DRAFT BANK PROTECTION/STABILIZATION WHITE PAPER

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List of Abbreviations and Acronyms

BMP	best management practice
CEQ	Council on Environmental Quality
Corps, the	U.S. Army Corps of Engineers
Ecology	Washington State Department of Ecology
ESA	Endangered Species Act
ESU	Evolutionarily Significant Unit
GIS	geographic information system
HCP	Habitat Conservation Plan
HPA	Hydraulic Project Approval
HPMS	Hydraulic Project Management System
ITP	Incidental Take Permit
LWD	large woody debris
MHHW	mean higher high water
MLLW	mean lower low water
NOAA	National Oceanic and Atmospheric Administration
OHWL	ordinary high water line
PAH	polycyclic aromatic hydrocarbon
RCW	Revised Code of Washington
RMS	root mean square
SEL	sound exposure level
SWD	small woody debris
TRA	Tidal Reference Area
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WDNR	Washington Department of Natural Resources
WRIA	Water Resource Inventory Area
WSDOT	Washington State Department of Transportation

List of Units of Measure

C	Celsius
cm	centimeter
dB	decibels
dB_{peak}	peak decibels during each pulse (either maximum or minimum)
dB_{SEL}	decibels sound exposure level
dB_{RMS}	decibels root mean square – square root of sound energy divided by impulse duration
F	Fahrenheit
Hz	hertz
m	meter
mg/L	milligrams per liter
mm	millimeter
NTU	nephelometric turbidity unit

Note: In general, English measurement units (e.g., feet, inches, miles) are used in this white paper; when the source material expresses a value in metric units, that measurement is also provided in parentheses. However, measurements that by convention are typically made only in metric units are reported in those units (e.g., mg/L). Temperatures are reported in both Fahrenheit and Celsius, regardless of the scale used in the source material.

EXECUTIVE SUMMARY

Overview

In Washington State, construction or performance of work that will use, divert, obstruct, or change the natural bed[1] or flow of state waters requires a Hydraulic Project Approval (HPA) from the Washington Department of Fish and Wildlife (WDFW) (Revised Code of Washington [RCW] 77.55). The purpose of the HPA program is to ensure that such activities are completed in a manner that prevents damage to public fish and shellfish resources and their habitats. To ensure that the HPA program complies with the Endangered Species Act (ESA), the WDFW is considering preparing a programmatic, multispecies Habitat Conservation Plan (HCP) to obtain an Incidental Take Permit from the U.S. Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration (NOAA) Fisheries Service (known as NOAA Fisheries). WDFW's objective is to avoid, minimize, or compensate for the incidental take of species potentially covered under the HCP resulting from the implementation of permits issued under the HPA authority. In this context, to "take" means to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect or to attempt to engage in any such conduct.

To evaluate the feasibility of and develop a scientific foundation for the HCP, the WDFW has commissioned a series of white papers that will review and summarize the best available science for up to 21 HPA activities that could be included in the HCP.

This white paper compiles and synthesizes existing scientific information on bank protection and stabilization projects, referred to here as bank protection projects. Bank protection structures are defined by WDFW as "permanent or temporary structures constructed parallel to and immediately adjacent to the shoreline and landward of the shoreline for the purpose of protecting or stabilizing the bank (e.g., bulkheads, retaining walls, etc.)."

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[1] Bed is defined as the land below the ordinary high water line of the state waters, but does not include irrigation ditches, canals, stormwater runoff devices, or other artificial watercourses except where they exist in a natural watercourse that has been altered by humans.

The objectives of this white paper are:

1. To compile and synthesize the best available scientific information related to the potential human impacts on potentially covered species, their habitats, and associated ecological processes resulting from the construction and operation of bank protection structures permitted under the HPA authority
2. To use this scientific information to estimate the circumstances, mechanisms, and risk of incidental take potentially or likely resulting from construction and operation of various types of bank protection structures
3. To identify appropriate and practicable measures, including policy directives, conservation measures, and best management practices (BMPs), for avoiding, minimizing, or mitigating the risk of incidental take of potentially covered species

The literature review conducted for this white paper identified seven impact mechanisms associated with the construction and presence of bank protection that could potentially affect aquatic species being considered for coverage under the HCP ("potentially covered species"). These mechanisms describe modifications to habitat arising from activities that can be temporary or permanent in duration. The impact mechanisms evaluated in this white paper are:

- Construction Activities
- Channel Processes and Morphology
- Substrate Modifications
- Habitat Accessibility
- Aquatic Vegetation
- Riparian Vegetation
- Water Quality

Following a brief description of bank protection activities and existing Washington Administrative Code (WAC) provisions pertinent to bank protection structures and their installation, the 52 aquatic species being considered for coverage under the HCP are described. Based on this information, the potential direct and indirect impacts to the potentially covered species or their habitats are discussed. In addition, the potential for cumulative impacts is discussed. Next, the risk for incidental take of potentially covered species is qualitatively estimated and the applicability of existing WAC provisions to address take mechanisms is reviewed. The white paper then identifies data gaps (i.e., instances in which the data or literature are insufficient to allow conclusions on the risk of take). The white paper concludes by providing habitat protection, conservation, mitigation, and management strategies consisting of actions that could be taken to avoid or minimize the impacts of bank protection structures. Key elements of the white paper are summarized below.

Activity Description

As defined above, the bank protection structures addressed in this paper are those constructed parallel to the shoreline. This category of activities is distinguished from shoreline modifications, which are structures constructed perpendicular or nearly perpendicular to the shoreline and that extend into the water (e.g., jetties, groins, breakwaters, and bank barbs). Shoreline modifications will be the topic of a separate white paper.

The RCW and WAC contain sections that define the limitations to the bank protection activities that are allowed. The following sections of the RCW and WAC provide specific information pertinent to bank protection activities:

- Marine Beach Front Protective Bulkheads or Rockwalls (Chapter 77.55.141 RCW)
- Bank Protection (WAC 220-110-050)
- Temporary Bypass Culvert, Flume, or Channel (WAC 220-110-120)
- Freshwater Lake Bulkheads (WAC 220-110-223)
- Saltwater Habitats of Special Concern (WAC 220-110-250)
- Common Saltwater Technical Provisions (WAC 220-110-270)
- Prohibited Work Times in Saltwater Areas (WAC 220-110-271)
- Bulkheads and Bank Protection in Saltwater Areas (Non-single Family Residence) (WAC 220-110-280)
- Single-family Residence Bulkheads in Saltwater Areas (WAC 220-110-285)

A wide range of bank protection techniques is available and has been authorized under HPAs. Hard, soft, and integrated bank protection techniques are identified and described.

Species and Habitat Use

This white paper considers impacts on 52 potentially covered species and the geographic distribution and habitat requirements of those species. That information is used elsewhere in the paper to assess potential impacts on the potentially covered species.

Conceptual Framework for Assessing Impacts

Bank protection can impact potentially covered species via a suite of potential mechanisms that affect organisms, their habitat, or critical ecological functions. A conceptual model developed by Williams and Thom (2001) provided the conceptual framework for assessing impacts. The conceptual framework provides a simple but effective characterization of the link between shoreline impacts, in this case bank protection structures, and the ecological functions supported by the habitat.

Direct and Indirect Impacts

The various impact mechanisms listed below affect essential life-history traits or particular habitat requirements of potentially covered species.

- **Construction Activities:** Construction activities may impact species through the noise they generate, increases in suspended solids concentrations, channel dewatering, and accidental release of chemical contaminants. For underwater noise, the only currently accepted injury and disturbance threshold is based on effects to threatened and endangered salmonids at 180 dB_{peak} (i.e., peak decibels during each pulse) for injury and 150 dB_{RMS} (i.e., decibels root mean square, the square root of sound energy divided by impulse duration) for behavioral disturbance. In general, the magnitude of impacts associated with increases in suspended solids concentrations will depend upon the amount of suspended solids, the duration of exposure, the frequency of exposure, water temperature, and the size of the suspended particles. Full and partial channel dewatering can cause fish stranding, removal and exclusion, and entrainment, as well as loss of invertebrates in the dewatered area. Chemical contaminants can impact sediments and water used by potentially covered species if they are accidentally released during construction; impacts would occur to prey production, egg viability, and water quality.
- **Channel Processes and Morphology:** The disruption of channel processes is the single most significant impact mechanism generated by bank protection projects.

Bank protection structures modify the river channel and are designed to limit or prevent natural channel processes along the length of the structure and affect wholesale changes in physical habitat, including channel characteristics, habitat complexity, substrate, floodplain connectivity, organic and gravel recruitment, and hyporheic flow. These alterations to channel processes and morphology can impact potentially covered species through concomitant reductions in habitat quantity, quality, and diversity.

- **Substrate Modifications:** Bank protection projects have the potential to directly or indirectly modify substrate conditions by substrate size changes, increased or reduced scour and deposition, and altered littoral drift. Because potentially covered species depend upon aquatic substrates for life history and habitat functions, impacts to substrates ultimately affect the species' distribution and ability to grow and survive. For fish, changes in substrates result in reductions or loss of spawning habitat or eggs, habitat that provides predator and velocity refuge, prey production, channel complexity, and habitat diversity and structure. Invertebrates may either be negatively impacted or may benefit from the new substrate (provided they are not buried due to deposition), depending on their needs for larger/harder or softer/smaller substrates.
- **Habitat Accessibility** combines the elements of physical features, time, and location to represent how potentially covered species would be impacted by loss of ability to access these features. Bank protection structures can be categorized as limiting habitat accessibility by loss of favorable depths, velocities, and floodplain habitats. Impacts to fish occur through the loss of habitat area, motility through and among habitats, and access to prey items, as well as a reduction in the ability to use diverse habitats (including side channels and slow-water areas). For invertebrates, impacts occur through an inability to access existing habitats or through direct habitat loss.
- **Aquatic Vegetation** of interest to potentially covered species includes marine and freshwater aquatic vegetation, both of which substantially influence the physical and chemical properties of the nearshore environment. Many potentially covered fish species highly depend upon this vegetation, and alteration or loss of vegetation would detrimentally impact their growth and survival. Impacts to fish and invertebrates would occur through changes in water quality, spawning or

reproductive processes, refugia and cover, flow patterns, nutrient cycling, and risk of predation.

- **Riparian Vegetation** adjacent to water bodies forms the transition zones between terrestrial and aquatic systems. Removal or disturbance of riparian vegetation during construction of bank protection projects can cause reduced shading and altered water temperature regime, reduced streambank and shoreline stability (which can increase sediment input), altered allochthonous inputs, altered groundwater influence, and altered habitat complexity and quality. Changes to water quality, and particularly temperature, are the most important of these impacts. However, key changes to habitat structure may also occur with removal of this vegetation.
- **Water Quality:** Bank protection structures have the potential to impact species and habitat by altering the following components of water quality: water temperature, dissolved oxygen, pH, and salinity. Most potentially covered species require cool, clean, and well-oxygenated water. Bank protection structures or construction activities that impair these conditions may produce behaviors (e.g., avoidance of an otherwise preferred location or increased feeding to meet increased metabolic demand) or physiological responses that reduce the organism's ability to survive and grow.

Cumulative Impacts

For the purposes of this paper, the cumulative impacts considered are the incremental impacts of individual projects considered in the context of other past, present, and reasonably foreseeable future actions. The cumulative impacts of bank protection structures are particularly important because: 1) the structures are often constructed to counteract or curtail natural habitat-forming processes, floodplain function, and channel maintenance; 2) the shorelines of Washington State's water bodies are often lined with numerous small parcels that individually may produce only minor impacts, but cumulatively may be significant; and 3) the bathymetry of Washington's inland marine waters is that of a fjord surrounded by a narrow vegetated habitat, which essentially concentrates the zone of impact. The installation or presence of multiple bank protection structures will result in cumulative impacts and, although impacts of individual structures may not be substantial, the aggregate of several structures may be significant. In addition, impacts of structures may be cumulative in time, in that the presence of the structures may cause additional scour and the need for more structures nearby and elsewhere; these effects may not be a linear increment, but could be interactive and synergistic. No sources were identified that established thresholds or quantified thresholds; however, it is a topic of discussion in numerous planning efforts throughout the country.

Potential Risk of Take

Incidental take may result from the impact mechanism pathways discussed above; the magnitude of the risk is highly dependent on how the impact is expressed and the size and location of the project. Risk of take is characterized for individual species as yes, no, or unknown, and the severity of take risk is evaluated for various bank protection scenarios. The federal agencies typically quantify the extent of anticipated take by the amount of impacted habitat, but no explicit take thresholds were identified during a review of bank protection-related biological opinions prepared by NOAA Fisheries and USFWS in recent years. Risk associated with construction-related impacts can often be avoided or minimized using BMPs or other conservation measures. The most significant long-term impacts and the highest risk of take are from bank protection projects for which the primary purpose and function is to prevent the habitat forming and sustaining fluvial processes of water bodies. Bank protection structures that incorporate natural features and/or allow for partial function of channel-forming and channel-maintaining processes would have a lower risk of take than techniques that stop the functions altogether, and many bank protection structures are indeed designed as habitat restoration projects with beneficial impacts. An understanding of the conditions and processes throughout a larger reach of the water body is necessary in order to work with natural processes and design an effective bank protection project that minimizes risk of take and incorporates beneficial habitat elements. It is important to note that the short-term benefits of a bank protection project may not outweigh its long-term impacts. In this regard, the location of the stream channel and bank protection project with respect to the floodplain is an important determining factor of potential impacts, because bank protection projects at or near the outermost extent of a floodplain would have lesser impacts than bank protection projects implemented in the middle of the floodplain.

Data Gaps

Much information is still needed on the science of bank protection and the impact to potentially covered species; current data gaps relevant to the degree of impact, construction practices, and management issues are identified. There is a general, overall need for controlled, hypothesis-based studies directed at documenting and understanding the biological impacts of bank protection structures and activities to estuarine, marine, and freshwater ecosystems, particularly the effects associated with the structures both before and after impacts occur. In addition, cumulative impact analysis techniques and a way to track and evaluate projects on larger scales are needed. Post-project information is needed, including monitoring studies for the efficacy of BMPs and post-project evaluations that address the use of adaptive management.

Habitat Protection, Conservation, Mitigation, and Management Strategies

Conservation measures are design elements intended to avoid or minimize impacts to habitats and species, and BMPs are measures used during the construction phase to avoid or minimize impacts. Many of these practices have been identified in the published literature as well as guidance documents, and they may be required by regulatory agencies as permit conditions. Mitigation for bank protection projects may be required by regulatory authorities when it is determined that the project will cause an adverse impact to species, habitats, or conservation values; in some situations, bioengineering and beach nourishment techniques may be considered self-mitigating (Cramer et al. 2003; Gerstel and Brown 2006). Management strategies provide the best opportunity for WDFW to guide the construction and design of bank protection structures; in this paper, such strategies are organized into the categories of Regulatory, Enforcement, Information Gathering, and Education. These strategies are intended to lead to better information for designing and reviewing projects, enhance the sharing of information, provide additional resources to contribute to lessening potential project impacts, and provide WDFW biologists and the entire department with the ability to adequately condition activities to ensure that they are sufficiently protective of potentially covered species.

1 INTRODUCTION

In Washington State, construction or performance of work that will use, divert, obstruct, or change the natural bed[2] or flow of state waters requires a Hydraulic Project Approval (HPA) from the Washington Department of Fish and Wildlife (WDFW) (Revised Code of Washington [RCW] 77.55.011). The purpose of the HPA program is to ensure that such activities are completed in a manner that prevents damage to public fish and shellfish resources and their habitats. Because several fish and aquatic species in the state are listed as threatened or endangered under the federal Endangered Species Act (ESA), many of the activities requiring an HPA may also require approvals from the National Oceanic and Atmospheric Administration Fisheries Service (known as NOAA Fisheries) and the U.S. Fish and Wildlife Service (USFWS). Such approvals can be in the form of an ESA Section 7 Incidental Take Statement or an ESA Section 10 Incidental Take Permit (ITP). As authorized in Section 10 of the ESA, ITPs may be issued for otherwise lawful activities that could result in the "take" of ESA-listed species or their habitats. In this context, to take means to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect or to attempt to engage in any such conduct (16 United States Code 1532(19)).

To ensure that the activities conducted under the HPA authority comply with the ESA and to facilitate ESA compliance for citizens conducting work under an HPA, WDFW is preparing a programmatic, multi-species Habitat Conservation Plan (HCP) to obtain an ITP from USFWS and NOAA Fisheries. An HCP must outline conservation measures for avoiding, minimizing, and mitigating, to the maximum extent practicable, the impacts of the permitted take on the potentially covered species[3]. The federal agencies must also find in their biological opinion that any permitted incidental take will not jeopardize the continued existence of the species, i.e., the taking will not appreciably reduce the likelihood of survival and recovery of the species in the wild.

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[2] Bed is defined as the land below the ordinary high water line of the state waters, but does not include irrigation ditches, canals, the outflow from stormwater runoff devices, or other artificial watercourses except where they exist in a natural watercourse that has been altered by humans.

[3] In this white paper, "potentially covered species" refers to fish and wildlife species that could be covered in the HCP; however, that determination would be made at the time the HCP is finalized between WDFW and the federal agencies.

To develop a scientific foundation for the HCP, WDFW has commissioned a series of white papers that will review and summarize the best available science for up to 21 HPA activities that could be included in the HCP. One of those activities, bank protection/stabilization, forms the subject of this white paper. Bank protection/stabilization projects, referred to here as bank protection projects, are defined by WDFW[4] as "permanent or temporary structures constructed parallel to and immediately adjacent to the shoreline and landward of the shoreline for the purpose of protecting or stabilizing the bank (e.g., bulkheads, retaining walls, etc.)."

This white paper compiles and synthesizes existing scientific information, describes potential take mechanisms, and makes recommendations for measures to avoid or minimize the impacts on the potentially covered fish and invertebrate species. Species being considered for coverage in the HCP for activities conducted under WDFW's HPA program (the "potentially covered species") are listed in Table 1.

Table 1
Potentially Covered Fish and Wildlife Species

Common Name	Scientific Name	Status	Habitat
California floater (mussel)	*Anodonta californiensis*	FSC/SC	Fresh water
Mountain sucker	*Catostomus platyrhynchus*	SC	Fresh water
Margined sculpin	*Cottus marginatus*	FSC/SS	Fresh water
Lake chub	*Couesius plumbeus*	SC	Fresh water
Giant Columbia River limpet	*Fisherola nuttalli*	SC	Fresh water
Great Columbia River spire snail	*Fluminicola columbiana*	FSC/SC	Fresh water
Western ridged mussel	*Gonidea angulata*	(none)	Fresh water
Western brook lamprey	*Lampetra richardsoni*	FSC	Fresh water
Olympic mudminnow	*Novumbra hubbsi*	SS	Fresh water
Westslope cutthroat trout	*Oncorhynchus clarki lewisi*	FSC	Fresh water
Redband trout	*Oncorhynchus mykiss gairdneri*	FSC	Fresh water
Pygmy whitefish	*Prosopium coulteri*	FSC/SS	Fresh water
Leopard dace	*Rhinichthys falcatus*	SC	Fresh water
Umatilla dace	*Rhinichthys umatilla*	SC	Fresh water
Coastal cutthroat trout	*Oncorhynchus clarki clarki*	FSC	Fresh water & Anadromous
Bull trout	*Salvelinus confluentus*	FT/SC	Fresh water & Anadromous
Sockeye salmon	*Oncorhynchus nerka*	FE/FT/SC	Fresh water (kokanee) & Anadromous
Pink salmon	*Oncorhynchus gorbuscha*	SPHS	Anadromous
Chum salmon	*Oncorhynchus keta*	FT/SC	Anadromous
Coho salmon	*Oncorhynchus kisutch*	FC/FSC	Anadromous
Steelhead	*Oncorhynchus mykiss*	FE/FT/SC	Anadromous
Chinook salmon	*Oncorhynchus tschawytscha*	FE/FT/SC	Anadromous
Green sturgeon	*Acipenser medirostris*	SPHS	Anadromous
White sturgeon	*Acipenser transmontanus*	SPHS	Anadromous
River lamprey	*Lampetra ayresi*	FSC/SC	Anadromous
Pacific lamprey	*Lampetra tridentata*	FSC	Anadromous

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[4] The definition of bank protection projects presented here was provided by WDFW in Appendix B of Exhibit B of the Request for Proposal for this project, RFP No. 06-0005.

Common Name	Scientific Name	Status	Habitat
Dolly Varden	*Salvelinus malma*	FP	Anadromous
Longfin smelt	*Spirinchus thaleichthys*	SPHS	Anadromous
Eulachon	*Thaleichthys pacificus*	FC/SC	Anadromous
Olympia oyster	*Ostrea lurida*	SC	Estuarine
Pacific sand lance	*Ammodytes hexapterus*	SPHS	Marine & Estuarine
Pacific herring	*Clupea harengus pallasi*	FC/SC	Marine & Estuarine
Surf smelt	*Hypomesus pretiosus*	SPHS	Marine & Estuarine
Pacific hake	*Merluccius productus*	FSC/SC	Marine & Estuarine
Lingcod	*Ophiodon elongatus*	SPHS	Marine & Estuarine
Pacific cod	*Gadus macrocephalus*	FSC/SC	Marine (occ. Estuarine)
Walleye pollock	*Theragra chalcogramma*	FSC/SC	Marine (occ. Estuarine)
Newcomb's littorine snail	*Algamorda subrotundata*	FSC/SC	Marine
Northern abalone	*Haliotis kamtschatkana*	FSC/SC	Marine
Brown rockfish	*Sebastes auriculatus*	SC	Marine
Copper rockfish	*Sebastes caurinus*	FSC/SC	Marine
Greenstriped rockfish	*Sebastes elongates*	SC	Marine
Widow rockfish	*Sebastes entomelas*	SC	Marine
Yellowtail rockfish	*Sebastes flavidus*	SC	Marine
Quillback rockfish	*Sebastes maliger*	FSC/SC	Marine
Black rockfish	*Sebastes melanops*	SC	Marine
China rockfish	*Sebastes nebulosus*	SC	Marine
Tiger rockfish	*Sebastes nigrocinctus*	SC	Marine
Bocaccio rockfish	*Sebastes paucispinis*	SC	Marine
Canary rockfish	*Sebastes pinniger*	SC	Marine
Redstripe rockfish	*Sebastes proriger*	SC	Marine
Yelloweye rockfish	*Sebastes ruberrimus*	SC	Marine

Notes:

FE = Federal Endangered
FP = Federal Protected
FT = Federal Threatened
FC = Federal Candidate
FSC = Federal Species of Concern
SC = State Candidate
SS = State Sensitive
SPHS = State Priority Habitat Species

Source: The list of species being considered for coverage under the HCP was provided in "WDFW Hydraulic Project Approval HCP Exhibit B HPA Final Grant Proposal," which was distributed with the Request for Proposal for this analysis.

Note: Species listed by habitat type; within habitat type, species listed in alphabetical order by scientific name.

The remainder of this white paper is organized as follows:

- Section 2 – Objectives
- Section 3 – Methodology
- Section 4 – Types of bank protection structures and relevant regulations
- Section 5 – Distributions and habitat use of the potentially covered species
- Section 6 – Conceptual framework for assessing impacts
- Section 7 – Analysis of direct and indirect impacts
- Section 8 – Analysis of cumulative impacts
- Section 9 – Analysis of the potential risk of take

- Section 10 – Identified data gaps
- Section 11 – Strategies and management recommendations to offset potential impacts
- Section 12 – Publication details for the references cited

2 OBJECTIVES

The objectives of this white paper are:

- To compile and synthesize the best available scientific information related to the potential human impacts on potentially covered species, their habitats, and associated ecological processes resulting from the construction, operation, and maintenance of bank protection structures permitted under the HPA authority
- To use this scientific information to estimate the circumstances, mechanisms, and risk of incidental take potentially or likely resulting from construction, operation, and maintenance of various types of bank protection structures
- To identify appropriate and practicable measures, including policy directives, conservation measures, and best management practices (BMPs), for avoiding, minimizing, or mitigating for the risk of incidental take of potentially covered species

3 METHODOLOGY

The following five principal tasks were performed in preparing this white paper:

1. Existing WDFW rules and guidance were reviewed to identify current knowledge and practices relevant to the analysis of the impacts to potentially covered species associated with bank protection structures. The WDFW information sources were the relevant Washington Administrative Codes (WACs), the *Integrated Streambank Protection Guidelines* (Cramer et al. 2003), the *Stream Habitat Restoration Guidelines* (Saldi-Caromile et al. 2004), and *Alternative Mitigation Policy Guidance Interagency Implementation Agreement* (Ecology 2000).
2. A literature review was conducted to compile information reflecting the current state of knowledge regarding potential impacts associated with bank protection structures and the potential to affect potentially covered species. The compiled literature included (a) relevant previous white papers prepared for WDFW; (b) copies of HPAs, provided by WDFW; (c) documents identified through keyword searches of the BIOSIS and Agricola databases, the Internet, and Google® Scholar; and (d) a review of biological opinions prepared by NOAA Fisheries and USFWS, addressing various projects in Washington and Oregon. The principal keyword search strategy was to look for documents linking terms describing the species (i.e., common and scientific names of potentially covered species) with terms describing bank protection structures or pathways of impact associated with the construction and presence of such structures. Additionally, some documents were identified by reviewing the bibliographies contained in documents identified through the preceding searches.
3. The compiled documents were reviewed to determine which potential pathways of impact were addressed in each document. The vast majority of collected documents considered impacts to salmonids or to physical habitat features, although documents that identified impacts to potentially covered species and their habitats other than salmonids were also identified and evaluated during the literature review. Documents located during the literature review were in turn used in Internet searches (mostly conducted using the Google® search tool) to locate additional relevant literature addressing specific impact pathways.
4. Impact mechanism analyses were prepared for each of the principal impact pathways and for each principal type of bank protection structure.

5. A draft version of this white paper was prepared and reviewed by technical specialists on the consultant team, then submitted to WDFW for comments. The white paper was amended based on the comments provided by WDFW and the white paper was finalized.

4 ACTIVITY DESCRIPTION

Bank protection structures are defined by WDFW[5] as "permanent or temporary structures constructed parallel to and immediately adjacent to the shoreline and landward of the shoreline for the purpose of protecting or stabilizing the bank (e.g., bulkheads, retaining walls, etc.)." This category of activities is distinguished from shoreline modifications, which are structures constructed perpendicular or nearly perpendicular to the shoreline that extend into the water (e.g., jetties, groins, breakwaters, and bank barbs). Shoreline modifications will be the topic of a separate white paper.

4.1 Statutes and Rules Regulating Bank Protection Structures

Regarding waters of the state, WDFW is charged by state law to preserve, protect, and perpetuate all fish and shellfish resources of the state. WDFW regulates bank protection activities in accordance with the Hydraulic Code set forth in the RCW related to construction projects in the State of Washington (RCW 77.55). The Hydraulic Code Rules establish "regulations for the construction of hydraulic projects or performance of other work that will use, divert, obstruct, or change the natural flow or bed of any of the salt or fresh waters of the state (WAC 220-110)." The RCW and WAC contain sections that further define the limitations to the bank protection activities that are allowed. The following sections of the RCW and WAC provide specific information pertinent to bank protection activities:

- Marine Beach Front Protective Bulkheads or Rockwalls (RCW 77.55.141)
- Bank Protection (WAC 220-110-050)
- Temporary Bypass Culvert, Flume, or Channel (WAC 220-110-120)
- Freshwater Lake Bulkheads (WAC 220-110-223)
- Saltwater Habitats of Special Concern (WAC 220-110-250)
- Common Saltwater Technical Provisions (WAC 220-110-270)
- Prohibited Work Times in Saltwater Areas (WAC 220-110-271)
- Bulkheads and Bank Protection in Saltwater Areas (Non-single Family Residence) (WAC 220-110-280)
- Single-family Residence Bulkheads in Saltwater Areas (WAC 220-110-285)

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[5] The definition of bank protection structures presented here was provided by WDFW in Appendix B of Exhibit B of the Request for Proposal for this project, RFP No. 06-0005.

These codes specify technical provisions relevant to bank protection projects (also discussed in Section 9 and Table 9). Specifically, they set bounds for the amount of disturbance to be allowed. In general, disturbance of existing vegetation and natural features is limited to the minimum necessary to protect against further erosion. All areas disturbed as a result of projects are to be protected or rehabilitated (e.g., vegetating, backfilling holes) shortly after project completion. The WAC allows one year for full bank revegetation, with three years of required maintenance (WAC 220-110-050).

Design of bank protection also carries stipulations. The bank face and protection material is to be placed only as far waterward of the ordinary high water line (OHWL) as necessary and should be constructed using the least impacting type of structure to protect habitat (WAC 220-110-280). Bank slope designs should prevent release of overburden material into the water (WAC 220-110-050). Design of placed rock and fish habitat components should be specified to withstand 100-year peak flows (WAC 220-110-050). Material choice is addressed in the various rules, which ban certain wood preservatives and rock sizes except where approved. Acquisition of this material is to occur off site; mining existing material from below the OHWL for use in such projects is prohibited (WAC 220-110-223).

Installation of bank protection material must be completed under specifications of minimum impact, including placing material from the bank or a barge and not dumping material onto the bank unless an established toe extending above the water surface is present (WAC 220-110-050). In addition, excavated or dredged material is not to be stockpiled waterward of the OHWL except within an approved work corridor, particularly for fine-grained materials that could cause turbidity problems. If this material is stockpiled, it is to be placed on and covered with fabric or other materials precluding erosion (WAC 220-110-280 and WAC 220-110-285).

Certain types of projects are nearly always prohibited in certain habitats. Construction of non-residential bulkheads in eelgrass areas and lingcod and rockfish settlement and nursery areas is not allowed (WAC 220-110-280) and construction of residential bulkheads is prohibited if it will result in permanent loss of critical food or shellfish habitat (RCW

77.55.141, WAC 220-110-285)[6]. Projects are subject to timing restrictions specified for the protection of listed salmonids or forage fish; these restrictions specify periods of the year, day, and/or tidal cycle when the species are expected to be in low numbers at the project site (WAC 220-110-271).

4.2 Environmental Setting of Bank Protection Structures

WDFW maintains the Hydraulic Project Management System (HPMS) database, which tracks the number of HPAs issued in each of the defined HPA activity categories. For projects that include a component of bank protection, the database tracks the environmental setting (i.e., estuarine, floodplain, fresh water, marine, or unspecified) and length of streambank modified. Between 1989 and mid-September 2006, the number of bank protection projects has been almost evenly distributed among freshwater and marine environments (Table 2).

Table 2
Count of HPAs Between 1989 and 2006 that Included Bank Protection as a Project Type

Environmental Setting	Number of HPAs Issued
Estuarine	151
Floodplain	107
Fresh water	7,904
Marine	4,544

Data source: WDFW HPMS Database.

4.3 Bank Protection Techniques

A wide range of bank protection techniques is available and has been authorized under HPAs. This section summarizes the general grouping of methods currently used in bank protection projects. Particularly useful technical details for these techniques are presented in the *Integrated Streambank Protection Guidelines* (Cramer et al. 2003) and *Stream Management* (Fischenich and Allen 2000). The HCP-covered bank protection activities would include an array of these techniques as discussed below. This list is not intended to be exhaustive, but addresses many of the most commonly applied techniques. Photographs and designs of these techniques are available in Cramer et al. (2003).

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[6] This statement is explicitly true for non-single family residential marine bulkheads, i.e., those not constructed under RCW 77.55.141. However, for those constructed under RCW 77.55.141, this is true only if the project will result in a permanent loss of critical food or shellfish habitat, as defined in WAC 220-110-285(1); otherwise, it only authorizes timing restrictions to protect these critical habitats.

Bank protection methods are described using the categories of hard approaches and soft approaches, following Williams and Thom (2001). Hard approaches armor the bank with material intended to resist shear forces experienced at the project site, such as riprap, concrete, or timber bulkheads that would prevent erosion of the bank. Soft approaches attempt to mimic natural processes with the use of biotechnical methods such as live plantings, rootwads, and large woody debris (LWD); soft approaches are used where shear forces are relatively low. Many projects integrate both hard and soft approaches, as described in the *Integrated Streambank Protection Guidelines* (Cramer et al. 2003).

4.3.1 Hard Approaches

4.3.1.1 Vertical Retaining Walls

Vertical or near-vertical walls along banks and shores have many names, including bulkheads, seawalls, and cribwalls. These features typically contain various materials, including concrete, metal, wood, and rock (Zelo et al. 2000). Bulkheads, seawalls, and cribwalls consist of a vertical wall constructed of vertical sheets of material or of piling with horizontal lagging and backfill.

Vertical walls are typically applied as bank protection on very steep slopes, in instances when landowners want to increase level property adjacent to the water, when floodplain encroachment has occurred, and/or when a near-vertical structure is necessary due to space limitations or to protect an eroding streambank. Issues of material choice, material preservation, and design for these walls typically depend on the project site and habitat concerns.

Cribwalls can be useful in stabilizing steep slopes where a near-vertical structure is required to protect an eroding streambank. Cribwalls are built as log-cabin-shaped structures parallel to the bank to deflect erosive currents away from the bank.

4.3.1.2 Rock Revetments

“Revetment” is a generic term for sloping structures placed parallel to the contours of a shoreline in order to absorb incoming energy from stream or wave flow and to protect the slope (Williams and Thom 2001). Rock revetments are those revetments constructed of rock materials, including the following:

- **Riprap**: Riprap is large, angular rock used for bank protection that is typically placed over a filter layer of gravel or synthetic filter fabric; riprap is the most common material used for bank protection in the United States (Cramer et al. 2003). Recent concerns about reduced habitat value and geomorphic repercussions of riprap have spawned development of alternative techniques, many of which are discussed in this white paper. The *Integrated Streambank Protection Guidelines* (Cramer et al. 2003) recommends that new riprap installations be built "only where bank failure would have intolerable consequences or where site conditions are extreme," such as in instances of massive bank failure.
- **Gabions**: Gabions are wire mesh baskets filled with soil or rock material that are used along a shoreline (Freeman and Fischenich 2000). Gabions are often used where available rock sizes for a bank protection project are too small to withstand erosive forces, as well as to achieve a smoother bankside appearance for aesthetic reasons. Vegetation may or may not be incorporated into the structure, depending on needs for long-term stability, weathering, and habitat considerations.
- **Concrete-filled Bags**: These bags are placed in bricklaying fashion on the bank and the concrete is allowed to cure to the shape of the bag.
- **Interlaced Concrete Forms**: These forms consist of flexible, interlocking matrices of concrete blocks of uniform size and weight connected by a series of cables.
- **Cellular Blocks**: These pre-cast concrete blocks are designed to be placed on a prepared bank in a manner that leaves many openings, allowing planted vegetation to grow from cavities.

4.3.1.3 Rock Toes

Rock toes function to prevent erosion by providing the foundation for upper-bank features such as reinforced soil lifts or vegetative plantings (Cramer et al. 2003). These toes feature angular rock components for roughness attributes, may contain LWD, and may be installed in concert with other bioengineered bank protection measures. LWD may be incorporated into roughened-rock toes as a habitat feature and to provide additional roughness. Like log toes (see Section 4.3.2.1), rock toes can be used when there is less risk to infrastructure and when habitat mitigation must be incorporated into the treatment. Roughened-rock toes can also be employed as a complementary toe treatment to other bank protection methods.

4.3.1.4 Levees

Levees are not bank protection per se, but are earthen embankments built to provide flood protection from occasional high-water events. Levees are more stable than a continuous form of bank protection, such as revetments on bank curves greater than 30 degrees (Fischenich and Allen 2000). Because they direct flow, levees can cause channel changes and clearly become ineffective when overtopped with high water.

4.3.2 Soft Approaches

4.3.2.1 Log/Rootwad Toes

Log and rootwad toes are added as a preventive measure to stem erosion at the toe of a bank or shore, providing the basis for upper-bank treatments such as reinforced soil or resloped banks (Cramer et al. 2003). Typically, these toes consist of logs installed parallel to the bank and backfilled with gravel and may contain additional LWD features or other rock protection. Log and rootwad toes provide erosion protection and are not intended to function as structural retaining walls. Their top elevation does not exceed the lower limit of vegetation on the bank. LWD for bank protection is intended to resist shear until such time as vegetation can be reestablished, after which it can rot out with little risk. Currently, the *Integrated Streambank Protection Guidelines* (Cramer et al. 2003) considers this technique experimental because so few log and rootwad toe structures have been installed and monitored. The technique is likely best used where there is less risk to infrastructure and when habitat mitigation is required, because habitat elements can be incorporated into the design.

4.3.2.2 Beach Nourishment

Beach nourishment in Washington State is most commonly employed using coarse gravel to combat shoreline erosion at relatively small sites (Williams and Thom 2001). This method entails placing fill material either as an independent activity or integrated with hard structures or bioengineered solutions. Fill is typically required to be similar in size to existing native material, be contaminant-free, and have low silt/clay components to preclude turbidity issues. Beach nourishment is considered a temporary fix to a sediment supply problem and is undertaken with an ongoing commitment for periodic maintenance (Williams and Thom 2001).

4.3.2.3 Subsurface Drainage Systems

Subsurface drainage systems are typically installed under or behind other bank treatments in order to decrease the saturation of soil and increase slope stability on side banks (Cramer et al. 2003). Techniques include chimney drains, collection drains, and gravel seams, which may be gravity-based or pumped systems.

4.3.2.4 Biotechnical Bank Protection

Soft approaches to bank protection include a suite of developing biotechnical protection methods in which natural materials are used or vegetation is planted to address slope stability. Current biotechnical bank protection methods are as described below and in much of the available literature (e.g., Allen and Leech 1997; Cramer et al. 2003; Zelo et al. 2000; Saldi-Caromile et al. 2004; Fischenich and Allen 2000; Williams and Thom 2001):

- **Riparian Plantings**: Plantings may be added to bank protection projects in an effort to stabilize banks by the establishment of root material at the shoreline. Native herbaceous cover and woody plants of various species are added, depending on the project goals.
- **Live Stakes or Poles**: Live stakes or poles are the simplest form of vegetation planting along a shoreline, consisting of stakes of live material inserted into the ground, providing reinforcement of surface soil layers. Sometimes a row of stakes or poles features a basket-like live brush mat called a wattle. The live cuttings eventually root and provide long-term reinforcement and may provide some control over internal seepage.
- **Brush Packing, Layering, and Mattressing**: Brush packing involves alternating layers of live branches and earth to fill localized slumps. The branches protrude beyond the face of the slope and reinforce the bank, while the stems provide frictional resistance to shallow slides. The live cuttings eventually root and provide long-term reinforcement. Brush layering

involves alternating layers of brush packed materials across larger areas than in brush packing. Brush mattresses lie along the slope with their root ends in a trench at the toe of the slope, as opposed to being planted along the slope.

- **Live Fascines**: Live fascines are sausage-shaped bundle structures made from cuttings of living woody plant material that are placed in a shallow trench along a bank slope contour (Sotir and Fischenich 2001). The live cuttings eventually root and provide long-term reinforcement. The live fascine is constructed from the elevation of baseflow along the face of an eroded streambank. Live fascines are used for bank and toe protection as well as improvement of erosion control, infiltration, and other riparian zone functions.
- **Live Pole Drains**: Live pole drains are used to remove moisture from wet, unstable slopes that could occur adjacent to an active channel. The pole drains are long bundles of live branch cuttings bound together into rope- or sausage-like bundles that are placed in a shallow trench. The live cuttings eventually root and provide a long-term structure.
- **Roughness Trees/Tree Revetments/LWD/Tree Kickers**: Roughness trees, which are also called tree revetments, function to slow down the water velocity in an active channel and reduce hydraulic shear stress, helping sediments accumulate at the site and enabling the establishment of vegetation (Cramer et al. 2003). This process ultimately results in the protection of vulnerable or eroding banks. These revetments may be expanded by installation of LWD, which is often anchored for stability, in the channel or along the banks (Fischenich and Morrow 1999). "Tree kickers" placed at an angle to the bank may be used in concert with these strategies or alone to deflect streamflow away from unstable bank areas.

4.3.2.5 Bank Reshaping or Regrading

Bank reshaping or regrading is employed to stabilize an eroding streambank by reducing the angle of its slope without changing the location of the toe. This technique is almost always conducted along with other bank protection treatments and may include vegetated components and a new toe installation. Regrading is most often applied along vertical and/or eroding banks, but the ability to reshape banks may be limited where access is difficult for heavy equipment, and regrading may be unsuitable where mature riparian vegetation or infrastructure exists. The technique is not considered effective to prevent continuing erosion at a reach level because it does not address the actual mechanisms of failure.

4.3.2.6 Soil Reinforcement

Soil reinforcement refers to a system of soil layers or lifts encapsulated or otherwise reinforced with a combination of natural or synthetic materials and vegetation, sometimes in a terraced fashion. These systems are also known as fabric-encapsulated soil, fabric-wrapped soil, soil burritos, vegetated geogrids, or soil pillows. This technique is best used on eroding banks on small creeks, large rivers of lower gradients, and estuaries where a resilient and bioengineered or biotechnical treatment is needed and where a wide range of bank-failure mechanisms occurs, including toe erosion, mass wasting, and scour.

4.3.2.7 Coir and Straw Logs

Coir and straw logs are similar to soil reinforcement in that they provide a system of layered materials, typically with integrated vegetation. Coir logs are long, sausage-shaped bundles of coir (coconut fiber) or straw, bound together with additional coir or synthetic netting (Allen and Fischenich 1999). They may be planted with herbaceous or woody vegetation and function to provide temporary biodegradable protection to banks while the vegetation develops. In addition, they also encourage sediment retention during overbank flows.

4.3.3 Integrated Approaches

Integrated approaches to bank protection have been developed to incorporate some of the best attributes of both hard and soft approaches (Cramer et al. 2003). One important general goal of integrated bank protection is to use habitat features that can deteriorate and ultimately allow the bank to protect itself through maturation of the design. For example, woody toe protection will deteriorate as native vegetation matures and begins to provide support and structure to a bank. Further examples of these approaches include integrating vegetation, coir logs, and woody debris into gabion or riprap structures; integrating vegetation and woody debris into rock or log toes to create habitat structure at the bank; and integrating rock toes with biotechnical soil reinforcement for toe and bank stability. Many of the hard and soft approaches discussed above can be similarly combined to protect against bank erosion while allowing habitat-forming processes to occur.

5 POTENTIALLY COVERED SPECIES HABITAT USE

Table 3 identifies the approximate range for each of the potentially covered species by noting its documented presence by Water Resource Inventory Area (WRIA) for freshwater environments or by Tidal Reference Area (TRA) for marine and estuarine environments. Figures in Appendix A show the locations of WRIAs and TRAs in Washington State. Since the WRIAs and TRAs represent large areas, species habitat requirements are further identified in Table 4, which describes the critical life-history stages of each species and the habitat dependency for each life-history stage.

Table 3
Range of Potentially Covered Species Listed in Table 1

Common Name	Scientific Name	Water Resource Inventory Area*	Tidal Reference Area (see list below)*
Green sturgeon	*Acipenser medirostris*	22, 24, 25, 26, 27, 28	All
White sturgeon	*Acipenser transmontanus*	3, 22, 24-37, 40-42, 44-61 (Columbia and Snake rivers)	All
Newcomb's littorine snail	*Algamorda subrotundata*	Marine	14, 15, 16, 17
Pacific sand lance	*Ammodytes hexapterus*	Marine	All
California floater (mussel)	*Anodonta californiensis*	30, 36, 37, 40, 42, 47-49, 52-54, 58-61	N/A
Mountain sucker	*Catostomus platyrhynchus*	23, 26-33, 35-41, 44-46 (Columbia, Snake, and Yakima rivers)	N/A
Pacific herring	*Clupea harengus pallasi*	Marine	All]
Margined sculpin	*Cottus marginatus*	32, 35	N/A
Lake chub	*Couesius plumbeus*	48, 61; other locations unknown	N/A
Giant Columbia River limpet	*Fisherola nuttalli*	35, 36, 40, 47-49; 54, 57; other locations unknown	N/A
Great Columbia River spire snail	*Fluminicola columbiana*	35, 45, 48, 49; other locations unknown	N/A
Pacific cod	*Gadus macrocephalus*	Marine	All
Western ridged mussel	*Gonidea angulata*	1, 3-5, 7-11, 13, 21-42, 44-55, 57-62	N/A
Northern abalone	*Haliotis kamtschatkana*	Marine	10
Surf smelt	*Hypomesus pretiosus*	Marine	All
River lamprey	*Lampetra ayresi*	1, 3, 5, 7-16, 20-40	N/A
Western brook lamprey	*Lampetra richardsoni*	1, 3, 5, 7-14, 16, 20-40	N/A
Pacific lamprey	*Lampetra tridentata*	1, 3, 5, 7-42, 44-46, 58, 61	N/A
Pacific hake	*Merluccius productus*	Marine	All
Olympic mudminnow	*Novumbra hubbsi*	5, 7-14, 20-24, 26	N/A
Coastal cutthroat trout	*Oncorhynchus clarki clarki*	1-5, 7-30	All
Westslope cutthroat trout	*Oncorhynchus clarki lewisi*	37-39, 44-55, 58-62	N/A
Pink salmon	*Oncorhynchus gorbuscha*	1, 3-5, 7-13, 16-19, 21	All
Chum salmon	*Oncorhynchus keta*	1, 3-5, 7-29	All
Coho salmon	*Oncorhynchus kisutch*	1-42, 44-48, 50	All
Redband trout	*Oncorhynchus mykiss gairdneri*	37-40, 45-49, 54-57	N/A
Steelhead	*Oncorhynchus mykiss*	1, 3-5, 7, 8, 9, 10-12, 14, 15, 17-41, 44-50	All
Sockeye salmon	*Oncorhynchus nerka*	1, 3-5, 7-12, 16, 19-22, 25-33, 35-37, 40, 41, 44-50, Columbia and Snake rivers	All
Chinook salmon	*Oncorhynchus tschawytscha*	1-41, 44-50	All
Lingcod	*Ophiodon elongatus*	Marine	All
Olympia oyster	*Ostrea lurida*	Marine	1-14, 17
Pygmy whitefish	*Prosopium coulteri*	7, 8, 19, 39, 47, 49, 53, 55, 58, 59, 62	N/A
Leopard dace	*Rhinichthys falcatus*	21, 26-41, 44-50	N/A
Umatilla dace	*Rhinichthys umatilla*	31, 36-41, 44-50, 59-61	N/A

Common Name	Scientific Name	Water Resource Inventory Area*	Tidal Reference Area (see list below)*
Bull trout	*Salvelinus confluentus*	1-23, 26, 27, 29-41, 44-55, 57-62	All
Dolly Varden	*Salvelinus malma*	1, 3, 5, 7, 17-22, 24	6-10, 14-17
Brown rockfish	*Sebastes auriculatus*	Marine	All
Copper rockfish	*Sebastes caurinus*	Marine	All
Greenstriped rockfish	*Sebastes elongates*	Marine	All
Widow rockfish	*Sebastes entomelas*	Marine	All
Yellowtail rockfish	*Sebastes flavidus*	Marine	All
Quillback rockfish	*Sebastes maliger*	Marine	All
Black rockfish	*Sebastes melanops*	Marine	All
China rockfish	*Sebastes nebulosus*	Marine	All
Tiger rockfish	*Sebastes nigrocinctus*	Marine	All
Bocaccio rockfish	*Sebastes paucispinis*	Marine	All
Canary rockfish	*Sebastes pinniger*	Marine	All
Redstripe rockfish	*Sebastes proriger*	Marine	All
Yelloweye rockfish	*Sebastes ruberrimus*	Marine	All
Longfin smelt	*Spirinchus thaleichthys*	Reported in 1 and 8; assumed in 3, 5-15, 22, 24 at mouths of rivers and streams	1-9, 15-17 (mouths of rivers and streams; Lake Washington)
Eulachon	*Thaleichthys pacificus*	20-29 (mouths of major rivers)	14-17 (tidal areas of rivers)
Walleye pollock	*Theragra chalcogramma*	Marine	All

Tidal Reference Areas:

TRA 1 – Shelton	TRA 2 – Olympia	TRA 3 – South Puget Sound	TRA 4 – Tacoma	TRA 5 – Seattle	TRA 6 – Edmonds
TRA 7 – Everett	TRA 8 – Yokeko Point	TRA 9 – Blaine	TRA 10 – Port Townsend	TRA 11 – Union	TRA 12 – Seabeck
TRA 13 – Bangor	TRA 14 – Ocean Beaches	TRA 15 – Westport	TRA 16 – Aberdeen	TRA 17 – Willapa Bay	

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* The distribution of all fish species in this table is based on visual examination of range maps published by Wydoski and Whitney (2003) and comparison to published maps showing WRIA and TRA boundaries. The distribution of all non-fish (invertebrate) species is based on narrative descriptions presented by the Washington Department of Natural Resources (WDNR 2006b). Please refer to Appendix A for figures showing WRIA and TRA locations. Estuarine and marine distributions are characterized by TRA rather than WRIA.

Note: Species listed in alphabetical order by scientific name.

Table 4
Habitat Requirements of Potentially Covered Species

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
Green sturgeon	*Acipenser medirostris*	Habits and life history not well known; found in all marine waters in Washington and in estuaries; spend much of life in marine nearshore waters and estuaries, returning to rivers to spawn; spawn in deep pools, substrate preferences unclear but are likely large cobbles, although range from sand to bedrock; reside in lower reaches of fresh water for up to 3 years; age at sexual maturity uncertain; feed on fishes and invertebrates (Wydoski and Whitney 2003; Nakamoto and Kisanuki 1995; Adams et al. 2002; Emmett et al. 1991)	Spawning: Spring Incubation and Emergence: Large eggs sink to bottom, weak swimmers (Kynard et al. 2005)
White sturgeon	*Acipenser transmontanus*	Found in marine waters and major rivers in Washington; in marine settings, adults and subadults use estuarine and marine nearshore, including some movement into intertidal flats to feed at high tide; some landlocked populations behind dams; seasonally use main channels and sloughs; juveniles also occupy boulder and bedrock substrate; prefers swift (2.6 to 9.2 feet per second) and deep (13 to 66 feet) water on bedrock substrate for spawning; juveniles feed on mysid shrimp and amphipods; large fish feed on variety of crustaceans, annelid worms, molluscs, and fish (Parsley et al. 1993; Wydoski and Whitney 2003; Emmett et al. 1991)	Spawning: April to July Incubation: Approx. 7 days Emergence: Approx. 7 days
Newcomb's littorine snail	*Algamorda subrotundata*	Found in Grays Harbor and Willapa Bay on Washington coast; current distribution uncertain; algae feeder occupying narrow band in Salicornia salt marshes above mean higher high water (MHHW); not a true marine gastropod (Larsen et al. 1995)	Egg Laying: Unknown
Pacific sand lance	*Ammodytes hexapterus*	Schooling plankton feeders; spawn on sand and gravel at tidal elevations of 4 to 5 feet (+1.5 meters [m]) MHHW; larvae and young rear in bays and nearshore; adults feed during the day and burrow into the sand at night (Garrison and Miller 1982, In: Nightingale and Simenstad 2001b; WDFW 1997b, In: NRC 2001).	Spawning: November to February Incubation: On sand substrate Emergence: January to April
California floater (mussel)	*Anodonta californiensis*	Freshwater filter feeder requiring clean, well-oxygenated water; declining through much of historical range; known to occur in Columbia and Okanogan rivers and several lakes; intolerant of habitats with shifting substrates, excessive water flow fluctuations, or seasonal hypoxia; fertilization takes place within the brood chambers of the female mussel; the fertilized eggs develop into a parasitic stage called glochidia; released glochidia attach to species-specific host fish; juvenile and adult mussels attach to gravel and rocks (Nedeau et al. 2005; Larsen et al. 1995; Brim Box et al. 2004; Frest and Johannes 1995, In: WDNR 2006b)	Spawning: Spring Incubation: In brood pouch, duration unknown; glochidia attach to host fish during metamorphosis
Mountain sucker	*Catostomus platyrhynchus*	Distribution restricted to Columbia River system; found in clear, cold mountain streams less than 40 feet wide and in some lakes; prefer deep pools in summer with moderate current; juveniles prefer slower side channels or weedy backwaters; food consists of algae and diatoms (Wydoski and Whitney 2003)	Spawning: June and July
Pacific herring	*Clupea harengus pallasi*	18 separate stocks in Puget Sound; utilize shallow subtidal habitats (between 0 and –10 feet mean lower low water [MLLW]) for spawning and juvenile rearing; spawning has also occurred above MLLW; widely distributed throughout Puget Sound and coastal wetlands; feed on harpacticoid copepods; important forage fish (WDFW 1997a; Simenstad et al. 1979, In: NRC 2001 and In: Nightingale and Simenstad 2001b).	Spawning: Late January to early April, oviparous Egg Incubation: 10 to 14 days; eggs adhere to eelgrass, kelp, seaweed Emergence: Larvae are pelagic (i.e., free floating)

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
Margined sculpin	*Cottus marginatus*	Endemic to southeastern Washington; habitat is in deeper pools and slow-moving glides in headwater tributaries with silt and small gravel substrate; spawn under rocks in pools; prefer cool water less than 68 degrees Fahrenheit (F) (20 degrees Celsius [C]); avoid high-velocity areas; food is unknown (Wydoski and Whitney 2003; Mongillo and Hallock 1998)	Spawning: May to June Incubation and Emergence: Unknown
Lake chub	*Couesius plumbeus*	Bottom dwellers inhabiting a variety of habitats in lakes and streams; prefer small, slow streams; spawn on rocky and gravelly substrate in tributary streams to lakes; juveniles feed on zooplankton and phytoplankton; adults feed on insects (Wydoski and Whitney 2003)	Spawning: April to June, broadcast spawn
Giant Columbia River limpet	*Fisherola nuttalli*	Also known as the shortface lanx; occupies fast-moving and well-oxygenated streams, specifically the Hanford Reach, Wenatchee and Methow rivers; found in shallow, rocky areas of cobble to boulder substrate; species feeds by grazing on algae and small crustaceans attached to rocks (Neitzel and Frest 1990, In: WDNR 2006b)	Unknown
Great Columbia River spire snail	*Fluminicola columbiana*	Also known as the Columbia pebblesnail and ashy pebblesnail; current range is restricted to rivers, streams, and creeks of the Columbia River basin; require clear, cold streams with highly oxygenated water; found in riffle pool on substrates ranging from sand to gravel or rock; graze on algae and small crustaceans (Neitzel and Frest 1990; Neitzel and Frest 1989, In: WDNR 2006b)	Unknown
Pacific cod	*Gadus macrocephalus*	Adults and large juveniles found over clay, mud, and coarse gravel bottoms; juveniles use shallow vegetated habitats such as sand-eelgrass; opportunistic feeders on invertebrates (worms, crabs, shrimp) and fishes (sand lance, pollock, flatfishes); larval feeding unknown (Bargmann 1980; Hart 1973; Dunn and Matarese 1987; NMFS 1990; Garrison and Miller 1982; Albers and Anderson 1985, In: NRC 2001 and In: Nightingale and Simenstad 2001b)	Spawning: Oviparous Incubation: Late fall to early spring, 1 to 4 weeks Emergence: Larvae and juveniles are pelagic
Western ridged mussel	*Gonidea angulata*	Specific information on this species is generally lacking; reside on substrates ranging from dense mud to coarse gravel in creeks, streams, and rivers; found in a variety of flow regimes; species may tolerate seasonal turbidity but is absent from areas with continuous turbidity (WDNR 2006b)	Larvae generally attach to the gills of fish for 1 to 6 weeks; post-larval mussels “hatch” from cysts as free living juveniles to settle and bury in the substrate
Northern abalone	*Haliotis kamtschatkana*	Also known as pinto abalone; limited to the Strait of Juan de Fuca and the San Juan Islands; occupies bedrock and boulders from extreme low to 100 feet (30 m) below MLLW; usually associated with kelp beds; larger individuals feed on detached, drift algae (Gardner 1981; West 1997; In: WDNR 2006b; Jamieson 1999)	Spawning: Broadcast spawners; release pelagic gametes that develop into free-swimming larvae; mature larvae settle on crustose corralline algae
Surf smelt	*Hypomesus pretiosus*	Schooling plankton-feeding forage fish, spawn at the highest tides at high slack tide on coarse sand and pea gravel; juveniles rear in nearshore areas and adults form school offshore; feed on planktonic organisms; important forage fish (WDFW 1997c; Penttila 2000a, In: NRC 2001 and In: Nightingale and Simenstad 2001b)	Spawning: Year round in north Puget Sound, fall and winter spawning in south Puget Sound, and summer spawning along the coast Incubation: 2 to 5 weeks Emergence: Varies with season; 27 to 56 days in winter; 11 to 16 days in summer

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
River lamprey	*Lampetra ayresi*	Detailed distribution records not available for Washington; occupy fine silt substrates in backwaters of cold-water streams; larvae (ammocoetes) are filter feeders in mud substrates of cold-water streams; juveniles believed to migrate to Pacific Ocean several years after hatching; adults spend May to September in ocean before migrating to fresh water; adults attach to and feed on fish (Wydoski and Whitney 2003)	Spawning: April to July Incubation: April to July Emergence: 2 to 3 weeks after spawning
Western brook lamprey	*Lampetra richardsoni*	Found in small coastal and Puget Sound rivers and lower Columbia and Yakima river basins; spend entire life in fresh water; adults found in cool water (52 to 64 degrees F; 11 to 17.8 degrees C) on pebble/rocky substrate; ammocoetes inhabit silty stream bottoms in quiet backwaters; ammocoetes are filter feeders; mature adults do not feed (Wydoski and Whitney 2003)	Spawning: April to July Incubation and Emergence: Adhesive eggs hatch in 10 days
Pacific lamprey	*Lampetra tridentata*	Found in most large coastal and Puget Sound rivers and Columbia, Snake, and Yakima river basins; larvae (ammocoetes) are filter feeders in mud substrates of cold-water streams; juveniles migrate to Pacific Ocean 4 to 7 years after hatching; attach to fish in ocean for 20 to 40 months before returning to rivers to spawn (Wydoski and Whitney 2003)	Spawning: April to July Incubation: April to July Emergence: 2 to 3 weeks after spawning
Pacific hake	*Merluccius productus*	The coastal stock of hake is migratory; Puget Sound stocks reside in estuaries and rarely migrate; schooling fish; larvae feed on calanid copepods; juveniles and small adults feed on euphausiids; adults eat amphipods, squid, herring, smelt (Bailey 1982; NMFS 1990; Quirollo 1992; McFarlane and Beamish 1986, In: NRC 2001)	Spawning: May spawn more than once per season Incubation: January to April Emergence: Pelagic eggs and larvae
Olympic mudminnow	*Novumbra hubbsi*	Occur in the southern and western lowlands of the Olympic Peninsula, the Chehalis River drainage, lower Deschutes River drainage, and south Puget Sound lowlands west of the Nisqually River and in King County; require (1) soft mud substrate, (2) little or no flow, and (3) dense aquatic vegetation; prefer bogs and swamps; feed on annelids, insects, and crustaceans (Harris 1974; Mongillo and Hallock 1999, In: WDNR 2006a; Wydoski and Whitney 2003)	Spawning: Late November to December Early March to mid-June Incubation: 9 days Emergence: 7 days after hatching
Coastal cutthroat trout	*Oncorhynchus clarki clarki*	NOAA Fisheries recognizes three Evolutionarily Significant Units (ESUs) in Washington: (1) Puget Sound; (2) Olympic Peninsula; (3) Southwestern Washington; coastal cutthroat trout exhibit resident (stays in streams), fluvial (migrates to rivers), adfluvial (migrates to lakes), and anadromous life-history forms; resident coastal cutthroat trout utilize small headwater streams for all of their life stages; coastal cutthroat trout are repeat spawners; typically rear in the natal streams for up to 2 years; juveniles feed primarily on aquatic invertebrates but are opportunistic feeders; utilize estuaries and nearshore habitat but has been caught offshore (Johnson et al. 1999; Pauley et al. 1988, In: WDNR 2006a)	Spawning: Late December to February Incubation: 2 to 4 months Emergence: 4 months
Westslope cutthroat trout	*Oncorhynchus clarki lewisi*	Subspecies of cutthroat trout; three possible life forms: adfluvial, fluvial, or resident; all three life forms spawn in tributary streams in the spring when water temperature is about 50 degrees F (10 degrees C); fry spend 1 to 4 years in their natal streams; cutthroat trout tend to thrive in streams with more pool habitat and cover; fry feed on zooplankton, fingerlings feed on aquatic insect larvae, and adults feed on terrestrial and aquatic insects (Liknes and Graham 1988; Shepard et al. 1984; Wydoski and Whitney 2003)	Spawning: March to July Incubation: April to August Emergence: May to August

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
Pink salmon	*Oncorhynchus gorbuscha*	Pink salmon is the most abundant species of salmon, with 13 stocks identified in Washington; pink salmon, the smallest of the Pacific salmon, mature and spawn on a 2-year cycle; opportunistic feeder in marine habitat, foraging on a variety of forage fish, crustaceans, ichthyoplankton, and zooplankton; will spawn in rivers with substantial amounts of silt; migrate downstream almost immediately after emergence, moving quickly to marine nearshore habitats where they grow rapidly, feeding on small crustaceans, such as euphausiids, amphipods, and cladocerans (Hard et al. 1996; Heard 1991, In: WDNR 2006a)	Spawning: August to October Incubation: 3 to 5 months Emergence: 3 to 5 months
Chum salmon	*Oncorhynchus keta*	NOAA Fisheries recognizes four ESUs in Washington: (1) Hood Canal summer run; (2) Columbia; (3) Puget Sound/Strait of Georgia; (4) Pacific Coast; little is known regarding their ocean distribution; maturing individuals that return to Washington streams have primarily been found in the Gulf of Alaska; usually found in the rivers and streams of the Washington coast, Hood Canal, Strait of Juan de Fuca, and Puget Sound; in the Columbia River basin, their range does not extend above the Dalles Dam; chum salmon rear in the ocean for the majority of their adult lives; at maturity, adults migrate homeward between May and June, entering coastal streams from June to November; chum fry feed on chironomid and mayfly larvae, as well as other aquatic insects; chum fry arrive in estuaries earlier than most salmon; juvenile chum reside in estuaries longer than most other anadromous species (Quinn 2005; Salo 1991; Healey 1982, In: Wydoski and Whitney 2003 and WDNR 2006a)	Spawning: October to December Incubation: 0.5 to 4.5 months Emergence: 6 months
Coho salmon	*Oncorhynchus kisutch*	NOAA Fisheries recognizes three ESUs in Washington: (1) Lower Columbia River/SW Washington; (2) Puget Sound and Strait of Georgia; and (3) Olympic Peninsula; this species is found in a broader diversity of habitats than any of the other native anadromous salmonids; coho spend between 1 and 2 years in the ocean before returning to spawn; adult coho feed on invertebrates but become more piscivorous as they grow larger; spawning occurs in gravel free of heavy sedimentation; developing young remain in gravel for up to 3 months after hatching; coho fry feed primarily on aquatic insects and prefer pools and undercut banks with woody debris; coho rear in fresh water for 12 to 18 months before moving downstream to the ocean in the spring (Meehan 1991; Groot and Margolis 1991, In: WDNR 2006a; Wydoski and Whitney 2003)	Spawning: September to late January Incubation: 1.5 to 2 months Emergence: 2 to 3 weeks
Redband trout	*Oncorhynchus mykiss gairdneri*	Redband trout is a subspecies of rainbow trout found east of the Cascade Mountains; prefer cool water, less than 70 degrees F (21 degrees C), and occupy streams and lakes containing high amounts of dissolved oxygen; spawn in streams; food consists of Daphnia and chironomids as well as fish eggs, fish, and insect larvae and pupae (Busby et al. 1996; Wydoski and Whitney 2003).	Spawning: March to April Incubation: 1 to 3 months Emergence: 3 months

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
Steelhead	*Oncorhynchus mykiss*	NOAA Fisheries recognizes 15 ESUs of steelhead, seven of which occur in Washington; during their ocean phase of life, steelhead are generally found within 10 to 25 miles of the shore; steelhead remain in the marine environment 2 to 4 years; most steelhead spawn at least twice in their lifetimes; a summer spawning run enters fresh water in August and September, and a winter run occurs from December through February; escape cover, such as logs, undercut banks, and deep pools, is important for adult and young steelhead; after hatching and emergence, juveniles establish territories feeding on microscopic aquatic organisms and then larger organisms such as isopods, amphipods, and aquatic and terrestrial insects; steelhead rear in fresh water for up to 4 years before migrating to sea (McKinnell et al. 1997, In: WDNR 2006a; Wydoski and Whitney 2003)	Spawning: March to April Incubation: 1 to 3 months Emergence: 3 months
Sockeye salmon	*Oncorhynchus nerka*	WDFW recognizes nine sockeye salmon stocks in the state; of these, three are in Lake Washington and two in the Columbia River. Sockeye are found in the Snake and Okanogan, Lake Wenatchee, Lake Quinault, Lake Ozette, Baker River, Lake Pleasant, and Big Bear Creek drainages. Kokanee (landlocked sockeye) occur in many lakes, with the larger populations in Banks and Loon Lakes and Lake Whatcom and Lake Washington-Sammamish; spawn in shallow gravelly habitat in rivers and lakes and live in lakes 1 to 2 years before migrating to ocean; juveniles feed on zooplankton, adults feed on fishes, euphausiids, and copepods (Wydoski and Whitney 2003)	Spawning: August to October Incubation: 3 to 5 months Emergence: 3 to 5 months
Chinook salmon	*Oncorhynchus tschawytscha*	Chinook exhibit one of two life-history types or races: the stream-type and the ocean-type; stream-type Chinook tend to spend 1 (or less frequently 2) years in freshwater environments as juveniles prior to migrating to salt water as smolts; stream-type Chinook are much more dependent on freshwater stream ecosystems than ocean-type Chinook; spring Chinook are especially dependent on high water quality and good access to spawning areas; stream-type Chinook do not extensively rear in estuarine and marine nearshore environments; rather, they head offshore and begin their seaward migrations Ocean-type chinook enter salt water at one of three phases: immediate fry migrants soon after yolk resorption, fry migrants 60 to 150 days after emergence, and fingerling migrants, which migrate in the late summer or fall of their first year; ocean-type Chinook are more dependent on estuarine habitats to complete their life history than any other species of salmon. Chinook "runs" are designated on the basis of adult migration timing. Early, spring-run Chinook salmon tend to enter fresh water as immature fish, migrate far upriver, and finally spawn in the late summer and early autumn. Late, fall-run Chinook salmon enter fresh water at an advanced stage of maturity, move rapidly to their spawning areas on the mainstem or lower tributaries of the rivers, and spawn within a few days or weeks of freshwater entry. Chinook generally feed on invertebrates, but become more piscivorous with age (Wydoski and Whitney 2003; Myers et al. 1998, In: WDNR 2006a; Healey 1991)	Spring Chinook: Spawning: mid-July to mid-December Incubation: 6 to 8 months Emergence: 6 to 9 months Fall Chinook: Spawning: Late October to early December Incubation: 1 to 6 months Emergence: 6 months

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
Lingcod	*Ophiodon elongatus*	Spawn in shallow water and intertidal zone; juveniles prefer sand habitats while adults prefer rocky substrates; larvae and juveniles found in upper 115 feet (35 m) of water; adults prefer slopes of submerged banks with macrophytes and channels with swift currents; larvae feed on copepods and amphipods; juveniles feed on small fishes, adults on demersal fishes and squid and octopi (Adams and Hardwick 1992; Giorgi 1981; NMFS 1990; Emmett et al. 1991, In: NRC 2001)	Spawning: January to late March Incubation and Emergence: February to June; egg masses adhere to rocks
Olympia oyster	*Ostrea lurida*	Species found throughout the inland waters of Puget Sound, as well as in Willapa Bay and possibly Grays Harbor; also grown commercially in Puget Sound; occupy nearshore ecosystem on mixed substrates with solid attachment surfaces; found from 1 foot (0.3 m) above MLLW to 2 feet (0.6 m) below MLLW; intolerant of siltation; larvae settle onto hard substrate such as oyster shells, rocks (West 1997; Baker 1995; In: WDNR 2006b)	Spawning: Spring to fall; reproduce when water temperatures are between 54 and 61 degrees F (12.5 and 16 degrees C) Incubation and Emergence: After 8 to 12 days, larvae develop into free-swimming larvae; larvae are free-swimming for 2 to 3 weeks
Pygmy whitefish	*Prosopium coulteri*	In Washington, pygmy whitefish occur at the extreme southern edge of their natural range; pygmy whitefish were once found in at least 15 Washington lakes but have a current distribution in nine; most often occur in deep, oligotrophic lakes with temperatures less than 50 degrees F (10 degrees C); use shallow water or tributary streams during the spawning season; feed on zooplankton, such as cladocerans, copepods, and midge larvae (Hallock and Mongillo 1998, In: WDNR 2006a; Wydoski and Whitney 2003)	Spawning: July to November Incubation and Emergence: Unknown
Leopard dace	*Rhinicthys falcatus*	Within Washington, leopard dace currently inhabit the lower, mid, and upper reaches of the Columbia, Snake, Yakima and Similikameen rivers; utilize habitat on or near the bottom of streams and small to mid-sized rivers with velocities less than 1.6 feet/sec (0.5 m/second); prefers gravel and small cobble substrate covered by fine sediment with summer water temperatures ranging between 59 and 64 degrees F (15 and 18 degrees C); juveniles feed primarily on aquatic insects, adult leopard dace consume terrestrial insects; little is known about leopard dace spawning habitat or behavior (Wydoski and Whitney 2003)	Spawning: May to July Incubation and Emergence: Unknown
Umatilla dace	*Rhinicthys umatilla*	Umatilla dace are benthic fish found in relatively productive, low-elevation streams; inhabit streams with clean substrates of rock, boulders, and cobbles in reaches where water velocity is less than 1.5 feet/second; juveniles occupy streams with cobble and rubble substrates; adults occupy deeper water habitats; food habits are unknown (Wydoski and Whitney 2003)	Little known of reproduction Spawning: Early to mid-July Incubation and Emergence: Unknown
Bull trout	*Salvelinus confluentus*	Widely distributed in Washington; exhibits four life-history types – anadromous, adfluvial, fluvial, and resident; bull trout typically rear in their natal streams for 2 to 4 years, although resident fish may remain in these streams for their entire lives; multiple life-history forms occur together in the same water; young-of-the-year occupy side channels, with juveniles in pools, runs, and riffles; adults occupy deep pools; diet of juveniles includes larval and adult aquatic insects; subadults and adults feed on fish; bull trout in the nearshore ecosystem rely on estuarine wetlands and favor irregular shorelines with unconsolidated substrates (Wydoski and Whitney 2003; Goetz et al. 2004, In: WDNR 2006a)	Spawning: Late August to late December Incubation and Emergence: 4 to 6 months

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
Dolly Varden	*Salvelinus malma*	Species restricted to coastal areas and rivers that empty into them; species occurs sympatrically in streams in Olympic Peninsula; prefer pool areas and cool temperatures; spawn and rear in streams, may feed and winter in lakes; juveniles extensively use instream cover; ages 1 to 13 utilize beaches composed of sand and gravel; opportunistic feeders on aquatic insects, crustaceans, salmon eggs, fish (Leary and Allendorf 1997, In: Wydoski and Whitney 2003)	Spawn mid-September to November; hatch 129 days after fertilization
Brown rockfish	*Sebastes auriculatus*	Utilize shallow-water bays with natural and artificial reefs and rock piles; estuaries are used as nurseries; can tolerate water temperatures to at least 71 degrees F (22 degrees C); eat small fishes, crabs, isopods (Stein and Hassler 1989; Eschmeyer et al. 1983; Love 1991, In: NRC 2001)	Spawning: March to June Incubation: June
Copper rockfish	*Sebastes caurinus*	Occur both inshore and on open coast; adults prefer rocky areas in shallower water than other rockfish species; juveniles use shallow and nearshore macrophytes and eelgrass habitat; feed on crustaceans, fish, and molluscs (Eschmeyer et al. 1983; Matthews 1990a; Haldorson and Richards 1986; Stein and Hassler 1989, In: NRC 2001)	Spawning: March to May Incubation: April to June Emergence: Larvae are pelagic
Greenstriped rockfish	*Sebastes elongates*	Adults found in benthic and mid-water columns; utilize a variety of bottom types; feed on euphausiids, small fishes, and squid (Eschmeyer et al. 1983; Love et al. 1990, In: NRC 2001)	Spawning: Viviparous; spawn two or more times per season Emergence: Late April to late June
Widow rockfish	*Sebastes entomelas*	Adults found from 330- to 1,000-foot (100- to 300-m) depths near rocky banks, ridges, and seamounts; adults feed on pelagic crustaceans, Pacific hake, squids; juveniles feed on copepods, euphausiids (Eschmeyer et al. 1983; Laroche and Richardson 1981; NMFS 1990; Reilly et al. 1992, In: NRC 2001)	Spawning: Viviparous; October to December Incubation: 14 days Emergence: March to May
Yellowtail rockfish	*Sebastes flavidus*	Adults found from 165- to 1,000-foot (50- to 300-m) depths; adults semi-pelagic or pelagic over steep-sloping shores and rocky reefs; juveniles occur in nearshore area; opportunistic feeders on pelagic animals including hake, herring, smelt, squid, krill and euphausiids (Eschmeyer et al. 1983; Love 1991; O'Connell and Carlile 1993, In: NRC 2001)	Spawning: Viviparous; October to December Emergence: February to March Larvae and juveniles are pelagic
Quillback rockfish	*Sebastes maliger*	Shallow-water benthic species in inlets near shallow rock piles and reefs; juveniles use eelgrass/sand and beds of kelp; feed on amphipods, crabs, copepods (Clemens and Wilby 1961; Hart 1973; Love 1991; Matthews 1990b; Hueckel and Slayton 1982; Rosenthal et al. 1988, In: NRC 2001)	Spawning: Viviparous; April to July Emergence: May to July
Black rockfish	*Sebastes melanops*	Low and high rock substrates in summer, deeper water in winter; kelp and eelgrass for juveniles; feed on nekton and zooplankton (Boehlert and Yoklavich 1983; Stein and Hassler 1989, In: NRC 2001)	Spawning: February to April Emergence: Larvae and juveniles are pelagic
China rockfish	*Sebastes nebulosus*	Occur inshore and on open coast in sheltered crevices; feed on crustacea (brittle stars and crabs), octopi, and fishes (Eschmeyer et al. 1983; Love 1991; Rosenthal et al. 1988, In: NRC 2001)	Spawning: January to July
Tiger rockfish	*Sebastes nigrocinctus*	Semi-demersal to demersal species occurring at depths ranging from shallows to 1,000 feet (305 m); larvae and juveniles occur near surface and range of depth; adults use rocky reefs, canyons, and headlands; generalized feeders on shrimp, crabs, small fishes (Garrison and Miller 1982; Moulton 1977; Rosenthal et al. 1988, In: NRC 2001)	Spawning: Ovoviviparous; peak May and June Emergence: Juveniles are pelagic
Bocaccio rockfish	*Sebastes paucispinis*	Adults semi-demersal in shallow water over rocks with algae, eelgrass, and floating kelp; larvae feed on diatoms; juveniles feed on copepods and euphausiids (MBC Applied Environmental Sciences 1987; Garrison and Miller 1982; Hart 1973; Sumida and Moser 1984 In: NRC 2001)	Spawning: Ovoviviparous; year-round Incubation: 40 to 50 days Emergence: Released 7 days after hatching; larvae and juveniles are pelagic

Common Name	Scientific Name	Habitat and Life Requirements[1]	Reproductive Timing[2]: Spawning, Egg Incubation, Emergence
Canary rockfish	*Sebastes pinniger*	Adults use sharp dropoffs and pinnacles with hard bottoms; often associated with kelp beds (Sampson 1996); feed on krill and occasionally on fish (Boehlert 1980; Boehlert and Kappenman 1980; Hart 1973; Love 1991; Boehlert et al. 1989, In: NRC 2001)	Spawning: Ovoviviparous; January to March Emergence: Larvae and juveniles are pelagic
Redstripe rockfish	*Sebastes proriger*	Adults found at depths between 330 and 1,000 feet (100 and 350 m) and young often found in estuaries in high- and low-relief rocky areas; juveniles feed on copepods and euphausiids; adults eat anchovies, herring, squid (Hart 1973; Kendall and Lenarz 1986; Garrison and Miller 1982; Starr et al. 1996, In: NRC 2001)	Spawning: Ovoviviparous Emergence: July; larvae and juveniles are pelagic and semi-demersal
Yelloweye rockfish	*Sebastes ruberrimus*	Adults found from 80- to 1,800-foot (25- to 550-m) depths near reefs and cobble bottom; juveniles prefer shallow, broken-bottom habitat; feed on other rockfish species, cods, sand lance, herring, shrimp, snails (Clemens and Wilby 1961; Eschmeyer et al. 1983; Hart 1973; Rosenthal et al. 1988, In: NRC 2001)	Spawning: Ovoviviparous Emergence: June
Longfin smelt	*Spirinchus thaleichthys*	Marine species that spawns in streams not far from marine waters; juveniles utilize nearshore habitats of a variety of substrates; juveniles feed on small Neomysis; adults feed on copepods and euphausiids; most adults die after spawning (Wydoski and Whitney 2003; Lee et al. 1980, In: Alaska Natural Heritage Program 2006; Bargmann 1998)	Spawning: November to April Incubation and Emergence: Hatch in 40 days; larvae drift downstream to salt water
Eulachon	*Thaleichthys pacificus*	Eulachon occur from northern California to southwestern Alaska; occur in offshore marine waters and spawn in tidal portions of rivers; spawn in variety of substrates but sand most common; juveniles rear in nearshore marine areas; plankton-feeders eating crustaceans such as copepods and euphausiids; larvae and post-larvae eat phytoplankton, copepods; important prey species for fishes, marine mammals, and birds (Langer et al. 1977; Howell et al. 2001; Lewis et al. 2002; WDFW and ODFW 2001, In: Willson et al. 2006)	Spawning: During spring when water temperature is 40 to 50 degrees F (4 to 10 degrees C); eggs stick to substrate Incubation: Temperature-dependent, range 20 to 40 days Emergence: Larvae drift downstream to salt water
Walleye pollock	*Theragra chalcogramma*	Widespread species in northern Pacific; larvae and small juveniles found at 200-foot (60-m) depth; juveniles utilize nearshore habitats of a variety of substrates; juveniles feed on small crustaceans, adults feed on copepods, euphausiids, and young pollock; important prey species (Garrison and Miller 1982; Miller et al. 1976; Bailey et al. 1999; Livingston 1991, In: NRC 2001)	Spawning: February to April Incubation: Eggs suspended at depths ranging from 330 to 1,320 feet (100 to 400 m) Emergence: Pelagic larvae

Note: Species listed in alphabetical order by scientific name.

Definitions:

Definitions:	demersal—living near, deposited on, or sinking to the bottom
	oviparous—producing eggs that develop and hatch outside the maternal body
	ovoviviparous—producing eggs that develop within the maternal body and hatch before or immediately after release
	piscivorous—fish-eating
	viviparous—producing living young rather than eggs

[1] Comments related to distribution pertain only to the Washington portion of species distribution.

[2] Spawning is given as seasonal timing, when information is available. Incubation is the time elapsed between spawning and hatching. Emergence is the time elapsed between hatching and when juveniles enter the water column; as noted above where relevant, some hatchlings enter the water column immediately.

6 CONCEPTUAL FRAMEWORK FOR ASSESSING IMPACTS

Simply stated, bank protection is material placed with the objective of resisting lateral shear forces of flow, transferring the power of water away from an eroding bank, or attenuating the energy to minimize the erosive effect. This power is transferred through flowing water, waves, or a combination of the two. Groundwater hydraulics and deep-seated mass wasting can also contribute to shoreline erosion regardless of whether sediment is transported by either flowing water or repetitive wave action. The flowing water of rivers and streams is constantly shaping their shorelines, and wave action transports sediment across the beaches of lakes and the marine environment. Estuary shorelines may be shaped by both flowing water and wave energy. Bank protection can impact potentially covered species via a suite of potential mechanisms that affect organisms, their habitat, or critical ecological functions. The conceptual model developed by Williams and Thom (2001), and presented below as Figure 1, provides a simple but effective characterization of the link between shoreline impacts, in this case bank protection structures, and the ecological functions supported by the habitat.

Figure 1
Conceptual Framework for Assessment

The process begins with an impact, which in this case would consist of activities authorized under an HPA for bank protection. The impact will exert varying degrees of effect on the ecosystem's controlling factors (Williams and Thom 2001). Controlling factors are the physical processes or environmental conditions (e.g., flow conditions or wave energy) that control local habitat structure (e.g., substrate or vegetation). Habitat structure is linked to habitat processes (e.g., shading or cover), which are linked to ecological functions (e.g., refuge and prey production). These linkages form the "impact pathway," in which alterations to the environment associated with bank protection can lead to impacts to the ecological function of the habitat for potentially covered species. Impact mechanisms are the alternations to any of the conceptual framework components along the impact pathway that can result in an impact to ecological function and therefore to potentially covered species.

The literature review conducted for this white paper identified seven impact mechanisms associated with the bank protection structures. Table 5 lists and describes the impact mechanisms evaluated in this white paper.

Table 5
Principal Impact Mechanisms Evaluated

Mechanisms	Description
Construction activities	Noise, suspended solids, channel dewatering, and chemical contamination potentially resulting from construction activities
Channel processes and morphology	Changes in channel morphology due to bank protection alterations to channel processes, including hyporheic flow
Substrate modifications	Changes in substrate composition (grain size), including placement of non-erodible substrate, substrate coarsening through scour, increased substrate deposition, and altered littoral drift
Habitat accessibility	Changes in habitat accessibility due to changes in hydraulics and habitat connectivity
Aquatic vegetation	Alterations to submerged marine and freshwater vegetation
Riparian vegetation	Alterations to riparian vegetation
Water quality	Water quality changes, including temperature, dissolved oxygen, pH, and salinity

7 DIRECT AND INDIRECT IMPACTS

Potentially covered species are vulnerable to incidental take via certain impact pathways, as identified in Section 6. The following section describes each of these pathways and the manner in which it is linked to essential life-history traits or particular habitat requirements of potentially covered species. In order to support the characterization of the potential risk and severity of take for potentially covered species (Section 9), the description of impact pathways focuses on the detrimental impacts of bank protection projects. Bank protection projects can benefit habitat conditions and many projects are constructed with habitat restoration as a primary or secondary goal. However, all bank protection projects, even those with some identifiable beneficial outcomes, are constructed because the natural processes have become "problems" for (or because of) the anthropogenic uses of adjacent lands.

7.1 Construction Activities

Four primary impacts of construction activities were identified:

- Increased noise
- Increased suspended solids
- Channel dewatering
- Chemical contamination

7.1.1 Noise

Construction noise from heavy equipment would primarily originate from upland staging areas, though in-water generated noise would occur if rock is placed into the water. For some bank protection projects, pile driving may be required to anchor bank protection structures. Bank protection activities that do not include pile driving, or that drive piles with a vibratory hammer, would produce less sound and therefore be less likely to produce noise-related impacts. Of the few projects that require pile driving, it is likely that most of them would use sheetpiling rather than hollow pipe piles. Sheetpiles are lengths (or sheets) of steel generally installed using a vibratory hammer.

7.1.1.1 Impacts to Fish

Most of the literature on the effects of noise on fish is based on steel pipe pile driving using an impact hammer. Studies on steel piling show that the impact hammer on the top of the pile causes a wave to travel down the pile, which causes the pile to resonate down and out (like a bell). Most of the acoustic energy is a result of the outward and inward movement of the steel pipe pile wall as the compression wave moves down the pile from the hammer to the end of the pile buried in the sediment. Since water is virtually incompressible, the outward movement of the pile wall by even a fraction of an inch sends an underwater pressure wave in all directions. The molecular elasticity of the steel pipe pulls the pile wall back inward, resulting in an under-pressure wave. The steel pipe resonates, sending out a succession of waves, even as it is pushed several inches deeper into the bottom (Hastings and Popper 2005; NMFS 2001a).

Most of the research available on noise generated during sheetpile driving has focused on airborne noise. However, given the linear shape of the sheetpile and that it is installed with a vibratory hammer, the acoustic energy is expected to be less than that generated by driving a pipe pile. Since the effects of noise generated during the installation of sheetpiling is not well understood, the discussion below provides a “worst-case” scenario for the impacts associated with pile driving for streambank protection.

Hastings and Popper (2005) recently performed a comprehensive literature review to evaluate the current best available science regarding noise thresholds at which fish would be injured by the percussive sound generated by pile driving. Several studies have been undertaken, but there are no conclusions as to the effects relative to distance, species, exposure time, noise attenuation devices, or fish behavior. Research efforts are continuing throughout the West Coast of the United States and Canada to improve our understanding of the effects of pile driving-generated noise on fish.

Noise generated by using an impact hammer to drive steel pipe piles can cause direct mortality, non-lethal physical impacts, and behavioral impacts to fish (Hastings and Popper 2005). As the sound pressure wave passes through a fish with a swim bladder, the swim bladder is rapidly squeezed due to the high pressure and then rapidly expanded as the under-pressure portion of the wave passes through the fish (Moyle and Cech 1988; NMFS 2004a). As high sound pressure levels are produced through multiple strikes of an impact hammer, the swim bladder may repeatedly expand and contract, thus damaging the fish's internal organs (Gaspin 1975). Hastings and Popper (2005) caution that fish with different swim bladder structural properties and shapes may show very different soft tissue damage (including swim bladder rupture) attributable to the same sound signals. Among the potentially covered fish species, only sand lance, lingcod, and lamprey do not have swim bladders. The literature review for this paper did not identify any information regarding the vulnerabilities of these species to sound waves compared to other fishes.

The specific noise-related effects of pile driving on fish appear to depend on a wide range of factors, including the type of piles and hammer used, fish species and life stages present, the environmental setting, and many other controlling factors (Hastings and Popper 2005; Popper et al. 2006). There is considerable variability in the severity of impacts depending on received sound energy, presence of gas bubbles (e.g., swim bladder), mass of fish, body shape, and biomechanical properties of the swim bladder wall (Hastings and Popper 2005; Popper et al. 2006; Scholik and Yan 2002).

7.1.1.1.1 Direct Mortality

Fish are sometimes injured or killed by the impact of sounds generated by percussive pile driving (Yelverton et al. 1975; Hastings 1995, in Hastings and Popper 2005; NMFS 2004a). The injuries caused by such pressure waves are known as barotraumas and include hemorrhage and rupture of internal organs, including the swim bladder and kidneys, and damage to the auditory system. Death can be instantaneous or occur within minutes of exposure or several days later (NMFS 2004a).

Turnpenny et al. (1994) reported a mortality rate of 57 percent for brown trout (*Salmo trutta*), 24 hours after exposure to 90-second bursts of pure tones at 95 hertz (Hz) at peak pressures below 173 decibels (dB). The authors suggested that the threshold for continuous sounds was lower than that for pulsed sounds such as seismic airgun blasts. This difference is thought to be due to the longer duty cycle of the pure tone bursts.

Fish larva and eggs whose movement is often at the mercy of currents or that are adhered to stationary objects may be particularly vulnerable to sound, including the vibrations of the sediments produced with a vibratory hammer, because they cannot leave the area (Hastings and Popper 2005). Data on the effects of sound on developing eggs and larvae are limited, although a study by Banner and Hyatt (1973) found increased mortality in eggs and embryos of sheepshead minnow (*Cyprinodon variegates*) exposed to broadband noise (100 to 1,000 Hz) that was about 15 dB above the ambient sound level. Hatched fry of sheepshead minnow and fry of longnose killifish (*Fundulus similes*) were not affected in this study.

7.1.1.1.2 Non-lethal Physical Impacts

Physical impacts to fish may include temporary hearing loss (referred to as temporary threshold shift), permanent hearing loss (referred to as permanent threshold shift), damage or rupture of gas organs such as the swim bladder and the surrounding tissues, rupture of capillaries in the skin, neurotrauma, and eye hemorrhage (Hastings and Popper 2005). It is important to note that non-lethal injuries may lead to higher predation risks and greater susceptibility to other forms of mortality, but it is difficult to assess these non-lethal injuries since they may not be observable until the fish have left the project area.

7.1.1.1.3 Behavioral Impacts

Behavioral and indirect effects may include movement of fish away from feeding grounds (avoidance), reduced fitness to survive, increased vulnerability to predators, reduced success locating prey, effects on fish communications, effects on the fish’s sense of the physical environment, and many other possible scenarios (Hastings and Popper 2005).

Observations of fish behavior during the installation of concrete panel (sheetpile) in the marine environment in Everett, Washington, documented no observable alterations to juvenile chum salmon behaviors despite pile driving taking place within 50 to 150 feet of the fish (Bonar 1995). Another investigation of fish behavior during pile driving in Everett that provides additional observations of juvenile chum salmon behavior has been reported separately in Anderson (1990) and Feist et al. (1992). The pile driving activities entailed the installation of solid and hollow concrete piles. Anderson (1990) reported larger schools, but fewer schools (i.e., fewer total fish) at pile driving sites compared to non-pile driving sites. These findings suggest some subtle fish avoidance, but pile driving did not drive all fish from the site. Feist et al. (1992) reports that fewer schools occurred over the course of the day of pile driving, not instantaneously upon the start of pile driving activities. Anderson (1990) noted that juvenile chum salmon were often observed "milling around the pile driving rigs during active pile driving." Feist et al. (1992) further explained that the fish did not change their location relative to shore during periods of pile driving, thus suggesting that fish moving into or remaining in areas near pile driving did not move offshore or into other habitats that would make them more susceptible to predation.

Grette (1985) conducted an investigation of adult Chinook, coho, and sockeye salmon migrations in the marine environment and reported no changes in the number of salmon ascending a fish ladder during pile driving activities. The fish ladder was located approximately 100 feet upstream from the installation of sheetpile. This study suggests that adult salmonids are not affected by pile driving; however, as the authors point out, the study did not investigate more subtle behavioral changes and some of the fish that entered the fish ladder may have been upstream of the pile driving area before pile driving activities commenced.

In a study providing information on rockfish responses to loud noises, Skalski et al. (1992) showed a 52 percent decrease in rockfish catch when the area of catch was exposed to a single airgun emission at 186 to 191 dB (mean peak level) (see also Pearson et al. 1992, in Hastings and Popper 2005). The authors also demonstrated that fish would show a startle response to sounds as low as 160 dB, but this level of sound did not appear to elicit a decline in catch.

7.1.1.1.4 Impact Thresholds for Fish

Not enough is known to provide discrete injury thresholds for different fish species, and even less is known regarding behavioral thresholds (Hastings and Popper 2005; Popper et al. 2006). NOAA Fisheries and USFWS have adopted injury and disturbance thresholds for threatened and endangered salmonids at 180 dB_{peak} (i.e., peak decibels during each pulse) for injury and 150 dB_{RMS} (i.e., decibels root mean square, the square root of sound energy divided by impulse duration) for behavioral disturbance (WSDOT 2006a and numerous biological opinions).

Recently, after extensive review of the existing literature (Hastings and Popper 2005), Popper et al. (2006) recommended using a combined, interim single-strike criterion as a threshold for pile driving injury to salmonids: 187 dB_{SEL} and 208 dB_{peak}, where SEL is the sound exposure level, which accounts for the accumulation of energy over a complete pile strike. These thresholds are considered conservative by the authors, but current science limits the extrapolation of the single-strike SEL to estimate the effects on fish due to accumulated energy from multiple pile strikes. Discussions on the use of these proposed dual criteria are currently in progress.

7.1.1.2 Impacts to Invertebrates

Although studies of noise impacts on invertebrates have consistently shown that very high sound pressure levels (in excess of 217 dB) can cause serious injury, the information is sparse, is poorly reported, and was obtained without due experimental rigor (Turnpenny et al. 1994). The studies reported in Turnpenny et al. (1994) exposed mussels, periwinkles, amphipods, squid, scallops, and sea urchins to high airgun and slow-rise-time sounds at between 217 dB and 260 dB. Mussels, periwinkles, and amphipods showed no detectable effect at 229 dB (Kosheleva 1992, in Turnpenny et al. 1994), although one Iceland scallop (*Chlamys islandica*) suffered a split shell after being exposed to 217 dB from a single airgun strike (Matishov 1992, in Turnpenny et al. 1994).

7.1.2 Suspended Solids

Construction activities could disturb fine sediment in channels and on banks that could lead to increased suspended solids. Disturbance of instream sediment during instream work or stormwater runoff from upland portions of construction sites may increase suspended sediment levels (E. Molash, pers. comm., in Bash et al. 2001). Sediment disturbance could be further increased by instream operation of equipment or storage of excavated material within a floodplain (Reid et al. 2004).

7.1.2.1 Impacts to Fish

Of all the taxonomic groups, fish (particularly salmon) have received the most attention from researchers studying the effects of suspended solids on aquatic resources. Suspended solids and the water turbidity (murkiness) that high concentrations of suspended solids can produce are natural features of many aquatic systems. As a result, fish in systems that naturally produce periods of elevated suspended solids concentrations can encounter prolonged periods in these conditions. For example, some of the largest salmon-producing river systems are turbid (see Gregory 1993) and juvenile salmon occupy turbid areas for significant portions of their early life (Levy and Northcote 1982; Simenstad et al. 1982, in Gregory 1993). In an investigation of the effects of turbidity on juvenile marine species (several mullet and perch-like species) in southeastern Africa, Cyrus and Blaber (1987) concluded that some species appeared to prefer turbid (10 to 80 nephelometric turbidity units [NTUs]) over clear water (less than 10 NTUs). Since elevated suspended solids can occur naturally, it is not surprising that the range of potential impacts associated with elevated suspended solids includes some beneficial impacts.

Turbid water can provide a form of cover from potential fish or bird predators because many are visual predators that need to see their prey (Cyrus and Blaber 1987; Gregory 1993). For example, several researchers have documented that turbidity can reduce predation pressure on young salmonids by providing protective cover that enables them to avoid detection or capture by predators (Gregory 1993; Gregory and Levings 1996).

While elevated suspended solid concentrations can occur naturally, the episodes resulting from the construction of bank protection structures are unnatural and can produce detrimental impacts. There are several mechanisms by which suspended sediment can detrimentally impact fish, including direct mortality, non-lethal impacts, and behavioral changes. These mechanisms are discussed in the sections below. The potential impacts associated with the deposition of suspended particles are discussed with other substrate modifications in Section 7.3. The potential impacts of suspended solids on aquatic vegetation are discussed in Section 7.5.

In general, the magnitude of impacts associated with increases in suspended solid concentrations will depend upon the amount of suspended solids, the duration of exposure, the frequency of exposure, water temperature, and the size of the suspended particles. Servizi and Martens (1992) characterized these as synergistic factors affecting the physiological response in salmonids. That is, the combination of factors will elicit a greater total effect than would be expected by the "sum" of the individual effects. A primary relationship among these factors is that smaller increases in suspended solids concentrations that occur over an extended period of time may produce similar impacts to greater suspended solids concentrations encountered during a shorter time period (Newcombe and Jensen 1996). Newcombe and MacDonald (1991, in NMFS 2004b) identify exposure duration as the critical determinant of the occurrence and magnitude of physical or behavioral effects for salmonids. This finding is supported by the fact that salmonids have evolved in systems that periodically experience short-term pulses (days to weeks) of high suspended solids loads, often associated with flood events, and are adapted to such short-term, high-pulse exposures. The timing of exposure to suspended sediment is also very important, as it may affect different life-history stages in different ways (Berry et al. 2003). Appendix B provides two tables of literature summaries of the reported effects of suspended solids on salmonids by life stage. The sources of these tables are Bash et al. (2001) and Lloyd (1987) as reported in Bash et al. (2001).

7.1.2.1.1 Direct Mortality

Direct mortality may result from suspended solids depending upon the concentrations encountered, the duration of exposure, the size and shape of the particles, as well as other environmental stressors (e.g., high water temperatures or low dissolved oxygen). Mortality could result from the damage to fish gills caused by the abrasive properties of suspended solids. As sediment begins to accumulate in the gill filaments, fish excessively open and close their gills to expunge the silt. If irritation continues, mucus is produced to protect the gill surface, which may impede the circulation of water over gills and interfere with fish respiration (Berg 1982, in Bash et al. 2001). An investigation of juvenile sockeye salmon exposed to Fraser River sediments demonstrated increased lethality of solids with increasing particle size, specifically for particles described as angular to subangular (Servizi and Martens 1987, in Bash et al. 2001). The authors reported that fine sediments (0 to 740 micrometers) lodged in gills and caused gill trauma at 3,148 milligrams per liter (mg/L) or 20 percent of the 96-hour LC50 value (the concentration that is lethal to 50 percent of a sample population).

7.1.2.1.2 Non-lethal Impacts

The non-lethal impacts of elevated suspended solid concentrations on fish could include reduction in feeding rates, physiological responses (e.g., gill trauma, altered osmoregulation, and altered blood chemistry), and habitat degradation, particularly as it would relate to the potential reduction in aquatic vegetation growth (Bash et al. 2001; Newcombe and Jensen 1996). Newcombe and Jensen (1996) documented differences in the onset of these non-lethal impacts among juvenile and adult salmonids, egg and larval salmonids, adult non-salmonid estuarine species, and adult non-salmonid freshwater species. Juvenile and adult salmonids exhibited widely variable impact thresholds both in terms of duration of exposure and concentration of exposure. Juvenile salmonids exhibited more impacts related to very short-term exposure (1 hour) than the other species groups. In reviewing the information presented by Newcombe and Jensen (1996), as well as additional, more recent information, U.S. Environmental Protection Agency (USEPA) scientists concluded that (with the possible exception of salmonids) insufficient information exists to confidently establish a dose response model at this time (Berry et al. 2003). However, the USEPA scientists conclude that with additional research it may be possible to develop national dose response criteria for suspended solids. Berry et al. (2003) provides a tabular summary of the widely variable dose response data for many species (included as Appendix C).

7.1.2.1.3 Behavioral Impacts

The behavioral effects of suspended solids on fish are generally described by laboratory and field studies in the categories of avoidance and changes in territoriality, foraging, predation, homing, and migration. For salmonids, behavioral avoidance of turbid waters may be one of the most important effects of suspended solids (Bisson and Bilby 1982; Birtwell et al. 1984). Salmonids have been observed to move laterally and downstream to avoid turbid plumes (McLeay et al. 1984, 1987; Sigler et al. 1984; Lloyd 1987; Servizi and Martens 1991).

Bash et al. (2001) exhaustively reviewed 40 years of research on the physiological and behavioral effects of turbidity and suspended solids on salmonids. This review found that salmonids generally avoid areas of increased turbidity in laboratory and field studies. Moderate turbidity levels (11 to 49 NTUs) were shown to cause juvenile steelhead and coho to leave rearing areas (Sigler et al. 1984), and suspended solids concentrations of 10 mg/L caused avoidance responses in rainbow trout (*Onchorhynchus mykiss*) (Wildish and Power 1985). Juvenile chum salmon, classified by Nightingale and Simenstad (2001a) as "turbidity tolerant compared to other fishes," also exhibited avoidance behavior in response to elevated turbidity levels (Salo et al. 1979). However, the size of the turbidity plume may be important; turbidity plumes that do not extend from bank to bank would not be expected to significantly impact the behavior of migrating salmonids, as the fish are able to avoid the areas of high turbidity (Nightingale and Simenstad 2001a). Laboratory studies have shown alterations in social interactions and decreased territoriality in response to increases in turbidity. It has been suggested that decreased territoriality and a breakdown in social structure can lead to secondary effects such as altered feeding and growth rates, which may in turn lead to increased mortality. Some laboratory studies have shown a negative impact of increased turbidity on foraging, possibly due to reduced visibility, while other studies have shown a positive effect of increased turbidity on foraging, possibly due to reduced risk of predation. Laboratory and field studies have shown a link between increased turbidity and reduced primary production and prey availability. Field studies have indicated that while increased turbidity may delay salmonid migration, it does not seem to alter homing ability (Bash et al. 2001).

Studies on other species have also shown that increased turbidity affects fish behavior in ways similar to its effects on salmonids (Berry et al. 2003). Avoidance responses of Atlantic herring (*Clupea harengus*) to suspended sediment were observed at concentrations of 20 mg/L (Wildish and Power 1985). Herring and American shad (*Alosa sapidissima*) exhibited changes in depth preferences in the presence of turbid conditions (Johnson and Wildish 1982; Dadswell et al. 1983, both in Berry et al. 2003). These and other studies maintain that water clarity is important to fish that are visual feeders and for young fish with limited prey capture aptitude. Visual feeders would generally experience reductions in feeding rates or success at elevated turbidity levels (Boehlert and Morgan 1985, Vinyard and O'Brien 1976, Johnson and Wildish 1982, all in Berry et al. 2003; Rowe and Dean 1998; Breitburg 1988). However, the amount that turbid conditions would modify feeding would be affected by various factors, including species' visual acuity, target prey type, and adaptation to turbid habitats. Striped bass (*Morone saxatilis*) larvae observed feeding under turbid conditions had varying success rates with different prey items (Breitburg 1988). In Midwestern U.S. prairie fishes, Bonner and Wilde (2002) found that elevated turbidity had less effect on prey consumption by chub species that are adapted to highly turbid habitats than on shiner species characteristic of less-turbid habitats.

The effects of turbidity on larval fish feeding are not well understood. Larval fish typically have short reactive distances and require high prey densities. Larval salmonids, in particular, have little or no swimming capability, are visual feeders, and undergo high mortality rates due to starvation (Nightingale and Simenstad 2001a). Increased turbidity and reduced water clarity could negatively impact the already limited prey-catching ability of these larval fish (Nightingale and Simenstad 2001a).

7.1.2.1.4 Impact Thresholds For Fish

In an analysis to support a biological opinion for an intensive 0.2-mile project that entailed “rebuilding” a severely eroded bank on the Stillaguamish River, Washington, USFWS and NOAA Fisheries calculated suspended solid concentrations and periods of exposure that would result in adverse impacts to bull trout and Chinook salmon (NMFS and USFWS 2005). This calculation depended upon site-specific information and was clearly intended for project-specific use; however, it provides an example of thresholds developed and approved by the federal agencies. The calculation depended upon the ratio of turbidity (measured in NTUs) to suspended solids (measured in mg/L), an estimate of the length of time that sediments would be suspended, and a USFWS draft guidance document[7]. The federal agencies determined that adverse effects to bull trout and Chinook salmon will occur in the following circumstances:

- When background NTU levels are exceeded by 96 NTUs at any point in time
- When background NTU levels are exceeded by 35 NTUs for more than 1 hour cumulatively over a workday
- When background NTU levels are exceeded by 13 NTUs for more than 3 hours cumulatively over a workday

To assess the potential downstream extent of these effects, USFWS reviewed its monitoring database and found that for construction activities involving cofferdam removal, bank stabilization, and river scour protection, the state water quality standards were not met in some cases until more than 600 feet downstream. USFWS identified another bank protection project in its database in which peak turbidity levels of more than 130 NTUs over background were detected 4,300 feet downstream of the work area (the farthest point downstream

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[7] Based on nine years of water quality data in the river, the ratio was determined to be 1.0 NTU:4.2 mg/L suspended solids. The length of time was estimated to be during daylight hours for six weeks. The USFWS guidance document identified (*Sediment Biological Review*, draft May 2005) was not available for use in this paper.

at which monitoring occurred) in a plume that lasted over 5 hours. USFWS determined that the plume persisted at an intensity and duration sufficient to adversely affect salmonids for several miles. Based on known extent, duration, and intensity of sediment plumes from previous instream work, the scale and methods of the proposed project, and the characteristics of the river in the action area, the federal agencies anticipated that turbidity levels that result in adverse effects to bull trout and Chinook salmon were reasonably certain to occur as far downstream as 3.3 miles (NMFS and USFWS 2005). For the specific bank protection project under review, the federal agencies concluded that the adverse impacts would extend downstream more than 16 times the length of the project.

7.1.2.2 Impacts to Invertebrates

Elevated concentrations of suspended solids could have a wide range of impacts on both pelagic and benthic invertebrates (Cordone and Kelly 1961; Peddicord 1980; Waters 1995; Wilber and Clarke 2001, in Berry et al. 2003). The limited mobility of many invertebrates would prevent them from escaping even temporary pulses of increased suspended sediment loads. The direct impacts to invertebrates could include clogging of filtration mechanisms, thereby interfering with ingestion and respiration; abrasion; and in extreme cases, smothering and burial resulting in mortality (Berry et al. 2003). Indirect effects would primarily be related to light attenuation that could lead to changes in feeding efficiency and behavior (i.e., drift and avoidance) and alteration of habitat that would result from changes in substrate composition, which would affect the distribution of infaunal and epibenthic species (Donahue and Irvine 2003; Waters 1995; Zweig and Rabeni 2001, in Berry et al. 2003). Berry et al. (2003) provides a tabular summary of the widely variable dose response data for many species of invertebrates (included as Appendix C).

7.1.3 Channel Dewatering

Channel dewatering occurs primarily in freshwater settings and is typically associated with the need to work “in the dry” during construction of bank protection structures. Dewatering usually requires the installation of a cofferdam and a bypass system to divert flowing water around the construction site and allow work to occur in the dry. (Such dewatering can entail full channel dewatering or partial dewatering as “work cells" are drained to allow work in the dry.) Several organism and habitat issues arise with channel dewatering, including fish stranding, removal and exclusion, and entrainment and loss of invertebrates in the dewatered area.

7.1.3.1 Impacts to Fish

To reduce stranding, fish removal and exclusion from the construction zone is usually part of channel dewatering activities. This is typically accomplished through passive methods, such as the volitional movement of fish from the construction area during its slow dewatering, or through active methods, such as the use of hand nets, beach seines, or electrofishing equipment to capture and move fish from the construction area that will be dewatered (NMFS 2006). Passive capture of fish typically involves installing an upstream block net and a cofferdam and slowly dewatering the construction area. It has been suggested that reductions in flow of 80 percent result in the greatest percentage of fish (50 to 75 percent) volitionally moving out of the dewatered construction area (NMFS 2006). This type of passive fish removal eliminates the need to capture and handle some fish. Less commonly, active methods of fish removal may be used, such as the use of a beach seine to "herd" fish downstream to a point beyond the construction area and/or the use of electrofishing equipment to remove fish.

In addition to removing fish from the area, dewatering a portion of a stream channel also requires installing a flow bypass system that relies either on gravity or a pump to convey the flow around the dewatered portion of the channel. This type of activity has the potential to entrain fish within the bypass system. If pumps are used to bypass water around a work site or to dewater residual pools within a portion of the dewatered channel, the hose or pipe pulling water from the channel is typically fitted with a protective screen to prevent entrainment of aquatic life into the intake hose/pipe of the pump. Such measures are required for all pumped diversions (WAC 220-110-190), and specific criteria for screens, including approach velocity, mesh site, and screen location, have been developed by NMFS (1996) and WDFW (1998).

Installation of a flow bypass system typically requires in-water work, which can disturb substrates and bank material and cause an increase in turbidity levels. Once the system is installed, operation of a flow bypass system generally will not result in disturbance to the streambed or cause an elevation in turbidity levels, unless the discharge at the outlet results in scouring of substrate material or erosion of streambanks. Removal of the stream bypass also requires in-water work and results in some disturbance to the streambed and banks as the cofferdam is removed and flow is returned to the channel. Generally, the downstream cofferdam is removed first to allow backwatering of a portion of the channel that was dewatered. Then the upstream cofferdam is removed, and flow is slowly returned to the channel to minimize resuspension of fine sediments and increases in turbidity.

The following sections describe the direct mortality and non-lethal physical impacts of channel dewatering on potentially covered fish species. Increases in suspended solid concentrations resulting from channel dewatering activities are discussed in Section 7.1.2.

7.1.3.1.1 Direct Mortality

Fish that remain in a dewatered reach during construction may encounter lethal conditions. Such stranding could impact potentially covered fish species by desiccation, suffocation, trampling, predation, and/or exposure to impaired or lethal water quality conditions (e.g., high temperature or high turbidity). Fish that live in close association with the substrates, particularly those that hide in the substrate (e.g., juvenile salmonids, lamprey, and sculpin), would be most vulnerable to stranding.

Fish removal efforts such as beach seining and electrofishing could inadvertently result in fish mortality. The amount of unintentional mortality (and non-lethal injury) attributed to seining would vary widely depending on the seine used, the ambient conditions, and the expertise of the field crew (NMFS 2006). Professional experience has shown that beach seining in areas of dense aquatic vegetation or in muddy areas could also result in significant mortality of seined fish that become trapped in a mass of vegetation or mud.

Electrofishing could also kill both juvenile and adult fish if improperly conducted. Mortality could result from direct trauma or from indirect factors (e.g., as a result of disease or subsequent fungal attack due to scale loss).

There generally would be fewer adverse impacts associated with seining compared to electrofishing, and first using a seine to remove fish would minimize the adverse effects of electrofishing (NMFS 2006).

7.1.3.1.2 Non-lethal Physical Impacts

The primary non-lethal physical impacts to fish associated with channel dewatering activities would be due to handling during fish removal, changes in turbidity, and reductions in prey availability. Active fish removal methods such as beach seining could affect fish in several ways, including stress, scale loss, physical damage, suffocation, and desiccation. Anesthetics such as tricaine methane sulfonate (also known as MS-222) and clove oil are often used to sedate fish to facilitate easier fish handling and reduce fish stress.

Electrofishing could also result in sublethal effects, such as spinal injury (NMFS 2006; Snyder 2003). The following excerpt from NMFS (2006) concisely describes the state of the knowledge pertaining to electrofishing impacts:

> Most of the studies on the effects of electrofishing have been conducted on adult fish greater than 12 inches in length (Dalbey et al. 1996). The relatively few studies that have been conducted on juvenile salmonids indicate that spinal injury rates are substantially lower than they are for large fish. Smaller fish intercept a smaller head-to-tail potential than larger fish (Sharber and Carothers 1988) and may therefore be subject to lower injury rates (e.g., Dalbey et al. 1996, Thompson et al. 1997). McMichael et al. (1998) found a 5.1 percent injury rate for juvenile middle Columbia River steelhead captured by electrofishing in the Yakima River subbasin while Ainslie et al. (1998) reported injury rates of 15% for direct current applications on juvenile rainbow trout. The incidence and severity of electrofishing damage is

> partly related to the type of equipment used and the waveform produced (Sharber and Carothers 1988, Dalbey et al. 1996, Dwyer and White 1997). Continuous direct current or low-frequency (equal or less than 30 Hz) pulsed direct current have been recommended for electrofishing (Fredenberg 1992, Dalbey et al. 1996) because lower spinal injury rates, particularly in salmonids, occur with these waveforms (Fredenberg 1992, Dalbey et al. 1996, Ainslie et al. 1998). Only a few recent studies have examined the long-term effects of electrofishing on salmonid survival and growth (Ainslie et al. 1998, Dalbey et al. 1996). These studies indicate that although some of the fish suffer spinal injury, few die as a result. However, severely injured fish grow at slower rates and sometimes they show no growth at all (Dalbey et al. 1996).

Channel dewatering decreases benthic prey availability for young salmonid life stages and other species that feed upon benthic prey in the area near the dewatered zone. Bell (1991) reported that the permanent wetted area of a channel is the governing factor in food production for salmonids because aquatic food supplies do not shift in streams as water levels rise or fall. The loss of prey is generally temporary, and as flow is returned to the dewatered portion of the channel, benthic macroinvertebrates from outside the dewatered area and those that sought refuge in the hyporheic zone recolonize the previously dewatered channel. The amount of time necessary for the benthic macroinvertebrate community to recolonize a dewatered reach will depend upon the size and duration of dewatering, the size and life cycles of the benthic macroinvertebrate community in nearby areas, and the season of disturbance (NMFS 2001b, 2005).

7.1.3.2 Impacts to Invertebrates

Typically, potentially covered benthic invertebrate species are not removed during channel dewatering and so would be subject to injury or mortality. Loss of macroinvertebrates can result from excavation, installation of bank protection structures, and placement of associated fill material.

Mussels provide a good example of potentially covered invertebrate species that may be affected by desiccation, as they exhibit sensitivities related to periodicity of inundation as well as temperature. Although no studies were located that specifically examined the impacts of construction-related dewatering, several studies have examined the influence of dam operations on freshwater mussel habitats, providing insight on the potential impacts from construction dewatering (summarized in Watters 1999). Depending on the use of the dam, water levels may fluctuate at regular intervals (for hydroelectric purposes) or random intervals (for flood control). In some areas, water levels may become shallow enough that thermal buffering is lost, allowing extreme temperatures to occur (Watters 1999). Blinn et al. (1995, in Watters 1999) reported that substrate subjected to 2- to 12-hour exposures to air required more than four months for mussels to regain a biomass similar to that in unexposed habitat. Federally endangered mussel species were reported by Neck and Howells (1994, in Watters 1999) as casualties of scheduled dewatering processes, and Riggs and Webb (1956) reported that several thousand mussels died in the tailwaters of Lake Texoma, an impoundment of the Red River formed by Denison Dam, when water levels dropped, in turn allowing water temperatures to become excessively warm (greater than 79 degrees Fahrenheit [F], 26 degrees Celsius [C]).

Combined with desiccation, exposure to cold air may be equally lethal to mussels. Nagel (1987, in Watters 1999) suggested that mussels would be more sensitive to cold water during frosts than to warm water during temporary droughts. Blinn et al. (1995) showed that a single overnight exposure to subzero temperatures resulted in at least a 90 percent loss of invertebrate biomass, and Valovirta (1990) reported that mussels were killed when water froze to the river bottom.

7.1.4 Chemical Contamination

Construction activities associated with the installation of bank protection structures would have the potential to introduce chemical contaminants to the environment through the accidental release of fuel, oil, or other contaminants. Operation of back-hoes, excavators, and other equipment will require the use of products such as fuel and lubricants that, if spilled into a water body or the adjacent riparian zone, can injure or kill aquatic organisms (NMFS 2005). Petroleum-based contaminants, such as fuel, oil, and some hydraulic fluids, contain polycyclic aromatic hydrocarbons (PAHs), which could be acutely toxic to salmonids at high levels of exposure and could also cause chronic lethal and acute and chronic sublethal effects to aquatic organisms (Neff 1985; Hatch and Burton 1999). Chemical contaminants can also impact prey production by limiting the suitability of substrates in the impacted area. Fish eggs can be particularly vulnerable to chemical contaminant exposure due to their inability to move out of the impacted area. Invertebrates can be similarly vulnerable due to the inability to move (or move quickly) out of the impacted area.

7.2 Channel Processes and Morphology

Rivers are naturally dynamic systems that adjust to tectonic, climatic, and environmental changes (Dollar 2000). The environmental components that contribute to channel processes are influenced by local and basin-scale variations in sediment supply, transport capacity, and the effects of vegetation (Montgomery and Buffington 1998). River systems continually adjust to maintain a steady state, or dynamic equilibrium (Soar and Thorne 2001). The adjustments of a river system are made over a continuum of spatial and temporal scales that result in corresponding gain, loss, or redistribution of habitat features.

The quantity, quality, and diversity of aquatic habitats are the products of the fundamental channel processes entailing the conveyance of water, sediment, nutrients, and organic matter (Miller et al. 2001). The hydraulic forces acting in a river carve channels; recruit LWD; create scour pools; and transport, sort, and deposit coarse and fine bed materials. The resulting variety of depths, velocities, substrate types, and cover provides habitat diversity and meets the needs of the various life stages of fish and other aquatic organisms (Gore 1985).

The anthropogenic alteration of the river environment, such as through the addition of bank protection structures, can disrupt the balance of the channel processes that form and maintain habitats throughout a river system (Fischenich and Allen 2000). Bank protection structures will have direct effects on river processes because they modify river channels and are designed to limit or prevent natural channel processes along the length of the structure. For this reason, the disruption of channel processes is the most significant impact mechanism generated by bank protection projects. Bank protection structures in or adjacent to channels can produce the following alterations to the channel processes and morphology:

- Channel straightening and shortening
- Channel narrowing
- Reduced habitat complexity
- Channel incision/increased scour
- Substrate coarsening
- Channel braiding/increased deposition
- Decreased floodplain connectivity
- Decreased channel migration and side channel creation
- Reduced LWD and organic material recruitment
- Reduced gravel recruitment
- Disrupted flow through the hyporheic zone[8]

Bank protection structures, particularly those that are designed for flood control (such as levees), tend to straighten and shorten channels (Brookes 1988, in Bolton and Shellberg 2001). If a bank protection structure is placed below the OHWL, the channel will be effectively narrowed or constrained. These types of changes to the channel will result in reduced habitat complexity, especially when the removal of logs or snags will coincide with the placement of the structure (Bolton and Shellberg 2001). For example, in the Skagit River, a comparison of protected conditions to natural riverbank conditions showed that habitat complexity and off-channel refugia were higher along natural banks (Hayman et al. 1996). River sections with extensive bank protection structures generally tend to create primarily glide habitat with poorly sorted substrates (Bolton and Shellberg 2001).

Because some bank protection structures, especially levees, are designed to increase flood capacity in a more vertical than horizontal configuration, the flow confined between the levees during high flows will tend to be deeper and faster than if the floodplain could be accessed. This will place higher shear stress on the channel bed and banks, which could lead to greater erosional forces along the structure and downcut the channel. Channel

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[8] Hyporheic zone is a broad term that defines the "saturated interstitial areas beneath the stream bed and into stream banks that contain some proportion of channel water or that have been altered by channel water infiltration (advection)" (White 1993, in Bolton and Shellberg 2001).

incision will also occur if the bank protection structure or material (e.g., riprap) reduces channel roughness and generates an increase in water velocity and turbulence near the bank protection structure (Fischenich 2001; Miller et al. 2001). The increased scour and channel incision will usually occur along the toe of the structure and/or immediately downstream (Fischenich 2003). Channel incision can lower the groundwater table and desiccate riparian vegetation. The substrate modification impacts associated with increased scour, specifically substrate coarsening, are discussed in Section 7.3.

The additional sediment movement associated with the increased scour and channel incision will result in increased volumes of sediment deposited at some distance downstream. The downstream river setting, including slope, floodplain width, and flow volume, as well as the volume of bedload material transported downstream, will contribute to where the material is deposited and what impacts it may have on habitat and species. Similarly, areas upstream of bank protection structures may also encounter sediment deposition if associated channel narrowing backs up water to some extent. Such sediment deposition could contribute to upstream river instability, which could threaten land, including the parcels with bank protection.

A disconnected floodplain and single stream channel are often goals of bank protection, despite the fact that an active floodplain connection plays a critical role in the dynamic equilibrium of rivers. Bank protection structures typically restrict the inundation of the floodplain. In the case of levees, which are designed and built for the purpose of increasing the flow capacity of a channel as a means of flood control (Bolton and Shellberg 2001), the disconnection of the floodplain is often perceived as the proper alternative to maintain the safety of life and property. The disconnection of a floodplain can be exacerbated by the channel incision process described above. The disconnection of the floodplain will result in more isolation of side channels and wetlands (Bolton and Shellberg 2001).

An associated outcome of the disconnected floodplain would be the limitation of lateral channel migration. The lateral migration of rivers, as well as riparian succession, is a necessary process for the maintenance of appropriate energy levels in a system, and thus promotes habitat diversity (Fischenich 2001). In this way, the reduction in channel migration will tend to limit the creation of complex main channel and side channel habitats

(Beamer et al. 2005). If a bank protection structure is installed when the channel alignment is unstable, the structure will attempt to keep the river in an unstable alignment (Saldi-Caromile et al. 2004), which may reduce the structure's effectiveness.

Channel incision, floodplain disconnectivity, and reduced lateral migration will all contribute to a reduction in the recruitment of LWD, organic matter, and gravel. LWD is a major component of pool formation, channel braiding, cover, and habitat complexity (Bisson et al. 1987). Woodsmith and Buffington (1996) found that the number of pools in a channel system was highly correlated with the quantity of LWD. The inundation of floodplain areas will recruit additional organic matter and nutrients that provide the base of a productive food web, which can result in high yields of fish (Bayley 1991, 1995). Gravel sources along river routes supply substrate for the continual natural replacement and transport downstream. In-channel gravel provides several functions for multiple trophic levels, including spawning substrate for fish, attachment points for sedentary invertebrates and aquatic vegetation, and habitat for epibenthic invertebrates.

Bank protection structures can disrupt exchange of groundwater and surface water in the hyporheic zone by creating a physical barrier (Fischenich 2003). The exchange of groundwater and stream flow through the hyporheic zone can provide several important ecological functions, including retention and storage of water, regulation of water releases to streams, promotion of habitat complexity, regulation of stream temperatures, refuge for fish eggs and invertebrates, and nutrient enrichment (Bolton and Shellberg 2001).

As described above, these impacts to channel processes will often occur in areas beyond the immediate extent of a bank protection structure. The type and extent of the alterations will depend upon the geomorphic and hydrologic setting of the river (Bolton and Shellberg 2001). For example, an alluvial river system with a channel bed and banks comprised of sediments will more easily incise and scour than a channel over bedrock. As discussed in Section 8, the amount of existing bank protection along a river will also factor into the cumulative impacts associated with an individual project.

7.2.1 Impacts to Fish

The alteration of channel processes and morphology can impact fish through the reduction of habitat quantity, quality, and diversity. These impacts can range from subtle shifts in the distribution and abundance of species to complete dislocation of a species from a particular locale.

Habitat quantity and complexity will be reduced by the shortening of the river and narrowing of the river cross section. The reduction in the amount of side channel and floodplain areas can impact fish species that rely on any of the associated habitats, including wetlands, beaver ponds, bogs, and off-channels. Even the availability of backwater areas and off-channel habitat can be reduced by bank protection structures.

For juvenile salmonids and other small fish species, the loss of side channel and floodplain habitats will reduce the availability of refuge habitat during high flows as well as summer rearing and overwintering habitats. Juvenile coho salmon are particularly impacted by a reduction in off-channel habitats and beaver ponds, and numerous studies have documented their reliance on those habitat types (e.g., Bustard and Narver 1975; Brown and Hartman 1988; Swales and Levings 1989). For example, in Carnation Creek watershed (a drainage in Vancouver, British Columbia), between 15 and 25 percent of the total coho smolt yield was captured in off-channel sites (Brown and Hartman 1988, in Henning 2004). Chinook (Swales and Levings 1989), sockeye (Burgner 1991), chum (Salo 1991), and steelhead (Puget Sound Steelhead Biological Review Team 2005) all rely on off-channel habitats to a lesser extent, but would be impacted by the loss of habitat. Pink salmon rely very little on off-channel habitats (Heard 1991) and would therefore be least impacted by the reduction of such habitats. Among trout and char, coastal cutthroat utilize off-channel environments the most (Lister and Finnigan 1997) and would be the most likely to be impacted by the loss of habitat.

The loss of side channel and floodplain habitat could also impact species such as lamprey and mountain suckers that rely on slow-moving backwater areas for habitat. Olympic mudminnows require access to floodplain wetlands and bogs and would be similarly impacted by the loss of habitat. In an investigation of the role of regulated floodplain wetlands in the Chehalis River as rearing (i.e., feeding and refugia) habitat for fishes, Henning (2004) documented high fish utilization in seasonally flooded habitats. The study captured 19 different fish species, including juvenile salmonids, Olympic mudminnows, and Pacific lampreys. Based on the high number and frequency of catch, it appears that these seasonally flooded habitats are preferred habitats for Olympic mudminnows (Henning 2004).

As a result of the loss of side channel and floodplain habitats during high-flow events, fish could be displaced downstream or would require higher energetic outputs to maintain position in the higher velocities. For territorial species or life stages (e.g., coho juveniles), the displacement would require the fish to locate and establish a new territory with suitable habitat conditions. Presumably, this could impact any fish that may have been occupying the new habitat and trigger its displacement.

Habitat quality would be impaired through the possible increases in velocity and bank slope. As described above, the higher velocities would be unsuitable for some species and life stages, while other species and life stages that may continue to use the habitat would need to expend higher energetic outputs to maintain position. This could impact growth rates and predation risks. In the case of larval fish, a study of fish use along natural and channelized habitats in the Willamette River, Oregon, concluded that continuous revetments are not good larval fish habitat (Li et al. 1984, in Bolton and Shellberg 2001). The authors determined that the combination of proximity to fast water, steep bank slopes, greater water depth, and cooler temperatures does not provide suitable habitat for larval fish.

Higher bank slope and velocity would also impact substrate composition and distribution such that the benthic and epibenthic invertebrates that are important in the diets of many fish species may no longer be as abundant or available. A shift in invertebrate species composition and abundance that affects diets would further exacerbate the problems created by increased energetic demand.

The reduction in LWD recruitment will diminish the habitat complexity as LWD is a major component of pool formation, channel braiding, cover, and habitat complexity

(Bisson et al. 1987). This reduction in pools and LWD would impact many potentially covered species, including salmonids because their abundance is typically greater in streams with more LWD (Bilby and Bisson 1998; Fausch and Northcote 1992). Decreases in juvenile salmonid abundance have been documented following wood removal from channels throughout the Pacific Northwest (Bilby and Bisson 1998). Peters et al. (1998) documented that juvenile salmon densities were generally positively correlated with increasing surface of LWD and increasing amounts of overhead riparian cover with 12 inches (30 centimeters [cm]) of water.

The disruption of flow through the hyporheic zone can also impact fish. Geist (2000a, 2000b) found that fall Chinook salmon chose spawning sites in the Hanford Reach of the Columbia River where groundwater was upwelling; where there was no upwelling, no spawning activity occurred. The dissolved oxygen content of upwelling groundwater was 9 mg/L, but only 7 mg/L or less where there was no hyporheic discharge (Geist 2000a, 2000b).

7.2.2 Impacts to Invertebrates

Freshwater mussels are nearly sedentary filter feeders and occupy stable gravel substrate; therefore, they are sensitive to changes in channel hydraulics and sediment transport. Alterations to bank protection and channel confinement could erode suitable substrate and dislodge the animals that occupy the habitat (Brim Box et al. 2004). McDowell (2001, in Brim Box et al. 2004) found that populations of western pearlshell (*Margaritifera falcata*), a freshwater mussel, were denser in reaches of the Middle Fork John Day River having no channel modification compared to modified reaches.

7.3 Substrate Modifications

Bank protection projects have the potential to directly or indirectly modify substrate conditions. The available literature describes a variety of potential impacts to habitats and species, which are discussed below in the context of the potentially covered species. Most of the literature that examines bank protection and substrate has focused on salmonid species.

Substrate modifications can have the following primary impacts on habitats of potentially covered species:

- Addition of non-erodible substrate
- Increased scour of substrate
- Increased deposition of substrate
- Altered littoral drift

These impacts are discussed below. In this paper, substrate scour and deposition address issues in moving river, stream, and estuary settings, while altered littoral drift addresses issues in marine and lake settings. The discussion of the placement of non-erodible substrate addresses substrate modifications at the location of the bank protection structure, whereas the scour and deposition discussions pertain to potential impacts that can extend far beyond the project site.

7.3.1 Addition of Non-erodible Substrate

Substrates larger than those occurring naturally are often placed in or along water bodies as part of bank protection projects. Placement of large rock that will remain stationary (i.e., is non-erodible) during high flows is more often a component of hard bank protection techniques than soft or integrated techniques. The size of the material placed, the substrate covered, and other environmental conditions will determine the degree to which substrate-dependent functions are impacted. Because potentially covered species depend upon aquatic substrates for life history and habitat functions, impacts to substrates will ultimately affect the species' distribution and ability to grow and survive. Available studies on the impacts of adding non-erodible substrates are primarily focused on the effects of riprap on salmonids.

7.3.1.1 Impacts to Fish

The addition of large substrate for bank protection would generally negatively impact habitat for cold-water species that use shallow margin habitats for feeding and refuge (Fischenich 2003), but would positively impact species that are associated with rock structure and interstitial spaces. Generally, species benefiting from the placement of rock may be non-native species that are piscivorous (e.g., brook trout) (Schmetterling et al. 2001). The potential benefits for rockfish, a group of marine fish that are typically associated with hard, reef-like structures, are unknown but are expected to be negligible because the various rockfish species typically do not occur along the immediate shoreline where bank protection structures would be placed.

Surf smelt and sand lance spawn on sand and gravel substrates in the upper intertidal zone and would be negatively impacted by the replacement of suitably sized substrates with larger substrates. These species are important prey items for salmonids and other piscivorous species, therefore the impacts to these “forage fish” would extend up the food chain to other potentially covered species. The detrimental impacts of increased substrate size for forage fish spawning are further discussed in Section 7.3.4.3.

In general, the addition of artificial substrates will decrease habitat suitability for juvenile salmonids and will change the character of the shoreline that was previously conducive to their use (e.g., Li et al. 1984; Knudsen and Dilley 1987; Peters et al. 1998; Schaeffter et al. 1983, in USFWS 2000), whereas for fish found in the interstices or relying on prey found there (e.g., sculpin), artificial substrates can increase habitat availability and usage (Li et al. 1984). While data indicate habitat use of riprapped banks by yearling and older trout species may be equal to or higher than natural banks, use by sub-yearling trout, coho, and Chinook salmon is lower (Weitkamp and Schadt 1982; Hayman et al. 1996; Beamer and Henderson 1998; Peters et al. 1998; Schmetterling et al. 2001; Knudsen and Dilley 1987; Garland et al. 2002). Knudsen and Dilley (1987) found that abundance of juvenile salmonids was reduced by bank reinforcement activities due to a loss of structural diversity and that these reductions were correlated with the severity of habitat alteration, the size of the stream, and the size of the fish. Size of material is also relevant, as greater fish densities have been generally correlated with larger rock (Beamer and Henderson 1998; Lister et al. 1995; Garland et al. 2002). Lister et al. (1995) found that salmonid densities were greater along banks with riprap greater than 1 foot (30 cm) median diameter compared to natural banks composed of cobble-boulder material. In the marine environment of Elliott Bay in Puget Sound, Toft et al. (2004) found similar densities of juvenile salmonids at sand/cobble beaches and riprap sites in settings where the riprap extended only into the upper intertidal zone. When riprap extended to the subtidal zone, higher densities of juvenile salmonids were found along riprap than at sand/cobble beaches. Toft et al. (2004) hypothesized that this finding may be based on the fact that the shallow-water habitats preferred by juvenile salmonids were compressed along the highly modified shorelines with steep slopes, therefore their snorkel observations were able to record all juvenile salmonids present. In comparison, at the sand/cobble beaches, the slopes were more gentle, the zone of shallow water was much wider, and densities were therefore lower because the fish were more spread out.

Additionally, as noted in Kahler et al. (2000), bulkheads that are nearly vertical and constructed of large boulders with large interstitial spaces can provide concealment to piscivores. No studies documenting the occurrence of increased predation of juvenile salmonids in riprap areas were identified. However, a study of fish diets in the Willamette River (Portland, Oregon) found that smallmouth bass (*Micropterus dolomieui*), yellow perch (*Perca flavescens*), and other centrarchids captured at riprap locations (although not likely to occupy interstitial spaces) were more likely to have fish in their stomachs than the same species captured along natural shorelines (Vile et al. 2004). Sculpins are piscivores that occupy interstitial spaces and, when larger than approximately 2 inches (50 millimeters [mm]), can prey upon juvenile salmonids (Tabor et al. 1998). Based on the Tabor et al. (1998) observation that more and larger sculpin were found in locations with larger substrates, Kahler et al. (2000) infers that increased predation to juvenile salmonids may occur in those areas.

These patterns in juvenile salmonid habitat use are generally attributed to the impacts of the bank protection material on localized hydraulics, substrate, and available food and cover for fish at stream sites where hard bank protection materials are used. Rock riprap can disrupt flows, reduce food delivery, and create difficult swimming for small fish (Michny and Deibel 1986; Schaffter et al. 1983). In addition, riprap shorelines will be less likely than natural shorelines to retain wood at the bank for increased habitat structure (Schmetterling et al. 2001). Of importance, several researchers (Beamer and Henderson 1998; Peters et al. 1998; Michny and Deibel 1986; Schaffter et al. 1983) found that where large, complex wood deposits have been either maintained or incorporated into riprap, fish densities were higher than densities at sites without such structures. The mechanisms affecting why yearling salmonids occur in higher numbers in riprap areas are not well understood. As described above, Toft et al. (2004) attributed their observations of higher juvenile salmonid densities in riprap areas to the reduced amount of shallow-water habitat in riprap areas relative to the wider sand/cobble beaches. Thus, in their snorkel observations they saw all juvenile salmon along the riprap because the zone of preferred shallow depths was quite narrow, whereas along sand/cobble beaches the fish were spread out in the shallow water beyond where the observers could see.

It is of note that the impacts associated with substrate modification do not apply to beach nourishment projects; these projects also typically place artificial substrate, but this material is generally sand and gravel and is placed with the intent to recreate original or favorable shoreline substrate conditions (Shipman 2001).

7.3.1.2 Impacts to Invertebrates

Little has been documented regarding impacts to invertebrates that use altered substrates of bank protection projects, other than the finding that the addition of riprap usually results in an increase in macroinvertebrate biomass and density of those species using interstices and hard substrates (Fischenich 2003). Ahn and Choi (1998) found that in the presence of a new seawall, sediment grain size became significantly coarser and some shifts in dominance of abundant species occurred, including a tenfold increase in total abundance and biomass of the surf clam (*Mactra veneriformes*).

Species that rely upon small substrate or vegetation growing in small substrate would be impacted by the change to large substrate resulting from the installation of armoring. For potentially covered invertebrate species, the Western ridged mussel lives in small substrates that would be less available in areas where bank protection structures add large substrate. Similarly, Newcomb's littorine snail may lose suitable habitat if large substrate is placed on top of substrate in the upper intertidal and supratidal areas that could otherwise support the snail's pickleweed (*Salicornia virginica*) vegetation habitat.

Mitigation may be available for the change from fine to coarse substrates (to some degree), as demonstrated by some projects that attempt to restore sand and gravel substrates to areas exhibiting large substrate. Monitoring in these projects has documented that epibenthic crustacean salmonid prey benefit from smaller substrate both in density and diversity of species (Parametrix 1985; Simenstad et al. 1991). Similarly, Thompson (1995) found an increase in hardshell clam abundance following beach graveling.

7.3.2 Increased Scour of Substrate

Bank protection structures intended to address bank erosion at the point of installation often result in the long-term reverse effect of increasing scour via alterations to hydraulics. Scour is potentially an issue in all channel types, although it is most often a concern in affluvial plane-bed and pool-riffle channels, which have a relatively mobile bed. The term “scour” is usually used to refer to flow-driven horizontal excavation of the streambed, but it can also occur laterally along stream margins and result in bank erosion. Scour may occur as a short-term or long-term outcome of having a bank protection structure in place, but the impacts tend to persist over an extended period of time (Fischenich 2001). Scour chiefly occurs in conjunction with high-flow events that account for the largest fraction of annual sediment transport. Scour usually occurs at the toe of the structures and may extend into the stream approximately two to three times the scour depth (Fischenich 2001).

Changes in velocities and substrate sizes may accompany increased scour. In freshwater habitats, riprap substrates (and, presumably, any substrates permanently simplifying channel margins) provide reduced complexity and diversity along the channel margin, leading to increased water velocity (Cramer et al. 2003). Bank protection structures that constrict the channel will generally lead to greater increases in velocities along the length of the structure compared to structures that do not constrict the channel (Fischenich 2001). This channel constriction can lead to incision or downcutting of the channel at the constricted section, as erosion occurs across the entire channel bed at the constriction (Cramer et al. 2003). The intrinsic ability of flow to transport sediment increases in a deepened channel, which can result in a coarsening of substrates within and downstream of a constricted section (Naiman and Bilby 1998). Such increases usually have no effect on the average cross-sectional velocity; rather, there is a redistribution of velocities, such that higher velocities occur adjacent to the structure (Fischenich 2001).

Increased scour can also have effects on floodplain processes. The geometry of a deepened channel disconnects it from the floodplain by creating a perched floodplain, or terrace, high enough above the channel that it is either no longer or less frequently inundated by the current hydrologic regime (Cramer et al. 2003). This can lead to abandonment of side channels and ponds in the short term and to reduction or prevention of sediment and nutrient delivery to the floodplain in the long term (Naiman and Bilby 1998). In addition, the formation of the terrace disconnects that surface from the water table and affects the establishment and survival of riparian vegetation. Other effects include bank instability as a result of:

- Oversteepening
- Groundwater discharge
- Increased shear stress because of very high peak flows within the channel
- Loss of wetland/floodplain habitat and backwater areas

In addition, hard approaches to armoring tend to transfer energy downstream of the protected shore, and an increase in bank erosion and/or a loss of habitat in an adjacent reach can be readily anticipated (Cramer et al. 2003). At marine shorelines, bulkheads have been shown to sort and coarsen existing substrate by increasing turbulence, wave reflection, and scour in front of the structure (e.g., Williams and Thom 2001). This often leads to a need for further supplemental armoring of foreshore and adjacent beach areas (Cox et al. 1994), often occurring in the form of additional riprap at the toe of the bulkhead. This topic in marine settings is addressed further in the discussion of littoral drift (Section 7.3.4).

7.3.2.1 Impacts to Fish

Substrate scour can affect fish egg nests by dislodging eggs and transporting them downstream before they have incubated sufficiently. In addition to the location of the egg deposits in the channel and the bedload movement associated with flows, the vulnerability of these egg deposits depends upon the depth to which they are

deposited. The increased velocities and bedload movement associated with bank protection structures and other modifications in the watershed that can impact peak flows encountered during flood events (e.g., logging, addition of impervious surfaces, removal of riparian vegetation) contribute to exacerbate the natural scour conditions that fish may be adapted to and therefore can reduce egg survival. Montgomery et al. (1996) measured both scour and egg pocket burial depths of chum salmon and determined that a small increase in scour would affect the integrity of a large proportion of redds. There is a growing body of evidence (e.g., Montgomery et al. 1996, Montgomery et al. 1999) that salmon are adapted to natural bedload movement conditions. For example, based on observations that chum salmon bury their eggs just below scour depths during bankfull flow, Montgomery et al. (1996) hypothesized that the depths to which salmon bury their eggs represent an adaptation to the depths of scour during typical winter storms.
Further, Montgomery et al. (1999) provides evidence that salmon spawning distributions and timing are adapted to basin-specific scour conditions. These adaptations can result in salmon eggs being vulnerable to increases in the frequency and size of bedload movement associated with bank armoring. Such vulnerabilities could presumably be more severe for smaller fish species that bury eggs (e.g., lamprey, Olympic mudminnow, and resident trout). Smaller fish tend to spawn in smaller substrates and bury eggs at shallower depths than salmon and therefore may be more likely to be dislodged during unnaturally high scour events.

The increased velocities and scour can also impact fish by reducing the production of potential macroinvertebrate prey items. As described by Bolton and Shellberg (2001), velocity is one of the critical factors contributing to the presence and abundance of macroinvertebrate species. Many species require low turbulence habitat for substrate. Bank protection activities that include channelization disrupt invertebrate communities (Bolton and Shellberg 2001). Reductions in the availability of prey can reduce the carrying capacity of a river system.

7.3.2.2 Impacts to Invertebrates

Freshwater mussels are particularly vulnerable to scour because they are long-lived, sessile organisms. Mussels are commonly found on relatively coarse (gravel to boulder) substrates in microsites that constitute flow refugia with low risk of scour (Cuffey 2002; Brim Box et al. 2004).

7.3.3 Increased Deposition of Substrate

The entrainment of fine sediments and other material during construction activities, as well as the increase in bedload movement associated with any increased scour, will result in the deposition of materials downstream from the project area. These sediments may accumulate in slackwater areas nearby or farther downstream. The increase in deposited materials may impact potentially covered species through burial or increased embeddedness of occupied habitats downstream.

7.3.3.1 Impacts to Fish

Deposition effects depend on the particle size distribution and amount of sediment. When sedimentation occurs, salmonids may be negatively affected in several ways:

- Buried salmonid eggs may be smothered and suffocated.
- Prey habitat may be displaced.
- Future spawning habitat may be displaced (Spence et al. 1996; Wood and Armitage 1997).
- Juveniles and small fish may be prevented from using the interstices as refuge (Spence et al. 1996).

At the outset of spawning, adult fish winnow fine sediment from their gravel redds, mobilizing fine sediment into the water column and in the process coarsening the bed in the immediate vicinity of the spawning nest (Kondolf et al. 1993; Montgomery et al. 1999). However, if fine sediments are deposited again after redd construction, this material fills pore spaces between gravel particles in and over the redd. Deposition of fine sediment may degrade instream spawning habitat and reduce survival from egg to emergence by smothering interstices (Phillips et al. 1975; Chapman 1988). The probability of pore space filling increases if the sediments are particularly fine, if the sediment amount is large, and if flows/currents are relatively low (Bjornn and Reiser 1991). For salmon, the process may be exacerbated by downwelling hyporheic flows, which often occur at salmonid spawning sites in Pacific Northwest rivers (Tonina and Buffington 2003, 2005). Consequences of this embedding include reduced water flow around the eggs, reduced dissolved oxygen uptake by developing embryos, and reduced flushing of metabolic waste, which can result in low embryo survival (Bjornn and Reiser 1991). The amount of sediment does not need to be large to cause these smothering effects. Although redds of large salmonids are usually buried beneath at least 6 inches (15 cm) and as much as 1 foot (30 cm) of gravel (DeVries 1997; Bjornn and Reiser 1991), near-surface deposits of fine sediment may be sufficient to reduce water flow through the redd and create a surface layer that physically prevents alevin emergence (Everest et al. 1987; Bjornn and Reiser 1991). Fines under approximately 0.03 inch (0.85 mm) in diameter have been shown to be particularly detrimental to salmon eggs through the associated decrease in dissolved oxygen (Chapman 1988). Research has documented significant declines in salmonid egg survival when the percentage of fine sediments under 0.03 inch (0.85 mm) in diameter reaches the range of 10 percent (Tappel and Bjornn 1983) to 13 percent (McHenry et al. 1984; see Chapman 1988).

In addition to effects on the larval stage of salmon, embedding also reduces prey for foraging juveniles by promoting a shift from epibenthic to benthic infaunal macroinvertebrates, which are not easily preyed upon by young salmonids (Bash et al. 2001; Suttle et al. 2004).

7.3.3.2 Impacts to Invertebrates

Sediment deposition can impair the growth and survival of filter-feeding organisms or organisms living on the substrate (Bash et al. 2001) by filling interstitial spaces needed for respiration and feeding. While the exact mechanisms are not known, it is clear that siltation causes changes in water flow through the gravel and results in a shift in algal and microbial communities (Tucker and Theiling 1998). In freshwater mussels, Tucker and Theiling (1998) described a study in which fine sediment (silt) deposition of as little as 0.25 inch (6.35 mm) caused death in mussels. Siltation also is detrimental to young mussels and reduces their survival (Scruggs 1960, in Tucker and Theiling 1998). Juvenile survival (even of hardy species) may be reduced in silt-impacted mussel beds, which can limit recruitment of young in the entire bed (Tucker and Theiling 1998). It is also understood that different mussel species show varying responses to fine sediment inputs (Brim Box and Mossa 1999).

7.3.4 Altered Littoral Drift

Wave dynamics in marine and lake environments are analogous to riverine channel hydraulics, in that wave action striking shorelines at an angle transports sediment parallel to shore in the direction of the prevailing wind (Jacobsen and Schwartz 1981). While littoral processes are most conspicuous in marine waters, they can occur along lake shores as well, where fetch and wind speed combine to produce waves and subsequent longshore currents strong enough to move shoreline sediments.

Washington State contains thousands of miles of shorelines, including about 2,000 miles in Puget Sound alone. Much of this shoreline consists of poorly consolidated bluffs of glacial sediments faced with cobble beaches in the upper intertidal zone and sandy sediments in the lower intertidal and subtidal areas. Erosion and occasional landslides on these bluffs provide the greater volume of sediment on Puget Sound shores compared with sediment delivered by rivers and streams (MacDonald et al. 1994). Local geomorphology, weather, fetch, and sediment sources determine the volume, timing, and direction of sediment transported past an individual beach. Shoreline sediment transport occurs along generally discrete segments ranging from a few hundred feet to several miles. These shoreline segments, called drift cells, include sediment source areas, sediment transport areas, and depositional areas. Sediment sources are the low and high bluffs that “feed” the beach with sand and gravel. Through littoral drift, sediments are transported along the shoreline. In this way, actively eroding bluffs contribute to habitat conditions throughout the drift cell they support. The direction of drift within a drift cell may reverse between winter and summer as prevailing wind and wave directions change, causing sand to redistribute among beach areas (Cox et al. 1994).

Bank protection structures and other artificial shoreline features can affect littoral drift through their influence on sediment supply and sediment transport. Alteration of sediment supply and transport conditions can impact the natural processes that build spits and beaches and provide substrates required for plant propagation, fish and shellfish settlement and rearing, and forage fish spawning (Parametrix and Battelle 1996, Penttila 2000b, Thom et al. 1994, all in Nightingale and Simenstad 2001b; Thom and Shreffler 1996).

7.3.4.1 Sediment Supply

Bank protection structures, as the term suggests, are constructed to prevent bank erosion. A structure such as a bulkhead, if functioning correctly, prevents potential bank and bluff material from supplying the aquatic system (Johannessen et al. 2005). Along the Puget Sound shoreline, this disconnection or impoundment of natural sediment sources is possibly the most significant impact of shoreline protection measures (MacDonald et al. 1994). Bank protection structures that inhibit the erosion of feeder bluffs or transport of sediment stored high on the beach would cause erosion of material on the beach at the face of the structure and from the beach downdrift of the structure. As a result, beaches located in front of, and downdrift from, shoreline armoring can experience coarsening of the substrate and beach lowering (Dean 1986; Everts 1985; MacDonald et al. 1994; Zelo et al. 2000; Anchor Environmental et al. 2002; Johannessen et al. 2005). In addition, the beach profile is likely to lower and narrow (Galster and Schwartz 1990). The negative impact of sediment impoundment is most pronounced when armoring occurs along actively eroding bluffs, because these areas supply beach substrate throughout the length of the drift cells they support (MacDonald et al. 1994).

Similarly in freshwater settings, bank protection structures can limit habitat-forming processes such as the introduction of suitably sized substrates for spawning fish and LWD for habitat (e.g., NMFS 2003). It is important to note, however that there are certain situations in which bank protection structures, particularly soft-shore techniques, can benefit habitat conditions by limiting sediment introduction. These benefits occur in settings where there is an overabundance of sediments and/or the sediment sources being disconnected are particularly fine sediments.

7.3.4.2 Sediment Transport

Bank protection structures can impact sediment transport through changes in wave energy reflection and attenuation, as well as changes to littoral currents. Hard shoreline structures in the wave zone reflect wave energy with little attenuation of power (Miles et al. 2001). Silvester (1977, in Gabriel and Terich 2005) found that the presence of seawalls doubled the littoral energy applied to the sediment, which led to increased scour downdrift. As a result, more small sediment (e.g., sand and gravel) is entrained and moved than would occur along a natural shoreline that attenuates wave energy. This scouring impact is generally greater in vertical structures, such as bulkheads, compared to artificially or naturally sloped beaches (Zelo et al. 2000). The result is a coarsening of the beach as sand and small gravel are transported away from the beach, consequently lowering the beach elevation (Dean 1986; Everts 1985, Zelo et al. 2000; Anchor Environmental et al. 2002; Johannessen et al. 2005). Vertical structures also tend to focus wave energy on adjacent beach and backshore areas, which could contribute to erosion in areas downdrift of the bulkhead (MacDonald et al. 1994).

Revetments tend to have slightly reduced impacts relative to vertical bulkheads because of the materials used and their configuration. Revetments are generally constructed of non-erosive material (e.g., riprap or quarry spall) that varies in size depending on water levels and wave energy of a specific site and are usually built to a slope of 1.5 or 2 horizontal units to every 1 vertical unit.(Williams and Thom 2001). Revetments can partially attenuate wave energy (the remaining energy is reflected) and water can filter through the rock material in the swash zone, protecting the underlying beach sediment. Although wave energy can be attenuated by revetments, sediment supply is still isolated from the littoral drift system.

Soft shore protection structures tend to absorb and attenuate wave energy better than hard structures by mimicking natural processes (Johannessen et al. 2005). Soft shore protection structures that maintain more natural slopes and materials that can be reshaped (e.g., an enhanced gravel berm) can absorb incoming wave water and attenuate the energy before the water percolates out gradually.

Studies on impacts from bank protection structures have quantitatively measured conditions in front of a bulkhead and at adjacent un-bulkheaded shores and have shown that in front of a bulkhead, the suspended sediment volume and littoral drift rate all increased substantially compared to unarmored shores, which resulted in beach scouring and lowering along the armored shores studied (Miles et al. 2001). One example of the impacts of bank protection on sediment supply and transport conditions is Seahurst Park in central Puget Sound (Burien, Washington). At

Seahurst Park, the placement of bank protection structures in the 1970s resulted in dramatic changes to the habitat conditions in the park and reduced the amount of sand and gravel available throughout the 11-mile-long drift cell. The park shoreline was armored using a combination of stacked gabions, vertical concrete bulkhead, and riprap. A survey conducted in 2001 demonstrated that since shoreline armoring, beach elevations in the park have dropped approximately 3 to 4 feet. Further, the former sand, gravel, and small cobble beach now consists of larger substrates because the bank protection structures caused an increase in the erosive energy of waves moving sediment offshore and disconnection of the beach from primary sediment sources (bluffs) (Anchor Environmental et al. 2002).

7.3.4.3 Impacts to Fish

Alteration of sediment supply and transport conditions can impact the natural processes that support the entire food web (Thom et al. 1994). Pacific salmon, Pacific herring, surf smelt, sand lance, and a variety of other fish may be affected by habitat changes due to structures that affect littoral drift (Thom et al. 1994). Suitable surf smelt spawning areas were adversely impacted by littoral drift alterations resulting from bulkheads along the Hood Canal (Penttila 1978, in Thom et al. 1994). Typical spawning substrates consist of fine gravel and coarse sand, with broken shells intermixed in some cases (Thom et al. 1994). Surf smelt make no attempt to bury their demersal, adhesive eggs, but rely on wave action to cover the eggs with a fine layer of substrate (Thom et al. 1994). Therefore, any alteration of substrate composition of surf smelt spawning areas may affect surf smelt spawning and egg survival. Pacific sand lance spawn in the high intertidal zone on substrates varying from sand to sandy gravel. Sand lance also rely on sandy substrates for burrowing at night. Like surf smelt, sand lance spawning is susceptible to deleterious effects of littoral alterations because sand lance rely on a certain beach profile and specific substrate compositions (Penttila 1995).

Any species dependent on eelgrass, such as Pacific herring, are susceptible to changes in littoral drift because bank protection structures can limit the occurrence of suitable substrate sizes to support eelgrass. Eelgrass typically grows in sand and mud substrates in sheltered or turbulent waters (Phillips 1984), and Pacific herring spawn on the blades of eelgrass and other macroalgae (WDNR 2006a). It is consistently documented that the vegetation assemblages associated with eelgrass support increased numbers of juvenile salmonid epibenthic prey (Nightingale and Simenstad 2001b). Studies of eelgrass communities in Padilla Bay show that a specific group of copepods (*Harpacticus uniremis*, and other copepods of the genera *Zaus* and *Tisbe*) is unique to the eelgrass epiphyte assemblage and the principal prey of juvenile chum salmon, Pacific herring, Pacific sand lance, and surf smelt (Nightingale and Simenstad 2001b). Pacific herring is also a direct food source of larger predators, including adult Chinook salmon, bull trout (Nightingale and Simenstad 2001b), Pacific hake (Bailey 1982; NMFS 1990; Quirollo 1992; McFarlane and Beamish 1986, in NRC 2001), Pacific lamprey, rockfish (WDNR 2006a), and many other species (WDNR 2006a). Thus, a reduction in Pacific herring productivity could produce indirect adverse impacts on a number of the potentially covered fish species.

7.3.4.4 Impacts to Invertebrates

Benthic communities, including invertebrate populations, are impacted by sediment alterations (Nightingale and Simenstad 2001b). For instance, the Olympia oyster is an epibenthic filter feeder found throughout the inland waters of Puget Sound, as well as in Willapa Bay and possibly Grays Harbor (WDNR 2006b). They occupy nearshore areas on mixed substrates with solid attachment surfaces and are found from 1 foot (0.3 meter [m]) above mean lower low water (MLLW) to 2 feet (0.6 m) below MLLW; the larvae settle onto hard substrate such as oyster shells and rocks (West 1997; Baker 1995, both in WDNR 2006b). Olympia oysters are intolerant of siltation and do best on firm substrates (WDNR 2006b). Therefore, it follows that local impacts to littoral drift can alter preferred substrate or smother oysters beneath silt. Newcomb’s littorine snail is found primarily in association with a narrow band of nearshore intertidal habitat that contains certain marsh plant species (Larsen et al. 1995); because detailed reproductive and habitat needs are not known, it might be conservatively assumed that Newcomb’s littorine snail is also subject to smothering or substrate changes in this area. Other potentially covered species inhabit deeper or riverine habitats and would not be affected by littoral drift.

7.4 Habitat Accessibility

Thus far, this paper has described impact mechanisms of bank protection structures that are related to single processes or habitat features, such as channel form or substrate. The mechanism of habitat accessibility differs from these other mechanisms because it combines the elements of physical features, time, and location to represent how potentially covered species would be impacted by loss of ability to access these features. In Figure 1, habitat processes and structure are depicted as affecting ecological functions. Access to habitat is one of the ecological functions that is important to potentially covered species and that may be impaired to some degree by bank protection structures. Bank protection structures can be categorized as limiting habitat accessibility by:

- Loss of favorable depths
- Loss of favorable velocities
- Loss of floodplain habitats

7.4.1 Loss of Favorable Depths

Aquatic species must be able to access habitat with water depths favorable to their habitat needs. When favorable depths are lost, species are cut off from habitats they require. Isolation of species from shallow-water habitats can occur when armoring is placed waterward of the OHWL or into the intertidal zone of marine habitats, and the area immediately adjacent to the structure exists at a deeper point than nearshore species can inhabit, forage, or find refuge. The deep water condition can be exacerbated if armoring further causes scour of the bank, erosion of sediment, and lowering of shore elevation.

7.4.2 Loss of Favorable Velocities

Potentially covered species also must be able to access habitats with velocities favorable to their physiological needs as a species or a life stage. For example, such species as mountain sucker and lamprey require slow water as a general habitat need, while juvenile salmonids require slow-moving water for cover and energy refuge. Many species find the quiescent habitats they need in off-mainstem channels, backwaters, tidal sloughs, and shallow water areas. When bank protection degrades and reduces access to these habitats and to off-channel refugia habitat found in floodplains (Beamer et al.

2005), species can either be displaced or be unable to seek refuge and must expend excess energy to maintain position and avoid being flushed out of preferred habitats.

7.4.3 Loss of Floodplain Habitats

Potentially covered species require habitats that offer varying depths, velocities, and cover for refuge from their predators and from needlessly expending energy. Floodplain habitats provide these diverse habitat conditions. As discussed in detail in Section 7.2.1, a reduction in the amount of side channel and floodplain can impact species that rely on any floodplain-associated habitats, including wetlands, beaver ponds, bogs, and off-channels. Even the availability of backwater areas can be reduced by bank protection structures.

7.4.4 Impacts to Fish

Bank protection structures that alter the flow regime, and thus depth and velocity, can impact fish habitat accessibility where water velocity exceeds their swimming ability or creates areas without adequate water depth or sufficient refuge areas. Most fish, and mobile species such as salmonids, must be able to move freely upstream and downstream during both juvenile and adult stages (Sargeant et al. 2004). Adult salmon returning to their spawning streams must have unobstructed upstream migration corridors. Juvenile salmon rearing in rivers have been found to move both upstream and downstream to utilize rearing habitat, even in streams where spawning has not been documented (Kahler and Quinn 1998). This optimization of habitat implies that access to all stream reaches, even those absent of adult salmon, is needed by juvenile salmon. Hayman et al. (1996) found sub-yearling Chinook in higher densities at backwater and off-channel habitat than in mainstem edge habitat of the Skagit River. Heiser and Finn (1970) found that juvenile salmonids avoided deep-water areas along bulkheaded shorelines. In marine areas, altered water depths along the marine shallow-water migration corridor preclude their use by migrating juvenile salmon (Thom and Shreffler 1994). Similar effects would be expected for any potentially covered species that uses shallow depths and slow velocities for refuge, habitat, or migration.

Fish also require structural diversity and complexity within habitats that already provide favorable depths and velocities, and this may differ by life stage. Li et al. (1984)

documented lower larval and juvenile fish densities and richness along revetted versus natural shorelines in the Willamette River, but higher adult abundances. Species captured by Li et al. (1984) included Chinook salmon, speckled dace (*Rhinichthys osculus*), torrent sculpin (*Cottus rhotheus*), and largemouth bass (*Micropterus salmoides*). Knudsen and Dilley (1987) found that abundance of juvenile salmonids was reduced by bank reinforcement activities due to a loss of structural diversity and that these reductions were correlated with the severity of habitat alteration, the size of the stream, and the size of the fish. Jennings et al. (1999) found that even within armoring types, those that provided higher structural diversity exhibited higher species richness. Moreover, many freshwater studies have documented that fish species richness and abundance are negatively correlated with bulkheads in general (see review by Kahler et al. 2000). Lange (1999) found that the presence of bank bulkheads was negatively correlated to fish abundance and species richness in Lake Simcoe, Ontario, and juvenile fall Chinook in the Columbia and Snake rivers were found to avoid riprap shorelines (Key et al. 1994; Garland and Tiffan 1999).

In addition, bank protection structures that alter depths and velocities in the marine intertidal zone can limit habitat access for prey of potentially covered species; in particular, forage fish such as surf smelt and sand lance spawn on fine-grained substrate in the upper intertidal zone, which may be locally reduced along armored shorelines. Further, Pacific herring spawn on submerged eelgrass and macroalgae in shallow-water areas that may also be reduced along armored shorelines (Thom and Shreffler 1994).

Impacts to fish by loss of floodplain habitats is discussed in detail in Section 7.2.1. A reduction in the amount of side channel and floodplain areas can impact fish species that rely on any of the associated habitats, including wetlands, beaver ponds, bogs, and off-channels.

7.4.5 Impacts to Invertebrates

Loss of habitat access would also limit potentially covered invertebrate species. The potentially covered freshwater mussels migrate through their range as larvae attached to fish gill membranes (Brim Box et al. 2004), and loss of habitat access for the host fish would also lead to a reduction of the mussels’ range. Among the 35 fish that Brim Box et al. (2004) found to be carrying mussel larvae, 34 were speckled dace and one was redside shiner (*Richardsonius balteatus*). Brim Box et al. (2004) found no mussel larvae attached to the small numbers of smallmouth bass, northern pikeminnow (*Pyctocheilus oregonensis*), and largescale sucker (*Catostomus macrocheilus*) that they inspected.

Newcomb's littorine snail requires a narrow band of nearshore intertidal habitat that contains certain marsh plant species (pickleweed, *Salicornia virginica*; Larsen et al. 1995), and inadequate water depth or velocity conditions caused by bank armoring that threaten this plant would also impact the snail. Other potentially covered invertebrates are typically found in deeper-water areas (snails) or in mudflat habitats (oysters), where access to habitat would not be limited by bank protection structures.

7.5 Aquatic Vegetation

Aquatic vegetation that may be impacted by bank protection structures includes marine and freshwater aquatic vegetation.

7.5.1 Alteration of Marine Aquatic Vegetation

In this paper, the term marine aquatic vegetation refers to eelgrass (*Zostera* spp.); kelps (e.g., bull kelp [*Nereocystis leutkeana*]); other green, brown, and red macroalgae species; and intertidal wetland vascular plants (i.e., saltmarsh plants) that grow in the marine and estuarine habitats of the state. The Washington State Hydraulic Code Rules (WAC 220-110-250) designate eelgrass, kelp, and intertidal vascular plants as saltwater habitats of special concern and require that hydraulic projects result in no net loss of these habitats. Two species of eelgrass grow in Washington State: native eelgrass (*Z. marina*) and a smaller, non-native species (*Z. japonica*) (Wyllie-Echeverria and Phillips 1994). Typically, *Z. marina* grows at lower intertidal and subtidal elevations than *Z. japonica* and may either form extensive beds covering many acres or exist in smaller patches (Phillips 1984). *Z. japonica* is generally found at higher elevations than *Z. marina* and typically grows in patches or a narrow fringe (Phillips 1984). Both species typically grow in sand and mud substrates in sheltered or turbulent waters (Phillips 1984). Many species of macroalgae (e.g., brown algae) also grow in the marine waters of Washington, generally attached to rocky substrates (i.e., small cobbles and larger sediment size classes) and always within the nearshore photic zone (Kozloff 1993). In the estuarine salt marshes of Washington, bulrushes (*Scirpus* spp.) and sedges (*Carex* spp.) are the most commonly found vegetation types (Kozloff 1993). Other common vegetation types include rushes (*Juncus* spp.), salt grass (*Distichlis spicata*), dune grass (*Leymus mollis*), and pickleweed (*Salicornia virginica*) (Seliskar and Gallagher 1983).

Marine aquatic vegetation is a fundamental structural and ecological component of the nearshore ecosystem and substantially influences the physical and chemical properties of the nearshore environment (Nightingale and Simenstad 2001b). Marine aquatic vegetation forms an important component of the base of the aquatic (and terrestrial) food web (Seliskar and Gallagher 1983). The primary production of marine aquatic vegetation supports all other trophic levels. As it decomposes, marine aquatic vegetation also provides significant organic detritus to the food web (Simenstad 1983). Marine aquatic vegetation provides habitat for fish, shellfish, and other invertebrates in the marine nearshore and estuarine ecosystems. Eelgrass, macroalgae, and saltmarsh plants are very productive and support marine food webs through their plant biomass and detritus, as well as providing substrate for colonies of epiphytic algae and refuge for crustaceans (Seliskar and Gallagher 1983; Phillips 1984). The vertical structure of marine aquatic vegetation can also trap and stabilize sediments, and vegetation that grows through the entire water column, such as bull kelp, can dissipate wave energy before it hits the shoreline (Jackson 1984).

Bank protection structures in marine waters have the potential to affect marine aquatic vegetation through direct or indirect disturbance and displacement. Saltmarsh vegetation growing along the upper intertidal shoreline fringe, the backshore, or in larger saltmarsh complexes is highly susceptible to disturbance through the potential hydraulic disconnection, burial, or conversion of habitat associated with bank protection structures. Marine aquatic vegetation may be uprooted or displaced as the vegetation itself may be removed for projects constructed below the OHWL. During construction, vegetation may be trampled or subject to spills from construction equipment in the project area or work corridor. Vegetation may also be disturbed as a result of vessel grounding or propeller wash (Lagler et al. 1950, in Carrasquero 2001; Haas et al. 2002), which can entrain air bubbles and introduce sediment suspension (Haas et al 2002). Because light availability is a fundamental requirement for eelgrass and macroalgae growth, turbid conditions limit their ability to thrive. Bank protection projects can indirectly impact marine aquatic vegetation distributions through the sediment coarsening that occurs as a result of the altered wave regime or disruption of littoral drift (e.g., Johannessen et al. 2005). The sediment coarsening may result in substrates too large to support marine aquatic vegetation.

7.5.1.1 Impacts to Fish

Many potentially covered fish species highly depend upon marine aquatic vegetation for prey production, habitat structure, reproduction, and rearing. In the absence of this vegetation, these species would experience substantial impacts to growth and survival, both directly and indirectly. As stated in previous sections, studies of eelgrass communities in Padilla Bay indicate that one group of copepods (*Harpacticus uniremis* and other copepods of the genera *Zaus* and *Tisbe*) is unique to the eelgrass epiphyte assemblage and comprises the principal prey of juvenile chum salmon, Pacific herring, Pacific sand lance, and surf smelt (Nightingale and Simenstad 2001b). Also, recent dietary investigations in central Puget Sound found that juvenile Chinook salmon fed extensively on a polychaete worm (*Platynereis bincanaliculata*) that builds tubes on eelgrass and macroalgae (Brennan et al. 2004).

Salt marshes provide important feeding opportunities and predator refuge for fishes. For example, juvenile chum and fall Chinook salmon have been observed to selectively forage for chironomid larvae and adults in a restored marsh, suggesting that restored salt marsh provides indirect benefits to fisheries by production of preferred prey items through detritus-based food chains (Shreffler et al. 1992). Seliskar and Gallagher (1983) identified seven of the potentially covered species as associated with marsh habitats: Chinook, chum, coho, sockeye, and pink salmon, longfin smelt, and surf smelt. In the Fraser River estuary, most of the fish populations are dependent upon a small array of benthic invertebrates, many of which are tidal marsh inhabitants (Northcote et al. 1979). Salt marshes are highly sensitive to human disturbance (Seliskar and Gallagher 1983). The destruction of salt marshes can significantly impact the refuge habitat available for fish and the important functions that salt marshes provide at the base of the food web. Levy and Northcote (1981) concluded that juvenile salmon use the entire length of tidal channels and, therefore, that bank protection structures along any part of a marsh area can significantly reduce the estuary's capacity as a rearing area.

The vertical structure off the seafloor (substrate) that marine aquatic vegetation provides is important habitat for fish and invertebrates, including salmon, forage fish, and juvenile rockfish (Phillips 1984). In Blackmon et al.'s (2006) synopsis of research on the use of seagrass and kelp habitats by fish, it was noted that forage fish and juvenile Pacific salmon species preferentially use eelgrass over other habitats. Juvenile salmon are also found in kelp habitat, and rockfish (*Sebastes* sp.) produce planktonic larvae that settle in eelgrass, shallow kelp beds, and floating kelp mats. Both eelgrass and macroalgae provide substrate for herring spawning (Bargmann 1998).

7.5.1.2 Impacts to Invertebrates

Fish prey invertebrates occurring in marine aquatic vegetation will be subject to the direct and indirect impacts discussed above in Section 7.5.1. Additionally, two potentially covered marine invertebrate species are associated directly with vegetated habitats. The first, northern abalone, would be impacted because of its typical association with kelp beds (Gardner 1981). Northern abalone typically cling to rocks in thick kelp beds (Pacific Biodiversity Institute 2006). Larger northern abalone feed on detached, drifting algae and their growth rate can be influenced by the amount of algae available (Jamieson 1999). The second, Newcomb's littorine snail, is found primarily in association with a narrow band of nearshore intertidal habitat that contains certain marsh plant species (Larsen et al. 1995). Because detailed reproductive and habitat needs of Newcomb's littorine snail are not known, it might be conservatively assumed that Newcomb's littorine snail is subject to habitat loss if marine aquatic vegetation, particularly marsh plant species, is absent.

7.5.2 Alteration of Freshwater Aquatic Vegetation

Freshwater aquatic vegetation is submerged and emergent plant material that is rooted below the OHWL of freshwater bodies such as rivers, streams, lakes, ponds, and open-water wetlands. This vegetation functions in many ways to support the freshwater system. It provides habitat structure and cover, as fish use aquatic plants for cover and invertebrates use aquatic plants for shelter and as substrate for attachment (Petr 2000). Aquatic plants also support the base of the food web through photosynthesis, nutrient cycling, and as food for herbivores and detritivores (Petr 2000). Aquatic vegetation can modify its own physicochemical environment by slowing water velocity, trapping sediment, and altering temperature and water quality (Chambers et al. 1999). Emergent aquatic vegetation can reduce wave-induced bank erosion (Coops et al. 1996).

Bank protection activities in freshwater settings have the potential to affect freshwater aquatic vegetation through direct disturbance or indirect disturbance and displacement. Construction of bank protection structures can result in a direct reduction of submerged and floating leafy vegetation due to excavation of banks below the OHWL, or the use of water-based construction operations that contact the substrate and produce trampling and propeller scour (Lagler et al. 1950, in Carrasquero 2001). Bank protection structures positioned waterward of the OHWL will encroach upon areas that support or potentially would support freshwater aquatic vegetation.

Indirect effects to freshwater aquatic vegetation include changes in energy and substrate, as well as the introduction and existence of noxious aquatic weeds. Increased wave reflection can cause unsuitable energy conditions for vegetation, as well as the flushing out of small substrate that supports plant growth. The introduction of noxious weeds is a concern in aquatic environments (Chambers et al. 1999; WNWCB 2006) because they can out-compete native vegetation and lead to a reduction in habitat quality for native fish species (Chambers et al. 1999). Eurasian milfoil, a common freshwater noxious weed, is known to cause several adverse habitat conditions for freshwater fish, including reduced dissolved oxygen and reduced access to habitat (Chambers et al. 1999).

For bank protection structures, these weeds can be introduced to freshwater environments if vessels used in construction carry invasive plants from other water bodies. For example, the Lake Washington shorelines have developed extensive beds of Eurasian milfoil since it was first observed in the lake in 1974 (WNWCB 2005), and interlake transfer from boats is thought to be the chief means by which Eurasian milfoil is spread (WNWCB 2005).

7.5.2.1 Impacts to Fish

Cowx and Welcomme (1988) identified the following functions of freshwater aquatic vegetation for freshwater fish:

- Water purification, both direct (for example, by oxygenation and conversion of toxic ammonia to usable nitrates) and indirect (for example, by plants providing a large surface area for microbes to do the same tasks)
- Nutrient recycling, including nutrient removal during the growth season and return during senescence
- Physical link between water and air for many invertebrates, e.g., larvae and nymphs of caddis flies, mayflies, and chironomids, which are food for fish and have aquatic larval stages and aerial adults
- Refugia for zooplankton, which graze phytoplankton and keep water clear
- Cover for a large variety of invertebrates, many of which are food for fish
- Cover for fish, which varies as to value and type with the age and species of fish, as well as type of vegetation
- Spawning areas and sites of oviposition for many fish species
- Food web support and direct food sources for herbivorous and detritivorous fish
- Effects on flow patterns, i.e., accretion of sediments and deflection of flow, thus providing quiescent waters and faster shallows
- Creation of discrete habitat that is as functional as physical structure

In addition to these functions, aquatic vegetation has also been found to reduce predation rates by providing cover refuge for prey fish (Gregory and Levings 1996). Through this broad list of functions, it is apparent that reductions in freshwater aquatic vegetation resulting from bank protection structures can negatively impact the growth and survival of potentially covered species with freshwater distributions. In particular, the Olympic mudminnow may be most vulnerable because it requires areas with dense aquatic vegetation (Harris 1974) and has been shown to no longer occupy areas where vegetation was removed (Mongillo and Hallock 1999).

7.5.2.2 Impacts to Invertebrates

Fish prey invertebrates will be subject to the impacts that relate to alteration of freshwater vegetation as discussed above in Section 7.5.2.1. In addition, one potentially covered freshwater invertebrate species would be directly impacted by loss of habitat if freshwater aquatic vegetation were disturbed or removed; the larvae of the California floater mussel in Curlew Lake depend primarily on the Tui chub (*Gila bicolor*) as a host (Pacific Biodiversity Institute 2006), and juvenile Tui chub typically stay close to vegetation until they are longer than 0.5 inch (Wydoski and Whitney 2003).

7.6 Riparian Vegetation

Riparian zones are the upland areas adjacent to water bodies that form the transition zones between terrestrial and aquatic systems; riparian zones are an important component of freshwater, estuarine, and marine systems. Removal or disturbance of riparian vegetation during construction of bank protection projects can have several potential impacts to habitat and species in each of these systems, including:

- Reduced shading and altered temperature regime
- Reduced streambank and shoreline stability
- Altered allochthonous inputs
- Altered groundwater influence
- Altered habitat complexity and quality

These impacts, as they relate to bank protection structures, are discussed below.

7.6.1 Reduced Shading and Altered Temperature Regime

Removal of riparian vegetation as part of bank protection projects impacts water temperature in the riparian zone in various ways, including shading and trapping of air near the water surface. Riparian vegetation provides shade from solar radiation (Murphy and Meehan 1991). The influence of riparian vegetation on water temperature generally diminishes as the size of the stream increases, because of the proportionally reduced area in which riparian vegetation can insulate against solar radiation and trap air next to the water surface (Knutson and Naef 1997; Quinn 2005; Poole and Berman 2001; Murphy and Meehan 1991). Removal of riparian vegetation can result in higher water temperatures by allowing increased direct solar radiation to reach the water surface. Alternatively, riparian vegetation removal can also cause streams to lose heat more rapidly when air temperatures are colder because of the loss of the insulating properties that riparian vegetation can provide. Removal of trees can thus affect the water temperature in streams both by affecting local air temperatures and by increasing incident radiation and heat loss (Quinn 2005; Bolton and Shellberg 2001; Poole and Berman 2001; Knutson and Naef 1997; Murphy and Meehan 1991). In still-water systems, such as lakes or ponds, water temperatures generally change gradually through the year with the seasons, show less change from night to day, and are often stratified vertically.

In the marine environment, Rice (2006) documented elevated intertidal substrate temperatures at a bulkheaded Puget Sound beach with no overhanging riparian vegetation compared to an adjacent site with extensive riparian vegetation. Peak temperatures at the modified site averaged nearly 20 degrees F (11 degrees C) higher than at the unmodified site: 81 degrees F (27.3 degrees C) versus 61.7 degrees F (16.5 degrees C), respectively. These increases in substrate temperature coincided with lower relative humidity. This is a significant finding because temperatures and desiccation are major limiting factors for upper intertidal organisms (Brennan 2004; Brennan and Culverwell 2004). For example, Penttila (2001) reported much higher egg mortality rates among surf smelt, a potentially covered species, for eggs deposited on unshaded beaches compared to those sites with intact overhanging riparian vegetation. The author hypothesizes that the higher rate of mortality was due to increased egg desiccation when exposed to direct sunlight for longer periods at the sites without riparian vegetation to provide shade. The Rice (2006) study strongly supports this hypothesis.

7.6.2 Reduced Streambank/Shoreline Stability

The root structure of riparian vegetation naturally resists the shear stresses created by flowing water and thus retards bank cutting by streams, stabilizes streambanks and shorelines, maintains undercut banks along stream margins, and inhibits sediment from entering streams by dissipating the erosive energy of flood waters, wind, and rain (Knutson and Naef 1997; Levings and Jamieson 2001; Brennan and Culverwell 2004). If riparian vegetation is removed as part of bank protection projects, streambanks and shorelines are exposed to the erosive effects of wind, rain, and current and the input of fine sediments to the aquatic system is increased (Waters 1995).

7.6.3 Altered Allochthonous Input

Removal of freshwater riparian vegetation as part of bank protection projects would decrease the input of externally derived (allochthonous) materials to the nearby aquatic environment and food web. Riparian vegetation provides allochthonous inputs such as terrestrial macroinvertebrates, which supplement the diets of fishes, and detritus-like leaves and branches, which provide food sources for benthic macroinvertebrates (Knutson and Naef 1997; Murphy and Meehan 1991; Bilby and Bisson 1998; Cummins 1980). Additionally, riparian vegetation supplies LWD to the aquatic environment, which in streams influences channel morphology/habitat complexity, retains organic matter, and provides essential cover for fish (Quinn 2005; Naiman et al. 2002; Knutson and Naef 1997; Murphy and Meehan 1991). Without allochthonous inputs, the forage detritus available for benthic macroinvertebrates is compromised, also diminishing habitat and species diversity of these prey items (Murphy and Meehan 1991).

The importance of terrestrial contributions from marine riparian vegetation is a relatively new finding and is not as well documented as the linkages established for freshwater systems (Lemieux et al. 2004; Brennan and Culverwell 2004). Recent studies indicate that for those salmonids known to be most dependent upon shallow marine nearshore habitats (i.e., Chinook and chum salmon, coastal cutthroat trout), insects derived from the terrestrial environment comprise major portions of their diets (Wipfli 1997; Levings and Jamieson 2001; Brennan et al. 2004; Brennan and Culverwell 2004; Toft and Cordell 2006). Thus, the removal of marine riparian vegetation as part of bank protection projects would cause decreases in important terrestrial input of organic matter and nutrients (Spence et al. 1996; Maser and Sedell 1994; Williams et al. 2001; Brennan et al. 2004).

7.6.4 Altered Groundwater Influence

Alteration or removal of riparian vegetation would appreciably change the interface between plants, soil, and water on and near the bank surface. Riparian vegetation acts as a filter for groundwater, filtering out sediments and taking up nutrients (Knutson and Naef 1997). It also, in conjunction with upland vegetation, moderates stream flow by intercepting rainfall, contributing to water infiltration, and using water via evapotranspiration. Plant roots increase soil porosity, and vegetation helps to trap water flowing on the surface, thereby aiding in infiltration as the water stored in the soil is later released to streams through subsurface flows. Through these processes, riparian and upland vegetation help to moderate storm-related flows and reduce the magnitude of peak flows and the frequency of flooding. Riparian vegetation, the litter layer, and silty soils absorb and store water during wet periods and release it slowly over a period of months, maintaining stream flows during rainless periods (Knutson and Naef 1997).

Bank protection structures such as bulkheads may cause a physical barrier between the bank and hyporheic flow and prevent exchange between the bank and aquatic ecosystem. The interface between flow within the hyporheic zone and the stream channel is an important buffer for stream temperatures (Poole and Berman 2001), so alteration of groundwater flow can affect stream temperature. The magnitude of the influence depends on many factors, such as stream channel pattern and depth of the aquifer (Poole and Berman 2001).

7.6.5 Altered Habitat Complexity and Quality

Major reductions in habitat complexity and quality will occur when riparian vegetation is removed as part of bank protection projects, for both freshwater and marine habitats. A key mechanism by which riparian vegetation contributes significantly to habitat complexity in freshwater environments is by the input of woody debris. Thus, installation of shoreline armoring where there is concomitant removal of the riparian zone would significantly decrease current and potential wood sources to the water body.

Wood debris in fresh water (Naiman et al. 2002) controls channel morphology, regulates the storage and transport of sediment and particulate organic matter, and creates and maintains fish habitat (Murphy and Meehan 1991). Within streams, approximately 70 percent of structural diversity is derived from root wads, trees, and limbs that fall into the stream as a result of bank undercutting, mass slope movement, normal tree mortality, or windthrow (Knutson and Naef 1997). In small streams, LWD is a major factor influencing pool formation in plane-bed and step-pool channels. Bilby (1984, in Naiman et al. 2002) and Sedell et al. (1985, in Naiman et al. 2002) found that approximately 80 percent of the pools in several small streams in southwest Washington and Idaho are associated with wood. In larger streams, the position of LWD strongly influences the size and location of pools (Naiman et al. 2002). In larger streams, LWD is typically oriented downstream due to powerful streamflow, which favors formation of backwater pools along margins of the mainstem (Naiman et al. 2002).

In marine environments, driftwood and/or LWD contributes to build and maintain beach habitat structure. Documented LWD functions for beach stability include its contribution to roughness and sediment trapping (Gonor et al. 1988; Brennan and Culverwell 2004) and to inputs of organic matter, moisture, and nutrients that assist in the establishment and maintenance of dune and marsh plants (Williams and Thom 2001). Eilers (1975) found that piles of downed trees in the Nehalem salt marsh (Oregon) trapped enough sediment to support vegetation, wherein marsh islands that trapped sedge seeds provided an elevated substrate for less salt-tolerant vegetation. Herrera (2005) suggested that driftwood at the top of the beach may also slow littoral drift and erosion by reducing wave energy and wave reflection energy and by creating pockets where larger sediment will accumulate. It has been suggested that estuarine wood can affect water flow and subsequent formation of bars and mudbanks (Gonor et al. 1988). The beneficial habitat structure functions of LWD along marine shorelines may be maximized if trees that fall perpendicular to beaches typically remain in place, as in the case of a recent study that found local fallen trees tend to stay in place along Thurston County shorelines (Herrera 2005). The perpendicular alignment of LWD across the beach provides the LWD structure for the widest possible portion of the aquatic habitat, thus maximizing the potential area for sediment trapping and organic matter contributions.

Marine shorelines with bank protection armoring tend to have less LWD and driftwood than unarmored beaches (Higgins et al. 2005; Herrera 2005). MacDonald et al. (1994) also reported that shoreline armoring limited driftwood accumulation on a beach. Higgins et al. (2005) suggested that the mechanisms for the apparent reduction in LWD appear to be the removal of adjacent riparian vegetation during and following placement of the bank protection; reduced shoreline roughness at armored sites, which causes more LWD to be transported away; and limited upper intertidal and backshore areas that allow for LWD deposition above tidal elevations that are routinely inundated.

Because LWD is used in some marine soft-shore armoring instances to attenuate wave energy and lessen the potential for erosion, it is assumed that naturally occurring LWD on beaches would do the same, but this has not been empirically tested. Herrera (2005) describes how multiple layers of LWD along a shoreline could provide effective energy dissipation, decreasing the amount of wave reflection during high water levels, by increasing the roughness of the shoreline and by decreasing its slope relative to a vertical bulkhead.

7.6.6 Impacts to Fish

Impacts to fish as a result of the alteration or removal of the riparian zone can occur via changes to water temperature, predator/prey availability, and habitat structure. Because many potentially covered fish and aquatic invertebrate species require cool and well-oxygenated water, changes in water temperature and dissolved oxygen associated with the removal of riparian vegetation will have deleterious effects on fish and other aquatic organisms by various physical mechanisms, including the following (Knutson and Naef 1997):

- Inhibiting growth and altering metabolism
- Amplifying effects of toxic substances
- Increasing susceptibility to disease and pathogens
- Increasing potential risk of eutrophication through increased growth of bacteria and algae

A technical workgroup convened to develop water quality criteria for the USEPA developed useful guidelines for temperature thresholds leading to the onset of negative impacts for anadromous salmonids and bull trout (Table 6).

Table 6
Estimates of Thermal Conditions Known to Support Salmonids[1]

Consideration	Anadromous Salmon	Bull Trout
Temperature of common summer habitat use	50-63°F (10-17°C)	43-54°F (6-12°C)
Lethal temperatures (one-week exposure)	Adults: >70-72°F (>21-22°C) Juveniles: >73-75°F (>23-24°C)	Juveniles: >72-73°F (>22-23°C)
Adult migration	Blocked: >70-72°F (>21-22°C)	Cued: 50-55°F (10-13°C)
Swimming speed	Reduced: >68°F (>20°C) Optimal: 59-66°F (15-19°C)	
Gamete viability during holding	Reduced: >55-61°F (>13-16°C)	
Disease rates	Severe: >64-68°F (>18-20°C) Elevated: 57-63°F (14-17°C) Minimized: <54-55°F (<12-13°C)	
Spawning	Initiated: 45-57°F (7-14°C)	Initiated: <48°F (<9°C)
Egg incubation	Optimal: 43-50°F (6-10°C)	Optimal: 36-43°F (2-6°C)
Optimal growth	Unlimited food: 55-66°F (13-19°C) Limited food: 50-61°F (10-16°C)	Unlimited food: 54-61°F (12-16°C) Limited food: 46-54°F (8-12°C)
Smoltification	Suppressed: >52-59°F (>11-15°C)	

Source: Poole et al. 2001; original material presented in degrees Celsius.

[1] Estimates of thermal conditions known to support various life stages and biological functions of bull trout (a species extremely intolerant of warm water) and anadromous (ocean-reared) salmon. These numbers do not represent rigid thresholds, but rather represent temperatures above which adverse effects are more likely to occur. In the interest of simplicity, important differences between various species of anadromous salmon are not reflected in this table and requirements for other salmonids are not listed. Likewise, important differences in how temperatures are expressed are not included (e.g., instantaneous maximums, daily averages, etc.). These numbers are taken from the Physiology technical summary; that summary should be consulted for more detailed discussions and for references to scientific literature that supports these numbers.

The removal of riparian vegetation can increase the mortality rates of surf smelt eggs through desiccation (Penttila 2001). Surf smelt spawn in the upper intertidal zone and incubate for approximately two to four weeks before hatching. Sand lance, another potentially covered species that spawns in the upper intertidal zone, would presumably encounter similar impacts on egg survival when riparian vegetation is removed. These fish are often referred to as “forage fish” because they are preyed upon by a wide variety of fish, including salmonids, and birds. Another way increased water temperatures may impact potentially covered species is by allowing expanded distributions and/or increased activity of warm-water piscivorous fish that may be potential predators to potentially covered species.

The removal of marine and freshwater riparian vegetation also limits the future input of woody debris as a habitat structure element and can limit habitat complexity, foraging opportunities, and predator avoidance (Quinn 2005; Schmetterling et al. 2001; Spence et al. 1996). Juvenile salmonid abundance in rivers in winter, particularly juvenile coho salmon abundance, is positively correlated to abundance of LWD (Hicks et al. 1991). In lakes, estuaries, and marine waters, LWD provides cover and foraging opportunities for fish (Quinn 2005). Tabor et al. (2004, 2006) have documented the importance of small woody debris as habitat structure in Lake Washington, where it may provide important periodic refuge from predators for juvenile Chinook salmon.

The bank instability that can result from the removal of riparian vegetation associated with bank protection structures can impact fish by elevating suspended solids concentrations and increasing the volume of fine sediments deposited. The impacts of elevated suspended solids concentrations are described in Section 7.1.2.1. The impacts of the deposition of fine sediments are described in Section 7.3.3.1.

7.6.7 Impacts to Invertebrates

Fish prey invertebrates will be subject to the impacts that relate to alteration of riparian vegetation (e.g., Murphy and Meehan 1991). Several potentially covered invertebrate species would be impacted by the water conditions that could accompany riparian vegetation removal. In fresh water, the California floater and Western ridged mussels and the giant Columbia River limpet are all intolerant of low oxygen and high temperature conditions (WDNR 2006b) that can occur along shorelines lacking vegetation, although species profiles identified for this paper did not provide thresholds or ranges. In marine areas, Newcomb's littorine snail is found primarily in association with a narrow band of nearshore intertidal habitat that contains certain marsh plant species (Larsen et al. 1995); because detailed reproductive and habitat needs are not known, it might be conservatively assumed that Newcomb's littorine snail is subject to habitat loss or direct desiccation if riparian aquatic vegetation is impacted.

The bank instability that can result from the removal of riparian vegetation associated with bank protection structures can impact invertebrates by elevating suspended solids concentrations and increasing the volume of fine sediments deposited. The impacts of elevated suspended solids concentrations are described in Section 7.1.2.2. The impacts of the deposition of fine sediments are described in Section 7.3.3.2.

7.7 Water Quality

Bank protection structures and their installation can adversely impact water quality by altering shoreline and riparian conditions. These activities have the potential to impact species and habitat by altering the following components of water quality:

- Water temperature in freshwater environments
- Dissolved oxygen in freshwater environments
- pH
- Salinity

Suspended solids concentrations can also increase due to bank protection projects. The impacts of increased suspended solids related to construction activities are discussed in Section 7.1.

7.7.1 Water Temperature in Freshwater Environments

Much of the research identified pertaining to water quality effects on fish addresses salmonids. Reducing the riparian shade allows an increase of exposure to solar radiation that may lead to an increase of water temperature (Fischenich 2003). Correlated with increased water temperature are reduced levels of dissolved oxygen and potential for stressors on aquatic organisms, especially juvenile salmon (Ecology 2000). Guidelines of temperature thresholds leading to the onset of negative impacts for anadromous salmonids and bull trout are presented in Table 6.

7.7.2 Dissolved Oxygen in Freshwater Environments

Juvenile salmon are highly sensitive to reductions in dissolved oxygen concentrations (USFWS 1986) and so are probably among the more vulnerable potentially covered species with regard to dissolved oxygen impairments. Salmon generally require dissolved oxygen levels of greater than 5 mg/L for optimal survival and growth. It has been hypothesized that resuspension of large quantities of anoxic sediments, an effect more commonly associated with dredging activities than with the construction of bank protection structures, may reduce dissolved oxygen levels in surrounding water as a result of oxidation reactions (Nightingale and Simenstad 2001a). However, the likelihood of bank protection projects causing markedly decreased dissolved oxygen concentrations appears low and therefore the risk of incidental take associated with this impact mechanism appears to be low.

7.7.3 pH Impacts

Structures constructed in aquatic settings can adversely impact the pH of surrounding water via contact between water and uncured concrete (Ecology 1999). When uncured concrete comes in contact with water, some or all of it dissolves and increases the pH (high alkalinity) (DFO 2006). For example, when Portland cement, an active ingredient in concrete, contacts water it dissolves and produces a pH of up to 12 at 77 degrees F (25 degrees Celsius) (DFO 2006).

In Washington, the surface water quality standards require pH to be between 6.5 and 8.5 in fresh water and between 7.0 and 8.5 in marine water (WAC 173-201). Fish species tend to have very narrow ranges of pH preference, and levels outside of this range will impact their health. The effects of high pH on fish may include death; damage to outer surfaces such as gills, eyes, and skin; and an inability to dispose of metabolic wastes (DFO 2006). Little information was identified regarding pH requirements of the potentially covered species, although an investigation of landlocked sockeye salmon in Japan, brown trout (*Salmo trutta*), and Japanese char (*Salvelinus leucomaenis*) found that spawning activities and upstream migration were significantly inhibited in weakly acidic water of pH 5.8 to 6.4 (Ikuta et al. 2003). The authors further noted that landlocked sockeye salmon were the most sensitive of the three species. Researchers on Atlantic salmon (*Salmo salar*) report that smolts are the life stage most sensitive to low pH (Staurnes et al. 1995). Staurnes et al. (1995) reports that to be protective of Atlantic salmon, the Norwegian water quality criteria for pH during the smolting season (February 1 to July 1) is 6.5 compared to 6.2 during the balance of the year. An investigation of brook trout (*Salvelinus fontinalis*), a non-native char, exposure to extremely low pH revealed that survival time was directly related to fish size and inversely related to temperature (Robinson et al. 1976). The authors also concluded that the tolerance to low pH had a genetic component (i.e., some fish populations are more predisposed to tolerate low pH than others).

No studies of pH tolerance among the potentially covered invertebrate species were identified, but a study of pH tolerance in zebra mussels (*Dreissena polymorpha)* found that pH levels as low as 9.3 caused mortality between Days 17 and 31 of exposure (Bowman and Bailey 1998).

7.7.4 Salinity

Bank protection structures at the mouths of rivers and streams entering the marine environment can contribute to the alteration of a natural salinity gradient. This alteration could occur through the shortening of a river through the lower reaches in which tidal water extends into the river or stream. Dredging activities that may accompany bank protection measures can exacerbate this impact.

Salinity gradients are particularly important for anadromous species because of the physiological adjustment necessary to transition from fresh water to salt water and vice versa. An abbreviated salinity transition area can affect anadromous species' acclimation to the new environments, thus making them vulnerable to predation, and may alter foraging patterns. Juvenile salmonids entering the estuarine and marine environment undergo a significant physiological (osmoregulatory) transition, and an extended transition zone of increasing salinity can function as an area of physiological refuge as the body adapts. For example, the tendency for Chinook and chum salmon fry to occupy lower salinity habitats, such as marsh channels, or freshwater regions after arriving at the estuary is hypothesized to be in part due to a need to acclimate to saline water over an extended period of time (Aitken 1998; Fresh and Averill 2005). No information sources were identified to document the occurrence or magnitude of this potential impact related to bank protection structures; therefore, it should be considered theoretical.

7.7.5 Impacts to Fish and Invertebrates

Each of the water quality parameters discussed can significantly affect the distribution, health, and survival of potentially covered species. Salmon, trout and other cold-water fish, and many aquatic invertebrates require cool, clean, and well-oxygenated water. Bank protection structures or construction activities that impair these conditions may produce behaviors (e.g., avoidance of otherwise preferred location or increased feeding to meet increased metabolic demand) or physiological responses that reduce the organism's ability to survive and grow. The magnitude of the potential impacts will depend upon:

- The magnitude, duration, and frequency of the impact
- The vulnerability of the affected life-history stage
- The inability of the organism to avoid the impact through avoidance behavior
- The physiological, developmental, and behavioral impairments suffered by the organism
- Indirect mechanisms such as exposure to predation

With the exception of elevated suspended sediment concentrations (Section 7.1.2), alteration to the freshwater water temperature associated with the installation and presence of bank protection structures appears to be the most significant water quality alteration that may impact potentially covered species. Guidance temperature thresholds leading to the onset of negative impacts for anadromous salmonids and bull trout are presented in Table 6. No temperature thresholds for the potentially covered invertebrate species were identified.

8 CUMULATIVE IMPACTS

The cumulative impacts evaluated for the purposes of consultation under ESA are those effects of "future state or private activities, not involving Federal activities, that are reasonably certain to occur within the action area of the Federal action subject to consultation" (50 Code of Federal Regulations 402.02). The "reasonably certain" language regarding activities is too restrictive to meet this paper's objective of providing a general evaluation of cumulative effects of bank protection. Therefore, a broader interpretation of cumulative effects is considered here. For the purposes of this paper, the cumulative impacts considered are the incremental impacts of individual projects considered in the context of other past, present, and reasonably foreseeable future actions.

The cumulative impacts of bank protection structures are particularly important because:

1. The structures are often constructed to counteract or curtail natural habitat-forming processes.
2. The shorelines of Washington State's water bodies are often lined with numerous small parcels that individually may produce only minor impacts, but cumulatively may be significant.
3. As noted by Nightingale and Simenstad (2001b), the bathymetry of Washington's inland marine waters is that of a fjord surrounded by a narrow vegetated habitat, which essentially concentrates the zone of impact.

Assessing cumulative impacts falls into the category of "an emerging science." No sources were identified that established quantified thresholds. However, the literature search identified numerous planning efforts throughout the country where cumulative impacts are identified as a topic to be addressed.

Among the available information on the topic, literature reviews conducted by MacDonald et al. (1994), Canning and Shipman (1994), and Zelo et al. (2000) conclude that shoreline armoring does have cumulative effects and that while impacts of individual structures may not be substantial, the aggregate of several structures may be significant where littoral sediment supplies, transport, and beach substrate are altered. Reynolds (1983, in MacDonald et al. 1994) concludes that the cumulative effect of structural response to beach erosion is the escalation of engineered structures and the consequent loss of beach. Silvester (1977, in Gabriel and Terich

2005) found that the littoral energy applied to the sediment doubled in the presence of seawalls, which lead to increased scour downdrift. In this way, the cumulative effect of an incremental increase of seawalls would not necessarily be a linear addition of effects but could be interactive and synergistic.

The Council on Environmental Quality (CEQ 1997) presents a simple typology of cumulative impacts where cumulative effects arise from single or multiple actions and accumulate in an additive or interactive manner. This typology and bank protection examples are presented in Table 7.

Table 7
Types and Examples of Cumulative Impacts

Cumulative Impact Type (CEQ 1997)	Example
Type 1. Repeated "additive" (*or deletion*) effects from a single project	A single bulkhead disrupts sediment transport and after each storm event sediment is transported from the downdrift beach section without being replaced. The deletion of sediment accumulates incrementally over time.
Type 2. Stressors from a single source that interact with biota to have an "interactive" (nonlinear) net effect.	A single bulkhead disrupts sediment transport as illustrated above and reflects wave energy that scours sediment from the beachfront along the bulkhead. The beach becomes coarser due to scour and lack of sediment resupply. Intertidal habitat is altered and no longer available for the benthic fauna such as bivalves.
Type 3. Effects arising from multiple sources that affect environmental resources additively.	In addition to construction of a bulkhead, the riparian vegetation is removed. The bulkhead reduces the shore roughness and no longer retains LWD, and recruitment of LWD is lost due to clearing of the riparian vegetation. Shade provided by riparian vegetation is also lost, thereby increasing solar radiation and water temperature.
Type 4. Effects arising from multiple sources that affect environmental resources in an interactive (i.e., countervailing or synergistic) fashion.	Additional bulkheads are constructed due to concentration of wave energy from existing bulkhead or due to perceived threats increasing the length of protected shoreline. Effects accumulate in a linear manner to a threshold where habitat structure and composition are substantially changed, leading to an alteration of habitat processes and ultimately a shift in ecological function. This would be manifested in a reduction of habitat and loss of species richness.

This conceptual framework of cumulative impacts could be applied at a regional scale, where individual impacts could be quantified. However, due to the complexity of quantifying impacts and the lack of specific data, cumulative impacts are often assessed descriptively. In the absence of a quantitative analysis of cumulative impacts, the following sections qualitatively describe the cumulative impacts of each impact mechanism.

8.1 Construction Activities

Cumulative impacts associated with the construction activities of multiple projects could amplify the behavioral alterations or physical impacts that could occur as a result of individual projects. In speaking of cumulative noise impacts to marine mammals, Dr. Sylvia Earle, former chief scientist at NOAA, has stated that "each sound by itself is probably not a matter of much concern," but taken together, "the high level of [ocean] noise is bound to have a hard, sweeping impact on life in the sea" (Holing 1994, in Radle 2005). Applying this concept to the potentially covered species, the repeated occurrence of noise could prompt organisms to migrate away from an area. Conceivably, minor physical impacts associated with individual projects could become more severe if several projects in an area result in the same type of impact. Also, an organism or its habitat could be more vulnerable to physical damage due to the impacts of preceding activities.

Although natural turbidity-causing mechanisms may vary greatly in magnitude and duration, they are more likely to occur in an isolated fashion and affect different portions of the stream network at different times (Bash et al. 2001). This variation allows fish to use refuge areas that might otherwise be impacted by these events (Bash et al. 2001). Professional experience has shown that anthropogenic sediment disturbance is often different; such events are more likely to occur simultaneously in many scattered areas or in overlapping time frames across a watershed, causing secondary impacts and lingering effects with greater potential to affect larger portions of a stream network at any given time. In addition, anthropogenic disturbances may more frequently result in temporary barriers to fish movement, which could reduce the existence of or limit accessibility to refugia (Bash et al. 2001).

Cumulative impacts of channel dewatering will most likely be associated with fish removal/exclusion methods, disturbance of the streambed, and modification of invertebrate habitat and consequent changes in species diversity. Alteration of flow and increased turbidity are temporary and are therefore not likely to have cumulative impacts to aquatic species or habitat. Fish removal/exclusion will result in the capture and handling of fish, which can cause stress, harm, and mortality. Cumulatively, the impacts to fish populations resulting from multiple permitted activities within a watershed that require fish removal/exclusion could be measurable at the population scale depending on several factors, including watershed and population size. The threshold for watershed and population size and the number of activities that must occur within a particular watershed to have a measurable cumulative impact are not established in the literature.

Disturbance of the streambed associated with dewatering may result in temporary loss of habitat. The significance of the loss depends on the size of the watershed, whether the loss is permanent or temporary, the amount of habitat cumulatively lost, and the significance of the habitat lost to the population (i.e., spawning, rearing, or migration habitat). The cumulative impacts of repeated channel dewatering efforts could lead to changes to benthic macroinvertebrate populations or species diversity that may lead to subsequent changes to fish populations or habitat occupancy. Benthic macroinvertebrate populations generally recolonize disturbed areas quickly, but this recovery time may be extended when repeated disturbances occur (e.g., NMFS 2003).

8.2 Channel Processes and Morphology

The cumulative impacts of multiple bank protection projects on channel processes and morphology is a significant data gap. As mentioned above, the fact that bank protection projects typically work in direct opposition to natural channel processes results in the potential for significant cumulative impacts. As evidenced by the listing of several salmon populations as threatened or endangered under the ESA, significant habitat alterations, including bank protection, can cumulatively generate lasting impacts that have great implications for population viability.

8.3 Substrate Modifications

The cumulative impacts of each component of substrate modification can lead to a reduction in the quantity and quality of habitat for potentially covered species. As noted by Quinn (2005), the incremental loss of spawning and rearing habitat has contributed to the declines in salmonid populations. Substrate modifications associated with bank protection along marine shorelines have reduced the availability of suitable spawning habitat for surf smelt and sand lance. The cumulative impacts of these modifications are unknown; however, a crash in their populations could further impact salmonids and other piscivorous fish. Newcomb’s littorine snail is particularly vulnerable to cumulative impacts of substrate modifications given the species' small geographic range (Grays Harbor and Willapa Bay) and specific habitat preference (*Salicornia virginica* marshes).

8.4 Habitat Accessibility

The cumulative impacts of reduced habitat accessibility can have significant impacts on the distributions of potentially covered species. The cumulative loss of access to floodplain and off-channel habitats can significantly reduce availability of required refuge, rearing, and spawning habitats. Such cumulative habitat accessibility losses would impact all freshwater species, but especially salmonids, lampreys, and Olympic mudminnow. Among the potentially covered invertebrate species, Newcomb's littorine snail is a particularly vulnerable species. The cumulative impacts to habitat accessibility could significantly impact Newcomb's littorine snail given the species' small geographic range (Grays Harbor and Willapa Bay) and specific habitat preference (*Salicornia virginica* marshes).

8.5 Aquatic Vegetation

Aquatic vegetation is a fundamental structural component in marine, estuarine, and lake environments. Numerous species utilize the vegetation for cover, feeding, and spawning. The successive incremental losses of aquatic vegetation by multiple bank protection projects could impact the species distributions and productivity. While aquatic vegetation may be resilient in recolonizing disturbed areas if suitable conditions are provided, the potential isolation of vegetation patches through the impacts of multiple projects could lead to the disappearance of the patch. It has been documented that areas where eelgrass has been lost through direct disturbance or alteration of habitat conditions are sometimes colonized by other macroalgae species (Thom et al. 1994). This shift in aquatic vegetation would also be a shift in habitat structure, which could lead to a shift of fauna assemblages (Williams and Thom 2001). For example, Pacific herring would be vulnerable to alterations in the aquatic vegetation community such that eelgrass is not as widely distributed. Pacific herring deposit eggs on eelgrass blades and may encounter reduced egg survival if other macroalgae species replace eelgrass.

8.6 Riparian Vegetation

Although there have been numerous evaluations on the effects of large-scale removal of riparian habitat to aquatic habitats, few studies reviewed for this white paper specifically addressed cumulative impacts from the localized removal of riparian and shoreline vegetation as part of bank protection projects. It is expected that permitting multiple activities within a watershed can have cumulative impacts to riparian vegetation, including increased likelihood that the impacts will be measurable and thus more likely to have an adverse impact to aquatic species and habitat.

8.7 Water Quality

The cumulative impacts of bank protection projects on water quality appear to have more potential for significant impacts than the generally short-term impacts that may result from an individual project. When combined with the impacts of land uses, it is conceivable that species tolerances could be exceeded for temperature and dissolved oxygen, which would lead to mortality or displacement (avoidance).

9 POTENTIAL RISK OF TAKE

Table 8 summarizes whether potentially covered species may be exposed to incidental take resulting from the impact pathways discussed earlier. Table 8 characterizes risk of take as Y (yes; potential for take), N (no potential for take), or U (unknown potential for take). These determinations are based on general consideration of the species distribution (only in terms of fresh water versus marine), habitat use (e.g., movements into immediate shoreline areas during some life stage), habitat requirements (e.g., substrate preferences), prey resources (specifically related to habitat elements promoting their production), and water quality. The magnitude of the risk is highly dependent on how the impact is expressed. For species for which there is no potential for take, no additional conservation measures would be required apart from those currently employed. For species for which the potential for take is unknown, a lack of information on species life history or other data gaps identified in Section 10 preclude reaching a conclusion.

Table 8
Summary of Potential for Incidental Take of Potentially Covered Species

Common Name	Scientific Name	Impact Mechanisms of Bank Protection Projects							Comments
		Construction Activities	Channel Processes	Substrate Modifications	Habitat Accessibility	Aquatic Vegetation	Riparian Vegetation	Water Quality	
Green sturgeon	*Acipenser medirostris*	Y	Y	Y	N	N	N	Y	Most vulnerable to projects that limit availability of deep pools and lead to scour of substrate holding incubating eggs
White sturgeon	*Acipenser transmontanus*	Y	Y	Y	N	N	Y	Y	Most vulnerable to projects that limit availability of deep pools
Newcomb's littorine snail	*Algamorda subrotundata*	Y	N	Y	Y	N	Y	Y	Particularly vulnerable to projects that reduce *Salicornia virginica* habitat in Grays Harbor and Willapa Bay
Pacific sand lance	*Ammodytes hexapterus*	Y	N	Y	Y	N	Y	Y	Particularly vulnerable to marine projects that encroach intertidal zone or lead to reduction in availability of sand in upper intertidal
California floater mussel	*Anodonta californiensis*	Y	Y	Y	Y	U	U	Y	Particularly vulnerable to burial, substrate modifications, and water quality impairment
Mountain sucker	*Catostomus platyrhynchus*	Y	Y	U	Y	U	Y	Y	Most vulnerable to projects that reduce the availability/accessibility of side channel or backwater habitats
Pacific herring	*Clupea harengus pallasi*	Y	N	Y	Y	Y	Y	Y	Particularly vulnerable to projects that reduce availability of marine aquatic vegetation, especially eelgrass
Margined sculpin	*Cottus marginatus*	Y	Y	Y	Y	Y	Y	Y	Particularly vulnerable to projects that impair water quality or reduce availability of sand and gravel substrate
Lake chub	*Couesius plumbeus*	Y	Y	U	Y	Y	Y	Y	Particularly vulnerable to projects that impair water quality, reduce availability of gravel substrate, or reduce availability of terrestrial insects

Common Name	Scientific Name	Impact Mechanisms of Bank Protection Projects							Comments
		Construction Activities	Channel Processes	Substrate Modifications	Habitat Accessibility	Aquatic Vegetation	Riparian Vegetation	Water Quality	
Giant Columbia River limpet	*Fisherola nuttalli*	Y	Y	Y	N	U	U	Y	Particularly vulnerable to burial, substrate modifications, water quality impairment, and high flows
Great Columbia River spire snail	*Fluminicola columbiana*	Y	Y	Y	N	U	U	Y	Particularly vulnerable to burial, substrate modifications, and water quality impairment
Pacific cod	*Gadus macrocephalus*	Y	N	Y	N	Y	N	Y	Most vulnerable to projects affecting lower intertidal zone and availability of sand habitats for juveniles
Western ridged mussel	*Gonidea angulata*	Y	Y	Y	Y	Y	Y	Y	Particularly vulnerable to burial, substrate modifications, and water quality impairment; also vulnerable if larva distribution on fishes is limited by habitat accessibility conditions
Northern abalone	*Haliotis kamtschatkana*	Y	N	N	N	Y	N	Y	Particularly vulnerable to burial, substrate modifications, and projects that reduce the availability of marine aquatic vegetation, especially kelp beds
Surf smelt	*Hypomesus pretiosus*	Y	N	Y	Y	N	Y	Y	Particularly vulnerable to marine projects that encroach intertidal zone or lead to reduction in availability of sand and gravel in upper intertidal
River lamprey	*Lampetra ayresi*	Y	Y	Y	Y	N	N	Y	Particularly vulnerable to projects that impair water quality or reduce the availability/accessibility of backwater habitats and other areas with mud/silt accumulations
Western brook lamprey	*Lampetra richardsoni*	Y	Y	Y	Y	N	N	Y	Particularly vulnerable to projects that impair water quality or reduce the availability/accessibility of backwater habitats and other areas with mud/silt accumulations

Common Name	Scientific Name	Impact Mechanisms of Bank Protection Projects							Comments
		Construction Activities	Channel Processes	Substrate Modifications	Habitat Accessibility	Aquatic Vegetation	Riparian Vegetation	Water Quality	
Pacific lamprey	*Lampetra tridentata*	Y	Y	Y	Y	N	N	Y	Particularly vulnerable to projects that impair water quality or reduce the availability/accessibility of backwater habitats and other areas with mud/silt accumulations; species is often concentrated in extremely high numbers, therefore short-term lethal conditions (e.g., chemical spills or extremely high suspended solids) can affect large portion of population
Pacific hake	*Merluccius productus*	Y	N	Y	N	Y	N	Y	Most vulnerable to projects affecting lower intertidal zone and availability of sand habitats for juveniles
Olympic mudminnow	*Novumbra hubbsi*	Y	Y	Y	Y	Y	Y	Y	Particularly vulnerable to projects that impair water quality or reduce the availability/accessibility of quiet water habitats, such as bogs or swamps, with mud and dense aquatic vegetation
Coastal cutthroat trout	*Oncorhynchus clarki clarki*	Y	Y	Y	Y	Y	Y	Y	Potential vulnerability via all impact mechanisms
Westslope cutthroat trout	*Oncorhynchus clarki lewisi*	Y	Y	Y	Y	Y	Y	Y	Potential vulnerability via all impact mechanisms
Pink salmon	*Oncorhynchus gorbuscha*	Y	Y	Y	Y	Y	Y	Y	Potential vulnerability via all impact mechanisms
Chum salmon	*Oncorhynchus keta*	Y	Y	Y	Y	Y	Y	Y	Potential vulnerability via all impact mechanisms
Coho salmon	*Oncorhynchus kisutch*	Y	Y	Y	Y	Y	Y	Y	Potential vulnerability via all impact mechanisms
Redband trout	*Oncorhynchus mykiss gairdneri*	Y	Y	Y	Y	Y	Y	Y	Potential vulnerability via all impact mechanisms
Steelhead	*Oncorhynchus mykiss*	Y	Y	Y	Y	Y	Y	Y	Potential vulnerability via all impact mechanisms

Common Name	Scientific Name	Impact Mechanisms of Bank Protection Projects							Comments
		Construction Activities	Channel Processes	Substrate Modifications	Habitat Accessibility	Aquatic Vegetation	Riparian Vegetation	Water Quality	
Sockeye salmon	*Oncorhynchus nerka*	Y	Y	Y	Y	Y	Y	Y	Potential vulnerability via all impact mechanisms
Chinook salmon	*Oncorhynchus tschawytscha*	Y	Y	Y	Y	Y	Y	Y	Potential vulnerability via all impact mechanisms
Lingcod	*Ophiodon elongatus*	Y	N	Y	N	Y	N	Y	Most vulnerable to projects affecting lower intertidal zone and availability of sand habitats for juveniles
Olympia oyster	*Ostrea lurida*	Y	N	Y	Y	N	Y	Y	Particularly vulnerable to burial, substrate modifications, and water quality impairment
Pygmy whitefish	*Prosopium coulteri*	Y	Y	U	Y	U	U	Y	Most vulnerable to projects that impair water quality or reduce the availability/accessibility of shallow water and tributary streams
Leopard dace	*Rhinichthys falcatus*	Y	Y	U	Y	Y	Y	Y	Most vulnerable to projects that reduce the availability/accessibility of slow-moving shallow water, decrease habitat structure used for refuge, or reduce prey availability
Umatilla dace	*Rhinichthys umatilla*	Y	Y	U	Y	U	U	Y	Most vulnerable to projects that impair water quality; lack of information on food habits precludes evaluation of impacts to prey availability
Bull trout	*Salvelinus confluentus*	Y	Y	Y	Y	Y	Y	Y	Potential vulnerability via all impact mechanisms
Dolly Varden	*Salvelinus malma*	Y	Y	Y	Y	Y	Y	Y	Potential vulnerability via all impact mechanisms
Brown rockfish	*Sebastes auriculatus*	Y	N	Y	N	Y	N	Y	Marine species not closely associated with immediate vicinity of bank protection projects
Copper rockfish	*Sebastes caurinus*	Y	N	Y	N	Y	N	Y	Marine species not closely associated with immediate vicinity of bank protection projects
Greenstriped rockfish	*Sebastes elongates*	Y	N	Y	N	Y	N	Y	Marine species not closely associated with immediate vicinity of bank protection projects
Widow rockfish	*Sebastes entomelas*	Y	N	Y	N	Y	N	Y	Marine species not closely associated with immediate vicinity of bank protection projects

Common Name	Scientific Name	Impact Mechanisms of Bank Protection Projects							Comments
		Construction Activities	Channel Processes	Substrate Modifications	Habitat Accessibility	Aquatic Vegetation	Riparian Vegetation	Water Quality	
Yellowtail rockfish	*Sebastes flavidus*	Y	N	Y	N	Y	N	Y	Marine species not closely associated with immediate vicinity of bank protection projects
Quillback rockfish	*Sebastes maliger*	Y	N	Y	N	Y	N	Y	Marine species not closely associated with immediate vicinity of bank protection projects
Black rockfish	*Sebastes melanops*	Y	N	Y	N	Y	N	Y	Marine species not closely associated with immediate vicinity of bank protection projects
China rockfish	*Sebastes nebulosus*	Y	N	Y	N	Y	N	Y	Marine species not closely associated with immediate vicinity of bank protection projects
Tiger rockfish	*Sebastes nigrocinctus*	Y	N	Y	N	Y	N	Y	Marine species not closely associated with immediate vicinity of bank protection projects
Bocaccio rockfish	*Sebastes paucispinis*	Y	N	Y	N	Y	N	Y	Marine species not closely associated with immediate vicinity of bank protection projects
Canary rockfish	*Sebastes pinniger*	Y	N	Y	N	Y	N	Y	Marine species not closely associated with immediate vicinity of bank protection projects, but often associated with kelp beds
Redstripe rockfish	*Sebastes proriger*	Y	N	Y	N	Y	N	Y	Marine species not closely associated with immediate vicinity of bank protection projects
Yelloweye rockfish	*Sebastes ruberrimus*	Y	N	Y	N	Y	N	Y	Marine species not closely associated with immediate vicinity of bank protection projects
Longfin smelt	*Spirinchus thaleichthys*	Y	Y	U	Y	N	N	Y	Most vulnerable to projects that impair water quality and access to streams
Eulachon	*Thaleichthys pacificus*	Y	Y	Y	Y	N	Y	Y	Most vulnerable to projects that impair water quality and availability of sandy habitats in marine, estuarine, and lower rivers
Walleye pollock	*Theragra chalcogramma*	Y	N	Y	N	Y	N	Y	Marine species not closely associated with immediate vicinity of bank protection projects

When evaluating risk of take for habitat-modifying projects, including bank protection projects, the federal agencies generally do not attempt to quantify the number of fish injured or killed because the relationship between habitat conditions and the distribution and abundance of those individuals in the action area cannot accurately be determined. Instead, the federal agencies tend to quantify the extent of anticipated take by measure of the amount of impacted habitat (e.g., length of streambank modified or area below the OHWL modified). In this way, every project had some level of take that was quantified only in terms of the physical size of the project. No explicit take thresholds (such as shoreline length) were identified during a review of bank protection-related biological opinions prepared by NOAA Fisheries and USFWS in recent years. However, it can be interpreted that by characterizing a project's incidental take based on project size, the federal agencies deem bank protection projects of any size as having some level of take. This approach provides the federal agencies with assurances that consultation with them will be re-initiated if a project is anticipated to expand in size and that such expansion cannot occur without additional consultation.

For the purposes of evaluating the risk of take, the potential impacts were divided into two categories: those associated with the installation of the bank protection structures and those associated with the existence of the structure once it is in place. Potential impacts associated with the construction of the bank protection structure are generally short term, e.g., elevated suspended solids and noise, although longer-term impacts can occur, e.g., lack of shade due to riparian vegetation removal. Many of the potential construction-related impacts can be avoided or minimized using BMPs or other conservation measures, such as those described in the WACs and RCWs pertinent to bank protection structures and those described in Section 11. The potential risk of take associated with construction activities will therefore be highly dependent upon the measures taken to avoid or minimize impacts. Little information is available on potential thresholds based on the available literature presented in Section 7, which almost exclusively focused on impacts to salmonids.

The presence of bank protection structures can generate lasting impacts that may have greater implications for species take, distribution, and population viability than any short-term construction-related impacts. These long-term impacts can vary greatly over time and are therefore less predictable and quantifiable. Bank protection projects for which the primary purpose and function is to prevent the habitat-forming and sustaining processes of water bodies, e.g., those projects focused on flood control and the protection of uplands, will generally have the most significant long-term impacts on the habitat and therefore the highest risk of take. However, project-specific details such as size, location (both in terms of species distributions and position/function within a reach), and technique all contribute significantly to the risk of take associated with a bank protection structure.

A project's size and location certainly dictate the potential for and magnitude of take. As described above, NOAA Fisheries and USFWS generally characterize a project's incidental take as the length or area of habitat impacted. In many cases, an evaluation of project-specific impacts may conclude there are only small, incremental levels of take; however, bank protection projects have the potential to generate significant risks of take when the cumulative impacts of multiple projects are considered. That is, many of the potential impacts associated with bank protection may be more evident in an evaluation of cumulative impacts than in a project-specific evaluation. For example, in rivers, bank protection structures generally limit or eliminate channel-forming and channel-sustaining processes along a finite portion of a water body and therefore incrementally diminish the water body's ability to naturally function.

Neither a technique for evaluating the cumulative effects nor the outcome of such an evaluation was identified. The literature review conducted for this paper also did not identify information sources that would support a recommended threshold for the amount of shoreline with bank protection structures beyond which the degree of water body impairment becomes significant. The reasons for the lack of a threshold may include a lack of data as well as the existence of water body-specific conditions that would limit the applicability of a threshold to other systems. If such a technique were to be developed, then among the most significant water body-specific conditions that should be considered are spatial distribution of bank protection structures, spatial distribution of gravel sources, spatial distribution and width of floodplain, gradient, and flow.

In terms of the risk of take associated with different types of bank protection techniques, bank protection projects that incorporate natural features and/or allow for partial function of channel-forming and channel-maintaining processes would have a lower risk of take than techniques that stop the functions. In this way, soft armoring techniques have a lower risk of take than hard armoring techniques. In situations where some hard armoring techniques are necessary to adequately protect a bank, then integrated techniques that incorporate hard and soft elements would produce an intermediate risk of take.

Activities that occur subsequently on land protected by bank protection structures can also contribute to the long-term risk of take. Bank protection structures can provide landowners with a false sense of safety, particularly regarding large floods and bluff erosion. As a result, upland structures are built closer to the shoreline or bluff than would occur otherwise and may be imperiled in the long term or may allow the landowner to aggressively maintain structures that significantly impact habitat for potentially covered species.

Although the focus of this paper is on the detrimental impact mechanisms of bank protection structures in order to evaluate the risk of take, it is necessary to point out that bank protection projects can have beneficial impacts, and many bank protection projects are indeed designed as habitat restoration projects. For example, a bank protection project that addresses mass wasting and fine sediment contributions can be beneficial to habitats and species if properly designed. A distinguishing feature of beneficial bank protection projects is a project design that works with natural processes and that incorporates large wood to add habitat complexity to a reach. In river, stream, and estuarine environments, bank protection projects that allow continuation of full or partial function of the natural processes associated with floodplain connectivity, side channel formation, and sediment (gravel) source additions can provide beneficial outcomes. In marine and lake environments, bank protection structures that allow continuation of full or partial function of the natural littoral drift processes, including the sediment source entrainment and sediment transport, can provide beneficial outcomes. The placement of large wood in the channel (either random or designed) can add habitat complexity by creating habitats in areas where the natural processes, including LWD recruitment, have been altered. In fact, properly designed bank protection projects can re-establish natural processes, e.g., wood recruitment in pool-forming structures or littoral drift along marine shorelines. Along this same line of discussion, it should be noted that where bank protection projects are often needed is in highly modified (e.g., flow altered, channelized, armored, denuded) rivers and streams where, because of substantial capital improvements and infrastructure, it is unrealistic to expect that truly "natural river erosion/deposition processes" will be restored. In these rivers and streams, properly designed bank protection projects may provide some of the better fish habitat opportunities in the reach.

In order to work with natural processes and design an effective bank protection project that incorporates beneficial habitat elements, an understanding of the conditions and processes throughout a larger reach of the water body is necessary. The *Integrated Streambank Protection Guidelines* (Cramer et al. 2003) provides a reach level assessment technique for understanding the natural habitat-forming processes of an area. The *Stream Habitat Restoration Guidelines* (Saldi-Caromile et al. 2004) describes approaches for assessing and designing bank protection projects for habitat restoration in river and stream settings. There is no guideline counterpart for working along marine or lake shorelines, although the recently completed *Alternative Shoreline Stabilization Evaluation Project* (Gerstel and Brown 2006) and *Alternative Bank Protection Methods for Puget Sound Shorelines* (Zelo et al. 2000) describe bank protection techniques other than vertical bulkheads or riprap that have been implemented with the purposes of providing bank protection and minimizing the interruption of natural littoral drift processes.

It is important to note that a long-term perspective is necessary when considering the potential impacts of a bank protection project, and potential short-term benefits of a bank protection project may not outweigh its long-term impacts. In this regard, the location of the stream channel and bank protection project with respect to the floodplain is an important determining factor of potential impacts. If the bank protection is located on the stream channel at the outer limits of the 100- or 500-year floodplain, the potential impacts are much different (generally much less) than if the same project were implemented on property located in the middle of a 1-mile-wide floodplain.

9.1 Evaluation of Risk of Take Under Existing Rules and Statutes

The existing WAC rules and RCW statutes contribute to reduce the risk of take associated with bank protection structures. Table 9 describes the existing rules and statutes pertaining to the reduction of impact of each mechanism and evaluates the effectiveness of the provisions in minimizing the risk or severity of take. The rules and statutes presented in Table 9 are not verbatim. In order to maintain the terminology of the WACs, the term saltwater is used in Table 9 to refer to marine and estuarine habitats.

Table 9
Evaluation of Existing WAC and RCW Provisions and Risk of Take

Impact Mechanism Generating Risk of Take	Existing WACs and RCWs Related to Impact Mechanism	Evaluation of Existing WACs Effectiveness In Reducing Risk of Take
Construction-Related Activities: General	All Environments *No provisions* Freshwater HPAs may also be subject to additional special provisions to address project- or site-specific considerations not adequately addressed by the technical provisions (WAC 220-110-032) Saltwater • Construction timing limitations may be applied to residential bulkheads for the protection of critical habitats in the marine environment (Chapter 77.55.141 (2d) RCW) • Work waterward of OHWL is prohibited during specific times of the year (WAC 220-110-271) if the department determines that the project may affect critical food fish or shellfish habitat (WAC 220-110-285) • If the surf smelt spawning season for the project location is six months or longer, work may be permitted if it commences within forty-eight hours after the location is inspected by a department representative or biologist acceptable to the department and it is determined that no spawning is occurring or has recently occurred. The project may be further conditioned to require completion within a particular time (WAC 220-110-271 and WAC 220-110-285) • If a fish kill occurs or fish are observed in distress, the project activity shall immediately cease and WDFW shall be notified immediately (WAC 220-110-270) • The use of equipment on the beach area shall be held to a minimum and confined to specific access and work corridors (WAC 220-110-270) • Project activities within the beach area shall not occur when the project area, including the work corridor, is inundated by tidal waters (WAC 220-110-280 and WAC 220-110-285) • On non-single family residence property, replacement or repair of an existing structure shall utilize the least impacting method of construction (WAC 220-110-280) • On single-family residence property, if the bulkhead is to be constructed of rock, then work shall be limited to daylight hours in a twenty-five-foot wide corridor immediately waterward of the new bulkhead face (excluding the area occupied by a grounded barge) and construction work shall not occur if tidal waters are within thirty feet of the new bulkhead face or within the stockpile area, whichever is greater. The department may permit rock to be stockpiled within fifty feet of the new bulkhead face (WAC 220-110-285) • On single-family residence property, if the bulkhead is to be constructed of material other than rock, work shall be limited to daylight hours in a fifteen-foot-wide corridor immediately waterward of the new bulkhead face (excluding the area occupied by a grounded barge) and construction work shall not occur if tidal waters are within twenty feet of the new bulkhead face (WAC 220-110-285)	No specific WACs apply to limiting the potential for take associated with construction-related activities in fresh water, although WAC 220-110-032 authorizes the use of "special provisions to address project or site-specific considerations not adequately addressed by the technical provisions." Such special provisions usually include timing restrictions. To ensure minimization of the potential risk of take, freshwater construction timing restrictions that consider all potentially covered species should be developed and included specifically in the WACs. Similarly, saltwater construction timing restrictions will need to be expanded to consider all potentially covered species in order to minimize the potential for take.
Construction-Related Activities: Noise	*No provisions*	The WACs do not establish construction requirements to minimize the risk of take associated with noise in freshwater or saltwater environments, although generated noise impacts can range from a brief startle response to mortality.
Construction-Related Activities: Suspended Solids	All Environments *No provisions* Freshwater • Bank sloping shall be accomplished in a manner that avoids release of overburden material into the water (WAC 220-110-050) • Alteration or disturbance of riparian vegetation will be minimized and replanted with native vegetation within one year and maintained for three years (WAC 220-110-050) • Excavated material shall not be stockpiled waterward of the OHWL (WAC 220-110-223) Saltwater	The WACs associated with freshwater construction activities do not address as wide a range of project elements that can minimize increases to suspended solids concentrations compared to the WACs pertaining to saltwater construction activities. On this basis, freshwater construction activities have the higher potential for take based on construction activities elevating suspended solids concentrations in the water.

Impact Mechanism Generating Risk of Take	Existing WACs and RCWs Related to Impact Mechanism	Evaluation of Existing WACs Effectiveness In Reducing Risk of Take
	• Project activities shall be conducted to minimize siltation of the beach area and bed (WAC 220-110-270) • Project activities within the beach area shall not occur when the project area, including the work corridor, is inundated by tidal waters (WAC 220-110-280 and WAC 220-110-285) • Excavated materials containing silt, clay, or fine-grained soil shall not be stockpiled below the OHWL (WAC 220-110-280 and WAC 220-110-285) • If sand, gravel and other coarse material is to be temporarily placed where it will come into contact with tidal waters, this material shall be covered with filter fabric and adequately secured to prevent erosion and/or potential entrainment of fish (WAC 220-110-280 and WAC 220-110-285)	
Construction-Related Activities: Channel Dewatering	All Environments *No provisions* Freshwater • [• Bypass channel will be large enough to pass flows and debris throughout duration of project (WAC 220-110-120) • Prior to returning water to the project area, all bank protection armoring materials will be in place (WAC 220-110-120) • • Fish removal required if fish “may be adversely impacted” (WAC 220-110-120) • Saltwater *No provisions*	The WACs pertaining to freshwater reduce the potential for take by requiring fish removal from the project area if fish “may be adversely impacted.” Additional reduction in the risk could be realized by providing more specificity to the language regarding when and how fish removal must occur.
Construction-Related Activities: Chemical Contamination	All Environments *No provisions* Freshwater • All materials treated with preservative must be sufficiently cured. Creosote and pentachlorophenol cannot be used in lakes (WAC 220-110-223) Saltwater • No debris or deleterious material shall be disposed of or abandoned waterward of the OHWL except at an approved in-water site (WAC 220-110-270) • All debris or deleterious material resulting from construction shall be removed from the beach area or bed and prevented from entering the water (WAC 220-110-270) • No petroleum products or other deleterious materials shall enter the water (WAC 220-110-270)	The WACs pertaining to fresh water do not address the potential for chemical releases due to spills, although WAC 220-110-032 authorizes the use of “special provisions to address project or site-specific considerations not adequately addressed by the technical provisions.” Such special provisions usually include measures to reduce potential chemical contamination and could therefore reduce the risk of take.
Channel Processes: General	All Environments • Bank protection projects shall incorporate mitigation measures as necessary to achieve no-net-loss of productive capacity of fish and shellfish habitat (WAC 220-110-050, WAC 220-110-223, WAC 220-110-280, and WAC 220-110-285) Freshwater • Bio-engineering is the preferred method of bank protection where practicable (WAC 220-110-050 and WAC 220-110-223) • Bank protection work shall be restricted to work necessary to protect eroding banks (WAC 220-110-050) Saltwater • On non-single family residence property, replacement or repair of an existing, functioning structure shall utilize the least impacting type of structure and minimize further waterward encroachment (WAC 220-110-280)	WACs pertaining generally to channel processes are broad and may not provide enough specificity to minimize the risk of take. For example, the provision that bank protection work shall be restricted to work necessary to protect eroding banks does not indicate a method or expectation for evaluating what portion of a project is “necessary.”
Channel Processes: Altered Channel Morphology	All Environments *No provisions*	WACs focus on avoiding or minimizing the bank protection structure’s encroachment below the OHWL, which is important for minimizing risk of take.

Impact Mechanism Generating Risk of Take	Existing WACs and RCWs Related to Impact Mechanism	Evaluation of Existing WACs Effectiveness In Reducing Risk of Take
	Freshwater • The toe of the bulkhead shall be placed landward of the OHWL (WAC 220-110-223) • Bank protection material placement waterward of the OHWL shall be restricted to the minimum amount necessary to protect the toe of the bank, or for installation of mitigation features approved by the department (WAC 220-110-050) • Fish habitat components may be required as mitigation (WAC 220-110-050) Saltwater • The extent to which the waterward face of new marine bulkheads or rockwalls encroaches the intertidal zone will be minimized to extend only as far as necessary to protect the structure's footing or base and will not extend more than six feet waterward of the OHWL (Chapter 77.55.141 (2a) RCW) • Repairs or replacement of existing marine bulkheads or rockwalls will be placed in the same alignment as the structure it is replacing unless for the purposes of structural stability it is necessary to keep the existing structure in place and construct the replacement structure immediately waterward (Chapter 77.55.141 (2b) RCW and WAC 220-110-285) • For single-family residence bulkheads, the waterward face of a new bulkhead shall be located at or above the OHWL. Where this is not practicable due to geological, engineering, or safety concerns, the waterward face of the new bulkhead shall be located only as far waterward of the OHWL as necessary to excavate for footings or place base rock for the structure and under no conditions shall the waterward face of the bulkhead be located more than six feet waterward of the OHWL. In addition, the waterward face of any bulkhead shall be located as close to the toe of the bank as possible (WAC 220-110-285) • For non-single family residence property bulkhead and bank protection projects, the waterward face of a new structure shall be constructed according to an approved design, utilizing the least impacting type of structure and shall minimize encroachment waterward of the OHWL to protect juvenile salmonid migration corridors and other habitats of special concern (WAC 220-110-280) • All natural habitat features on the beach larger than twelve inches in diameter including trees, stumps and logs, and large rocks shall be retained on the beach following construction (WAC 220-110-280 and WAC 220-110-285)	
Channel Processes: Disconnected Floodplain and Side Channels	*No provisions*	WACs do not include provisions that would minimize risk of take associated with disconnecting floodplain and/or side channel habitat.
Channel Processes: Disrupted Hyporheic Flow	*No provisions*	WACs do not include provisions that would minimize risk of take associated with disrupting hyporheic flow.
Substrate Modifications: General	All Environments • Bank protection projects shall incorporate mitigation measures as necessary to achieve no-net-loss of productive capacity of fish and shellfish habitat (WAC 220-110-050, WAC 220-110-223, WAC 220-110-280, and WAC 220-110-285) Freshwater HPAs may also be subject to additional special provisions to address project- or site-specific considerations not adequately addressed by the technical provisions (WAC 220-110-032) Saltwater *No provisions*	No specific WACs apply to limiting the potential for take associated with the impacts of sediment deposition in fresh water, although WAC 220-110-032 authorizes the use of "special provisions to address project or site-specific considerations not adequately addressed by the technical provisions." Such special provisions usually include measures to reduce sediment deposition impacts. The only WAC provision pertaining generally to substrate modifications is broad and while providing WDFW with a lot of latitude, may not provide enough specificity to minimize the risk of take.
Substrate Modifications: Addition of Non-erodible Substrate	All Environments *No provisions* Freshwater • When rock or other hard materials are approved for bank protection, bank protection material shall be angular rock. The project shall be designed and the rock installed to withstand 100-year peak flows. River gravels shall not be used as exterior armor, except as specifically approved by the department (WAC 220-110-050) • When rock or other hard materials are approved for bank protection, bank protection and filter blanket material shall be placed from the bank or a barge. Dumping onto the	WAC provisions focus on minimizing footprint of large substrate placement and keeping the material in place so it does not scatter over time. In this way, the WACs reduce the risk of take associated with large substrate replacing natural-sized substrates.

Impact Mechanism Generating Risk of Take	Existing WACs and RCWs Related to Impact Mechanism	Evaluation of Existing WACs Effectiveness In Reducing Risk of Take
	bank face shall be permitted only if the toe is established and the material can be confined to the bank face (WAC 220-110-050) • For freshwater bulkheads, rock used for the bulkhead construction shall be composed of clean, angular material of a sufficient size to prevent its being washed away by high water or wave action (WAC 220-110-223) Saltwater • Placement of appropriately sized gravel on the beach area shall be required following construction of bulkheads or other bank protection in identified surf smelt spawning areas (WAC 220-110-280 and WAC 220-110-285)	
Substrate Modifications: Increased Scour of Substrate	All Environments Freshwater • Fish habitat components such as logs, stumps, and/or large boulders may be required as part of the bank protection project to mitigate project impacts. These fish habitat components shall be installed according to an approved design to withstand 100-year peak flows (WAC 220-110-050) Saltwater *No provisions*	The only WAC provision pertaining to scour would contribute to reduce the risk of take associated with scour in freshwater environments. There is no comparable provision for saltwater environments.
Substrate Modifications: Increased Deposition of Substrate	All Environments *No provisions* Freshwater *No provisions* Saltwater • For marine and estuarine bank protection projects, project activities shall be conducted to minimize siltation of the beach area and bed (WAC 220-110-270)	The only WAC provision pertaining to substrate deposition applies only to saltwater environments. The broad language of the provision may reduce its effectiveness in minimizing the risk of take associated with deposition of substrate associated with bank protection projects.
Substrate Modifications: Altered Littoral Drift	All Environments • Bioengineering is the preferred method of bank protection where practicable. Bank protection projects shall incorporate mitigation measures as necessary to achieve no-net-loss of productive capacity of fish and shellfish habitat (WAC 220-110-050, WAC 220-110-223, and WAC 220-110-280) Freshwater • Bank protection material placement waterward of the OHWL shall be restricted to the minimum amount necessary to protect the toe of the bank, or for installation of mitigation features approved by the department (WAC 220-110-050) • The toe of the bulkhead shall be placed landward of the OHWL (WAC 220-110-223) • All trenches, depressions, or holes created within the OHWL shall be backfilled prior to inundation by high water or wave action (WAC 220-110-223) Saltwater • Repairs or replacement of existing marine bulkheads or rockwalls will be placed in the same alignment as the structure it is replacing unless for the purposes of structural stability it is necessary to keep the existing structure in place and construct the replacement structure immediately waterward (Chapter 77.55.141 (2b) RCW and WAC 220-110-285) • For single-family residence bulkheads, the waterward face of a new bulkhead shall be located at or above the OHWL. Where this is not practicable due to geological, engineering, or safety concerns, the waterward face of the new bulkhead shall be located only as far waterward of the OHWL as necessary to excavate for footings or place base rock for the structure and under no conditions shall the waterward face of the bulkhead be located more than six feet waterward of the OHWL. In addition, the waterward face of any bulkhead shall be located as close to the toe of the bank as possible (RCW 77.55.141(2a) and WAC 220-110-285) • All trenches, depressions, or holes created in the beach area shall be backfilled prior to inundation by tidal waters. Trenches excavated for footings or placement of base rock may remain open during construction, however, fish shall be prevented from	Existing WAC provisions attempt to minimize the impact of bank protection structures on sediment transport by minimizing the encroachment of the structures below the OHWL. However, the WAC provisions do not address maintaining the connectivity of sediment sources with the water. Such provisions would reduce the risk of take associated with altered littoral drift.

Impact Mechanism Generating Risk of Take	Existing WACs and RCWs Related to Impact Mechanism	Evaluation of Existing WACs Effectiveness In Reducing Risk of Take
	entering such trenches (WAC 220-110-280 and WAC 220-110-285) • For marine and estuarine bank protection projects, beach area depressions created during project activities shall be reshaped to pre-project beach level upon project completion (WAC 220-110-270) • Placement of dredged material will be allowed for beach nourishment (WAC 220-110-270)	
Habitat Accessibility: General	All Environments • Bank protection projects shall incorporate mitigation measures as necessary to achieve no-net-loss of productive capacity of fish and shellfish habitat (WAC 220-110-050, WAC 220-110-223, WAC 220-110-280, and WAC 220-110-285) Freshwater *No provisions* Saltwater *No provisions*	The only WAC provision pertaining generally to habitat accessibility is broad and while providing WDFW with a lot of latitude, may not provide enough specificity to minimize the risk of take.
Habitat Accessibility: Reduced Accessibility and Availability of Shallow-Water Habitats	All Environments *No provisions* Freshwater • Bank protection material placement waterward of the OHWL shall be restricted to the minimum amount necessary to protect the toe of the bank, or for installation of mitigation features approved by the department (WAC 220-110-050) • The toe of the bulkhead shall be placed landward of the OHWL (WAC 220-110-223) Saltwater • Repairs or replacement of existing marine bulkheads or rockwalls will be placed in the same alignment as the structure it is replacing unless for the purposes of structural stability it is necessary to keep the existing structure in place and construct the replacement structure immediately waterward (Chapter 77.55.141 (2b) RCW and WAC 220-110-285) • For single-family residence bulkheads, the waterward face of a new bulkhead shall be located at or above the OHWL. Where this is not practicable due to geological, engineering, or safety concerns, the waterward face of the new bulkhead shall be located only as far waterward of the OHWL as necessary to excavate for footings or place base rock for the structure and under no conditions shall the waterward face of the bulkhead be located more than six feet waterward of the OHWL. In addition, the waterward face of any bulkhead shall be located as close to the toe of the bank as possible (RCW 77.55141(2a) and WAC 220-110-285) • For non-single family residence property bulkhead and bank protection projects, the waterward face of a new structure shall be constructed according to an approved design, utilizing the least impacting type of structure and shall minimize encroachment waterward of the OHWL to protect juvenile salmonid migration corridors and other habitats of special concern (WAC 220-110-280) • Bank protection structures shall not result in the loss of eelgrass or permanent loss forage fish spawning habitat (WAC 220-110-280) • For non-single family residence property bulkhead and bank protection projects, the construction of bulkheads or other bank protection shall not result in a permanent loss of surf smelt, Pacific sand lance, or rock sole spawning beds (WAC 220-110-280) • For non-single family residence property bulkhead and bank protection projects, when stockpiling of sand, gravel, and other coarse material is allowed below the OHWL, it shall be placed within a designated work corridor waterward of the bulkhead footing or base rock. All excavated or stockpiled material shall be removed from the beach within seventy-two hours of bulkhead construction (WAC 220-110-280)	Existing WAC provisions attempt to minimize the impact of bank protection structures on the availability of shallow-water habitats by minimizing the encroachment of the structures below the OHWL. However, complete prohibition of structures below the OHWL would be necessary to fully avoid the risk of take (although in many settings this would render the structure ineffective in protecting the bank).
Habitat Accessibility: Reduced Accessibility and Availability of Side Channel and Floodplain Habitat	*No provisions*	As with the channel processes aspects of disconnecting floodplain and side channel habitat, no WAC provisions address maintaining accessibility to those habitats.
Habitat Accessibility: Velocity Barriers	*No provisions*	WACs do not include provisions that would minimize risk of take associated with potential velocity barriers limiting habitat accessibility.
Aquatic Vegetation: General	All Environments	The only WAC provision pertaining generally to aquatic vegetation is broad and while providing WDFW with a lot of latitude, may not provide enough specificity to minimize the risk

Impact Mechanism Generating Risk of Take	Existing WACs and RCWs Related to Impact Mechanism	Evaluation of Existing WACs Effectiveness In Reducing Risk of Take
	• Bank protection projects shall incorporate mitigation measures as necessary to achieve no-net-loss of productive capacity of fish and shellfish habitat (WAC 220-110-050, WAC 220-110-223, WAC 220-110-280, and WAC 220-110-285) <u>Freshwater</u> *No provisions* <u>Saltwater</u> *No provisions*	of take.
Aquatic Vegetation: Loss of Marine Aquatic Vegetation	<u>All Environments</u> <u>Freshwater</u> • Bank protection material placement waterward of the OHWL shall be restricted to the minimum amount necessary to protect the toe of the bank, or for installation of mitigation features approved by the department (WAC 220-110-050) <u>Saltwater</u> • Kelp (Order laminariales) or intertidal wetland vascular plants (except noxious weeds) adversely impacted due to construction of bulkheads or other bank protection shall be replaced using proven methodology (WAC 220-110-280) • For marine and estuarine bulkhead and bank protection projects on non-single family residence property, the construction of bulkheads or other bank protection is prohibited in eelgrass (Zostera spp), Pacific herring spawning beds, and lingcod and rockfish settlement and nursery areas (WAC 220-110-280) • Repairs or replacement of existing marine bulkheads or rockwalls will be placed in the same alignment as the structure it is replacing unless for the purposes of structural stability it is necessary to keep the existing structure in place and construct the replacement structure immediately waterward (Chapter 77.55.141 (2b) RCW and WAC 220-110-285) • For single-family residence bulkheads, the waterward face of a new bulkhead shall be located at or above the OHWL. Where this is not practicable due to geological, engineering, or safety concerns, the waterward face of the new bulkhead shall be located only as far waterward of the OHWL as necessary to excavate for footings or place base rock for the structure and under no conditions shall the waterward face of the bulkhead be located more than six feet waterward of the OHWL. In addition, the waterward face of any bulkhead shall be located as close to the toe of the bank as possible (RCW 77.55.141(2a) and WAC 220-110-285) • For non-single family residence property bulkhead and bank protection projects, the waterward face of a new structure shall be constructed according to an approved design, utilizing the least impacting type of structure and shall minimize encroachment waterward of the OHWL to protect juvenile salmonid migration corridors and other habitats of special concern (WAC 220-110-280) • The use of equipment on the beach area shall be held to a minimum and confined to specific access and work corridors (WAC 220-110-270) • Beach area depressions created during project activities shall be reshaped to pre-project beach level upon project completion (WAC 220-110-270)	Existing WAC provisions attempt to minimize the impact of bank protection structures on the marine aquatic vegetation by minimizing the encroachment of the structures below the OHWL. [. Mitigation typically focuses on the direct impact to eelgrass during construction and predicted impacts using shade models. The long-term loss of eelgrass and other macroalgae through the altered energy regime and coarsened substrate often associated with bulkheads below the OHWL is not currently evaluated or mitigated for and therefore creates some risk of take.
Aquatic Vegetation: Loss of Freshwater Aquatic Vegetation	<u>All Environments</u> *No provisions* <u>Freshwater</u> • Bank protection material placement waterward of the OHWL shall be restricted to the minimum amount necessary to protect the toe of the bank, or for installation of mitigation features approved by the department (WAC 220-110-050) • For freshwater bulkheads, the toe of the bulkhead shall be placed landward of the OHWL (WAC 220-110-223) • For freshwater bulkheads, all trenches, depressions, or holes created within the OHWL shall be backfilled prior to inundation by high water or wave action (WAC 220-110-223)	Existing WAC provisions attempt to minimize the impact of bank protection structures on the freshwater aquatic vegetation by minimizing the encroachment of the structures below the OHWL. Loss of freshwater vegetation is typically not mitigated for, although it creates some risk of take.

Impact Mechanism Generating Risk of Take	Existing WACs and RCWs Related to Impact Mechanism	Evaluation of Existing WACs Effectiveness In Reducing Risk of Take
	Saltwater *No provisions*	
Riparian Vegetation: Loss of Riparian Vegetation	All Environments *No provisions* Freshwater • Alteration or disturbance of riparian vegetation will be minimized and replanted with native vegetation within one year and maintained for three years (WAC 220-110-050 and WAC 220-110-120) Saltwater • Removal or destruction of overhanging bankline vegetation shall be limited to that necessary for construction of the bulkhead or other bank protection (WAC 220-110-280 and WAC 220-110-285)	The WACs pertaining to fresh water attempt to minimize the loss of riparian vegetation and have disturbed areas revegetated. Revegetated areas are only required to meet three-year performance measures based on plant survival. More extended maintenance of riparian vegetation would increase the likelihood of its survival and contribution to ecological function. Additional requirements to plant native vegetation in riparian areas that may have been void of substantial vegetation prior to the project would reduce the risk of take associated with the temporal loss of riparian vegetation. Provisions in saltwater to match fresh water requirements would reduce risk of take.
Water Quality: General	All Environments • Bank protection projects shall incorporate mitigation measures as necessary to achieve no-net-loss of productive capacity of fish and shellfish habitat (WAC 220-110-050, WAC 220-110-223, WAC 220-110-280, and WAC 220-110-285) Freshwater HPAs may also be subject to additional special provisions to address project- or site-specific considerations not adequately addressed by the technical provisions (WAC 220-110-032) [Saltwater • Project activities shall not degrade water quality to the detriment of fish life (WAC 220-110-270) • No debris or deleterious material shall be disposed of or abandoned waterward of the OHWL except at an approved in-water site (WAC 220-110-270) • All debris or deleterious material resulting from construction shall be removed from the beach area or bed and prevented from entering waters of the state (WAC 220-110-270)	No specific WACs apply to limiting the potential for take associated with water quality impacts in fresh water, although WAC 220-110-032 authorizes the use of "special provisions to address project or site-specific considerations not adequately addressed by the technical provisions." Such special provisions usually include measures to reduce potential water quality impacts. Existing WAC provisions pertaining generally to water quality emphasize the need to maintain water quality in salt water, but no provisions pertain specifically to fresh water. Additional emphasis on maintaining water quality in fresh water could contribute to lessening the risk of take.
Water Quality: Elevated Water Temperatures	All Environments *No provisions* Freshwater Alteration or disturbance of riparian vegetation will be minimized and replanted with native vegetation within one year and maintained for three years (WAC 220-110-050) Saltwater • Removal or destruction of overhanging bankline vegetation shall be limited to that necessary for construction of the bulkhead or other bank protection (WAC 220-110-280 and WAC 220-110-285)	Existing WAC provisions attempt to minimize the potential for increased water temperatures associated with the loss of riparian vegetation. The WAC provisions pertaining to fresh water require revegetated areas] to meet three-year performance measures based on plant survival. More extended maintenance of riparian vegetation would increase the likelihood of its survival and contribution to ecological function. Additional requirements to plant native vegetation in riparian areas that may been void of substantial vegetation prior to the project would reduce the risk of take associated with elevated water temperatures. Similar requirements in saltwater would further reduce risk of take.
Water Quality: Reduced Dissolved Oxygen	• Alteration or disturbance of riparian vegetation will be minimized and replanted with native vegetation within one year and maintained for three years (WAC 220-110-050) Saltwater Removal or destruction of overhanging bankline vegetation shall be limited to that necessary for construction of the bulkhead or other bank protection (WAC 220-110-280 and WAC 220-110-285)	Existing WAC provisions indirectly protect dissolved oxygen levels through limitations placed on alteration of riparian vegetation..
Water Quality: Elevated pH	All Environments *No provisions* Freshwater *No provisions* Saltwater • Wet concrete shall be prevented from entering waters of the state. Forms for any concrete structure shall be constructed to prevent leaching of wet concrete. Impervious material shall be placed over any exposed concrete not lined with forms	The only WAC provision specifically pertaining to pH applies only to salt water. Similar provisions for freshwater habitats would reduce the risk of take.

Impact Mechanism Generating Risk of Take	Existing WACs and RCWs Related to Impact Mechanism	Evaluation of Existing WACs Effectiveness In Reducing Risk of Take
	that will come in contact with waters of the state. Forms and impervious material shall remain in place until the concrete is cured (WAC 220-110-270)	
Water Quality: Altered Salinity Gradient	*No provisions*	WACs do not include provisions that would minimize risk of take associated with altered salinity gradients.

9.2 Evaluation of Relative Risk of Take Associated with Bank Protection Structures

All bank protection activities have potential for some take, unless no potentially covered species occur in the project area, including the areas upstream and downstream (or updrift and downdrift) that may be impacted by the structure. Table 10 provides some general guidelines regarding the project elements that contribute to a bank protection project of “low,” “moderate,” or “high” risk of take. These general categorizations are based on the best professional judgment of the analysis team and require interpretation beyond the empirical data available in the literature. The categorizations are intended to be widely applicable to potentially covered species; however, it is possible that the categorizations will not be valid for all species, particularly those with lesser known habitat and ecological requirements. Since much of the literature is based on impacts to salmonids, the categorizations are perhaps most applicable to salmonids.

For a bank protection project to be of “low” risk, it must meet all applicable requirements in the low-risk category, i.e., no “moderate” or “high” risk aspects to the project. In addition, the “low”-risk conditions in the row labeled “Construction-Related Activities” must also be satisfied for a project to be of “low” risk. In general terms, activities in the low-risk category appear to be well suited for programmatic approval, whereas activities in the high-risk category would likely require consideration of project-specific elements (e.g., environmental setting, size, and installation technique) and present a clear need to implement conservation measures to reduce the risk of take. The appropriateness of programmatic approval of activities in the moderate-risk category is debatable and would depend in part on the use of conservation measures. The risk evaluation summarized in Table 10 assumes that potentially covered species are present when the described impact occurs; thus, impacts may be avoided by performing the activities when or where potentially covered species are absent.

Table 10
Evaluation of Relative Risk of Take Associated with Bank Protection Structures

Activity	Risk of Take			Rationale and Assumptions
	Low	Moderate	High	
Construction-Related Activities	- In areas inhabited by only migratory potentially covered species (e.g., anadromous species) and/or species that move between habitats with some predictability (e.g., spawning runs from lakes to streams), activities that occur within allowable work windows based on tributary-specific species presence and periodicity data that avoid working during periods of species presence - Activities that do not entail removing native riparian vegetation, LWD, or small woody debris (SWD) - Pile-driving activities with peak underwater sound <150 dB - Activities that avoid need for dewatering	- In areas inhabited by only migratory potentially covered species (e.g., anadromous species) and/or species that move between habitats with some predictability (e.g., spawning runs from lakes to streams), activities that occur within allowable work windows based on general species presence information (e.g., statewide species distribution maps) and periodicity data that attempt to avoid working during periods of species presence - Project areas where non-migratory potentially covered fish species presence is presumed, but not documented - Activities that minimize the removal of native riparian vegetation and that replant (including maintenance) the cleared area's native vegetation upon construction completion - Pile-driving activities with peak underwater sound between 150 and 180 dB - Activities that minimize the dewatered area and length of time, remove species from area, and implement BMPs to minimize the addition of	- Project areas where potentially covered invertebrate species presence is documented - Project areas where any potentially covered fish species presence is documented and the construction timing coincides with their presence - Activities that do not minimize the removal of native riparian vegetation and/or that do not replant (including maintenance) the cleared area's native vegetation upon construction completion - Pile-driving activities requiring hammer pile driving with peak underwater sound >180 dB - Activities that include dewatering a portion of channel and either do not remove species from area or do not implement BMPs to reduce introduction of suspended solids	For areas inhabited by potentially covered species during in-water construction, bank protection activities represent a high risk of take due to the various disturbances to aquatic habitats that typically occur during in-water work. Risk of take is low when the project completely avoids timing in-water construction during species presence or known sensitivity periods. Moderate risk is indicated when in-water work is completed mostly within these periods, but still maintains some in-water work outside the periods. For bank protection activities that permanently remove native riparian vegetation, risk of take is high because bank vegetation is closely linked to habitat quality and direct survival (most importantly, via water temperature control) for many potentially covered species. For pile-driving activities, risk of take for potentially covered fish is set as high for bank protection projects that produce underwater sound above the injury and disturbance threshold for threatened and endangered salmonids, >180dB. Risk of take is moderate for projects producing peak underwater sound between the 180 dB injury threshold and the 150 dB threshold for behavioral disturbance. Activities producing peak underwater sound below 150 dB would be expected to exhibit a low risk of take for potentially covered fish. Because invertebrate sound studies are sparse, it is expected that these risk levels, which are set based on effects to fish, will adequately apply to invertebrate responses to construction-related sound. Activities that require dewatering may minimize the

Activity	Risk of Take			Rationale and Assumptions
	Low	Moderate	High	
		suspended solids		dewatered area and length of time of dewatering, remove species from the area, and implement BMPs to minimize the addition of suspended solids; however, under the take definition, these activities would still constitute take. Therefore, risk of take is high and severe for dewatering activities that do not minimize the dewatered area and length of time dewatered, and for those that do not remove species from the area, and that do not minimize suspended solids. Risk of take is moderate and less severe if these minimization measures are implemented. Risk of take is low when dewatering can be avoided.
Vertical Retaining Walls, Rock Revetments, and Rock Toes	• Reaches in all environments that are not sediment sources (i.e., not feeder bluffs) and in which the structure does not extend into intertidal zone or below OHWL	• Marine and estuarine reaches that do not contain sediment sources (i.e., not feeder bluffs) and in which the structure does not extend into intertidal zone, but forage fish spawning is known to occur • All environments in which rock toes support soft armoring approaches along remainder of bank	• Reaches in all environments that contain sediment sources (i.e., feeder bluffs) • Marine and estuarine reaches that do not contain sediment sources (i.e., not feeder bluffs) but in which the structure extends into intertidal zone • All environments along known spawning areas for potentially covered fish species • All environments along known areas that contain sessile potentially covered invertebrate species • All environments in which rock toes support upper bank rock or wall revetments	For vertical retaining walls, risk of take is high in marine environments where forage fish spawning could occur and salmonid migration occurs. Take risk is also high in other environments due to indirect effects because these structures isolate sediment supply, cause scour, reflect wave energy, and contribute to a loss of fine sediment, causing ensuing effects to biota and vegetation. For rock revetments, similar to vertical retaining walls, risk of take is high in marine environments potentially supporting forage fish spawning and salmonid migration due to indirect effects in reducing gravel recruitment and sediment transport and affecting shoreline currents. In addition, rock revetments can disrupt flows, reduce food delivery, and create difficult swimming for smaller fish. For rock toes, risk of take is moderate when toes support upper bank biostabilization structures, which function to improve overall habitat, but risk of take is high where rock toes are placed to support rock or wall revetments.

Activity	Risk of Take			Rationale and Assumptions
	Low	Moderate	High	
Levees		• Levee "setbacks" that increase the width of the channel, provide high flow refuge habitat, and incorporate LWD	• Levees other than those described as moderate risk	Risk of take is high for levees, except when the project is attempting habitat restoration by setting back existing levees or other bank protection structures. This is because levees limit channel hydraulics and sediment recruitment, sometimes isolating sediment supply to the substrate and transport of that sediment through the system. In addition, levees fragment ecosystem connectivity and limit habitat accessibility for many potentially covered species, depending on the habitat. For example, in an estuary, levees can isolate marsh areas and limit LWD distribution.
Log/Rootwad Toes	• All environments in which the toe is combined with other biotechnical bank approaches	• All environments in which the toe is combined with rock or concrete bank approaches		Risk of take is low for log and rootwad toes where they typically are used to support upper bank biostabilization structures. They also increase habitat complexity along the bank.
Beach Nourishment	• Marine and freshwater environments using pre-washed substrate in which turbidity increases are not likely to occur • Marine environments in which macroalgae or eelgrass is not covered • Freshwater environments in which aquatic vegetation is not covered • All environments in which material is placed above the OHWL or MHHW. • Marine and freshwater environments in which similarly sized materials as compared to an appropriate reference site are placed	• Marine environments in which turbidity increases are likely to occur • All environments in which material is placed below the OHWL or MHHW	• Marine environments in which macroalgae or eelgrass is covered • Freshwater environments in which aquatic vegetation is covered	Risk of take due to beach nourishment is low if material is pre-washed or of larger (pebble/gravel) size and not likely to increase turbidity on site, if existing eelgrass or macroalgae will not be disturbed. Risk of take is moderate for all environments in which beach nourishment occurs on the upper beach only, because this material may move down the beach and ultimately affect species occurring in lower elevations. Risk of take is moderate if material is fine/sand, if eelgrass, macroalgae, or aquatic vegetation will be disturbed, and/or if material is placed to a large extent below the OHWL or MHHW.

Activity	Risk of Take			Rationale and Assumptions
	Low	Moderate	High	
Avulsion Prevention	• All environments in which avulsion prevention elements involve natural logs, brush, rootwad structures			Risk of take due to avulsion prevention is low because these structures are typically natural logs, brush rootwads placed in the habitat, which increases habitat complexity and a host of other habitat functions.
Subsurface Drainage Systems	• All environments in which drainage system elements involve natural logs, brush, rootwad structures	• All environments in which drainage system elements involve synthetic pipes or installations		Similar to avulsion prevention techniques, risk of take due to subsurface drainage systems is low where these structures consist of natural materials that will eventually degrade and become part of the environment and long-term bank stability solution.
Biotechnical Bank Protection Techniques	• All environments			Risk of take due to biotechnical bank protection is low because these structures typically provide beneficial effects to aquatic species, such as increases of refugia and habitat structure along the bank or shoreline, detrital inputs, and vegetative cover.
Bank Reshaping or Regrading	• All environments in which no in-water work is used • All environments in which bank reshaping/regrading is combined with biotechnical toe	• All environments in which in-water work is used • All environments in which bank reshaping/regrading is combined with rock toe		Risk of take due to bank reshaping or regrading is moderate if in-water work is used, because of the high potential for turbidity increases during regrading/reshaping work. If work is completed in the dry, risk of take is low. If bank reshaping/regrading entails placing a rock toe, risk of take is higher than if a log or rootwad toe is used.
Soil Reinforcement	• All environments			Risk of take due to soil reinforcements is low because these elements are typically surrounded by fabric and do not entail placing exposed soil or sediment on the bank or shore.
Coir and Straw Logs	• All environments			Similar to soil reinforcement, risk of take due to coir and straw logs is low because these elements typically consist of natural, biodegradable fabric or material and do not entail placing exposed soil or sediment on the bank or shore.
Integrated Approaches	• See Vertical Retaining Walls, Rock Revetments, and Rock Toes; see Bank Reshaping or Regrading	• See Vertical Retaining Walls, Rock Revetments, and Rock Toes; see Bank Reshaping or Regrading	• See Vertical Retaining Walls, Rock Revetments, and Rock Toes; see Bank Reshaping or Regrading	See Vertical Retaining Walls, Rock Revetments, and Rock Toes; see Bank Reshaping or Regrading

10 DATA GAPS

Much information is still needed on the science of bank protection and the impact to potentially covered species. Current data gaps are outlined below as relevant to the degree of impact, construction practices, and management issues.

10.1 Direct Impacts of the Covered Activities to Potentially Covered Species

There is an overall need for controlled, hypothesis-based studies directed at documenting and understanding the biological impacts of bank protection structures and activities to estuarine, marine, and freshwater ecosystems, particularly the effects associated with the structures both before and after impacts occur. Most current knowledge is based on anecdotal observations after the fact or those collected intuitively over time. Specific study needs include:

- Studies on the magnitude of the loss of salmonid food resources caused by bulkheading
- Studies developing quantitative, comparative understanding of the effectiveness and habitat impacts of hard versus soft bank protection approaches/technologies
- Studies quantifying construction-related impacts related to specific bank protection activities (such as turbidity)
- Studies developing information on bank/shoreline morphology related to bank structures, such as:
    - Accurate estimates regarding the rate of marine beach erosion and accretion in the presence of bank structures, including both seasonal and long-term effects
    - Effect of marine bulkheads specific to wave reflection and erosion of the upper beach
    - Role of marine log structures in attenuation of energy at the shore
    - Role of marine log bank protection structures in recruiting and retaining sediment and naturally occurring driftwood
    - Differences in sediment transport at unarmored versus armored shorelines/banks and in areas with and without naturally occurring wood debris

10.2 Indirect Impacts of the Covered Activities to Potentially Covered Species

The following information needs have been identified:

- Basic understanding of nearshore and bank ecosystem functions (e.g., roles of marine riparian vegetation, impact of LWD reductions ecosystem-wide); this will help to support the rationale for installing, leaving undisturbed, or enhancing certain existing natural shoreline features
- More specific information on migration and movement requirements of non-salmonid potentially covered species related to banks and bank protection structures; most research has focused on salmonids in this regard
- Studies investigating effects of bank protection on predation, feeding behavior, and prey production for covered species; very few studies document the links between specific bank protection types and behavior/diet of shoreline-associated species
- Studies investigating linkages between bank protection project impacts and the context in the watershed and nearby upland systems

10.3 Cumulative Effects of the Covered Activities to Potentially Covered Species

The following information needs have been identified:

- Predictive cumulative impact tools that model the potential effect of armoring on specific sites as well as systems. A possible approach is to focus on floodplain disconnection by using historical aerial photography. Photo-interpretation of bank protection structure locations and corresponding side channel and high-flow channels at each time step could provide insight on the relationship between those parameters as well as stream length (as an indicator of amount of habitat available). Potentially, such an analysis could demonstrate whether disconnection of key sediment sources or river reaches had an inordinate impact on floodplain connectivity.
- Information on long-term and cumulative habitat effects or relative benefits to biota for biotechnical approaches.
- Information on how changes in habitat opportunity or capacity change with addition of bank protection and whether and how these affect biological resources on a landscape scale.
- Maps and updates based on existing databases and inventories that:
  - Illustrate historical and current channel and/or shoreline alignments
  - Determine/prioritize critical areas for protection or restoration
  - Identify ecosystems that are most at risk to cumulative impacts.

10.4 Conservation Measures, Best Management Practices, and Mitigation

The following information needs have been identified:

- Monitoring studies (short- and long-term) confirming that BMPs and conservation measures have had the desired effect
- Objective, post-project evaluations to maximize opportunities to learn from past experience and improve upon future design

10.5 Management Recommendations

The following information needs have been identified:

- Summary/collection of information on process and outcome for use of adaptive management related to bank protection
- System for tracking and evaluating impacts on watershed level

11 HABITAT PROTECTION, CONSERVATION, MITIGATION, AND MANAGEMENT STRATEGIES

If the impacts described in Section 7 of this document occur within habitat used by a potentially covered species, the result may be incidental take of aquatic animals through either physical harm to the animals or reduced capacity of the habitat to serve essential life functions, such as reproduction, foraging, and migration. The ESA requires that such impacts be avoided or, if unavoidable, minimized to the maximum extent practicable. Measures for avoiding or minimizing the risk of incidental take are identified below. Mitigation measures to compensate for unavoidable take and management strategies are also provided.

11.1 Avoidance and Minimization Techniques

Impact reduction measures for bank protection include both conservation measures and BMPs. Conservation measures in the context of bank protection can be defined as design elements that are intended to avoid or minimize impacts to habitats and species. BMPs are those measures used during the construction phase to avoid or minimize impacts. Many of these practices have been identified in the published literature as well as guidance documents, and they may be required by regulatory agencies as permit conditions. Table 11 summarizes these measures as currently known and practiced, organized by impact mechanism.

Table 11
Conservation Measures and BMPs

	Conservation Measures[ab]	Best Management Practices
Construction Activities	• Require construction set-back that will avoid the risks associated with slope retreat (high and low-no-bank sites) (Gerstel and Brown 2006). • Manage all surface water to contain and direct it appropriately to the base of the bluff (high-bank sites) (Gerstel and Brown 2006). • Develop guidelines for channel dewatering, including a protocol for WDFW review and approval of proposed dewatering plans. • Adopt guidance/protocols for fish and invertebrate removal and exclusion. Specifically, this refers to guidance/protocols for fish capture (including seining and electrofishing), fish handling, and reporting on the number and types of fish captured, fish injured, injuries observed, and mortality. An example protocol is provided by the Washington State Department of Transportation (WSDOT 2006b). • Define the qualifications of “qualified personnel” who can perform fish capture and handling activities or develop an appropriate training or qualification process for biologists. In addition, maintain a list of qualified fish biologists who can perform fish removal and exclusion activities. • Initiate channel dewatering to allow for volitional movement out of area. Then conduct fish and invertebrate removal activities. Have qualified personnel present to survey the area during dewatering and remove any additional fish and invertebrates encountered.	• Construction activities should be timed to occur when sensitive life stages of potentially covered species are less likely to be present. • As appropriate, species surveys (including forage fish egg surveys) should be conducted at site prior to initiation of construction to ensure no species present or to allow for removal plan to be prepared and implemented. • Use temporary erosion control measures, including application of mulch, hydroseeding, geotextiles, or soil stabilizers (Saldi-Caromile et al. 2004). • Use temporary soil trapping measures, including silt barriers such as straw bales or silt fences (Saldi-Caromile et al. 2004). • Use temporary bank protection techniques during construction (relevant to bank pull-back and revegetation; installation of deformable bank toes) (Saldi-Caromile et al. 2004). The following mitigation measures regarding suspended sediment are based on those proposed by Bash et al. (2001): • Prior to project construction, determine suspended sediment concentrations and collect information on particle size and shape as indicators of the nature of existing turbidity. • When evaluating cumulative impacts from turbidity, consider information from existing assessments of watershed condition to account for point and nonpoint source pollution loads from watershed sources other than the project, as well as legacy impacts of the system. • Set stockpile areas back from the bank and include erosion prevention BMPs, such as silt fencing and tarp covers. Use spill prevention plans and pollution and erosion control plans. To minimize noise generation: • Avoid use of impact hammer during any pile installation. • Use air bubble curtains and/or pile caps to attenuate sound pressure waves. • Fabric barriers or cofferdams can also serve to attenuate sound generation.

		• Require that construction vessels and propellers are washed and free of noxious weeds or invasive animals prior to entering water. • Avoid barge grounding. • Avoid propeller scour. • Require a spill prevention plan.
Channel Processes	• Adhere to guidelines in *Stream Habitat Restoration Guidelines* (Saldi-Caromile et al. 2004) and *Integrated Streambank Protection Guidelines* (Cramer et al. 2003) for project development and implementation. • Minimize structure footprint. • Site structure above OHWL and as far outside the active channel as possible. • Evaluate fluvial geomorphic processes, and consider natural and locally modified processes in project design and construction. • Develop and maintain upland infrastructure carefully and with consideration of potential effects on slope stability (high-bank sites) (Gerstel and Brown 2006). • Discourage backshore filling to create new home or other construction sites (Gerstel and Brown 2006).	• For activities requiring dewatering, plan for at least a one-year flow event to occur during construction and design dewatering systems accordingly (Saldi-Caromile et al. 2004).
Substrate Modifications	• If traditional armoring techniques are used, consider applying measures that reduce substrate and wave impacts (e.g., floating energy attenuators, weir-like revetments, walls open near bottom) (Cox et al. 1994). • Minimize area of large substrate placement. • Use suitably sized materials to minimize potential for displacement and scatter during high-flow or storm events. • Site structure above OHWL and as far outside the active channel as possible. • Reduce slope and/or integrate vegetated or riprapped bench areas, supporting sediment retention (Zelo et al. 2000).	• Schedule construction for times when project area is dry (or substrate is frozen) (Saldi-Caromile et al. 2004).
Habitat Accessibility	• Locate bank protection structures as far outside of the floodplain as possible to minimize the potential for precluding access to off-channel areas.	No specific measures identified.
Aquatic Vegetation	• Avoid impacts by locating structures away from aquatic vegetation, especially eelgrass, whenever possible. This will require a pre-construction survey of vegetation location, species assemblage, and density.	• Minimize the area of impact by using land-based construction operations that avoid trampling of aquatic vegetation. • Avoid barge grounding.

	• Require post-construction monitoring of vegetation for up to 10 years to investigate potential project impacts.	• Avoid propeller scour.
Riparian Vegetation	• Promote bank stability by leaving as many existing trees and vegetation in place as possible, early seeding in disturbed areas (Nunnally 1978). • Use and/or maintain native plant revegetation as a means to stabilize banks, where possible (Gerstel and Brown 2006; Lund 1976; Knutson and Woodhouse Jr. 1983; Myers 1993; Manashe 1993; MacDonald et al. 1994; Downing 1983; Cox et al. 1994; Zelo et al. 2000). • Above high-water level, cover riprap with soil and revegetate (Lund 1976). • To the extent practicable, do not permit removal or disturbance of riparian vegetation in areas with high erosion hazard (Knutson and Naef 1997). If such removal or disturbance is permitted, require replanting with native riparian vegetation or other appropriate erosion control measures. • Prepare revegetation plans for projects that temporarily disturb vegetation during construction. The revegetation plans should identify areas to be replanted with native riparian vegetation when construction is complete. Replanted vegetation should be monitored over several years (up to a 10-year period), and performance standards for plant survival and non-native plant exclusion should be established and required. • Submit monitoring reports to WDFW as part of the revegetation plan. Similar to the requirement of the U.S. Army Corps of Engineers (the Corps) for ESA Section 7 individual and programmatic consultations, two monitoring reports should be required, one to be submitted one year after project completion and the other to be submitted after the final required monitoring event. The monitoring reports must include information on the plant survival by species and maintenance activities (including plant replacement) needed during each monitoring cycle in order to meet performance standards. Monitoring reports should also state the cause of plant failure, a provision generally required by the Corps, NOAA Fisheries, and USFWS for Corps ESA Section 7 programmatic consultations. • WDFW should prepare or locate a revegetation guidance document that describes appropriate native vegetation to use; water, shade, and soil requirements; time of year most appropriate for planting; and other pertinent information to promote successful revegetation efforts.	To protect riparian habitat, construct any necessary access points and roads with the least impact possible, according to several activities listed by Saldi-Caromile et al. (2004) as lower impact:: • Access the site using an existing access point. • Access the site from the opposite bank and cross the stream (if necessary using a floating platform or driving equipment across the channel during low flows). • Construct any necessary access roads perpendicular to the streambank, implementing a rock work platform as needed and restoring following removal of platform. Other practices regarding access: • Clearly mark access through the riparian area to minimize impacts (Saldi-Caromile et al. 2004). • Use temporary mats to ”walk” equipment across sensitive areas, or fit applicable vehicles with extra wide tracks to reduce weight impacts and soil compaction (Saldi-Caromile et al. 2004). • In sensitive landscapes, use track-driven equipment when possible, as opposed to tire-driven, to distribute vehicle weight more evenly across surface (Saldi-Caromile et al. 2004).

	• Suggest that vegetation (specifically large trees and root wads) removed for the project be saved for later use in restoration efforts. This condition has often been required in recent individual and programmatic Section 7 consultations. Even if the material is not specifically useful for the permitted action, a WDFW area habitat biologist will generally know of ongoing or pending restoration projects in need of LWD and root wads.	
Water Quality	• Manage all surface water to contain and direct it appropriately to the base of the bluff (high-bank sites) (Gerstel and Brown 2006). • Evaluate and design for surface and groundwater flow issues (Gerstel and Brown 2006). • Avoid placing structures in areas that may affect flow connection from cold-water groundwater sources to surface water.	No specific measures identified.

Notes: a) In addition to these measures and BMPs, all applicable conservation measures should be applied from the Washington State Department of Ecology's Stormwater Management Manuals for Eastern and Western Washington (Ecology 2002, 2005), and all actions should be in compliance with the Hydraulic Code and its implementing rules.

b) Many of the measures discussed in this table are also given in the *Integrated Streambank Protection Guidelines* (Cramer et al. 2003).

11.2 Mitigation Strategies

Mitigation for bank protection projects may be required by regulatory authorities when it is determined that the project will cause an adverse impact to species, habitats, or conservation values. General strategies may include acreage-based habitat restoration, enhancement, or creation at an on- or off-site location or the acquisition of additional high-quality habitat property for preservation purposes. Because of the long-term positive impact on habitat, many bioengineering and beach nourishment techniques are discussed and referred to in the literature as self-mitigating due to their support of additional habitat and vegetation to the project site (Cramer et al. 2003; Gerstel and Brown 2006). The *Integrated Streambank Protection Guidelines* (Cramer et al. 2003) provides a matrix that identifies the bank protection actions likely to be self-mitigating and to what extent (Chapter 5, Matrix 3 in Cramer et al. 2003). Several specific measures that may be used to mitigate for various impact mechanisms are summarized in Table 12.

Table 12
Bank Protection-Specific Mitigation Strategies

Direct Impact	Compensatory Mitigation Strategy	Function of Mitigation
Construction Activities	• Several of the below strategies are typically used in or combined to mitigate for unavoidable construction impacts. BMPs are also used in conjunction with these measures.	• Mitigate for unavoidable construction-related impacts.
Channel Processes and Morphology	• Use energy dissipation structures for wave or flow (Gerstel and Brown 2006).	• Reduce wave or flow energy at shoreline to prevent or stem further erosion.
Substrate Modifications	• Use soft shore armoring or bioengineered solutions (see Section 4 of this document), some of which may be self-mitigating (Chapter 5, Matrix 3, Cramer et al. 2003). • Spawning gravel supplementation or beach nourishment (may require periodic supplementation) (Zelo et al 2000; Parametrix 1985; Simenstad et al. 1991).	• Reduce impact of armoring on shoreline habitat. Varied functions can be improved (e.g., long-line cabled logs can self-mitigate, contributing to ongoing capture of gravel, increase in local channel roughness and bank complexity, and protection or growth of riparian vegetation [Nichols and Sprague 2003]). • Provide additional or higher-quality substrate for forage fish (nearshore marine habitats) and salmonid spawning (freshwater channel habitats).
Habitat Accessibility	• Off-site construction of side channel(s) (reconnect side channel or oxbow) (Bonnell 1991; Cowan 1991).	• Provide additional rearing and spawning habitat.
Aquatic and Riparian Vegetation	• Replace lost aquatic vegetation and re-establish riparian buffer along bank shoreline (Saldi-Caromile et al. 2004). Retain removed vegetation for future restoration or mitigation effort (including LWD). • Mitigation to eelgrass and macroalgae is best achieved through avoidance, but if this vegetation is unavoidably impacted, apply natural regrowth or transplant methods (Thom et al. 2001).	• Provide additional vegetation for shoreline shading and detritus inputs. • Provide additional macroalgae habitats for juvenile salmonid prey production and forage fish habitat.
Water Quality	• Stormwater treatment or flow buffering for point sources (Osborne and Kovacic 1993) existing prior to bank protection project.	• Improve water quality and quantity of delivery to habitat by buffering of flows and/or reduction of pollutants to the project site.

11.3 Management Strategies

Management strategies provide the best opportunity for WDFW to guide the construction and design of bank protection structures. Recommendations for four types of management strategies are presented below: Regulatory, Enforcement, Information Gathering, and Education. These strategies are intended to lead to better information for design and review of projects, enhance the sharing of information, provide additional resources to contribute to lessening potential project impacts, and provide WDFW biologists and the entire department with the legal authority to prohibit activities that are not adequately protective of potentially covered species. Each of the recommendations requires additional WDFW staff availability because additional project oversight is recommended, and existing project oversight is already a significant challenge according to WDFW biologists around the State (Anchor Environmental et al. 2006).

11.3.1 Regulatory Recommendations

Regulatory recommendations are those changes to the WACs that are recommended in order to avoid, minimize, or mitigate impacts associated with bank protection structures. The WACs establish the rules that WDFW requires for bank protection projects. Many of the conservation measures and BMPs presented in Section 11.1 and the mitigation strategies presented in Section 11.2 could be incorporated into the WACs. In addition, the following regulatory recommendations have been identified:

- Require pre- and post-construction project monitoring to investigate conditions in the project area and adjacent areas.
- Require inspection during construction to ensure compliance with the HPA and a "sign off" by the inspector. WDFW could hire inspectors or license private engineering/environmental firms to inspect specific construction requirements related to fish habitat. Project components that would most benefit from inspection during construction are structural design, an instream habitat and/or instream mitigation, riparian vegetation, and revegetation progress.
- Prohibit bank protection structures that disconnect sediment sources unless life or property is at risk.
- Allow beach nourishment as a mitigation technique to address impacts of new and existing bank protection structures.
- Establish freshwater construction timing restrictions at the smallest geographic scale possible (ideally, basin-specific) based on species distributions and periodicity. Revisions to the WAC are recommended to address the lack of freshwater construction timing provisions, as well as saltwater timing provisions, based on consideration of the entire potentially covered species list to minimize the risk of take.
- Establish partnerships with other entities (e.g., the Corps and port authorities) to beneficially reuse clean dredged material to nourish beaches and have available as mitigation.
- Provide incentive mechanisms to promote "good" projects. Examples of potential incentives are simplified and accelerated permit review (i.e., "top of the

stack") and conducting or funding the monitoring activities required for the project. Such monitoring is envisioned to be conducted by crews (similar to Washington Conservation Corps or Ecology Youth Corps crews) whose sole responsibility is monitoring, rather than by WDFW biologists.

- As incentive, identify grant funding opportunities for projects incorporating habitat restoration components.
- Limit programmatic coverage to certain size, types or locations of bank protection structures. For example, the USACE (2002) Nationwide Permit 13 limits the size of the proposed bank protection structure to 500 feet or less in order to be eligible under the programmatic coverage. Similarly, the USACE (2005) Regional General Permit for Pend Orielle River and Lake Chelan limits the size of a bank protection structure to 250 feet or less.

11.3.2 Enforcement Recommendation

Commit to enforcing applicable regulations and providing sufficient staff to meet enforcement needs.

11.3.3 Information Gathering Recommendations

Establish and implement a plan to address data gaps identified in Section 10. A primary need is additional information on many of the potentially covered species' life histories, habitat needs, and habitat tolerances, as well as basin-specific information on distributions and periodicities. Developing and applying a technique for evaluating cumulative impacts of bank protection projects is also a significant information need.

It is recommended that additional information be tracked in the HPMS database. Useful additional information would include the size, specific type of structure, monitoring requirements, mitigation requirements, and a summary of monitoring findings. This information would be useful for analyses at a variety of scales (e.g., basin, stream, region, state) and for WDFW biologists during their reviews of proposed bank protection projects.

It is also recommended that WDFW develop guidelines on a series of topics relevant to designing, constructing, and monitoring bank protection projects, including:

- Beach nourishment
- Riparian revegetation
- Channel dewatering
- Fish and invertebrate species presence
- Fish and invertebrate removal

In addition, it is recommended that eelgrass/macroalgae guidelines be updated, possibly to incorporate technology-based approaches (e.g., towed video with diver-based ground-truthing and density data gathering) and standardize monitoring data delivery to facilitate its incorporation into a statewide database (similar to Ecology's SEDQUAL database).

11.3.4 Education Recommendations

Education recommendations apply to information sharing within WDFW and education of the public, particularly local jurisdictions and shoreline landowners.

The recommendations focused on information sharing within WDFW are:

- Educate staff through information- and monitoring data-sharing workshops for WDFW biologists.
- Develop an improved system of using monitoring data and making it more widely available. Presumably the use of data could be improved at both the project-specific level (i.e., monitoring data reviewed and acted upon to ensure project compliance) and more generally (i.e., to guide subsequent proposal reviews).
- Develop statewide clearinghouse for monitoring data, including aquatic and riparian vegetation, fish use, and physical habitat data.
- Use statewide clearinghouse of eelgrass data to generate updated geographic information system (also known as GIS) layers.

The recommendations focused on public education include:

- Educate the public on shoreline components, habitat function, and species vulnerabilities.

- Educate the public on potential impacts of bank protection projects and alternative techniques available.
- Develop a paper or web-based resource that highlights representative “good” and “bad” projects to help citizens understand the differences. The resource could consist of concise case studies for a variety of marine, estuarine, and freshwater settings (e.g., Eastern and Western Washington; feeder bluffs and accretion shoreforms; large, moderate, and small systems; high gradient and low gradient).
- Educate the public on the limitations of bank protection projects at providing full protection from extremely high-flow events to discourage construction close to shorelines or bluffs.
- Have staff available to assist in project design and/or implementation of the *Integrated Streambank Protection Guidelines* (Cramer et al. 2003) and the *Stream Habitat Restoration Guidelines* (Saldi-Caromile et al. 2004).
- Have staff available to assist in development of project monitoring plans and monitoring oversight, as necessary.

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APPENDIX A

MAPS: TRAs AND WRIAs

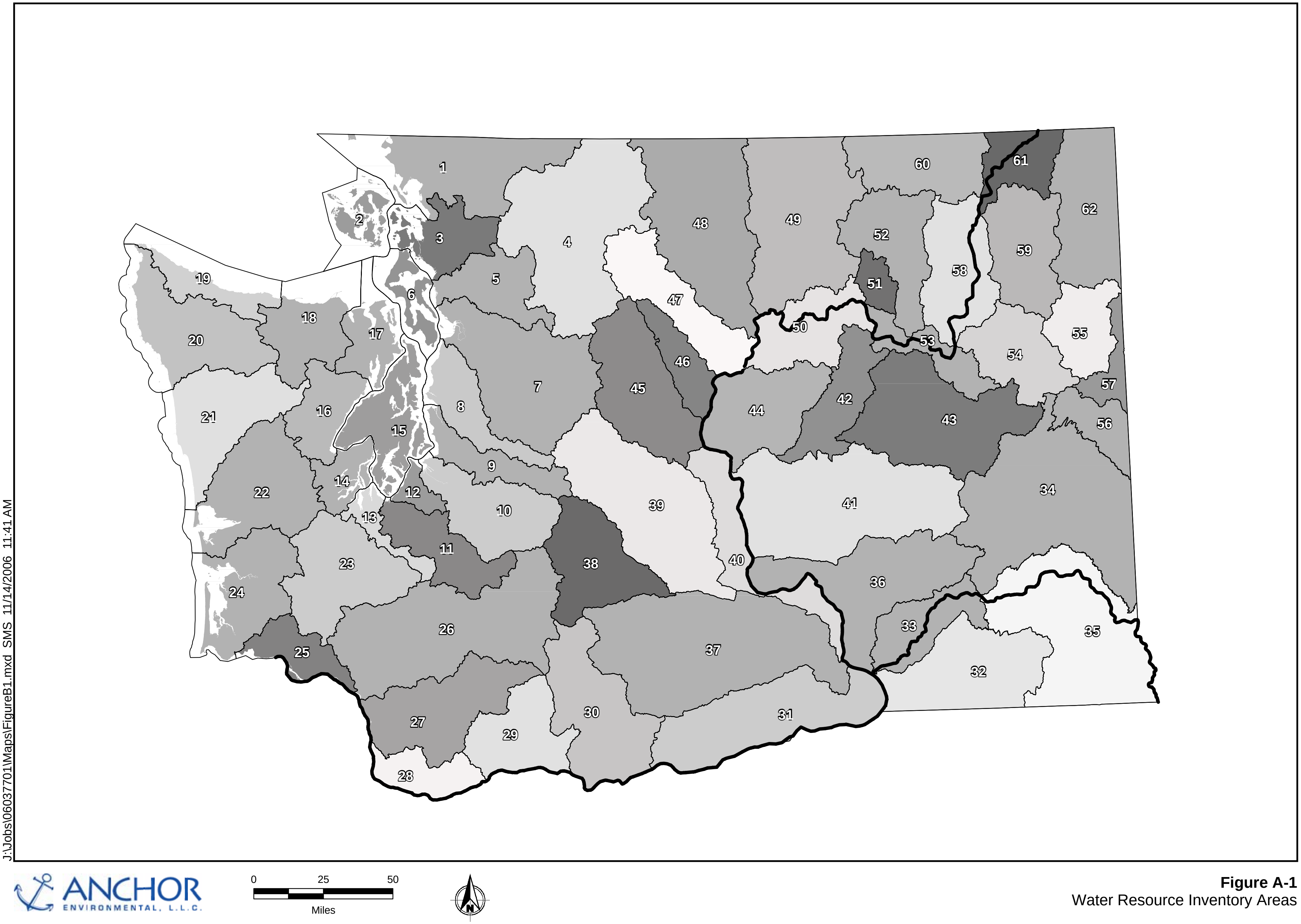

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Figure A-1
Water Resource Inventory Areas

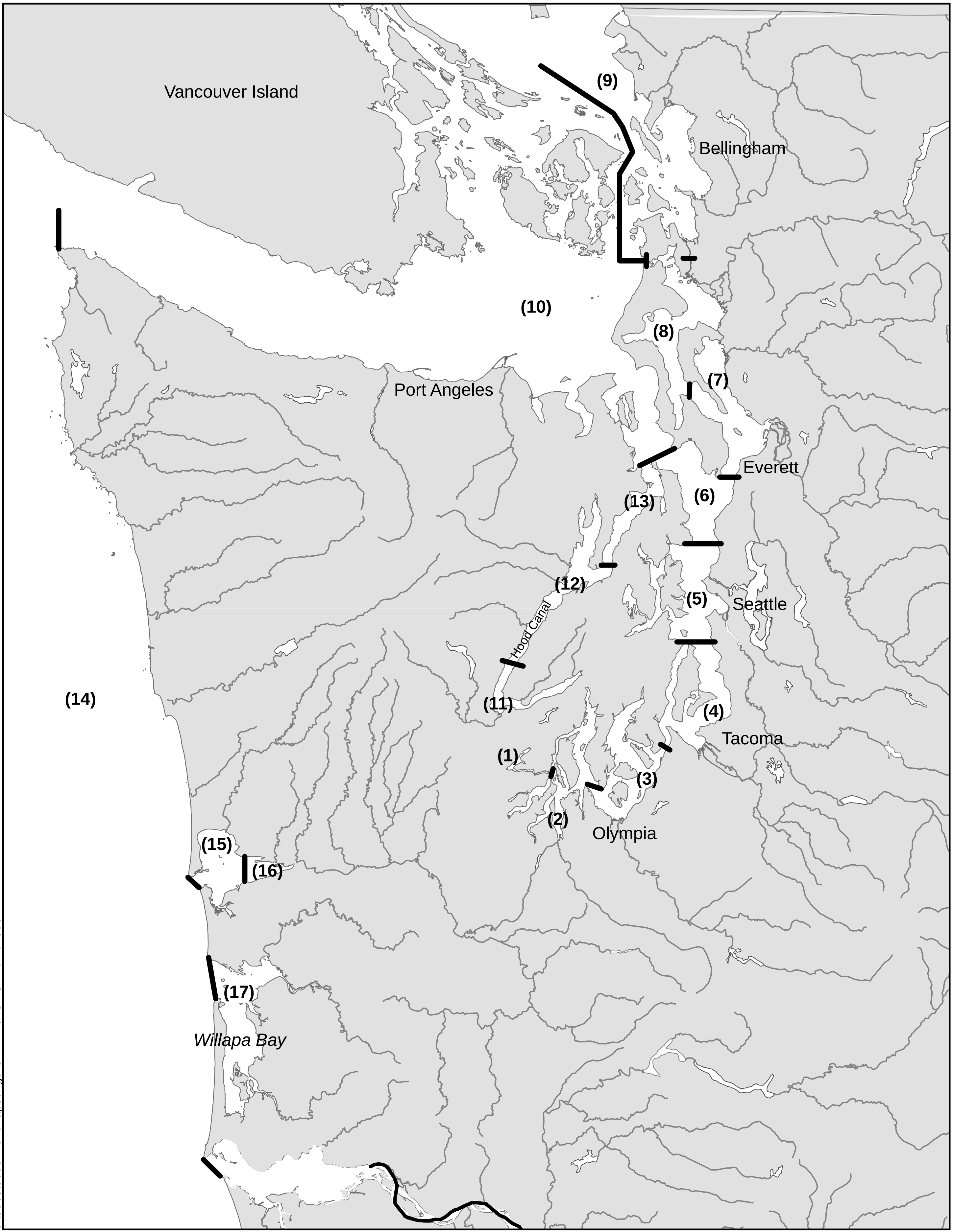

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Figure A-2
Tidal Reference Areas

APPENDIX B

DATA COMPILATION OF THE EFFECTS OF TURBIDITY AND SUSPENDED SEDIMENT ON SALMONIDS BY LIFESTAGE

(Source: Bash et al. 2001)

Table 2. Some reported effects of turbidity and suspended sediment concentrations on salmonids outside Alaska (Lloyd 1987).

Effect	Species[a] (life stage)	*Location*	Reported turbidity[b] or suspended sediment concentration	Reference
Fatal (96-h LC50)	Coho salmon (juveniles)	Washington	1,200 mg/l	Noggle (1978)
Fatal (96-h LC50)	Coho salmon (juveniles)	Washington	509; 1,217 mg/l	Stober et al. (1981)
Fatal (96-h LC50)	Chinook salmon (juveniles)	Washington	488 mg/l	Stober et al. (1981)
Reduced survival (marked)	Chum salmon (eggs)	British Columbia	97 mg/l	Langer (1980)
Reduced survival (marked)	Rainbow trout (eggs)	Great Britain	110 mg/l	Scullion and Edwards (1980)
Reduced survival (marked)	Rainbow trout (eggs)	Oregon	1,000-2,500 ppm	Campbell (1954)
Reduced survival (marked)	Rainbow trout (juveniles)	Great Britain	270 ppm	Herbert and Merkens (1961)
Reduced survival (marked)	Rainbow trout (juveniles)	Great Britain	200 ppm	Herbert and Richards (1963)
Reduced survival (marked)	Rainbow trout (juveniles)	Oregon	1,000-2,500 ppm	Campbell (1954)
Reduced survival (marked)	Rainbow trout (juveniles)	Great Britain	90 ppm	Herbert and Merkens (1961)
Reduced survival (marked)	Coho salmon (juveniles)	Pennsylvania	6; 12 mg Fe/l (15-27 JTU)	Smith and Sykora (1976)
Reduced survival (marked)	Coho salmon (adults)	Washington	1,400-1,600 mg/l	Stober et al. (1981)
Reduced abundance (marked)	Brown trout	Great Britain	1,000; 6,000 ppm	Herbert et al. (1961)
Reduced abundance (marked)	Lake trout	Northwest Territories	<10 FTU	McCart et al. (1980)
Reduced growth (marked)	Brook trout (juveniles)	Pennsylvania	50 mg Fe/l (86 JTU)	Sykora et al. (1972)
Reduced growth (slight)	Brook trout (juveniles)	Pennsylvania	12 mg Fe/l (32 JTU)	Sykora et al. (1972)
Reduced growth (slight)	Rainbow trout (juveniles)	Great Britain	50 ppm	Herbert and Richards (1963)
Reduced growth	Coho salmon (juveniles)	Idaho	25 NTU	Sigler et al. (1984)
Reduced growth (marked)	Arctic grayling (juveniles)	Yukon	1,000 mg/l	McLeay et al. (1984)
Reduced growth (slight)	Arctic grayling (juveniles)	Yukon	100; 300 mg/l	McLeay et al. (1984)

[a] Arctic grayling (*Thymallus arcticus*)
Brook trout (*Salvelinus fontinalis*)
Brown trout (*Salmo trutta*)
Chinook salmon (*Oncorhynchus tshawytscha*)
Chum salmon (*Oncorhynchus keta*)
Coho salmon (*Oncorhynchus kisutch*)
Cutthroat trout (*Salmo clarki*)
Lake trout (*Salvelinus namaycush*)
Rainbow trout (*Salmo gairdneri*)
Steelhead (anadromous *S. gairdneri*)

[b] Formazin (FTU), Jackson (JTU), and nephelometric (NTU) turbidity units.

[c] Information not available.

Table 2 (cont.). Some reported effects of turbidity and suspended sediment concentrations on salmonids outside Alaska (Lloyd 1987).

Effect	Species[a] (life stage)	*Location*	Reported turbidity[b] or suspended sediment concentration	Reference
Reduced food conversion	Rainbow trout (juveniles)	Arizona	< 70 JTU	Olson et al. (1973)
Reduced feeding (cessation)	Coho salmon (juveniles)	Washington	300 mg/l	Noggle (1978)
Reduced feeding	Coho salmon (juveniles)	Washington	100 mg/l	Noggle (1978)
Reduced feeding	Coho salmon (juveniles)	British Columbia	10-60 NTU	Berg (1982), Berg and Northcote (1985) Bachmann (1958)
Reduced feeding (cessation)	Cutthroat trout	Idaho	35 ppm	Bachmann (1958)
Reduced feeding	Brown trout	Pennsylvania	7.5 NTU	Bachman (1984)
Reduced feeding	Rainbow trout (juveniles)	Arizona	70 JTU	Olson et al. (1973)
Reduced feeding	Arctic grayling (juveniles)	Yukon	100; 300; 1,000 mg/L	McLeay et al. (1984)
Reduced condition factor	Rainbow trout (juveniles)	Great Britain	110 mg/l	Scullion and Edwards (1980)
Altered diet (terrestrial instead of aquatic)	Rainbow trout (juveniles)	Great Britain	110 mg/l	Scullion and Edwards (1980)
Stress (increased plasma cortisol, hematocrit, and susceptibility to pathogens)	Coho salmon (juveniles) Steelhead (juveniles)	Oregon	500 mg/l 2,000 mg/l	Redding and Schreck (1980)
Stress (increased metabolic rate, susceptibility to toxicants)	Arctic grayling	Yukon	300 mg/l	McLeay et al. (1984)
Stress (increased plasma glucose)	Arctic grayling (juveniles)	Yukon	50 mg/l	McLeay et al. (1983)
Stress (respiratory distress)	Coho salmon (juveniles)	Pennsylvania	6; 12 mg Fe/l (15-27 JTU)	Smith and Sykora (1976)
Stress (increased ventilation)	Brook trout	Lake Superior	231 NTU	Carlson (1984)
Disease (fin rot)	Rainbow trout (juveniles)	Great Britain	270 ppm	Herbert and Merkens (1961)
Disease (fin rot)	Rainbow trout (juveniles)	Great Britain	100; 200 ppm	Herbert and Merkens (1961)

[a] Arctic grayling (*Thymallus arcticus*)
Brook trout (*Salvelinus fontinalis*)
Brown trout (*Salmo trutta*)
Chinook salmon (*Oncorhynchus tshawytscha*)
Chum salmon (*Oncorhynchus keta*)
Coho salmon (*Oncorhynchus kisutch*)
Cutthroat trout (*Salmo clarki*)
Lake trout (*Salvelinus namaycush*)
Rainbow trout (*Salmo gairdneri*)
Steelhead (anadromous *S. gairdneri*)

[b] Formazin (FTU), Jackson (JTU), and nephelometric (NTU) turbidity units.

[c] Information not available.

Table 2 (cont.). Some reported effects of turbidity and suspended sediment concentrations on salmonids outside Alaska (Lloyd 1987).

Effect	**Species[a] (life stage)**	***Location***	**Reported turbidity[b] or suspended sediment concentration**	**Reference**
Avoidance	Chinook salmon (adults)	California	"Natural turbidity"	Sumner and Smith (1940)
Avoidance	Chinook salmon (adults)	Washington	650 mg/l	Whitman et al. (1982)
Avoidance	Chinook salmon (adults)	Washington	350 mg/l	Brannon et al. (1981)
Avoidance (sensitivity)	Lake trout	Lake Superior	6 FTU	Swenson (1978)
Avoidance	Coho salmon (juveniles)	Washington	70 NTU	Bisson and Bilby (1982)
Avoidance	Coho salmon, steelhead (juveniles)	Idaho	22-265 NTU	Sigler (1980), Sigler et al. (1984)
Displacement	Coho salmon, steelhead (juveniles)	Idaho	40-50 NTU	Sigler (1980)
Displacement	Arctic grayling (juveniles)	Yukon	300; 1,000 mg/l	McLeay et al. (1984)
Displacement	Rainbow trout (juveniles)	Great Britain	110 mg/l	Scullion and Edwards (1980)
Altered behavior (feeding)	Trout	c	25 JTU	Langer (1980)
Altered behavior (less use of overhead cover)	Brook trout	Wisconsin	7 FTU	Gradall and Swenson (1982)
Altered behavior (visual)	c	c	25-30 JTU	Bell (1984)
Altered behavior (visual)	Coho salmon (juveniles)	British Columbia	10-60 NTU	Berg (1982), Berg and Northcote (1985)
Altered behavior (loss of territoriality)	Coho salmon (juveniles)	British Columbia	10-60 NTU	Berg (1982), Berg and Northcote (1985)
Altered behavior (listlessness)	Coho salmon (juveniles)	Pennsylvania	6; 12 mg Fe/l (15-27 JTU)	Smith and Sykora (1976)
Change in body color	Arctic grayling (juveniles)	Yukon	300; 1,000 mg/l	McLeay et al. (1984)
Change in body color	Coho salmon (juveniles)	Pennsylvania	6; 12 mg Fe/l (15-27 JTU)	Smith and Sykora (1976)
Reduced tolerance to saltwater	Chinook salmon (juveniles)	Washington	3,109 mg/l	Stober et al. (1981)

a Arctic grayling (*Thymallus arcticus*)
Brook trout (*Salvelinus fontinalis*)
Brown trout (*Salmo trutta*)
Chinook salmon (*Oncorhynchus tshawytscha*)
Chum salmon (*Oncorhynchus keta*)
Coho salmon (*Oncorhynchus kisutch*)
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Lake trout (*Salvelinus namaycush*)
Rainbow trout (*Salmo gairdneri*)
Steelhead (anadromous *S. gairdneri*)

b Formazin (FTU), Jackson (JTU), and nephelometric (NTU) turbidity units.

c Information not available.

Table 4. Some reported effects of turbidity and suspended sediment concentrations on salmonids: 2001 Update. This table is derived from Lloyd (1987).

Effect	**Species (life stage)**	**Location**	**Reported turbidity or suspended sediment concentration**	**Reference**
Activity	Creek Chubs, Brook Trout	Wisconsin	Increase in moderately turbid waters	Gradall and Swenson (1982)*
Avoidance	Coho salmon (underyearling)	British Columbia	After 60 NTU pulse, fish move to substrate	Berg (1982)*
Avoidance	Coho salmon (underyearling)	British Columbia	Approx 25% at 7,000 mg/l – estimated that the threshold for avoidance in the vertical plane was 37 NTU	Servizi and Martens (1992)*
Avoidance	Creek Chubs	Wisconsin	Preferred 56.6 FTU	Gradall and Swenson (1982)*
Blood Sugar	Coho salmon (underyearling)	British Columbia	Elevated, proportional to SS exposure	Servizi and Martens (1992)*
Capture success per strike	Coho salmon (juvenile)	British Columbia	30 and 60 NTU	Berg and Northcote (1985)*
Cough Frequency	Coho salmon (underyearling)	British Columbia	Elevated eightfold over control levels at 240 mg/l	Servizi and Martens (1992)*
Feeding rates	Pacific herring (larval stage)	Oregon	Maximum feeding potential at 500 and 1000 mg/l	Boehlert and Morgan (1985)*
Feeding rates	Coho salmon (juvenile)	British Columbia	Prey consumption only 35% of feeding in clear water at 60 NTU	Berg (1982)*
Feeding rates	Coho salmon and steelhead (yearlings)	Oregon	When exposed to 2,000-3,000 mg/l of topsoil, kaolin clay, volcanic ash, 7-8 days	Redding et al. (1987)*
Feeding rates	Chinook salmon (juvenile)	British Columbia	Reduced at higher turbidities, highest rates at intermediate turbidity 35-150 NTU for surface and benthic prey	Gregory and Northcote (1993)*

* laboratory study
** field study

Table 4 (cont.). Some reported effects of turbidity and suspended sediment concentrations on salmonids: 2001 Update. This table is derived from Lloyd (1987).

Effect	**Species (life stage)**	**Location**	**Reported turbidity or suspended sediment concentration**	**Reference**
Feeding rates	Chinook salmon (juvenile)	British Columbia	Increased rates on surface and benthic prey in conditions of moderate turbidity (18-150 NTU) compared with lower (<1 NTU) or higher 370-810 NTU	Gregory (1992)*
Feeding rates	Chinook salmon (juvenile)	British Columbia	Above 150 NTU, juvenile chinook exhibit reduced feeding regardless of prey type and forager size	Gregory (1992)*
Feeding rates	Bluegills	North Carolina	14 prey per minute in clear water to 1, 10, 7 per minute in pools of 60, 120, and 190 NTU. Size selectivity independent	Gardner (1981)*
Gill trauma	Sockeye salmon (underyearling)	British Columbia	3,148 mg/l or 0.2 of the 96 h LC50 Value	Servizi and Martens (1987)*
Homing	Chinook salmon (adult)	Washington	Strong baseline preference for clean (ash-free) home water over a clean non-natal water source	Whitman et al. (1982)**
Impairment in hypo-osmoregulatory capacity	Sockeye salmon (underyearling)	British Columbia	Exposed 96 h to 14,407 mg/l of fine sediment	Servizi and Martens (1987)*
Percentage of prey ingested	Coho salmon (juvenile)	British Columbia	30 and 60 NTU	Berg and Northcote (1985)*
Plasma glucose increase	Sockeye salmon (underyearling)	British Columbia	Increased 150 and 39% from exposure to 1,500 and 500 mg/l of fine sediment	Servizi and Martens (1987)*

* laboratory study
** field study

Table 4 (cont.) . Some reported effects of turbidity and suspended sediment concentrations on salmonids: 2001 Update. This table is derived from Lloyd (1987).

Effect	Species (life stage)	Location	Reported turbidity or suspended sediment concentration	Reference
Predation rates	Chinook salmon (juvenile), chum, sockeye, cutthroat trout	British Columbia	Mean predation rates were 10-75% lower than those in controls (no vegetation and clear water); addition of turbidity reduced effect	Gregory and Levings (1996)*
Predator avoidance	Chinook salmon (juvenile)	British Columbia	In absence of risk, juvenile chinook were distributed randomly in 23 NTU, at bottom in clear water– with risk, all at bottom, and responses less marked and of shorter duration	Gregory (1993)*
Prey abundance	N/A	Columbia River Estuary	Reduction in amphipods in substrate with surface layer of ash	Brzezinski and Holton (1981)**
Prey abundance	N/A	Northwest Territories	Sediment addition increased total drift of invertebrates (avoidance reaction)	Rosenberg and Wiens (1978)**
Reaction distance	Coho salmon (juvenile)	British Columbia	30 and 60 NTU	Berg and Northcote (1985)*
Reaction distance	Chinook salmon (juvenile)	British Columbia	Decline with increasing turbidity	Gregory and Northcote (1993)*

* laboratory study
** field study

Table 4 (cont.). Some reported effects of turbidity and suspended sediment concentrations on salmonids: 2001 Update. This table is derived from Lloyd (1987).

Effect	**Species (life stage)**	**Location**	**Reported turbidity or suspended sediment concentration**	**Reference**
Reaction distance	Adult lake trout	Utah	Reaction distance increased w/ increasing light - <25 cm at .17 1x to about 100 cm at light threshold of 17.8 1x., declined with turbidity - > 80% of decline in reaction distance occurred over 0-5 NTU	Vogel and Beauchamp (1999)*
Reactive Distance	Rainbow Trout	Georgia	Reactive distances in 15 and 30 NTU treatments were only 80 and 45% respectively of those observed at ambient turbidities 4-6 NTU.	Barrett and Rosenfeld (1992)*
Reduced Growth	Coho salmon (juvenile)	Oregon	Significant decrease in fish production when fine sediments were 26-31% by volume	Crouse et al. (1981)*
Reduction in prey	Chinook salmon (juvenile)	Washington	Reduced appearance of highly utilized amphipod Corophium salmonis.	McCabe et al. (1981)**
Relation of turbidity and suspended solids	N/A	Alaska	Depth to which 1% of subsurface light penetrates has inverse correlation with sediment-induced turbidity	Lloyd et al. (1987)**
Stress (Gill Flaring)	Coho salmon (juvenile)	British Columbia	Increased at 30 and 60 NTU	Berg and Northcote (1985)*

* laboratory study
** field study

Table 4 (cont.). Some reported effects of turbidity and suspended sediment concentrations on salmonids: 2001 Update. This table is derived from Lloyd (1987).

Effect	**Species (life stage)**	**Location**	**Reported turbidity or suspended sediment concentration**	**Reference**
Stress (increased plasma cortisol)	Coho salmon and steelhead (yearlings)	Oregon	When exposed to 2-3 g/L of topsoil, 7-8 days	Redding et al. (1987)*
Stress (blood hematrocrits and plasma cortisol)	Coho salmon and steelhead (yearlings)	Oregon	Increased in fish exposed to high concentrations for two days, topsoil, kaolin clay, or ash.	Redding et al. (1987)*
Stress (resistance to bacterial pathogen)	Yearling steelhead and coho	Oregon	Vibrio anguillarum	Redding et al. (1987)*
Territoriality	Coho salmon (juvenile)	British Columbia	Territoriality ceases with 60 NTU pulse – re-established at 20 NTU – lateral displays minimized	Berg (1982)*

* laboratory study
** field study

APPENDIX C

DATA COMPILATION OF THE DOSE RESPONSE EFFECTS OF SUSPENDED SEDIMENT

(Source: Berry et al. 2003)

Appendix C

Available data on the effects of suspended sediments on biota. Data take from the original literature (unless otherwise noted) or Newcombe and Jensen (1996: "N&J")

Key:

Life Stage: A = Adult, J = Juvenile, L = Larval
Concentration: Material is listed if known: k = kaolin, ns = natural sediment
Source: Original data consulted unless otherwise noted. N&J = Newcombe and Jensen, 1996.
Duration: Duration is in hours unless otherwise noted. d = days. f = field studies.

SPECIES	Life Stage	Concentration in mg/l	Dura- tion in Hours	EFFECT (Response)	REFERENCE	Source
MOLLUSCA						
Eastern oyster *Crassostrea virginica*	L	400	12 d	10% mortality	Davis and Hidu 1969	
“ ”	L	500	12 d	18% mortality	“ ”	
	L	750	12 d	reduced growth		
	L	750	12 d	30% mortality		
	L	1000	12 d	40% mortality		
	L	1500	12 d	58 % mortality		
	L	2000	12 d	75% mortality		
	L	3000	12 d	99 % mortality		
Pacific Oyster *Cassostrea gigas*	L	$1200	2 d	abnormal shell development	Cardwell et. al. 1976	
	L	$800	2 d	50% mortality		
Hard Clam *Mercenaria mercenaria*	L	$750	10 d	10% mortality	Davis and Hidu 1969	
	L	3000	10 d	15% mortality		
	L	4000	11 d	30% mortality		
Eastern Oyster *Crassostrea virginica*	A	$1000	2 d	reduced pumping	Loosanoff, 1962	
Soft Shell Clam *Mya arenaria*	A	100	35 d	reduced growth	Grant and Murphy 1985	
Hard Clam *Mercenaria mercenaria*	A	27	14 d	reduced growth	Murphy, 1985	
“ ”	A	100	2 d	reduced growth	Turner and Miller, 1991	
“ ”	J	44	21 d	reduced growth	Bricelj et al.,1984	
Coast Mussels *Mytilus californiamus*	A	8100	17 d	10% mortality	Peddicord, 1980	
“ ”	J	15500	16 d	20-14% mortality	“ ”	
“ ”	A	80000	11 d	50% mortality	“ ”	
“ ”	A	85000	9 d	50% mortality	“ ”	
Blue Mussel *Mytilus edulis*	A	15000	8 d	0-20% mortality	Peddicord, 1976	

“ ”	J	100000	5 d	10% mortality	McFarland and Peddicors, 1980	
	A	60000	10 d	10% mortality	Wakeman et al., 1975	
Surf Clam *Spisula solidissima*	A	500	21 d	reduced growth	Robinson et al.,1984	
Bay Scallop *Argopecten irradians*	A	500	7 d	increased respiration	Morre, 1978	
“ ”	A	1000	7 d	increased respiration	“ ” “	
CRUSTACEA						
Sand Shrimp *Crangon nirgomaculata*		16000	8 d	10%mortality	Mc Farland and Peddicord 1980	
“ ”		50000	8 d	50% mortality	“ ”	
Grass Shrimp *Paleomon macrodactylus*		24000 (k)	10 d	10% mortality	“ ”	
“ ”		77000 (k)	8 d	20% mortality	“ ”	
Dungeness Crab *Cancer magister*		9200 (ns)	8 d	5% mortality	Peddicord and McFarland, 1976	
“ ”		11700 (ns)	7 d	20% mortality	“ ”	
“ ” juvenile	J	15900 (ns)	9 d	15% mortality	“ ”	
“ ” “	J	18900 (ns)	4 d	20% mortality	“ ”	
“ ” adult	A	10000 (k)	8 d	10% mortality	McFarland and Peddicord, 1980	
“ ” “	A	32000 (k)	8 d	50% mortality	“ ”	
Kuruma Prawn *Penaeus japonicus*	J	180 (ns)	21 d	10% mortality	Lin et al., 1992	
“ ”	J	370 (ns)	21 d	32% mortality	“ ”	
Black-tailed Sand Shrimp *Cragnon nigrocauda*		11900 (ns)	5 d	10% mortality	Peddicord, 1990	
“ ”		4300 (ns)	3 d	5% mortality	“ ”	
“ ”		9000 (b)	10 d	10% mortality	Wakeman et al. 1975	
Mysid Shrimp *Mysidopsis bahia*		230 (ns)	28 d	40 % mortality	Nimmo et al. 1982	

“ ”		1020 (ns)	28 d	60-80% mortality	“ ”	
Copepod *Eurytmora affinis*		>350 (ns)	f	reduced population growth	Sellner and Bundy, 1986	
Copepod		>100 (ns)	f	reduced vertical migration	Daborn and Brylinsky, 1981	
Copepod *Acartia tonsa*		>95 (ns)	f	reduced feeding	Tester and Turner, 1988	
Copepod *A.tonsa, E. affinis*		>250	f	reduced feeding	Sherk et al., 1976	
Daphnids		50-100 (ns)	<18 d	reduced feeding	Arruda et al., 1983	
Benthic Algae		2.0-4.2	f	decrease in biomass, growth	Wilson et al., 1999	
Freshwater Mussels		600-750 (ns)	f	decreased filter clearance	Aldridge et al., 1987	
Red Algae *Lemanea*		5000 (ns)	21 d	reduced primary production	Thirb and Benson-Evans 1985	
“ ” *Egeria*		30-40 (ns)	40 d	reduced growth	Tanner et al. 1993	
Oyster *Crassostrea virginica*		100	f	reduced pumping	Sherk et al. 1975	
FISH						
Adult salmonids and rainbow smelt						
Grayling (Arctic)	A	100	0.10	Fish avoided turbid water	Suchanek et al. (1984a, 1984b)	N & J
	A	100	1,008	Fish had decreased resistance to environmental stress	McLeay et al. (1984)	N & J
	A	100	1,008	Impaired feeding		N & J
Salmon	A	25	4	Feeding activity reduced	Phillips (1970)	N & J
	A	16.5	24	Feeding behavior apparently educed	Townsend (1983); Ott (1984)	N & J
	A	1,650	240	Loss of habitat caused by excessive sediment transport	Coats et al. (1985)	N & J
Salmon (Atlantic)	A	2,500	24	Increased risk of predation	Gibson (1933)	N & J

Salmon (chinook)	A	650	168	No histological signs of damage to olfactory epithelium	Brannon et al. (1981)	N & J
Salmon (chinook)	A	350	0.17	Home water preference disrupted	Whitman et al. (1982)	N & J
Salmon (chinook)	A	650	168	Homing behavior normal, but fewer test fish returned	Whitman et al. (1982)	N & J
Salmon (chinook)	A	39,300	24	No mortality (VA, <5-100 um; median, <15 um)	Newcomb and Flagg (1983)	N & J
Salmon (chinook)	A	82,400	6	Mortality rate 60% (VA, <5-100 um)	Newcomb and Flagg (1983)	N & J
Salmon (chinook)	A	207,000	1	Mortality rate 100% (VA, <5-100 um)	Newcomb and Flagg (1983)	N & J
Salmon (Pacific)	A	525	588	No mortality (other end points not investigated)	Griffin (1938)	N & J
Salmon (sockeye)	A	500	96	Plasma glucose levels increased 39%	Servizi and Martens (1987)	N & J
Salmon (sockeye)	A	1,500	96	Plasma glucose levels increased 150%	Servizi and Martens (1987)	N & J
Salmon (sockeye)	A	39,300	24	No mortality (VA, <5-100 um; median, <15 um)	Newcomb and Flagg (1983)	N & J
Salmon (sockeye)	A	82,400	6	Mortality rate 60% (VA, <5-100 um; median, <15 um)	Newcomb and Flagg (1983)	N & J
Salmon (sockeye)	A	207,000	1	Mortality rate 100% (VA)	Newcomb and Flagg (1983)	N & J
Smelt (rainbow)	A	3.5	168	Increased vulnerability to predation	Swenson (1978)	N & J
Steelhead	A	500	3	Signs of sublethal stress (VA)	Redding and Schreck (1982)	N & J
Steelhead	A	1,650	240	Loss of habitat caused by excessive sediment transport	Coats et al. (1985)	N & J
Steelhead	A	500	9	Blood cell count and blood chemistry change	Redding and Schreck (1982)	N & J
Trout	A	16.5	24	Feeding behavior apparently reduced	Townsend (1983); Ott (1984)	N & J
Trout	A	75	168	Reduced quality of rearing habitat	Slaney et al. (1977b)	N & J

Trout	A	270	312	Gill tissue damaged	Herbert and Merkens (1961)	N & J
Trout	A	525	588	No mortality (other end points not investigated)	Griffin (1938)	N & J
Trout	A	300	720	Decrease in population size	Peters (1967)	N & J
Trout (brook)	A	4.5	168	Fish more active and less dependent on cover	Gradall and Swenson (1982)	N & J
Trout (brown)	A	1,040	17,520	Gill lamellae thickened (VFSS)	Herbert et al. (1961)	N & J
Trout (brown)	A	1,210	17,520	Some gill lamellae became fused (VFSS)	Herbert et al. (1961)	N& J
Trout (brown)	A	18	720	Abundance reduced	Peters (1967)	N & J
Trout (brown)	A	100	720	Population reduced	Scullion and Edwards (1980)	N & J
Trout (brown)	A	1,040	8.760	Population one-seventh of expected size (River Fal)	Herbert et al. (1961)	N & J
Trout (brown)	A	5,838	8,760	Fish numbers one-seventh of expected size (River Par)	Herbert et al. (1961)	N & J
Trout (cutthroat)	A	35	2	Feeding ceased; fish sought cover	Cordone and Kelly (1961)	N & J
Trout (lake)	A	3.5	168	Fish avoided turbid areas	Swenson (1978)	N & J
Trout (rainbow)	A	66	1	Avoidance behavior manifested part of the time	Lawrence and Scherer (1974)	N & J
Trout (rainbow)	A	665	1	Fish attracted to turbidity	Lawrence and Scherer (1974)	N & J
Trout (rainbow)	A	100	0.10	Fish avoided turbid water (avoidance behavior)	Suchanek et al. (1984a, 1984b)	N & J
Trout (rainbow)	A	100	0.25	Rate of coughing increased (FSS)	Hughes (1975)	N & J
Trout (rainbow)	A	250	0.25	Rate of coughing increased (FSS)	Hughes (1975)	N & J
Trout (rainbow)	A	810	504	Gills of fish that survived had thickened epithelium	Herbert and Merkens (1961)	N & J

Trout (rainbow)	A	17,500	168	Fish survived: gill epithelium proliferated and thickened	Slanina (1962)	N & J
Trout (rainbow)	A	50	960	Rate of weight gain reduced (CWS)	Herbert and Richards (1963)	N & J
Trout (rainbow)	A	50	960	Rate of weight gain reduced (WF)	Herbert and Richards (1963)	N & J
Trout (rainbow)	A	810	504	Some fish died	Herbert and Merkens (1961)	N & J
Trout (rainbow)	A	270	3,240	Survival rate reduced	Herbert and Merkens (1961)	N & J
Trout (rainbow)	A	200	24	Test fish began to die on the first day (WF)	Herbert and Richards (1963)	N & J
Trout (rainbow)	A	80,000	24	No mortality	D. Herbert, personal communication to Alabaster and Lloyd (1980)	N & J
Trout (rainbow)	A	18	720	Abundance reduced	Peters (1967)	N & J
Trout (rainbow)	A	59	2,232	Habitat damage; reduced porosity of gravel	Slaney et al. (1977b)	N & J
Trout (rainbow)	A	4,250	588	Mortality rate 50% (CS)	Herbert and Wakeford (1962)	N & J
Trout (rainbow)	A	49,838	96	Mortality rate 50% (DM)	Lawrence and Scherer (1974)	N & J
Trout (rainbow)	A	3,500	1,488	Catastrophic reduction in population size	Herbert and Merkens (1961)	N & J
Trout (rainbow)	A	160,000	24	Mortality rate 100%	D. Herbert, personal communication to Alabaster and Lloyd (1980)	N & J
Trout (sea)	A	210	24	Fish abandoned traditional spawning habitat	Hamilton (1961)	N & J
Whitefish (lake)	A	0.66	1	Swimming behavior changed	Lawrence and Scherer (1974)	N & J

Whitefish (lake)	A	16,613	96	Mortality rate 50% (DM)	Lawrence and Scherer (1974)	N & J
Whitefish (mountain)	A	10,000	24	Fish died; silt-clogged gills	Langer (1980)	N & J
JUVENILE SALMONIDS						
Grayling (Arctic)	U	20	24	Fish avoided parts of the stream	Birtwell et al. (1984)	N & J
Grayling (Arctic)	U	10,000	96	Fish swam near the surface	McLeay et al. (1987)	N & J
Grayling (Arctic)	J	86	0.42	78% of fish avoided turbid water (NTU, <20)	Scannell (1988)	N & J
Grayling (Arctic)	U	100	1	Catch rate reduced (unfamiliar prey: drosophila)	McLeay et al. (1987)	N & J
Grayling (Arctic)	U	100	1	Catch rate reduced (unfamiliar prey: tubificids)	McLeay et al. (1987)	N & J
Grayling (Arctic)	U	300	1	Catch rate reduced (unfamiliar prey: drosophila)	McLeay et al. (1987)	N & J
Grayling (Arctic)	U	1,000	1	Feeding rate reduced (unfamiliar prey: tubificids)	McLeay et al. (1987)	N & J
Grayling (Arctic)	U	1,000	1	Feeding rate reduced (unfamiliar prey: drosophila)	McLeay et al. (1987)	N & J
Grayling (Arctic)	YY	3,810	144	Food intake severely limited	Simmons (1982)	N & J
Grayling (Arctic)	U	100	12	Reduced ability to tolerate high temperatures	McLeay et al. (1987)	N & J
Grayling (Arctic)	U	100	756	Fish moved out of the test	McLeay et al. (1987)	N & J
Grayling (Arctic)	U	1,000	1,008	Fish had frequent misstrikes while feeding	McLeay et al. (1987)	N & J
Grayling (Arctic)	U	1,000	1,008	Fish responded very slowly to prey	McLeay et al. (1987)	N & J
Grayling (Arctic)	U	300	1,008	Rate of feeding reduced	McLeay et al. (1987)	N & J
Grayling (Arctic)	U	1,000	840	Rate of feeding reduced	McLeay et al. (1987)	N & J
Grayling (Arctic)	U	1,000	1,008	Fish failed to consume all prey	McLeay et al. (1987)	N & J

Grayling (Arctic)	U	300	840	Serious impairment of feeding	McLeay et al. (1987)	N & J
Grayling (Arctic)	U	300	1,008	Respiration rate increased (FSS)	McLeay et al. (1987)	N & J
Grayling (Arctic)	U	300	1,008	Fish less tolerant of pentachlorophenol	McLeay et al. (1987)	N & J
Grayling (Arctic)	YY	3,810	144	Mucus and sediment accumulated in the gill lamellae	Simmons (1982)	N & J
Grayling (Arctic)	YY	3,810	144	Fish displayed many signs of poor condition	Simmons (1982)	N & J
Grayling (Arctic)	YY	1,250	48	Moderate damage to gill tissue	Simmons (1982)	N & J
Grayling (Arctic)	YY	1,388	96	Hyperplasia and hypertrophy of gill tissue	Simmons (1982)	N & J
Grayling (Arctic)	U	100	1,008	Growth rate reduced	McLeay et al. (1984)	N & J
Grayling (Arctic)	U	100	840	Fish responded less rapidly to drifting food	McLeay et al. (1987)	N & J
Grayling (Arctic)	U	300	1,008	Weight gain reduced	McLeay et al. (1987)	N & J
Grayling (Arctic)	U	1,000	1,008	Weight gained reduced by 33%	McLeay et al. (1987)	N & J
Grayling (Arctic)	U	300	756	Fish displaced from their habitat	McLeay et al. (1987))	N & J
Grayling (Arctic)	U	100,000	168	No changes in gill histology (not an end point)	McLeay et al. (1983)	N & J
Salmon (chinook)	S	943	72	Tolerance to stress reduced (VA)	Stober et al. (1981)	N & J
Salmon (chinook)	J	6	1,440	Growth rate reduced (LNFH)	MacKinley et al. (1987)	N & J
Salmon (chinook)	J	1,400	36	Mortality rate 50%	Newcomb and Flagg (1983)	N & J
Salmon (chinook)	J	9,400	36	Mortality rate 50%	Newcomb and Flagg (1983)	N & J
Salmon (chinook)	S	488	96	Mortality rate 50%	Stober et al. (1981)	N & J
Salmon (chinook)	S	11,000	96	Mortality rate 50%	Stober et al. (1981)	N & J
Salmon (chinook)	S	19,364	96	Mortality rate 50%	Stober et al. (1981)	N & J
Salmon (chinook)	J	39,400	36	Mortality rate 90% (VA)	Newcomb and Flagg (1983)	N & J
Salmon (chum)	J	28,000	96	Mortality rate 50%	Smith (1940)	N & J

Salmon (chum)	J	55,000	96	Mortality rate 50% (winter)	Smith (1940)	N & J
Salmon (coho)	J	53.5	0.02	Alarm reaction	Berg (1983)	N & J
Salmon (coho)	J	88	0.02	Alarm reaction	Bisson and Bilby (1982)	N & J
Salmon (coho)	U	20	0.05	Cough frequency not increased	Servizi and Martens (1992)	N & J
Salmon (coho)	J	53.5	12	Changes in territorial behavior	Berg and Northcote (1985)	N & J
Salmon (coho)	J	88	0.08	Avoidance behavior	Bisson and Bilby (1982)	N & J
Salmon (coho)	J	6,000	1	Avoidance behavior	Noggle (1978)	N & J
Salmon (coho)	U	300	0.17	Avoidance behavior within minutes	Servizi and Martens (1992)	N & J
Salmon (coho)	J	25	1	Feeding rate decreased	Noggle (1978)	N & J
Salmon (coho)	J	100	1	Feeding rate decreased to 55% of maximum	Noggle (1978)	N & J
Salmon (coho)	J	250	1	Feeding rate decreased to 10% of maximum	Noggle (1978)	N & J
Salmon (coho)	J	300	1	Feeding ceased	Noggle (1978)	N & J
Salmon (coho)	U	2,460	0.05	Coughing behavior manifest within minutes	Servizi and Martens (1992)	N & J
Salmon (coho)	J	53.5	12	Increased physiological stress	Berg and Northcote (1985)	N & J
Salmon (coho)	U	2,460	1	Cough frequency greatly increased	Servizi and Martens (1992)	N & J
Salmon (coho)	U	240	24	Cough frequency increased more than 5-fold	Servizi and Martens (1992)	N & J
Salmon (coho)	U	530	96	Blood glucose levels increased	Servizi and Martens (1992)	N & J
Salmon (coho)	J	1,547	96	Gill damage	Noggle (1978)	N & J
Salmon (coho)	U	2,460	24	Fatigue of the cough reflex	Servizi and Martens (1992)	N & J

Salmon (coho)	U	3,000	48	High level sublethal stress; avoidance	Servizi and Martens (1992)	N & J
Salmon (coho)	J	102	336	Growth rate reduced (FC, BC)	Sigler et al. (1984)	N & J
Salmon (coho)	U	8,000	96	Mortality rate 1%	Servizi and Martens (1991)	N & J
Salmon (coho)	J	1,200	96	Mortality rate 50%	Noggle (1978)	N & J
Salmon (coho)	J	35,000	96	Mortality rate 50%	Noggle (1978)	N & J
Salmon (coho)	U	22,700	96	Mortality rate 50%	Servizi and Martens (1991)	N & J
Salmon (coho)	F*	8,100	96	Mortality rate 50%	Servizi and Martens (1991)	N & J
Salmon (coho)	PS	18,672	96	Mortality rate 50%	Stober et al. (1981)	N & J
Salmon (coho)	S	509	96	Mortality rate 50%	Stober et al. (1981)	N & J
Salmon (coho)	S	1,217	96	Mortality rate 50% (VA)	Stober et al. (1981)	N & J
Salmon (coho)	S	28,184	96	Mortality rate 50% (VA)	Stober et al. (1981)	N & J
Salmon (coho)	S	29,580	96	Mortality rate 50%	Stober et al. (1981)	N & J
Salmon (sockeye)	S	1,261	96	Body moisture content reduced	Servizi and Martens (1987)	N & J
Salmon (sockeye)	S	7,447	96	Plasma chloride levels increased slightly	Servizi and Martens (1987)	N & J
Salmon (sockeye)	U	1,465	96	Hypertrophy and necrosis of gill tissue (CSS)	Servizi and Martens (1987)	N & J
Salmon (sockeye)	U	3,143	96	Hypertrophy and necrosis of gill tissue (FSS)	Servizi and Martens (1987)	N & J
Salmon (sockeye)	U	9,851	96	Hypertrophy and necrosis of gill tissue (MCSS)	Servizi and Martens (1987)	N & J
Salmon (sockeye)	U	17,560	96	Hypertrophy and necrosis of gill tissue (FSS)	Servizi and Martens (1987)	N & J

Salmon (sockeye)	U	23,790	96	Hypertrophy and necrosis of gill tissue (FSS)	Servizi and Martens (1987)	N & J
Salmon (sockeye)	U	2,688	96	Hypertrophy and necrosis of gill tissue (MCSS)	Servizi and Martens (1987)	N & J
Salmon (sockeye)	U	2,100	96	No fish died (MFSS)	Servizi and Martens (1987)	N & J
Salmon (sockeye)	U	9,000	96	No mortality	Servizi and Martens (1987)	N & J
Salmon (sockeye)	U	13,900	96	Mortality rate 10% (FSS)	Servizi and Martens (1987)	N & J
Salmon (sockeye)	U	9,850	96	Gill hyperplasia, hypertrophy, separation, necrosis (MFSS)	Servizi and Martens (1987)	N & J
Salmon (sockeye)	J	1,400	36	Mortality rate 50%	Newcomb and Flagg (1983)	N & J
Salmon (sockeye)	J	9,400	36	Mortality rate 50%	Newcomb and Flagg (1983)	N & J
Salmon (sockeye)	U	1,700	96	Mortality rate 50% (CSS)	Servizi and Martens (1987)	N & J
Salmon (sockeye)	U	4,850	96	Mortality rate 50% (MCSS)	Servizi and Martens (1987)	N & J
Salmon (sockeye)	U	8,200	96	Mortality rate 50% (MFSS)	Servizi and Martens (1987)	N & J
Salmon (sockeye)	U	17,560	96	Mortality rate 50% (FSS)	Servizi and Martens (1987)	N & J
Salmon (sockeye)	J	39,400	36	Mortality rate 90% (VA)	Newcomb and Flagg (1983)	N & J
Salmon (sockeye)	U	13,000	96	Mortality rate 90% (MFSS)	Servizi and Martens (1987)	N & J
Salmon (sockeye)	U	23,900	96	Mortality rate 90% (FSS)	Servizi and Martens (1987)	N & J
Steelhead	J	102	336	Growth rate reduced (FC, BC)	Sigler et al. (1984)	N & J
Trout (brook)	FF	12	5,880	Growth rates declined	Sykora et al. (1972)	N & J
Trout (brook)	FF	24	5,208	Growth rate reduced (LNFH)	Sykora et al. (1972)	N & J

Trout (brook)	FF*	100	1,176	Test fish weighed 16% of controls (LNFH)	Sykora et al. (1972)	N & J
Trout (brook)	FF	50	1,848	Growth rates declined (LNFH)	Sykora et al. (1972)	N & J
Trout (rainbow)	FF	1,750	480	Mortality rate 57% (controls 5%)	Campbell (1954)	N & J
Trout (rainbow)	J	4,887	384	Hyperplasia of gill tissue	Goldes (1983)	N & J
Trout (rainbow)	J	4,887	384	Parasitic infection of gill tissue	Goldes (1983)	N & J
Trout (rainbow)	J	171	96	Particles penetrated cells of branchial epithelium	Goldes (1983)	N & J
Trout (rainbow)	Y	90	456	Mortality rates 0-20% (DE)	Herbert and Merkens (1961)	N & J
Trout (rainbow)	Y	90	456	Mortality rates 0-15% (KC)	Herbert and Merkens (1961)	N & J
Trout (rainbow)	Y	270	456	Mortality rates 10-35% (KC)	Herbert and Merkens (1961)	N & J
Trout (rainbow)	Y	810	456	Mortality rates 35-85% (DE)	Herbert and Merkens (1961)	N & J
Trout (rainbow)	Y	810	456	Mortality rates 5-80% (KC)	Herbert and Merkens (1961)	N & J
Trout (rainbow)	Y	270	456	Mortality rates 25-80% (DE)	Herbert and Merkens (1961)	N & J
Trout (rainbow)	Y	7,433	672	Mortality rate 40% (CS)	Herbert and Wakeford (1962)	N & J
Trout (rainbow)	Y	4,250	672	Mortality rate 50%	Herbert and Wakeford (1962)	N & J
Trout (rainbow)	Y	2,120	672	Mortality rate 100%	Herbert and Wakeford (1962)	N & J
Trout (rainbow)	J	4,315	57	Mortality rate ~ 100% (CSS)	Newcombe et al. (1995)	N & J
SALMONID EGGS AND LARVAE						

Grayling (Arctic)	SF	25	24	Mortality rate 5.7%	J. LaPerriere (personal communication)	N & J
Grayling (Arctic)	SF	22.5	48	Mortality rate 14.0%	J. LaPerriere (personal communication)	N & J
Grayling (Arctic)	SF	65	24	Mortality rate 15.0%	J. LaPerriere (personal communication)	N & J
Grayling (Arctic)	SF	21.7	72	Mortality rate 14.7%	J. LaPerriere (personal communication)	N & J
Grayling (Arctic)	SF	20	96	Mortality rate 13.4%	J. LaPerriere (personal communication)	N & J
Grayling (Arctic)	SF	142.5	48	Mortality rate 26%	J. LaPerriere (personal communication)	N & J
Grayling (Arctic)	SF	185	72	Mortality rate 41.3%	J. LaPerriere (personal communication)	N & J
Grayling (Arctic)	SF	230	96	Mortality rate of 47%	J. LaPerriere (personal communication)	N & J
Salmon	E	117	960	Mortality; deterioration of spawning gravel	Cederholm et al. (1981)	N & J
Salmon (chum)	E	97	2,808	Mortality rate 77% (controls, 6%)	Langer (1980)	N & J
Salmon (coho)	E	157	1,728	Mortality rate 100% (controls, 16.2%)	Shaw and Maga (1943)	N & J
Steelhead	E	37	1,488	Hatching success 42% (controls, 63%)	Slaney et al. (1977b)	N & J
Trout	E	117	960	Mortality; deterioration of spawning gravel	Cederholm et al. (1981)	N & J
Trout (rainbow)	EE	1,750	144	Mortality rate greater than controls (controls, 6%)	Campbell (1954)	N & J
Trout (rainbow)	E	6.6	1,152	Mortality rate 40%	Slaney et al. (1977b)	N & J
Trout (rainbow)	E	57	1,488	Mortality rate 47% (controls, 32%)	Slaney et al. (1977b)	N & J

Trout (rainbow)	E	120	384	Mortality rates 60-70% (controls, 38.6%)	Erman and Lignon (1988)	N & J
Trout (rainbow)	E	20.8	1,152	Mortality rate 72%	Slaney et al. (1977a)	N & J
Trout (rainbow)	E	46.6	1,152	Mortality rate 100%	Slaney et al. (1977b)	N & J
Trout (rainbow)	E	101	1,440	Mortality rate 98% (controls, 14.6%)	Turnpenny and Williams (1980)	N & J
NONSALMONID EGGS AND LARVAE						
Bass (striped)	L	200	0.42	Feeding rate reduced 40%	Breitburg (1988)	N & J
Bass (striped)	E	800	24	Development rate slowed significantly	Morgan et al. (1983)	N & J
Bass (striped)	E	100	24	Hatching delayed	Schubel and Wang (1973)	N & J
Bass (striped)	E	1,000	168	Reduced hatching success	Auld and Schubel (1978)	N & J
Bass (striped)	L	1,000	68	Mortality rate 35% (controls, 16%)	Auld and Schubel (1978)	N & J
Bass (striped)	L	500	72	Mortality rate 42% (controls, 17%)	Auld and Schubel (1978)	N & J
Bass (striped)	L	485	24	Mortality rate 50%	Morgan et al. (1973)	N & J
Herring	L	10	3	Depth preference changed	Johnson and Wildish (1982)	N & J
Herring (lake)	L	16	24	Depth preference changed	Swenson and Matson (1976)	N & J
Herring (Pacific)	L	2,000	2	Feeding rate reduced	Boehlert and Morgan (1985)	N & J
Herring (Pacific)	L	1,000	24	Mechanical damage to epidermis	Boehlert (1984)	N & J
Herring (Pacific)	L	4,000	24	Epidermis punctured; microridges less distinct	Boehlert (1984)	N & J
Perch (white)	E	800	24	Egg development slowed significantly	Morgan et al. (1983)	N & J
Perch (white)	E	100	24	Hatching delayed	Schubel and Wang (1973)	N & J

Perch (white)	E	1,000	168	Reduced hatching success	Auld and Schubel (1978)	N & J
Perch (white)	L	155	48	Mortality rate 50%	Morgan et al. (1973)	N & J
Perch (white)	L	373	24	Mortality rate 50%	Morgan et al. (1973)	N & J
Perch (white)	L	280	48	Mortality rate 50%	Morgan et al. (1973)	N & J
Perch (yellow)	L	500	96	Mortality rate 37% (controls, 7%)	Auld and Schubel (1978)	N & J
Perch (yellow)	L	1,000	96	Mortality rate 38% (controls, 7%)	Auld and Schubel (1978)	N & J
Shad (American)	L	100	96	Mortality rate 18% (controls, 5%)	Auld and Schubel (1978)	N & J
Shad (American)	L	500	96	Mortality rate 36% (controls, 4%)	Auld and Schubel (1978)	N & J
Shad (American)	L	1,000	96	Mortality rate 34% (controls, 5%)	Auld and Schubel (1978)	N & J
ADULT NONSALMONIDS						
Anchovy (bay)	A	231	24	Mortality rate 10% (FE)	Sherk et al. (1975)	N & J
Anchovy (bay)	A	471	24	Mortality rate 50% (FE)	Sherk et al. (1975)	N & J
Anchovy (bay)	A	960	24	Mortality rate 90%	Sherk et al. (1975)	N & J
Bass (striped	A	1,500	336	Haematocrit increased (FE)	Sherk et al. (1975)	N & J
Bass (striped)	A	1,500	336	Plasma osmolality increased (FE)	Sherk et al. (1975)	N & J
Cunner	A	28,000	24	Mortality rate 50% (20.0-25.0° C)	Rogers (1969)	N & J
Cunner	A	133,000	12	Mortality rate 50% (15°C)	Rogers (1969)	N & J
Cunner	A	100,000	24	Mortality rate 50% (15°C)	Rogers (1969)	N & J
Cunner	A	72,000	48	Mortality rate 50% (15°C)	Rogers (1969)	N & J
Fish	A	3,000	240	Fish died	Kemp (1949)	N & J

Herring (Atlantic)	A	20	3	Reduced feeding rate	Johnson and Wildish (1982)	N & J
Hogchoker	A	1,240	24	Energy utilization increased	Sherk et al. (1975)	N & J
Hogchoker	A	1,240	120	Erythrocyte count increased	Sherk et al. (1975)	N & J
Hogchoker	A	1,240	120	Haematocrit increased	Sherk et al. (1975)	N & J
Killifish (striped)	A	960	120	Haematocrit increased	Sherk et al. (1975)	N & J
Killifish (striped)	A	3,277	24	Mortality rate 10% (FE)	Sherk et al. (1975)	N & J
Killifish (striped)	A	9,720	24	Mortality rate 10%	Sherk et al. (1975)	N & J
Killifish (striped)	A	3,819	24	Mortality rate 50%	Sherk et al. (1975)	N & J
Killifish (striped)	A	12,820	24	Mortality rate 50%	Sherk et al. (1975)	N & J
Killifish (striped)	A	16,930	24	Mortality rate 90%	Sherk et al. (1975)	N & J
Killifish (striped)	A	6,136	24	Mortality rate 90%	Sherk et al. (1975)	N & J
Menhaden (Atlantic)	A	154	24	Mortality rate 10% (FE)	Sherk et al. (1975)	N & J
Menhaden (Atlantic)	A	247	24	Mortality rate 50% (FE)	Sherk et al. (1975)	N & J
Menhaden (Atlantic)	A	396	24	Mortality rate 90% (FE)	Sherk et al. (1975)	N & J
Minnow (sheepshead)	A	200,000	24	Mortality rate 10% (15°C)	Rogers (1969)	N & J
Minnow (sheepshead)	A	300,000	24	Mortality rate 30% (10°C)	Rogers (1969)	N & J
Minnow (sheepshead)	A	100,000	24	Mortality rate 90% (19°C)	Rogers (1969)	N & J
Mummichog	A	300,000	24	No mortality (15°C)	Rogers (1969)	N & J
Mummichog	A	2,447	24	Mortality rate 10% (FE)	Sherk et al. (1975)	N & J
Mummichog	A	3,900	24	Mortality rate 50% (FE)	Sherk et al. (1975)	N & J
Mummichog	A	6,217	24	Mortality rate 90%	Sherk et al. (1975)	N & J
Perch (white)	A	650	120	Haematocrit increased	Sherk et al. (1975)	N & J

Perch (white)	A	650	120	Erythrocyte count increased	Sherk et al. (1975)	N & J
Perch (white)	A	650	120	Hemoglobin concentration increased	Sherk et al. (1975)	N & J
Perch (white)	A	305	120	Gill tissue may have been damaged	Sherk et al. (1975)	N & J
Perch (white)	A	650	120	Histological damage to gill tissue	Sherk et al. (1975)	N & J
Perch (white)	A	305	24	Mortality rate 10% (FE)	Sherk et al. (1975)	N & J
Perch (white)	A	985	24	Mortality rate 50%	Sherk et al. (1975)	N & J
Perch (white)	A	3,181	24	Mortality rate 90% (FE)	Sherk et al. (1975)	N & J
Rasbora (harlequin)	A	40,000	24	Fish died (BC)	Alabaster and Lloyd (1980)	N & J
Rasbora (harlequin)	A	6,000	168	No mortality	Alabaster and Lloyd (1980)	N & J
Shad (American)	A	150	0.25	Change in preferred swimming depth	Dadswell et al. (1983)	N & J
Silverside (Atlantic)	A	58	24	Mortality rate 10% (FE)	Sherk et al. (1975)	N & J
Silverside (Atlantic)	A	250	24	Mortality rate 50% (FE)	Sherk et al. (1975)	N & J
Silverside (Atlantic)	A	1,000	24	Mortality rate 90% (FE)	Sherk et al. (1975)	N & J
Spot	A	114	48	Mortality rate 10% (FE)	Sherk et al. (1975)	N & J
Spot	A	1,309	24	Mortality rate 10% (FE)	Sherk et al. (1975)	N & J
Spot	A	6,875	24	Mortality rate 10%	Sherk et al. (1975)	N & J
Spot	A	189	48	Mortality rate 50% (FE)	Sherk et al. (1975)	N & J
Spot	A	2,034	24	Mortality rate 50%	Sherk et al. (1975)	N & J
Spot	A	8,800	24	Mortality rate 50%	Sherk et al. (1975)	N & J
Spot	A	317	48	Mortality rate 90% (FE)	Sherk et al. (1975)	N & J
Spot	A	11,263	24	Mortality rate 90%	Sherk et al. (1975)	N & J
Stickleback (four spine)	A	100	24	Mortality rate <1% (IA)	Rogers (1969)	N & J

Stickleback (four spine)	A	10,000	24	No mortality (KS: 10-12°C)	Rogers (1969)	N & J
Stickleback (four spine)	A	300	24	Mortality rate ~50% (IA)	Rogers (1969)	N & J
Stickleback (four spine)	A	18,000	24	Mortality rate 50% (15.0-16.0°C)	Rogers (1969)	N & J
Stickleback (four spine)	A	50,000	24	Mortality rate 50% (KS)	Rogers (1969)	N & J
Stickleback (four spine)	A	53,000	24	Mortality rate 50% (10-12°C)	Rogers (1969)	N & J
Stickleback (four spine)	A	330,000	24	Mortality rate 50% (9.0-9.5°C)	Rogers (1969)	N & J
Stickleback (four spine)	A	500	24	Mortality rate 100%	Rogers (1969)	N & J
Stickleback (four spine)	A	200,000	24	Mortality rate 95% (KS)	Rogers (1969)	N & J
Stickleback (three spine)	A	28,000	96	No mortality in test designed to identify lethal threshold	LeGore and DesVoigne (1973)	N & J
Toadfish (oyster)	A	3,360	1	Oxygen consumption more variable in prestressed fish	Neumann et al. (1975)	N & J
Toadfish (oyster)	A	14,600	72	Fish largely unaffected, but developed latent ill effects	Neumann et al. (1975)	N & J
Toadfish (oyster)	A	11,090	72	Latent ill effects manifested in subsequent test at low SS	Neumann et al. (1975)	N & J
ADULT NONSALMONIDS						
Bass (largemouth)	A	62.5	720	Weight gain reduced ~ 50%	Buck (1956)	N & J
Bass (largemouth)	A	144.5	720	Growth retarded	Buck (1956)	N & J
Bass (largemouth)	A	144.5	720	Fish unable to reproduce	Buck (1956)	N & J
Bluegill	A	423	0.05	Rate of feeding reduced	Gardner (1981)	N & J
Bluegill	A	15	1	Reduced capacity to locate prey	Vinyard and O'Brien (1976)	N & J
Bluegill	A	144.5	720	Growth retarded	Buck (1956)	N & J
Bluegill	A	62.5	720	Weight gain reduced ~ 50%	Buck (1956)	N & J
Bluegill	A	144.5	720	Fish unable to reproduce	Buck (1956)	N & J

Carp (common)	A	25,000	336	Some mortality (MC)	Wallen (1951)	N & J
Darters	A	2,045	8,760	Darters absent	Vaughan (1979); Vaughan et al. (1982)	N & J
Fish	A	120	384	Density of fish reduced	Erman and Lignon (1988)	N & J
Fish	A	620	48	Fish kills downstream from sediment source	Hesse and Newcomb (1982)	N & J
Fish	A	900	720	Fish absent or markedly reduced in abundance	Herbert and Richards (1963)	N & J
Fish	A	2,045	8,760	Habitat destruction; fish populations smaller than expected	Vaughan (1979); Vaughan et al. (1982)	N & J
Fish (warm water)	A	100,000	252	Some fish died; most survived	Wallen (1951)	N & J
Fish (warm water)	A	200,000	1,125	Fish died; opercular cavities and gill filaments clogged	Wallen (1951)	N & J
Fish (warm water)	A	22	8,760	Fish populations destroyed	Menzel et al. (1984)	N & J
Goldfish	A	25,000	336	Some mortality (MC)	Wallen (1951)	N & J
Sunfish (green)	A	9,600	1	Rate of ventilation increased	Horkel and Pearson (1976)	N & J
Sunfish (red ear)	A	62.5	720	Weight gain reduced ~ 50% compared to controls	Buck (1956)	N & J
Sunfish (red ear)	A	144.5	720	Growth retarded	Buck (1956)	N & J
Sunfish (red ear)	A	144.5	720	Fish unable to reproduce	Buck (1956)	N & J