three cases were the effects of the dynamic physical presence of the device (e.g., strike), accidents, and effects of the static physical presence of the device (e.g., habitat alteration). Stressor–receptor pairs at the four highest tiers were dominated by marine mammals (cetaceans and pinnipeds) and birds (diving and non-diving); only the riverine case (Free Flow) included S–R pairs involving different receptors in the third tier (fish) and the fourth tier (benthic invertebrates).

---

[1] In terms of population stability, *K strategists* tend to produce few young that are relatively large in size compared to the adults and to invest more reproductive energy and parental care for their young. Alternatively, *r strategists* produce many young (or reproductive products such as eggs) that are small in comparison to the adults; little reproductive energy or parental care are invested in each young.

Table 4. Preliminary screening analysis results for three cases. Colors signify risk rank of S–R pairs. Red is highest rank, and green is lowest.

Tidal (OH) Stressor	Tidal (OH) Receptor	Wave (OPT) Stressor	Wave (OPT) Receptor	Riverine (FF) Stressor	Riverine (FF) Receptor
Physical presence (dynamic) strike	T&E[a] cetacean	Physical presence (static)	T&E cetacean	Physical presence (dynamic)	T&E diving bird
Accident (oil spills)	T&E cetacean	Physical presence (dynamic)	T&E diving bird	Accident (oil spill)	T&E diving bird
Physical presence (dynamic)	T&E diving bird	Physical presence (static)	T&E diving bird	Accident (oil spills)	Non T&E aquatic mammal
Accident (oil spill)	T&E diving bird	Accident (oil spill, lost gear)	T&E diving bird	Physical presence (dynamic)	MBTA[b] (non-T&E) diving bird
Physical presence (dynamic) strike	T&E pinniped	Physical presence (static)	T&E pinniped	Noise	T&E diving bird
Physical presence (static)	T&E cetacean	Noise	T&E cetacean	EMF[c]	T&E diving bird
Physical presence (static)	T&E pinniped	Noise	T&E pinniped	Leaching of toxic chemicals	T&E diving bird
Noise	T&E cetacean	Accident (lost gear and oil spills)	T&E cetacean	Accident (oil spill)	MBTA (non T&E) diving bird
Noise	T&E pinniped	Accident (lost gear and oil spills)	T&E pinniped	Leaching of toxic chemicals	Resident T&E fish
Accident (oil spills)	T&E pinniped	Noise	T&E diving bird	Physical presence (dynamic)	Migratory T&E fish
Physical presence (static)	T&E diving bird	EMF	T&E diving bird	Physical presence (dynamic)	Resident T&E fish
Noise	T&E diving bird	Leaching of toxic chemicals	T&E diving bird	EMF	Migratory T&E fish
EMF	T&E diving bird	EMF	T&E cetacean	EMF	Resident T&E fish
Leaching of toxic chemicals	T&E diving bird	EMF	T&E pinniped	Physical presence (static)	Migratory T&E fish
EMF	T&E cetacean	Leaching of toxic chemicals	T&E cetacean	Physical presence (static)	Resident T&E fish
EMF	T&E pinniped	Leaching of toxic chemicals	T&E pinniped	Noise	Migratory T&E fish

Table 4. (contd)

Tidal (OH) Stressor	Tidal (OH) Receptor	Wave (OPT) Stressor	Wave (OPT) Receptor	Riverine (FF) Stressor	Riverine (FF) Receptor
Leaching of toxic chemicals	T&E cetacean	Physical presence (dynamic)	MBTA diving bird	Noise	Resident T&E fish
Leaching of toxic chemicals	T&E pinniped	Physical presence (static)	MBTA diving bird	Leaching of toxic chemicals	Migratory T&E fish
Physical presence (dynamic) strike	Non-T&E cetacean	Physical presence (static)	MBTA non-diving bird	Accident (oil spill)	Migratory T&E fish
Physical presence (dynamic)	MBTA diving bird	Accident (oil spill, lost gear)	MBTA diving bird	Accident (oil spill)	Resident T&E fish
Accident (oil spill)	MBTA diving bird	Physical presence (static)	Non-T&E cetacean	EMF	Non-T&E benthic invertebrate
Physical presence (dynamic) strike	Non-T&E pinniped	Physical presence (static)	Non-T&E pinniped	Leaching of toxic chemicals	Non-T&E benthic invertebrate
Physical presence (static)	Non-T&E cetacean	Noise	Non-T&E cetacean	Accident (oil spill)	Non-T&E benthic invertebrate
Physical presence (static)	Non-T&E pinniped	Noise	Non-T&E pinniped		
Noise	Non-T&E cetacean	Accident (lost gear and oil spills)	Non-T&E cetacean		
Noise	Non-T&E pinniped	Accident (lost gear and oil spills)	Non-T&E pinniped		
Accident (oil spills)	Non-T&E cetacean				
Accident (oil spills)	Non-T&E pinniped				

(a) T&E = threatened and endangered.
(b) MBTA = *Migratory Bird Treaty Act of 1918*.
(c) EMF = electromagnetic field.

4.0 Discussion

The preliminary results of the three screening analyses indicate that biophysical risk factors and population strategy risk factors have a strong impact on the outcome, raising marine mammals and birds (diving and non-diving) high in the list of threats. However; the purpose of this risk assessment is to assist project developers and regulators with responsible deployment of MHK technology, therefore regulatory authority must be applied to the biophysical risk ranks. The application of the regulatory risk factors order the marine mammals and birds as the highest threats in the marine cases (OH and OPT) and diving birds in the riverine case study (FF). Risk factors for population strategy and values were applied to the preliminary risk rankings and had no major effect on the risk rankings shown in Table 4, with the exception of sea turtles in the wave (OPT) case. In this case, sea turtles, all of which are protected under the *Endangered Species Act of 1973* (ESA), did not appear to be an elevated risk as they are *r-strategists*. The sea turtle ranking is somewhat troublesome as these animals are highly endangered; consultation with outside experts may help to resolve the final risk ranking of the sea turtles for these cases.

The regulatory power of the ESA, combined with either the *Marine Mammal Protection Act of 1972 As Amended* (MMPA) or the *Migratory Bird Treaty Act of 1918* (MTBA), ensures that all threatened and endangered marine mammals or migratory birds will rank as the greatest risk from a regulatory perspective, regardless of whether they are the most vulnerable biological receptors. Marine mammals and birds not listed under the ESA will never be considered to represent as high a level of risk because of the possibility of gaining regulatory relief from the MMPA or MBTA. Similarly, fish and sea turtles listed under the ESA will never face the same regulatory protection as marine mammals or migratory birds. Invertebrates and habitats face lower levels of regulatory protection and are not likely to be considered as exceptionally high-risk at an MHK site.

5.0 Next Steps in Risk Assessment

The results summarized in this report are preliminary; additional subject matter expertise is needed to confirm or modify the following portions of the analysis:

- validity of overall process and “reasonableness” of the preliminary risk ranks
- choice and application of the biophysical risk factors
- ranking and applicability of the regulatory authorities.

Consultation with subject matter experts is planned for the first quarter of FY11; following that consultation, adjustments to the risk rankings for the three initial cases will be finalized as the screening analysis for the initial three cases.

Further refinement of the risk assessment will follow, including risk modeling of two sets of S–R interactions:

- toxicity from antifouling paints and coatings leaching from MHK devices – Risk: low vulnerability for receptors due to slow leaching rates and large volumes of water; high probability of occurrence.

- impacts from accidents, such as oil spills resulting from collision between MHK devices and surface vessels, causing the surface vessel to spill petroleum or other harmful products – Risk: high vulnerability for receptors; low probability of occurrence.

6.0 References

Anderson RM, SD Unwin, and FB Van Cleve. 2010. *Identification and Prioritization of Analysis Cases for Marine and Hydrokinetic Energy Risk Screening*. PNNL-19535, Pacific Northwest National Laboratory, Richland, Washington.

Endangered Species Act of 1973. 1973. Public Law 93-205, as amended, 16 USC 1531 et seq.

Marine Mammal Protection Act of 1972 As Amended. 2007. 16 USC 1361 et seq.

Migratory Bird Treaty Act of 1918. 1918. 40 Stat. 755, as amended, 16 USC 710.

Appendix

Details of the Risk Ranking Process and Intermediate Results Tables

Appendix

Details of the Risk Ranking Process and Intermediate Results Tables

A.1 Preparation for Screening Analysis

Screening analysis preparation consists of developing a list of S–R pairs. This was done following the steps below:

1. Identify the major groups of receptors of concern (Table 3, this report, p. 4). Subdivide receptor groups to reflect life history (e.g., cetaceans versus pinnipeds within aquatic mammals; migratory versus resident marine fish). Within each of those subdivisions, identify an example species for risk analysis that broadly represents the receptor group. The species or habitats used as examples for each receptor group are listed in Table A.1.
2. Identify the major stressors of concern. These are listed in Table 2 (this report, p. 3).
3. Produce the exhaustive list of risk-relevant S–R pairs for each of the three cases. These S–R pairs are the basis for screening analysis for each case.

Table A.1. Vulnerable receptor groups and the species or habitats used as representative examples for risk analysis, for each case.

Receptor group			OH	OPT	FF
Mammals	T&E[(a)]	Pinniped	Steller sea lion	Steller sea lion	N/A
		Cetacean	Killer whale	Gray whale	N/A
		Aquatic mammal	N/A	N/A	None
	Non-T&E	Pinniped	Harbor seals	Harbor seals	N/A
		Cetacean	Harbor porpoise	Harbor porpoise	N/A
		Aquatic mammal	N/A	N/A	None
Birds	T&E	Diving	Marbled murrelet	Marbled murrelet	Brown pelican
	Non-T&E, MBTA	Diving	Double-crested cormorant	Pelagic cormorant	Mallard duck
		Non-diving	N/A	Bonaparte's gull	N/A
Invertebrates	T&E	Benthic	None	None	Alabama heelsplitter
	Non-T&E	Benthic	Dungeness crab	Dungeness crab	Crayfish
Reptiles	T&E		None	Sea Turtle	None
	Non-T&E		None	None	American alligator
Fish	T&E	Migratory	Chinook salmon	Chinook salmon	Pallid sturgeon
		Resident	Bocaccio rockfish	None	None
	Non-T&E	Migratory	Sockeye salmon	Sockeye salmon	Paddlefish
		Resident	Lingcod	Shark or ray	Catfish
Far Field			Water, sediment circulation	Sediment circulation	Water circulation, height
Habitat Near Field			Rocky cobble, kelp	Sand, cobble	Sand, mud

(a) T&E = threatened and endangered.

A.2 Procedure for Ranking Impact Scenarios for Each Case

Preliminary assessment of the relative risk associated with stressor–receptor pairs for each case was conducted by PNNL staff for subsequent review by subject matter experts. The purpose of this assessment is to develop a ranked list of relative risks across receptor groups for each case. This assessment is subdivided into five steps to allow for transparency. The transparency serves two purposes: 1) to clearly show how risk has been assigned and 2) to allow for replacing each outcome as new data or information become available. The five steps follow an iterative process to assign relative risk using a series of risk factors.

1. *Separate S–R pairs by receptor group*. Separate the complete listing of S–R pairs by receptor into the seven receptor groups identified in Table 3. Although risk must be shown across receptor groups to develop a realistic impact scenario, a rigorous application of risk due to biophysical factors can be done only within a receptor group because the behavioral responses to stressors between receptor groups are not comparable. For example, the behavioral responses of several fish species to a surface float will be somewhat similar (shoaling or reefing around the float) as opposed to those of a marine mammal (avoidance or curious inspection) or a seabird (resting on float). The S–R pairs are considered separately for each case; however, the three cases are screened concurrently to ensure that a common level of risk factor application is maintained.

2. *Apply biophysical risk factors to rank S–R pairs for each receptor group*. Biophysical risk factors are used to order the stressor-receptor pairs in their receptor group by relative risk. Biophysical risk factors are described in Table A.2. Table A.3 shows an example of how biophysical risk factors were used to derive relative rank for the FY10 analyses. In this example for the mammal receptor group, a score of "1" was used to indicate potential risk for each S–R pair and across the seven applicable biophysical risk factors, and "0" was used to indicate no probable risk. In the first row of Table A.3, potential risk was associated with three risk factors: population size, risk to critical prey, and behavior that increases risk. Each is explained here to exemplify the process. The endangered status of the Southern Resident killer whale population could be impacted by interactions with the dynamic physical presence (i.e., strike) of an OpenHydro tidal turbine. In addition, the endangered Chinook salmon is the preferred prey of the Southern Resident killer whale. Due to its small population, Chinook salmon could also be impacted by the dynamic physical presence of the device. Finally, curiosity has been well documented in marine mammals, including Southern Resident killer whales, and this behavioral characteristic could put the animals at risk. Other risk factors posed no or unlikely risk to Southern Resident killer whales because no life stage was especially vulnerable to the dynamic physical presence, there was no significant impact to critical habitat, and predation or competition were not anticipated to be affected.

   Once risk factor scores were assigned, potential risk count was summed for each S–R pair. Stressor–receptor pairs with the highest sums were considered the highest risk and reassigned a relative rank value of 1. These are considered "first-tier" S–R pairs at this stage. Second-, third-, and fourth-highest sums also were assigned corresponding relative rank values (i.e., 2 or second tier, and so on).

   The ultimate result of this step will be an initial ranking of S–R pairs within each receptor group, derived from the application of biophysical risk factor scores (List A). The biophysical risk factor scores have two purposes: 1) to allow S–R pairs to be ranked relative to each other and 2) to update scores as new data and information pertaining to biophysical risks associated with S–R pairs become available.

3. *Regroup S–R pairs by case and by relative rank values*. First-tier (highest-ranked) S–R pairs from each receptor group are separated by case. Second-, third-, and fourth-tier S–R pairs from each receptor group also are separated by case. This step combines all first-tier S–R pairs from the seven

receptor groups so that all highest-ranked S–R pairs for each case and across all receptor groups can be ordered by regulatory risk factors. The same process also applies to second-, third-, and fourth-tier impact scenarios.

4. *For each case, apply regulatory and population strategy risk factors to S–R pairs, starting with tier 1 S–R pairs*. A second set of risk factors, regulatory risk factors, is used to rank S–R pairs within tiers. Regulatory risk factors are described in Table A.4 and divided into three levels to reflect the level of protection provided by the law or combination of laws. Level 1 law combinations that apply to S–R pairs are assigned a score of 1 to signify the highest risk. Level 2 laws are assigned a score of 2, and level 3 a score of 3. If applicable, population strategy risk factors (Table A.5) are used to break ties between S–R pairs with the same risk rank. Finally, S–R pairs that were all considered to be tier 1 in step 3 are re-ranked into new tiers based on regulatory and population strategy risk factors. The output of this step is a new, shorter list of tier-1 S/R pairs that collectively have the highest risk for biophysical, regulatory, and population strategy risk factors. This short list of tier-1 S–R pairs is set aside while remaining S–R pairs receive further risk screening with the second-tier S–R pairs from step 3 (i.e., second tier S–R pairs for biophysical risk factors).

5. *For each case, continue to apply regulatory and population strategy risk scores to remaining S–R pairs, tier by tier*. Stressor–receptor pairs remaining from step 4 (i.e., other than tier 1) are combined with tier-2 S–R pairs from step 3. Regulatory risk factors and population strategy risk factors are sequentially applied to tier 2 S–R pairs and then S–R pairs are re-ranked. Top-tier S–R pairs are set aside while remaining S–R pairs receive further risk screening with the third-tier S–R pairs from step 3. This process is repeated until the top risks from each of the four tiers are determined for each of the three cases. List B shows the final relative ranking for each of the four tiers of risk for each case.

Table A.2. Biophysical risk factors.

Biophysical Risk Factor	Description
Population size	Critically small populations of concern
At risk life stage	Timing and location of certain life stages that may increase risk to the population
Risk to critical prey	Decrease in available prey
Risk to critical habitat	Decrease in available habitat
Predation	Changes in behavior (for example, attraction to an MHK device) that may result in increased predation
Competition	Changes in behavior (for example, avoidance of an MHK device) that may result in a lower competitive advantage
Behavior that increases risk	Behavior of an animal that may increase risk of harm from an MHK device, for example, curiosity from a marine mammal.
Circulation that affects water quality	Farfield decreases in water quality that include dissolved oxygen, nutrient, and contaminant concentrations
Circulation that affects sediment patterns	Farfield changes in sediment transport and dynamics that include rate of sedimentation and sediment quality and quantity

Circulation that affect marine/aquatic food webs	Farfield changes in primary productivity and species at the base of the food web
Circulation that affects water level	Farfield changes in height of tidal prism or river stage that may effect nearshore habitats
Size of habitat	Changes in aerial extent and relief of nearfield habitat, especially small habitat areas
Sediment quality	Nearfield changes in sediment depth, grain size, organic content, and contaminants

Table A.3. Excerpt from the risk assessment template for the mammal receptor group of stressor-receptor scenario pairs.

			Biophysical Risk Factors							
Case	Stressor	Vulnerable Receptor	Population Size	At Risk Life Stage	Risk to Critical Prey	Risk to Critical Habitat	Increased Risk of Predation	Increased Competition	Behavior that Increases Risk	Sum
OH	Physical presence (dynamic)	T&E cetacean (killer whale)	1	0	1	0	0	0	0	3
OPT	Physical presence (static)	T&E cetacean (grey whale)	1	1	0	0	0	0	1	3
FF	Accident (oil spills)	Non-T&E aquatic mammal	0	1	1	0	0	0	0	2
OH	Noise	T&E pinniped (Steller sea lion)	1	0	0	0	0	0	1	2

Table A.4. Excerpt from list of tiered regulatory risk factors applied after biophysical risk factors (Table 4) to break ties.

Tier	Legislation	Rule
First	ESA[a] *and* MBTA[b]	Take prohibitions
	ESA *and* MMPA[c]	Take prohibitions
Second	Federal/state CWA[d] permit	Pollution discharge permits
	ESA	Take prohibitions; critical habitat protection
	MMPA	Marine mammal take prohibitions
	MBTA	Migratory bird take prohibitions
Third	State/tribal managed species	State/tribal fishery regulations
	State listed species	Take limitations; area closures
	MSA[e]	Fishery management plans; essential fish habitat

(a) *Endangered Species Act of 1973*.
(b) *Migratory Bird Treaty Act of 1918*.
(c) *Marine Mammal Protection Act of 1972 As Amended*.
(d) *Clean Water Act of 1977*.
(e) *Magnuson-Stevens Fishery Conservation and Management Act*.

Table A.5. Population strategy risk factors.

Population Strategy Risk Factors	General Description
Low reproductive potential (*K-strategists*)	Large size of eggs and young in comparison to adults, small number of young produced, slow reproductive rate, considerable parental investment in rearing young, long life expectancy
High reproductive potential (*r-strategists*)	Small size of eggs and young in comparison to adults, large number of young produced, fast reproductive rate, little parental investment in rearing

List A. Outcome of the application of biophysical risk factors to each stressor—receptor pair for receptor group.

Mammal Receptor Group

Technology	Stressor	Vulnerable Receptor	Applicability	Population Size	At Risk Life Stage	Risk to Critical Prey	Risk to Critical Habitat	Predation	Competition	Behavior that Increases Risk	Sum
OH	Physical presence (dynamic) strike	T&E cetacean (killer whale)		1	0	1	0	0	0	1	3
OH	Accident (oil spills)	T&E cetacean (killer whale)		1	1	1	0	0	0	0	3
PB	Physical presence (static)	T&E cetacean grey whale)		1	1	0	0	0	0	1	3
FF	Accident (oil spills)	non T&E aquatic mammal)		0	1	1	0	0	0	0	2
OH	Physical presence (dynamic) strike	non T&E cetacean (harbor porpoise)		0	0	1	0	0	0	1	2
OH	Physical presence (dynamic) strike	T&E pinniped (Steller sea lion)		1	0	0	0	0	0	1	2
OH	Physical presence (static)	T&E cetacean (killer whale)		1	0	0	0	0	0	1	2
OH	Physical presence (static)	T&E pinniped (Steller sea lion)		1	0	0	0	0	0	1	2
OH	Noise	T&E cetacean (killer whale)		1	0	0	0	0	0	1	2
OH	Noise	T&E pinniped (Steller sea lion)		1	0	0	0	0	0	1	2
OH	Accident (oil spills)	T&E pinniped (Steller sea lion)		1	1	0	0	0	0	0	2
PB	Physical presence (static)	T&E pinniped (Steller sea lion)		1	0	0	0	0	0	1	2
PB	Noise	T&E cetacean grey whale)		1	0	0	0	0	0	1	2
PB	Noise	T&E pinniped (Steller sea lion)		1	0	0	0	0	0	1	2
PB	Accident (lost gear and oil spills)	T&E cetacean grey whale)		1	1	0	0	0	0	0	2
PB	Accident (lost gear and oil spills)	T&E pinniped (Steller sea lion)		1	1	0	0	0	0	0	2
FF	Physical presence (dynamic) strike	non T&E aquatic mammal)		0	1	0	0	0	0	0	1
FF	Physical presence (static)	non T&E aquatic mammal)		0	0	0	0	0	0	1	1
OH	Physical presence (dynamic) strike	non T&E pinniped (harbor seal)		0	0	0	0	0	0	1	1
OH	Physical presence (static)	non T&E cetacean (harbor porpoise)		0	0	0	0	0	0	1	1
OH	Physical presence (static)	non T&E pinniped (harbor seal)		0	0	0	0	0	0	1	1
OH	Noise	non T&E cetacean (harbor porpoise)		0	0	0	0	0	0	1	1
OH	Noise	non T&E pinniped (harbor seal)		0	0	0	0	0	0	1	1

List A. (contd)

Mammal Receptor Group

Technology	Stressor	Vulnerable Receptor	Applicability	Population Size	At Risk Life Stage	Risk to Critical Prey	Risk to Critical Habitat	Predation	Competition	Behavior that Increases Risk	Sum
OH	EMF	T&E cetacean (killer whale)		1	0	0	0	0	0	0	1
OH	EMF	T&E pinniped (Steller sea lion)		1	0	0	0	0	0	0	1
OH	Leaching of toxic chemicals	T&E cetacean (killer whale)		1	0	0	0	0	0	0	1
OH	Leaching of toxic chemicals	T&E pinniped (Steller sea lion)		1	0	0	0	0	0	0	1
OH	Accident (oil spills)	non T&E cetacean (harbor porpoise)		0	1	0	0	0	0	0	1
OH	Accident (oil spills)	non T&E pinniped (harbor seal)		0	1	0	0	0	0	0	1
PB	Physical presence (static)	non T&E cetacean (harbor porpoise)		0	0	0	0	0	0	1	1
PB	Physical presence (static)	non T&E pinniped (harbor seal)		0	0	0	0	0	0	1	1
PB	Noise	non T&E cetacean (harbor porpoise)		0	0	0	0	0	0	1	1
PB	Noise	non T&E pinniped (harbor seal)		0	0	0	0	0	0	1	1
PB	EMF	T&E cetacean grey whale)		1	0	0	0	0	0	0	1
PB	EMF	T&E pinniped (Steller sea lion)		1	0	0	0	0	0	0	1
PB	Leaching of toxic chemicals	T&E cetacean grey whale)		1	0	0	0	0	0	0	1
PB	Leaching of toxic chemicals	T&E pinniped (Steller sea lion)		1	0	0	0	0	0	0	1
PB	Accident (lost gear and oil spills)	non T&E cetacean (harbor porpoise)		0	1	0	0	0	0	0	1
PB	Accident (lost gear and oil spills)	non T&E pinniped (harbor seal)		0	1	0	0	0	0	0	1
FF	Physical presence (dynamic) strike	T&E aquatic mammal)	N/A								0
FF	Physical presence (static)	T&E aquatic mammal)	N/A								0
FF	Noise	T&E aquatic mammal (N/A)	N/A								0
FF	Noise	non T&E aquatic mammal (river otter)		0	0	0	0	0	0	0	0
FF	EMF	T&E aquatic mammal)	N/A								0
FF	EMF	non T&E aquatic mammal)		0	0	0	0	0	0	0	0
FF	Leaching of toxic chemicals	T&E aquatic mammal)	N/A								0
FF	Leaching of toxic chemicals	non T&E aquatic mammal)		0	0	0	0	0	0	0	0
FF	Accident (oil spills)	T&E aquatic mammal)	N/A								0

List A. (contd)

Mammal Receptor Group

Technology	Stressor	Vulnerable Receptor	Applicability	Population Size	At Risk Life Stage	Risk to Critical Prey	Risk to Critical Habitat	Predation	Competition	Behavior that Increases Risk	Sum
OH	EMF	non T&E cetacean (harbor porpoise)		0	0	0	0	0	0	0	0
OH	EMF	non T&E pinniped (harbor seal)		0	0	0	0	0	0	0	0
OH	Leaching of toxic chemicals	non T&E cetacean (harbor porpoise)		0	0	0	0	0	0	0	0
OH	Leaching of toxic chemicals	non T&E pinniped (harbor seal)		0	0	0	0	0	0	0	0
PB	EMF	non T&E cetacean (harbor porpoise)		0	0	0	0	0	0	0	0
PB	EMF	non T&E pinniped (harbor seal)		0	0	0	0	0	0	0	0
PB	Leaching of toxic chemicals	non T&E cetacean (harbor porpoise)		0	0	0	0	0	0	0	0
PB	Leaching of toxic chemicals	non T&E pinniped (harbor seal)		0	0	0	0	0	0	0	0

List A. (contd)

Bird Receptor Group

Technology	Stressor	Vulnerable Receptor	Applicability	Population Size	At Risk Life Stage	Risk to Critical Prey	Risk to Critical Habitat	Predation	Competition	Behavior that Increases Risk	Sum
FF	Physical presence (dynamic)	T&E diving bird		1	0	0	0	0	0	1	2
FF	Accident (oil spill)	T&E diving bird		1	0	0	0	0	0	1	2
OH	Physical presence (dynamic)	T&E diving bird (marbled murrelet)		1	0	0	0	0	0	1	2
OH	Accident (oil spill)	T&E diving bird (marbled murrelet)		1	0	0	0	0	0	1	2
PB	Physical presence (dynamic)	T&E diving bird (marbled murrelet)		1	0	0	0	0	0	1	2
PB	Physical presence (static)	T&E diving bird (marbled murrelet)		1	0	0	0	0	0	1	2
PB	Accident (oil spill, lost gear)	T&E diving bird (marbled murrelet)		1	0	0	0	0	0	1	2
FF	Physical presence (dynamic)	MBTA (non T&E) diving bird		0	0	0	0	0	0	1	1
FF	Noise	T&E diving bird		1	0	0	0	0	0	0	1
FF	EMF	T&E diving bird		1	0	0	0	0	0	0	1
FF	Leaching of toxic chemicals	T&E diving bird		1	0	0	0	0	0	0	1
FF	Accident (oil spill)	MBTA (non T&E) diving bird		0	0	0	0	0	0	1	1
OH	Physical presence (dynamic)	MBTA (non T&E) diving bird		0	0	0	0	0	0	1	1
OH	Physical presence (static)	T&E diving bird (marbled murrelet)		1	0	0	0	0	0	0	1
OH	Noise	T&E diving bird (marbled murrelet)		1	0	0	0	0	0	0	1
OH	EMF	T&E diving bird (marbled murrelet)		1	0	0	0	0	0	0	1
OH	Leaching of toxic chemicals	T&E diving bird (marbled murrelet)		1	0	0	0	0	0	0	1
OH	Accident (oil spill)	MBTA (non T&E) diving bird		0	0	0	0	0	0	1	1
PB	Physical presence (dynamic)	MBTA (non T&E) diving bird		0	0	0	0	0	0	1	1
PB	Physical presence (static)	MBTA (non T&E) diving bird		0	0	0	0	0	0	1	1
PB	Physical presence (static)	MBTA (non T&E) non-diving bird		0	0	0	0	0	0	1	1
PB	Noise	T&E diving bird (marbled murrelet)		1	0	0	0	0	0	0	1
PB	EMF	T&E diving bird (marbled murrelet)		1	0	0	0	0	0	0	1
PB	Leaching of toxic chemicals	T&E diving bird (marbled murrelet)		1	0	0	0	0	0	0	1

List A. (contd)

Bird Receptor Group

Technology	Stressor	Vulnerable Receptor	Applicability	Population Size	At Risk Life Stage	Risk to Critical Prey	Risk to Critical Habitat	Predation	Competition	Behavior that Increases Risk	Sum
PB	Accident (oil spill, lost gear)	MBTA (non T&E) diving bird		0	0	0	0	0	0	1	1
FF	Physical presence (dynamic)	MBTA (non T&E) non-diving bird		0	0	0	0	0	0	0	0
FF	Physical presence (static)	T&E diving bird	N/A								0
FF	Physical presence (static)	MBTA (non T&E) diving bird	N/A								0
FF	Physical presence (static)	MBTA (non T&E) non-diving bird	N/A								0
FF	Noise	MBTA (non T&E) diving bird		0	0	0	0	0	0	0	0
FF	Noise	MBTA (non T&E) non-diving bird		0	0	0	0	0	0	0	0
FF	EMF	MBTA (non T&E) diving bird		0	0	0	0	0	0	0	0
FF	EMF	MBTA (non T&E) non-diving bird		0	0	0	0	0	0	0	0
FF	Leaching of toxic chemicals	MBTA (non T&E) diving bird		0	0	0	0	0	0	0	0
FF	Leaching of toxic chemicals	MBTA (non T&E) non-diving bird		0	0	0	0	0	0	0	0
FF	Accident (oil spill)	MBTA (non T&E) non-diving bird		0	0	0	0	0	0	0	0
OH	Physical presence (dynamic)	MBTA (non T&E) non-diving bird		0	0	0	0	0	0	0	0
OH	Physical presence (static)	MBTA (non T&E) diving bird		0	0	0	0	0	0	0	0
OH	Physical presence (static)	MBTA (non T&E) non-diving bird		0	0	0	0	0	0	0	0
OH	Noise	MBTA (non T&E) diving bird		0	0	0	0	0	0	0	0
OH	Noise	MBTA (non T&E) non-diving bird		0	0	0	0	0	0	0	0
OH	EMF	MBTA (non T&E) diving bird		0	0	0	0	0	0	0	0
OH	EMF	MBTA (non T&E) non-diving bird		0	0	0	0	0	0	0	0
OH	Leaching of toxic chemicals	MBTA (non T&E) diving bird		0	0	0	0	0	0	0	0
OH	Leaching of toxic chemicals	MBTA (non T&E) non-diving bird		0	0	0	0	0	0	0	0
OH	Accident (oil spill)	MBTA (non T&E) non-diving bird		0	0	0	0	0	0	0	0
PB	Physical presence (dynamic)	MBTA (non T&E) non-diving bird		0	0	0	0	0	0	0	0

List A. (contd)

Bird Receptor Group

Technology	Stressor	Vulnerable Receptor	Applicability	Population Size	At Risk Life Stage	Risk to Critical Prey	Risk to Critical Habitat	Predation	Competition	Behavior that Increases Risk	Sum
PB	Noise	MBTA (non T&E) diving bird		0	0	0	0	0	0	0	0
PB	Noise	MBTA (non T&E) non-diving bird		0	0	0	0	0	0	0	0
PB	EMF	MBTA (non T&E) diving bird		0	0	0	0	0	0	0	0
PB	EMF	MBTA (non T&E) non-diving bird		0	0	0	0	0	0	0	0
PB	Leaching of toxic chemicals	MBTA (non T&E) diving bird		0	0	0	0	0	0	0	0
PB	Leaching of toxic chemicals	MBTA (non T&E) non-diving bird		0	0	0	0	0	0	0	0
PB	Accident (oil spill, lost gear)	MBTA (non T&E) non-diving bird		0	0	0	0	0	0	0	0

List A. (contd)

Invertebrate Receptor Group

Technology	Stressor	Vulnerable Receptor	Applicability	Population Size	At Risk Life Stage	Risk to Critical Prey	Risk to Critical Habitat	Predation	Competition	Behavior that Increases Risk	Sum
FF	EMF	non T&E benthic invertebrates, crayfish		0	0	0	0	0	0	1	1
FF	Leaching of toxic chemicals	non T&E benthic invertebrates, crayfish		0	1	0	0	0	0	0	1
FF	Accident (oil spill)	non T&E benthic invertebrates, crayfish		0	1	0	0	0	0	0	1
OH	EMF	non T&E benthic invertebrates, Dungeness crab)		0	0	0	0	0	0	1	1
OH	Leaching of toxic chemicals	non T&E benthic invertebrates, Dungeness crab)		0	1	0	0	0	0	0	1
OH	Accident (oil spill)	non T&E benthic invertebrates, Dungeness crab)		0	1	0	0	0	0	0	1
PB	EMF	non T&E benthic invertebrates, Dungeness crab)		0	0	0	0	0	0	1	1
PB	Leaching of toxic chemicals	non T&E benthic invertebrates, Dungeness crab)		0	1	0	0	0	0	0	1
PB	Accident (oil spill)	non T&E benthic invertebrates, Dungeness crab)		0	1	0	0	0	0	0	1
FF	Physical presence (dynamic)	non T&E benthic invertebrates, crayfish		0	0	0	0	0	0	0	0
FF	Physical presence (static)	non T&E benthic invertebrates, crayfish		0	0	0	0	0	0	0	0
FF	Noise	non T&E benthic invertebrates, crayfish		0	0	0	0	0	0	0	0
OH	Physical presence (dynamic)	non T&E benthic invertebrates, Dungeness crab)		0	0	0	0	0	0	0	0
OH	Physical presence (static)	non T&E benthic invertebrates, Dungeness crab)		0	0	0	0	0	0	0	0
OH	Noise	non T&E benthic invertebrates, Dungeness crab)		0	0	0	0	0	0	0	0
PB	Physical presence (dynamic)	non T&E benthic invertebrates, Dungeness crab)		0	0	0	0	0	0	0	0
PB	Physical presence (static)	non T&E benthic invertebrates, Dungeness crab)		0	0	0	0	0	0	0	0
PB	Noise	non T&E benthic invertebrates, Dungeness crab)		0	0	0	0	0	0	0	0

List A. (contd)

Reptile Receptor Group

Technology	Stressor	Vulnerable Receptor	Applicability	Population Size	At Risk Life Stage	Risk to Critical Prey	Risk to Critical Habitat	Predation	Competition	Behavior that Increases Risk	Sum
PB	Physical presence (static)	T&E reptile		1	0	0	0	0	0	1	2
PB	EMF	T&E reptile		1	0	0	0	0	0	1	2
PB	Noise	T&E reptile		1	0	0	0	0	0	0	1
PB	Leaching of toxic chemicals	T&E reptile		1	0	0	0	0	0	0	1
PB	Accident (oil spills, lost gear)	T&E reptile		1	0	0	0	0	0	0	1
FF	Physical presence (dynamic)	T&E reptile	N/A								0
FF	Physical presence (dynamic)	non T&E reptiles	N/A							0	0
FF	Physical presence (static)	T&E reptile	N/A								0
FF	Physical presence (static)	non T&E reptile		0	0	0	0	0	0	0	0
FF	Noise	T&E reptile	N/A								0
FF	Noise	non T&E reptile	N/A								0
FF	EMF	T&E reptile	N/A								0
FF	EMF	non T&E reptile	N/A								0
FF	Leaching of toxic chemicals	T&E reptile	N/A								0
FF	Leaching of toxic chemicals	non T&E reptile	N/A								0
FF	Accident (oil spills)	T&E reptile	N/A								0
FF	Accident (oil spills)	non T&E reptile	N/A								0
OH	Physical presence (dynamic)	T&E reptile (sea turtle)	N/A								0
OH	Physical presence (dynamic)	non T&E reptiles	N/A								0
OH	Physical presence (static)	T&E reptile	N/A								0
OH	Physical presence (static)	non T&E reptile	N/A								0
OH	Noise	T&E reptile	N/A								0
OH	Noise	non T&E reptile	N/A								0
OH	EMF	T&E reptile	N/A								0
OH	EMF	non T&E reptile	N/A								0
OH	Leaching of toxic chemicals	T&E reptile	N/A								0
OH	Leaching of toxic chemicals	non T&E reptile	N/A								0

List A. (contd)

Reptile Receptor Group

Technology	Stressor	Vulnerable Receptor	Applicability	Population Size	At Risk Life Stage	Risk to Critical Prey	Risk to Critical Habitat	Predation	Competition	Behavior that Increases Risk	Sum
OH	Accident (oil spills)	T&E reptile	N/A								0
OH	Accident (oil spills)	non T&E reptile	N/A								0
PB	Physical presence (dynamic)	non T&E reptiles	N/A								0
PB	Physical presence (static)	non T&E reptile	N/A								0
PB	Noise	non T&E reptile	N/A								0
PB	EMF	non T&E reptile	N/A								0
PB	Leaching of toxic chemicals	non T&E reptile	N/A								0
PB	Physical presence (dynamic)	T&E reptile (sea turtle)	N/A								0
PB	Accident (oil spills, lost gear)	non T&E reptile	N/A								0

List A. (contd)

Fish Receptor Group

Technology	Stressor	Vulnerable Receptor	Applicability	Population Size	At Risk Life Stage	Risk to Critical Prey	Risk to Critical Habitat	Predation	Competition	Behavior that Increases Risk	Sum
FF	Leaching of toxic chemicals	resident T&E fish		1	1	1	1	0	0	0	4
PB	EMF	resident non T&E fish; shark or ray)		0	1	0	0	1	1	1	4
PB	Leaching of toxic chemicals	resident T&E fish		1	1	1	1	0	0	0	4
FF	Physical presence (dynamic)	migratory T&E fish, paddlefish)		1	1	0	0	1	0	0	3
FF	Physical presence (dynamic)	resident T&E fish		1	1	0	0	1	0	0	3
FF	EMF	migratory T&E fish, paddlefish)		1	1	0	0	0	0	1	3
FF	EMF	resident T&E fish		1	1	0	0	0	0	1	3
FF	Leaching of toxic chemicals	resident non T&E fish; catfish		0	1	1	1	0	0	0	3
OH	Physical presence (dynamic)	migratory T&E fish, Chinook salmon)		1	1	0	0	1	0	0	3
OH	Physical presence (dynamic)	resident T&E fish; bocaccio rockfish)		1	1	0	0	1	0	0	3
OH	EMF	migratory T&E fish, Chinook salmon)		1	1	0	0	0	0	1	3
OH	EMF	resident T&E fish; bocaccio rockfish)		1	1	0	0	0	0	1	3
PB	EMF	migratory T&E fish, Chinook salmon)		1	1	0	0	0	0	1	3
PB	EMF	resident T&E fish		1	1	0	0	0	0	1	3
PB	Leaching of toxic chemicals	resident non T&E fish; shark or ray)		0	1	1	1	0	0	0	3
FF	Physical presence (dynamic)	migratory non T&E fish		0	1	0	0	1	0	0	2
FF	Physical presence (dynamic)	resident non T&E fish; catfish		0	1	0	0	1	0	0	2
FF	Physical presence (static)	migratory T&E fish, paddlefish)		1	0	0	0	0	0	1	2
FF	Physical presence (static)	resident T&E fish		1	0	0	0	0	0	1	2
FF	Noise	migratory T&E fish, paddlefish)		1	0	0	0	0	0	1	2
FF	Noise	resident T&E fish		1	1	0	0	0	0	0	2
FF	EMF	migratory non T&E fish		0	1	0	0	0	0	1	2
FF	EMF	resident non T&E fish; catfish		0	1	0	0	0	0	1	2
FF	Leaching of toxic chemicals	migratory T&E fish, paddlefish)		1	1	0	0	0	0	0	2

List A. (contd)

Fish Receptor Group

Technology	Stressor	Vulnerable Receptor	Applicability	Population Size	At Risk Life Stage	Risk to Critical Prey	Risk to Critical Habitat	Predation	Competition	Behavior that Increases Risk	Sum
FF	Accident (oil spill)	migratory T&E fish, paddlefish)		1	1	0	0	0	0	0	2
FF	Accident (oil spill)	resident T&E fish		1	1	0	0	0	0	0	2
OH	Physical presence (dynamic)	migratory non-T&E fish, Pacific herring		0	1	0	0	1	0	0	2
OH	Physical presence (dynamic)	resident non-T&E fish; lingcod		0	1	0	0	1	0	0	2
OH	Physical presence (static)	migratory T&E fish, Chinook salmon)		1	0	0	0	0	0	1	2
OH	Physical presence (static)	resident T&E fish; bocaccio rockfish)		1	0	0	0	0	0	1	2
OH	Noise	migratory T&E fish, Chinook salmon)		1	0	0	0	0	0	1	2
OH	Noise	resident T&E fish; bocaccio rockfish)		1	1	0	0	0	0	0	2
OH	EMF	migratory non-T&E fish, Pacific herring		0	1	0	0	0	0	1	2
OH	EMF	resident non-T&E fish; lingcod		0	1	0	0	0	0	1	2
OH	Leaching of toxic chemicals	migratory T&E fish, Chinook salmon)		1	1	0	0	0	0	0	2
OH	Leaching of toxic chemicals	resident T&E fish; bocaccio rockfish)		1	1	0	0	0	0	0	2
OH	Accident (oil spill)	migratory T&E fish, Chinook salmon)		1	1	0	0	0	0	0	2
OH	Accident (oil spill)	resident T&E fish; bocaccio rockfish)		1	1	0	0	0	0	0	2
PB	Physical presence (static)	migratory T&E fish, Chinook salmon)		1	0	0	0	0	0	1	2
PB	Physical presence (static)	resident T&E fish		1	0	0	0	0	0	1	2
PB	Noise	migratory T&E fish, Chinook salmon)		1	0	0	0	0	0	1	2
PB	Noise	resident T&E fish		1	1	0	0	0	0	0	2
PB	EMF	migratory non T&E fish, sockeye salmon)		0	1	0	0	0	0	1	2
PB	Leaching of toxic chemicals	migratory T&E fish, Chinook salmon)		1	1	0	0	0	0	0	2
PB	Accident (oil spill)	migratory T&E fish, Chinook salmon)		1	1	0	0	0	0	0	2
PB	Accident (oil spill)	resident T&E fish		1	1	0	0	0	0	0	2
FF	Physical presence (static)	migratory non T&E fish		0	0	0	0	0	0	1	1
FF	Physical presence (static)	resident non T&E fish; catfish		0	0	0	0	0	0	1	1

List A. (contd)

Fish Receptor Group

Technology	Stressor	Vulnerable Receptor	Applicability	Population Size	At Risk Life Stage	Risk to Critical Prey	Risk to Critical Habitat	Predation	Competition	Behavior that Increases Risk	Sum
FF	Noise	migratory non T&E fish		0	0	0	0	0	0	1	1
FF	Noise	resident non T&E fish; catfish		0	1	0	0	0	0	0	1
FF	Leaching of toxic chemicals	migratory non T&E fish		0	1	0	0	0	0	0	1
FF	Accident (oil spill)	migratory non T&E fish		0	1	0	0	0	0	0	1
FF	Accident (oil spill)	resident non T&E fish; catfish		0	1	0	0	0	0	0	1
OH	Physical presence (static)	migratory non-T&E fish, Pacific herring		0	0	0	0	0	0	1	1
OH	Physical presence (static)	resident non-T&E fish; lingcod		0	0	0	0	0	0	1	1
OH	Noise	migratory non-T&E fish, Pacific herring		0	0	0	0	0	0	1	1
OH	Noise	resident non-T&E fish; lingcod		0	1	0	0	0	0	0	1
OH	Leaching of toxic chemicals	migratory non-T&E fish, Pacific herring		0	1	0	0	0	0	0	1
OH	Leaching of toxic chemicals	resident non-T&E fish; lingcod		0	1	0	0	0	0	0	1
OH	Accident (oil spill)	migratory non-T&E fish, Pacific herring		0	1	0	0	0	0	0	1
OH	Accident (oil spill)	resident non-T&E fish; lingcod		0	1	0	0	0	0	0	1
PB	Physical presence (dynamic)	migratory T&E fish, Chinook salmon)		1	0	0	0	0	0	0	1
PB	Physical presence (dynamic)	resident T&E fish		1	0	0	0	0	0	0	1
PB	Physical presence (static)	migratory non T&E fish, sockeye salmon)		0	0	0	0	0	0	1	1
PB	Physical presence (static)	resident non T&E fish; shark or ray)		0	0	0	0	0	0	1	1
PB	Noise	migratory non T&E fish, sockeye salmon)		0	0	0	0	0	0	1	1
PB	Noise	resident non T&E fish; shark or ray)		0	1	0	0	0	0	0	1
PB	Leaching of toxic chemicals	migratory non T&E fish, sockeye salmon)		0	1	0	0	0	0	0	1
PB	Accident (oil spill)	migratory non T&E fish, sockeye salmon)		0	1	0	0	0	0	0	1
PB	Accident (oil spill)	resident non T&E fish; shark or ray)		0	1	0	0	0	0	0	1
PB	Physical presence (dynamic)	migratory non T&E fish, sockeye salmon)		0	0	0	0	0	0	0	0
PB	Physical presence (dynamic)	resident non T&E fish; shark or ray)		0	0	0	0	0	0	0	0

List A. (contd)

Far-Field Receptor Group

Technology	Stressor	Vulnerable Receptor	Applicability	Circulation that Affects Water Quality	Circulation that Affects Sediment Patterns	Circulation that Affects Marine Food Web	Circulation that Affects Water Level	Sum
FF	Change in flow regime	Changes in Physical environment: far field		1	1	1	1	4
OH	Energy removal	Changes in Physical environment: far field		1	1	1	1	4
OH	Change in flow regime	Changes in Physical environment: far field		1	1	1	1	4
FF	Energy removal	Changes in Physical environment: far field		0	1	0	1	2
FF	Accident (oil spills)	Changes in Physical environment: far field		1	0	1	0	2
OH	Accident (oil spills)	Changes in Physical environment: far field		1	0	1	0	2
PB	Accident (oil spills, lost gear)	Changes in Physical environment: far field		1	0	1	0	2
PB	Energy removal	Changes in Physical environment: far field		0	1	0	0	1
PB	Change in flow regime	Changes in Physical environment: far field		0	1	0	0	1

List A. (contd)

Near-Field Receptor Group

Technology	Stressor	Vulnerable Receptor	Applicability	Size of Habitat	Sediment Quality	Sum
FF	Changes in flow regime	Changes in Physical Environment: Habitat near field		1	1	2
PB	Changes in flow regime	Changes in Physical Environment: Habitat near field		1	1	2
FF	Physical presence (static)	Changes in Physical Environment: Habitat near field		1	1	2
PB	Physical presence (static)	Changes in Physical Environment: Habitat near field		1	1	2
OH	Accident (oil spills, dragged gear)	Changes in Physical Environment: Habitat near field		1	1	2
FF	Accident (oil spills, dragged gear)	Changes in Physical Environment: Habitat near field		1	1	2
OH	Physical presence (static)	Changes in Physical Environment: Habitat near field		1	0	1
OH	Leaching of toxic chemicals	Changes in Physical Environment: Habitat near field		0	1	1
FF	Leaching of toxic chemicals	Changes in Physical Environment: Habitat near field		0	1	1
PB	Leaching of toxic chemicals	Changes in Physical Environment: Habitat near field		0	1	1
PB	Accident (oil spills)	Changes in Physical Environment: Habitat near field		0	1	1
OH	Changes in flow regime	Changes in Physical Environment: Habitat near field		0	0	0

List B. Final relative ranking for each of the four tiers of risk for each case, shown in the right-hand column. Relative biophysical rank, regulatory rank, and population resiliency rank also are shown.

Tidal Case (Open Hydro)

Technology	Stressor	Vulnerable Receptor	Biophysical Relative Rank	Regulatory Risk Rank	Population Strategy Rank	Final Rank
OH	Physical presence (dynamic) strike	T&E cetacean (killer whale)	1	1	1	1
OH	Accident (oil spills)	T&E cetacean (killer whale)	1	1	1	1
OH	Physical presence (dynamic)	T&E diving bird (marbled murrelet)	1	1	1	1
OH	Accident (oil spill)	T&E diving bird (marbled murrelet)	1	1	1	1
OH	Physical presence (dynamic) strike	T&E pinniped (Steller sea lion)	2	1	1	2
OH	Physical presence (static)	T&E cetacean (killer whale)	2	1	1	2
OH	Physical presence (static)	T&E pinniped (Steller sea lion)	2	1	1	2
OH	Noise	T&E cetacean (killer whale)	2	1	1	2
OH	Noise	T&E pinniped (Steller sea lion)	2	1	1	2
OH	Accident (oil spills)	T&E pinniped (Steller sea lion)	2	1	1	2
OH	Physical presence (static)	T&E diving bird (marbled murrelet)	2	1	1	2
OH	Noise	T&E diving bird (marbled murrelet)	2	1	1	2
OH	EMF	T&E diving bird (marbled murrelet)	2	1	1	2
OH	Leaching of toxic chemicals	T&E diving bird (marbled murrelet)	2	1	1	2
OH	EMF	T&E cetacean (killer whale)	3	1	1	3
OH	EMF	T&E pinniped (Steller sea lion)	3	1	1	3
OH	Leaching of toxic chemicals	T&E cetacean (killer whale)	3	1	1	3
OH	Leaching of toxic chemicals	T&E pinniped (Steller sea lion)	3	1	1	3
OH	Physical presence (dynamic) strike	non T&E cetacean (harbor porpoise)	2	2	1	4
OH	Physical presence (dynamic)	MBTA (non T&E) diving bird	2	2	1	4
OH	Accident (oil spill)	MBTA (non T&E) diving bird	2	2	1	4
OH	Physical presence (dynamic) strike	non T&E pinniped (harbor seal)	3	2	1	4
OH	Physical presence (static)	non T&E cetacean (harbor porpoise)	3	2	1	4
OH	Physical presence (static)	non T&E pinniped (harbor seal)	3	2	1	4
OH	Noise	non T&E cetacean (harbor porpoise)	3	2	1	4
OH	Noise	non T&E pinniped (harbor seal)	3	2	1	4
OH	Accident (oil spills)	non T&E cetacean (harbor porpoise)	3	2	1	4
OH	Accident (oil spills)	non T&E pinniped (harbor seal)	3	2	1	4

List B. (contd)

Wave Case (Ocean Power Technologies)

Technology	Stressor	Vulnerable Receptor	Biophysical Relative Rank	Regulatory Risk Rank	Population Strategy Rank	Final Rank
OPT	Physical presence (static)	T&E cetacean grey whale)	1	1	1	1
OPT	Physical presence (dynamic)	T&E diving bird (marbled murrelet)	1	1	1	1
OPT	Physical presence (static)	T&E diving bird (marbled murrelet)	1	1	1	1
OPT	Accident (oil spill, lost gear)	T&E diving bird (marbled murrelet)	1	1	1	1
OPT	Physical presence (static)	T&E pinniped (Steller sea lion)	2	1	1	2
OPT	Noise	T&E cetacean grey whale)	2	1	1	2
OPT	Noise	T&E pinniped (Steller sea lion)	2	1	1	2
OPT	Accident (lost gear and oil spills)	T&E cetacean grey whale)	2	1	1	2
OPT	Accident (lost gear and oil spills)	T&E pinniped (Steller sea lion)	2	1	1	2
OPT	Noise	T&E diving bird (marbled murrelet)	2	1	1	2
OPT	EMF	T&E diving bird (marbled murrelet)	2	1	1	2
OPT	Leaching of toxic chemicals	T&E diving bird (marbled murrelet)	2	1	1	2
OPT	EMF	T&E cetacean grey whale)	3	1	1	3
OPT	EMF	T&E pinniped (Steller sea lion)	3	1	1	3
OPT	Leaching of toxic chemicals	T&E cetacean grey whale)	3	1	1	3
OPT	Leaching of toxic chemicals	T&E pinniped (Steller sea lion)	3	1	1	3
OPT	Physical presence (dynamic)	MBTA (non T&E) diving bird	2	2	1	4
OPT	Physical presence (static)	MBTA (non T&E) diving bird	2	2	1	4
OPT	Physical presence (static)	MBTA (non T&E) non-diving bird	2	2	1	4
OPT	Accident (oil spill, lost gear)	MBTA (non T&E) diving bird	2	2	1	4
OPT	Physical presence (static)	non T&E cetacean (harbor porpoise)	3	2	1	4
OPT	Physical presence (static)	non T&E pinniped (harbor seal)	3	2	1	4
OPT	Noise	non T&E cetacean (harbor porpoise)	3	2	1	4
OPT	Noise	non T&E pinniped (harbor seal)	3	2	1	4
OPT	Accident (lost gear and oil spills)	non T&E cetacean (harbor porpoise)	3	2	1	4
OPT	Accident (lost gear and oil spills)	non T&E pinniped (harbor seal)	3	2	1	4

List B. (contd)

Riverine Case (Free Flow Power Corporation)

Technology	Stressor	Vulnerable receptor	Biophysical Relative Rank	Regulatory Risk Rank	Population Strategy Rank	Final Rank
FF	Physical presence (dynamic)	T&E diving bird	1	2	1	1
FF	Accident (oil spill)	T&E diving bird	1	2	1	1
FF	Accident (oil spills)	non T&E aquatic mammal)	2	2	1	2
FF	Physical presence (dynamic)	MBTA (non T&E) diving bird	2	2	1	2
FF	Noise	T&E diving bird	2	2	1	2
FF	EMF	T&E diving bird	2	2	1	2
FF	Leaching of toxic chemicals	T&E diving bird	2	2	1	2
FF	Accident (oil spill)	MBTA (non T&E) diving bird	2	2	1	2
FF	Leaching of toxic chemicals	resident T&E fish	1	2	2	3
FF	Physical presence (dynamic)	migratory T&E fish, paddlefish)	2	2	2	3
FF	Physical presence (dynamic)	resident T&E fish	2	2	2	3
FF	EMF	migratory T&E fish, paddlefish)	2	2	2	3
FF	EMF	resident T&E fish	2	2	2	3
FF	Physical presence (static)	migratory T&E fish, paddlefish)	3	2	2	3
FF	Physical presence (static)	resident T&E fish	3	2	2	3
FF	Noise	migratory T&E fish, paddlefish)	3	2	2	3
FF	Noise	resident T&E fish	3	2	2	3
FF	Leaching of toxic chemicals	migratory T&E fish, paddlefish)	3	2	2	3
FF	Accident (oil spill)	migratory T&E fish, paddlefish)	3	2	2	3
FF	Accident (oil spill)	resident T&E fish	3	2	2	3
FF	EMF	non T&E benthic invertebrates, crayfish	1	3	2	4
FF	Leaching of toxic chemicals	non T&E benthic invertebrates, crayfish	1	3	2	4
FF	Accident (oil spill)	non T&E benthic invertebrates, crayfish	1	3	2	4

A.3 References

Clean Water Act of 1977. 1977. Public Law 95-217, as amended, 33 USC 1251 et seq.

Endangered Species Act of 1973. 1973. Public Law 93-205, as amended, 16 USC 1531 et seq.

Magnuson-Stevens Fishery Conservation and Management Act. 1976. Public Law 94-265, as amended, 16 USC 2801-1882 et seq.

Marine Mammal Protection Act of 1972 As Amended. 2007. 16 USC 1361 et seq.

Migratory Bird Treaty Act of 1918. 1918. 40 Stat. 755, as amended, 16 USC 710.

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle *Since 1965*

U.S. DEPARTMENT OF
ENERGY

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352
1-888-375-PNNL (7665)
www.pnl.gov