WHITE PAPER

Channel Modifications

Prepared for
Washington Department of Fish and Wildlife

December 2007 Working Draft

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Executive Summary

The Revised Code of Washington (RCW) directs the Washington Department of Fish and Wildlife (WDFW) to "preserve, protect, perpetuate, and manage" the fish and wildlife species of the state as its paramount responsibility (RCW 77.04.012). Under RCW 77.55, any construction or work that uses, diverts, obstructs, or changes the natural bed or flow of state waters requires a Hydraulic Project Approval (HPA) issued by WDFW. The purpose of the HPA program is to ensure that hydraulic projects 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), WDFW is developing a programmatic multispecies Habitat Conservation Plan (HCP) to obtain an Incidental Take Permit (ITP) from the U.S. Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration (NOAA) Fisheries Service (also known as NOAA Fisheries), in accordance with Section 10 of the ESA. For WDFW, the objective is to ensure that activities conducted under an HPA avoid and/or minimize the incidental take of aquatic species potentially considered for coverage under the HCP (referred to in this white paper as "HCP species").

The HCP will address the impacts, potential for take, and mitigation measures for effects on HCP species from hydraulic projects that require HPAs. WDFW's intent is to build the scientific foundation for the effort to prepare an HCP for hydraulic projects that receive HPAs. To accomplish this, WDFW is compiling the best available scientific information related to the impacts, potential for incidental "take" of species that may be covered in the HCP (as defined in the ESA; see Section 9 of this white paper for a definition of "take"), and possible management directives and mitigation measures to avoid and/or minimize potential take to the maximum extent practicable. As the HPA authority covers all waters of the state, this white paper considers hydraulic project impacts in both freshwater and marine environments.

This white paper is one of a suite of white papers prepared to establish the scientific basis for the HCP and to assist WDFW decision-making on what specific HPA activities should be covered by the HCP. This particular white paper compiles and synthesizes existing scientific information on channel modification activities, which in this white paper analysis include dredging, gravel mining and bar scalping, sediment capping, and channel creation and alignment.

The objectives of this white paper are to:

- Compile and synthesize the best available scientific information related to the potential human impacts on HCP species, their habitats, and associated ecological processes resulting from the construction, maintenance, repair, replacement, modification, operation, and removal (hereafter collectively referred to as construction and maintenance) of dredging operations, gravel mining and bar scalping, sediment caps, and channel creation and alignment activities.

- Use this scientific information to estimate the circumstances, mechanisms, and risks of incidental take potentially or likely to result from channel modification activities as defined herein.

- Identify appropriate and practicable measures, including policy directives, conservation measures, and best management practices (BMPs) to avoid, minimize, or mitigate the risk of incidental take of HCP species.

The literature review conducted for this white paper identified seven impact mechanisms that could potentially affect HCP species. These mechanisms of impact are both direct and indirect and can have temporary, short-term effects or permanent, long-term effects. The impact mechanisms analyzed in this white paper are:

- Construction and maintenance activities
- Dredging equipment operation
- Hydraulic and geomorphic modifications
- Riparian vegetation modifications
- Aquatic vegetation modifications
- Water quality modifications.
- Ecosystem fragmentation

This white paper includes a discussion of the potential direct and indirect impacts on the 52 HCP species and their habitats due to exposure to the identified impact mechanisms. Following this discussion, an evaluation of potential for take of the 52 HCP species is included based on a separate analysis conducted using exposure-response matrices for each of the HCP species. This white paper also reviews data gaps and, where there is sufficient information, estimates the risk of take. In addition, habitat protection, conservation, mitigation, and management strategies that could avoid, minimize, or mitigate the identified potential impacts are provided. Key elements of the white paper are to:

- Identify the distribution of the 52 HCP species (i.e., whether they use fresh water, marine water, or both) and their habitat requirements.

- Identify the risk of “take” associated with each of these impact mechanisms based on the distribution information.

- Identify cumulative impacts.

- Identify data gaps.

- Identify habitat protection, conservation, and mitigation strategies.

1.0 Introduction

The Revised Code of Washington (RCW) directs the Washington Department of Fish and Wildlife (WDFW) to “preserve, protect, perpetuate, and manage” the fish and wildlife species of the state as its paramount responsibility (RCW 77.04.012). Under RCW 77.55, any construction or work that uses, diverts, obstructs, or changes the natural bed or flow of state waters requires a Hydraulic Project Approval (HPA) issued by WDFW. The purpose of the HPA program is to ensure that these 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), WDFW is developing a programmatic multispecies Habitat Conservation Plan (HCP) to obtain an Incidental Take Permit (ITP), in accordance with Section 10 of the ESA, from the U.S. Fish and Wildlife Service (USFWS) and the National Oceanic and Atmospheric Administration (NOAA) Fisheries Service (also known as NOAA Fisheries). For WDFW, the benefits of an HCP are to contribute to the long-term conservation of both listed and unlisted species through the minimization and mitigation of impacts on those species and their habitats, while ensuring that WDFW can legally proceed with the issuance of HPAs that might otherwise result in the incidental “take” of ESA-listed species (as defined in the ESA; see Section 9 of this white paper for a definition of “take”).

The HCP will identify the impacts on those aquatic species considered for coverage under the HCP, the potential for take, and mitigation measures for hydraulic projects that require HPAs. This white paper is part of the effort to compile the best available scientific information to protect these species during the construction, maintenance, and operation of channel modifications. To accomplish this, WDFW is analyzing the adequacy of existing rules (Washington Administrative Code [WAC] 220-110), as well as possible management directives and mitigation measures to avoid and/or minimize potential take to the maximum extent practicable. Because the HPA authority covers all waters of the state, this white paper considers hydraulic project impacts in both freshwater and marine environments. This white paper is one of a suite of white papers to establish the scientific basis for the HCP and to assist WDFW decision-making regarding what specific HPA activities should be covered by the HCP and what minimization and mitigation measures can be implemented to address the potential effects of hydraulic projects. This white paper addresses impacts and mitigation/minimization measures to be applied to the construction and maintenance of channel modifications. Species considered for coverage under the HCP (referred to in this white paper as “HCP species”) are listed in Table 1-1. For the purpose of this white paper, some of the HCP species have been grouped where appropriate (and each group is separated by a gray-shaded line in Table 1-1).

Table 1-1. The 52 HCP species addressed in this white paper.

Common Name	Scientific Name	Status[a]	Habitat
Chinook salmon	*Oncorhynchus tshawytscha*	FE/FT/SC	Freshwater, Estuarine, Marine
Coho salmon	*Oncorhynchus kisutch*	FT/FSC	Freshwater, Estuarine, Marine
Chum salmon	*Oncorhynchus keta*	FT/SC	Freshwater, Estuarine, Marine
Pink salmon	*Oncorhynchus gorbuscha*	SPHS	Freshwater, Estuarine, Marine
Sockeye salmon	*Oncorhynchus nerka*	FE/FT/SC	Freshwater, Estuarine, Marine
Steelhead	*Oncorhynchus mykiss*	FE/FT/SC	Freshwater, Estuarine, Marine
Coastal cutthroat trout	*Oncorhynchus clarki clarki*	FSC	Freshwater, Estuarine, Marine
Redband trout	*Oncorhynchus mykiss*	FSC	Freshwater
Westslope cutthroat trout	*Oncorhynchus clarki lewisii*	FSC	Freshwater
Bull trout	*Salvelinus confluentus*	FT/SC	Freshwater, Estuarine
Dolly Varden	*Salvelinus malma*	FP	Freshwater, Estuarine
Pygmy whitefish	*Prosopiim coulteri*	FSC/SS	Freshwater
Olympic mudminnow	*Novumbra hubbsi*	SS	Freshwater
Lake chub	*Couesius plumbeus*	SC	Freshwater
Leopard dace	*Rhinichthys falcatus*	SC	Freshwater
Margined sculpin	*Cottus marginatus*	FSC/SS	Freshwater
Mountain sucker	*Catostomus platyrynchus*	SC	Freshwater
Umatilla dace	*Rhinichthys umatilla*	SC	Freshwater
Pacific lamprey	*Lampetra tridentata*	FSC	Freshwater, Estuarine, Marine
River lamprey	*Lampetra ayresi*	FSC/SC	Freshwater, Estuarine
Western brook lamprey	*Lampetra richardsoni*	FSC	Freshwater
Green sturgeon	*Acipenser medirostris*	SPHS/FSC/FT	Freshwater, Estuarine, Marine
White sturgeon	*Acipenser transmontanus*	SPHS	Freshwater, Estuarine, Marine
Eulachon	*Thaleichthys pacificus*	FC/SC	Estuarine
Longfin smelt	*Spirinchus thaleichthys*	SPHS	Freshwater, Estuarine, Marine
Pacific sand lance	*Ammodytes hexapterus*	SPHS	Marine & Estuarine
Surf smelt	*Hypomesus pretiosus*	SPHS	Marine & Estuarine
Pacific herring	*Clupea harengus pallasi*	FC/SC	Marine & Estuarine
Lingcod	*Ophiodon elongatus*	SPHS	Marine & Estuarine
Pacific cod	*Gadus macrocephalus*	FSC/SC	Marine (occ. Estuarine)
Pacific hake	*Merluccius productus*	FSC/SC	Marine & Estuarine
Walleye pollock	*Theragra chalcogramma*	FSC/SC	Marine (occ. Estuarine)

Table 1-1 (continued). The 52 HCP species addressed in this white paper.

Common Name	Scientific Name	Status[a]	Habitat
Black rockfish	*Sebastes melanops*	SC	Marine
Bocaccio rockfish	*Sebastes paucispinis*	SC	Marine
Brown rockfish	*Sebastes auriculatus*	SC	Marine
Canary rockfish	*Sebastes pinniger*	SC	Marine
China rockfish	*Sebastes nebulosis*	SC	Marine
Copper rockfish	*Sebastes caurinus*	FSC/SC	Marine
Greenstriped rockfish	*Sebastes elongates*	SC	Marine
Quillback rockfish	*Sebastes maliger*	FSC/SC	Marine
Redstripe rockfish	*Sebastes proriger*	SC	Marine
Tiger rockfish	*Sebastes nigrocinctus*	SC	Marine
Widow rockfish	*Sebastes entomelas*	SC	Marine
Yelloweye rockfish	*Sebastes ruberrimus*	SC	Marine
Yellowtail rockfish	*Sebastes flavidus*	SC	Marine
Olympia oyster	*Ostrea lurida*	SPHS	Marine & Estuarine
Northern abalone	*Haliotis kamtschatkana*	FSC/SC	Marine
Newcomb’s littorine snail	*Algamorda subrotundata*	FSC/SC	Marine
Giant Columbia River limpet	*Fisherola nuttalli*	SC	Freshwater
Great Columbia River spire snail	*Fluminicola columbiana*	FSC/SC	Freshwater
California floater (mussel)	*Anodonta californiensis*	FSC/SC	Freshwater
Western ridged mussel	*Gonidea angulata*	None	Freshwater

Notes: For the purpose of this white paper, some of the HCP species have been grouped when appropriate (each group is separated by a gray-shaded line).

[a] Status:

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

2.0 Objectives

The objectives of this white paper are to:

- Compile and synthesize the best available scientific information related to the potential human impacts on HCP species, their habitats, and associated ecological processes resulting from the creation, construction, maintenance, installation, repair, replacement, modification, and removal (hereafter collectively referred to as construction and maintenance) of channel modification structures.

- Use this scientific information to estimate the circumstances, mechanisms, and risks of incidental take potentially or likely resulting from the construction and maintenance of channel modifications.

- Identify appropriate and practicable measures, including policy directives, conservation measures, and best management practices (BMPs), to avoid and/or minimize the risks of incidental take of HCP species.

3.0 Methods

Information presented in this white paper is based primarily on the compilation and synthesis of the best available scientific information related to human impacts on HCP species, their habitats, and associated ecological processes. The methods used here included the acquisition of existing literature, followed by an analysis of impacts based on a review of the literature. The conceptual framework for assessing potential impacts is described in detail in Section 6, and below is a discussion of the literature acquisition and review process.

To acquire literature supporting the best available scientific information, an extensive search of the available literature was conducted using the Thomson Scientific Web of Science (Thomson Scientific Web of Science 2007), which has electronic access to more than 8,500 scientific journals encompassing all fields of environmental science. This yielded several hundred relevant publications, most published within the last 10 years. In addition, literature cited in previous white papers and conference proceedings from the last four Puget Sound–Georgia Basin Research Conferences was reviewed to identify relevant "gray literature" sources. The University of Washington School of Aquatic and Fisheries Sciences, Fisheries Research Institute Reports (UW-FRI) database was also searched (this database that includes more than 500 reports pertaining to research conducted by Fisheries Research Institute personnel from its inception to the present). A thorough search of theses in the Summit system of libraries was performed to locate relevant student work. (Summit is a library catalog that combines information from Pacific Northwest academic libraries, including the Orbis and Cascade systems, into a single database available at URL = http://summit.orbiscascade.org/.) Finally, because this white paper was prepared by a diverse group of scientists from a wide range of backgrounds, many other primary resources (e.g., consultant reports and textbooks) were found in the personal collection of Herrera staff (the consulting firm working with WDFW to prepare this white paper).

To identify data gaps and evaluate the state of scientific knowledge applicable to the potential impacts of channel modification activities on the HCP species and their habitats, the acquired literature was examined to assess the broader issue of how these species use aquatic habitats and how channel modification activities and their construction may alter habitat functions.

Existing literature reviews, peer-reviewed journal articles, books, theses/dissertations, and technical reports were reviewed for information specific to aquatic species and how these species may be affected by channel modification activities. Through this process, a collection of information was assembled on the life history, habitat uses, and the potential impacts that these activities pose to HCP species.

Reference material from each of the above databases was compiled in an Endnote personal reference database (i.e., Endnote version X). Reference types collected and entered into the database included journal articles, reports, web pages, conference proceedings, theses, statutes, books, and book sections. Each entry in the database included descriptive information, including author(s), year, title, volume, pages, and publisher. Whenever an electronic copy of the reference material was available, a link between the reference entry and a PDF copy of the reference material was included in the database. If an electronic (.PDF) copy of a reference was not available, a hardcopy of the material was kept on file. All reference materials cited in the literature review were either linked to the reference database or retained in an associated file as a hardcopy.

Endnote X is the industry standard software for organizing bibliographic information. It features a fully searchable and field-sortable database that can contain an unlimited number of references. Reference information is entered into the database either by direct import from online databases or by manually entering the reference information into reference type templates. Once all the references were entered, the database was used for organizational and archival purposes. The final database is included as an electronic appendix to this white paper (Appendix B).

4.0 Hydraulic Project Description

RCW 77.55.011(7) defines a hydraulic project as "the construction or performance of work that will use, divert, obstruct, or change the natural flow or bed of any of the salt or freshwaters of the state." Hydraulic projects pertaining to channel modification subactivities considered in this white paper include dredging, gravel mining and bar scalping, sediment capping, and channel creation and alignment.

Because channels have a specific, environment-dependent meaning in regulatory language and because the subactivities described herein occur in various environments, the subactivities treated in this white paper are organized by the environment (i.e., riverine, lacustrine, and marine) in which they are planned. The environments have been separated in a geomorphic sense. That is, riverine environments are those where flow is dominantly unidirectional and confined in a single channel or a set of intersecting channels; lacustrine environments are those freshwater bodies surrounded by land; and marine environments are those where physical processes are dominated by tides and/or waves, and salinity is at least occasionally important. Marine environments include deltas and confined estuarine embayments (e.g., Puget Sound, Willapa Bay, Commencement Bay). These definitions mean that riverine environments may be tidally modulated, and marine environments may have varying salinity.

The mechanisms of impact on HCP species associated with these projects include the impacts from these subactivities that persist in the environment, which in most cases is of a permanent nature, and impacts from construction and maintenance activities that could result in physical habitat/process modifications. This includes modifications to hydraulic and geomorphic characteristics, aquatic and riparian vegetation, and water quality that could result in direct and indirect effects on HCP species. It also includes the effects of fish handling, relocation, and exclusion associated with such activities.

For the purposes of this white paper:

- **Dredging** includes the removal of substrate from riverine, lacustrine, and marine environments for purposes of improving vessel navigation, the maintenance of channels and sediment traps for flow conveyance and flood control, and hydraulic suction dredging to manage aquatic vegetation. This white paper does not address dredging related to mineral prospecting. Mineral prospecting was addressed in a separate white paper (Anchor 2006).

- **Gravel mining and bar scalping** is the extraction of gravel resources from the active channel or floodplain by means of pit mining, bar scalping or "skimming," bar excavation, gravel traps, or channel-wide instream gravel mining.

- **Sediment capping** refers to the placement of a subaqueous covering of clean material over contaminated sediments to isolate contaminants from riverine, lacustrine, and marine environments and biota.

- **Channel creation and alignment** includes the relocation, straightening, or meandering of an existing channel or the creation of a new channel where none existed before.

This white paper also includes a summary of the provisions in WAC (220-110) that would apply to channel modification projects in both freshwater and saltwater environments. Channel modification is a broad activity type, and consequently there are many different WACs that are applicable to channel modification activities. The WACs listed in Table 4-1 would apply (note: an asterisk (*) in the table indicates that the activity may be related to the topics covered in this white paper, but is not necessarily an implicit component of the activity as specified in the WAC).

4.1 Channel Modification Activities and Areas of Alteration

4.1.1 Dredging

Dredging is conducted for various purposes. Navigational and maintenance dredging is carried out primarily in fresh water and salt water to allow the passage of deep-draft vessels in channels and marinas (e.g., Columbia, Snake, and Cowlitz rivers; Puget Sound) and the embayments of the outer coast. Dredging for navigational purposes in the vicinity of marinas and terminals is discussed in the Marinas and Shipping/Ferry Terminals white paper (Herrera 2007a). Dredging also occurs to maintain and increase conveyance for flood and erosion control at bridges, along highways, and in irrigation channels. Dredging has been conducted to remove contaminated sediments.

The USACE (1983) describes three primary dredging techniques:

- *Suction dredging* – Removal of loose materials by dustpans, hoppers, hydraulic pipeline plain suction, and sidecasters, usually for maintenance dredging projects.

- *Mechanical dredging* – Removal of loose or hard, compacted materials by clamshell, dipper, or ladder dredges, either for maintenance or new work projects.

- *A combination of suction and mechanical dredging* – Removal of loose or hard, compacted materials by cutterheads, either for maintenance or new work projects.

Table 4-1. WAC sections potentially applicable to channel modifications.

Subactivity Types	Freshwater WACs (direct & indirect applicability)	Saltwater WACs (direct & indirect applicability)
Dredging	220-110-050* (FW banks) 220-110-120 (temp bypass) 220-110-130 (dredging) 220-110-130 (gravel removal) 220-110-150 (LWD) 220-110-223* (lake banks) 220-110-337 (aquatic plant dredging)	220-110-250 (habitats of concern) 220-110-270 (common) 220-110-271 (prohibited work windows) 220-110-280* (non-SFRM bank) 220-110-130 (dredging)
Gravel mining and scalping	220-110-050* (FW banks) 220-110-120 (temp bypass) 220-110-130 (dredging) 220-110-140 (gravel removal) 220-110-150 (LWD) 220-110-223* (lake banks) 220-110-337* (aquatic plant dredging)	No specific existing WACs for gravel mining or scalping 220-110-250 (habitats of concern) 220-110-270 (common) 220-110-271 (prohibited work windows) 220-110-280* (non-SFRM bank 220-110-320 (dredging)
Sediment caps	No specific existing WACs for sediment caps 220-110-050* (FW banks) 220-110-120 (temp bypass) 220-110-130 (dredging) 220-110-140 (gravel removal) 220-110-150 (LWD) 220-110-223* (lake banks) 220-110-337* (aquatic plant dredging)	No specific existing WACs for sediment caps 220-110-250 (habitats of concern) 220-110-270 (common) 220-110-271 (prohibited work windows) 220-110-280* (non-SFRM bank) 220-110-320 (dredging)
Channel creation and alignment	220-110-050 (FW banks) 220-110-080 (channel change) 220-110-120 (temp bypass) 220-110-130* (dredging) 220-110-140* (gravel removal) 220-110-150 (LWD) 220-110-223* (lake banks) 220-110-337* (aquatic plant dredging)	No specific existing WACs for channel creation/alignment 220-110-250 (habitats of concern) 220-110-270 (common) 220-110-271 (prohibited work windows) 220-110-280* (non-SFRM bank) 220-110-2850 (SFRM bank) 220-110-320* (dredging)

Note: * indicates that the activity may be related to the topics covered in this white paper, but it is not necessarily an implicit component of the activity as specified in the WAC.
LWD = large woody debris; SFRM = single-family residential marine.

There are two primary areas of impact with respect to dredging activities. The first is the site being dredged. This is generally relatively confined within the project area and is often a heavily trafficked or disturbed area. The second area of impact is the area that is exposed to sediments resuspended due to disturbance and those sediments lost during the dredging process. This can be much larger than the project area.

4.1.2 Gravel Mining and Scalping

Gravel is extracted from riverine environments for use as base material in the construction of roads, highways, and railroads and as aggregate mix in the construction of roads and buildings. Gravel sources include active river sediments and glacial sediments deposited during the Pleistocene by meltwater streams. Sources are ideally located close to markets to reduce transportation costs and maximize profit. Extraction methods can include the following (Kondolf et al. 2002):

- Dry-pit mining is the excavation of gravel within the active channel on dry intermittent or ephemeral streams beds.
- Wet-pit mining is the excavation of gravel within the riverine floodplain below the groundwater table, requiring the use of a dragline or hydraulic excavator.
- Bar scalping or "skimming" is the extraction of gravel from the surface of gravel bars above the low-flow water level.
- Bar excavation involves pit excavation at the downstream end of the gravel bar for gravel extraction.
- Gravel traps are channel-spanning hydraulic controls that promote ponding and sediment deposition. The collected sediment is then extracted during low-flow conditions.
- Channel-wide instream mining occurs in rivers with variable flow regimes and involves the excavation of gravel across the entire active channel width during the dry season.
- Floodplain and terrace-pit mining is similar to wet-pit mining but includes dewatering of the pit to work in the dry.

4.1.3 Sediment Capping

Sediments contaminated with heavy metals, nutrients, PCBs, PAHs, and other organic pollutants are frequently present in urbanized marine and freshwater benthic habitat. In most situations, contaminant levels are sufficiently low such that a "natural recovery"(Garbaciak et al. 1998) or no-action alternative is the most effective form of remediation. However, when contaminant concentrations reach levels that require a more rapid solution, sediment capping or dredging may occur. Sediment capping and dredging are frequently conducted in tandem as dredging spoils often need to be capped, and sediment capping material is frequently dredged from an adjacent clean sediment source (USACE 1991a). Information on dredging was presented above, and this section provides a background and description of sediment capping techniques and applications.

Sediment capping is defined as the placement of a contaminate-free isolating material over a contaminated sediment deposit (Palermo et al. 1998). A sediment cap serves multiple functions including isolation of the contaminated sediment from benthic organisms, physical stabilization of the contaminated sediment, and prevention of contaminant leaching into the water column. A sediment cap most frequently consists of sand or silt (Palermo et al. 1998), but more recent efforts have focused on the use of active barrier systems (ABS), that incorporate various supportive materials (Jacobs and Forstner 1999; Murphy et al. 2006). The sorptive materials (e.g., activated carbon, zeolite, calcium carbonate) reduce contaminant leaching, while the sediment itself acts as a physical barrier and stabilizing force.

Two primary forms of sediment capping are practiced:

- The placement of a sediment cap over dredging spoils
- The placement of a sediment cap over in-situ contaminated sediments

The advantage of capping dredged sediments is that the practitioner has control over the physical location of the spoils and cap. A low-energy environment with low densities of aquatic life can be selected to minimize cap erosion and the impact on aquatic biota. However, the impacts associated with dredging can be significant (see Section 7.1, *Dredging*) and consequently, in-situ sediment capping (ISC) is frequently a preferred alternative. ISCs commonly have less of an environmental impact than dredging and capping, but the practice is associated with more uncertainty in terms of cap erosion and maintenance (Reible et al. 2003). ISC is a remediation technique that is becoming more common on a global scale (Palermo et al. 1998) but is still a relatively uncommon remediation technique in Washington State. Despite this, some of the most widely studied sediment capping projects in the world have occurred in Puget Sound.

There are six general techniques for constructing a sediment cap, but each technique can be placed in one of two categories: (1) point dump, or (2) pump down (USACE 1991b). Point dump methods include pipeline placement, hopper placement, and barge placement. All of these techniques entail releasing a large quantity of capping sediment near the waters surface. These techniques are economical and produce a well compacted cap. Pump down techniques entail creating a sediment slurry and delivering it through a pipe to the surface of the contaminated sediment. Pump down methods include submerged diffusion, sand spreader placement, and gravity-fed downpiping (tremie). Tremie equipment consists of a large diameter vertical pipe through which capping material is gravity fed. This technique is similar to point dump techniques in that the velocity of the capping material is not controlled. Consequently, benthic displacement by capping material may become an issue (USACE 1991a). Submerged diffusion and sand spreader placement both control the capping material velocity through the use of pumps and diffusion techniques. These methods are characterized by a high degree of placement control and minimal displacement of the contaminated benthos (USACE 1991b).

HPAs issued for sediment capping encompass both dredging and capping projects and those projects that involve ISC with no associated dredging. Additionally, HPA authority over capping is limited by the WAC. For instance, certain remedial actions conducted under a court order or performed by the Washington State Department of Ecology are exempt from the procedural requirements of the Hydraulic Code but must comply with the substantive provisions of the Hydraulic Code.

4.1.4 Channel Creation and Alignment

Artificial realignment and relocation of channels, as described in this white paper, are extensive hydromodifications specifically designed to reconfigure the aquatic environment to promote human uses. Channel creation and alignment conducted primarily for purposes of habitat restoration are described in the Habitat Modifications white paper (Herrera 2007b). Relocation may also be used where a significant building or road is directly threatened by erosion. Channel relocation is often a means to solve problems of channel encroachment and/or confinement, and to foster the development of a new, static channel with healthy riparian buffers. A channel can be entirely relocated to a new alignment, or just moved laterally within the existing alignment. Channel relocation permanently changes the location of the channel while preserving or recreating other characteristics, such as the overall channel profile, pattern, cross-section, and bed elevation. Channel relocation is a major undertaking involving the reconstruction of the channel bed, habitat features, channel banks, and floodplain.

5.0 Potentially Covered Species and Habitat Use

This white paper identifies what is known about those activities associated with channel modifications and how such activities can pose risks of take for the 52 HCP species. To understand species-specific impacts, it is important to understand the geographic distribution and habitat use of these species. Table 5-1 lists the scientific name, Water Resource Inventory Area (WRIA) of occurrence, tidal reference area, and the reproductive patterns and habitat requirements of each of these HCP species. Through the identification of species-specific habitat needs, the potential for take associated with each mechanism of impact related to channel modifications can be identified. Once the potential for take has been identified, it can then be avoided. If unavoidable, the risk of take can be minimized by design and/or through the use of conservation and protection measures. (See Section 9 [*Potential Risk of Take*] and the exposure-response matrices in Appendix A.)

Table 5-1. Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Chinook salmon	*Oncorhynchus tshawytscha*	01–42, 44–50	All	**General Information (Habitats and Feeding/Life-history Types)** NOAA Fisheries recognizes eight evolutionarily significant units (ESUs) of Chinook salmon in Washington: (1) Upper Columbia River spring-run; (2) Snake River spring/summer run; (3) Snake River fall-run; (4) Puget Sound; (5) lower Columbia River; (6) Washington coast; (7) Mid-Columbia River spring-run; and (8) Upper Columbia River summer/fall-run. Chinook salmon 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. 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 migration soon after yolk is absorbed, fry migration 60–150 days after emergence, and fingerling migrants that migrate in the late summer or fall of their first year. Ocean-type Chinook are highly dependent on estuarine habitats to complete their life history. Chinook generally feed on invertebrates but become more piscivorous with age. **Reproduction/Life History** Chinook runs are designated on the basis of adult migration timing: • Spring-run Chinook: Tend to enter fresh water as immature fish, migrate far upriver, and finally spawn in the late summer and early autumn. • Fall-run Chinook: 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. • Spring Chinook: Spawning occurs from mid-July to mid-December, and incubation lasts approximately 1.5–7 months, depending on temperature. Emergence follows, 6–8 months from fertilization. • Fall Chinook: Spawning occurs from late October to early December, with incubation occurring for 1–6 months. Emergence follows, approximately 6 months after fertilization. (Healey 1991; Myers et al. 1998; WDNR 2006a; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Coho salmon	*Oncorhynchus kisutch*	01–42, 44–48, 50	All	**General Information (Habitats and Feeding)** NOAA Fisheries recognizes four ESUs of coho salmon in Washington: (1) Lower Columbia River; (2) Southwest Washington; (3) Puget Sound and Strait of Georgia; and (4) Olympic Peninsula. This species is found in a broader diversity of habitats than any of the other native anadromous salmonids. Fry feed primarily on aquatic insects and prefer pools and undercut banks with woody debris; adults feed on herring and other forage fish. **Reproduction/Life History** Coho adults spawn from September to late January, generally in the upper watersheds in gravel free of heavy sedimentation. Developing young remain in gravel for up to 3 months after hatching. Fry emerge from early March to late July. Coho rear in fresh water for 12–18 months before moving downstream to the ocean in the spring. Coho spend between 1 and 2 years in the ocean before returning to spawn. (Groot and Margolis 1991; Murphy and Meehan 1991; WDNR 2005, 2006a; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Chum salmon	*Oncorhynchus keta*	01, 03–05, 07–29	All	**General Information (Habitats and Feeding)** NOAA Fisheries recognizes four ESUs of chum salmon in Washington: (1) Hood Canal summer run; (2) Columbia River; (3) Puget Sound/Strait of Georgia; and (4) Pacific Coast. Little is known about their ocean distribution; maturing individuals that return to Washington streams have primarily been found in the Gulf of Alaska. Chum migrate into rivers and streams of Washington coast, Hood Canal, Strait of Juan de Fuca, Puget Sound, and the Columbia River basin to spawn, but their range does not extend upstream above the Dalles Dam in the Columbia River. Fry feed on chironomid and mayfly larvae, as well as other aquatic insects, whereas juvenile fish in the estuary feed on copepods, tunicates, and euphausiids. **Reproduction/Life History** Chum salmon have three distinct run times: summer, fall and winter. Summer chum begin their upstream migration and spawn from mid-August through mid-October, with fry emergence ranging from the beginning of February through mid-April. Chum fry arrive in estuaries earlier than most salmon, and juvenile chum reside in estuaries longer than most other anadromous species. Chum salmon rear in the ocean for the majority of their adult lives. Fall chum adults enter the rivers from late October through November and spawn in November and December. Winter chum adults migrate upstream from December through January and spawn from January through February. Fall and winter chum fry emerge in March and April and quickly emigrate to the estuary. Chum salmon utilize the low-gradient (from 1–2 percent grade), sometimes tidally influenced lower reaches of streams for spawning. (Healey 1982; Johnson et al. 1997; Quinn 2005; Salo 1991; WDNR 2005, 2006a; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Pink salmon	*Oncorhynchus gorbuscha*	01, 03–05, 07, 09–11, 16–19, 21	1–13	**General Information (Habitats and Feeding)** NOAA Fisheries recognizes two ESUs of pink salmon in Washington, neither of which is listed: (1) Odd-year; and (2) Even-year. The most abundant species of salmon, with 13 stocks identified in Washington. They are the smallest of the Pacific salmon and mature and spawn on a 2-year cycle in Washington (primarily spawning during odd years). Adults are opportunistic feeders in marine habitat, foraging on a variety of forage fish, crustaceans, ichthyoplankton, and zooplankton. Juveniles primarily feed on small crustaceans such as euphausiids, amphipods, and cladocerans. **Reproduction/Life History** Pink salmon will spawn in rivers with substantial amounts of silt. Spawning occurs from August through October. Fry emerge from their redds in late February to early May, depending on water temperature, and migrate downstream to the estuary within 1 month. Juveniles remain in estuarine or nearshore waters for several months before moving offshore as they migrate to the Pacific Ocean, where they remain approximately 1 year until the next spawning cycle. (Hard et al. 1996; Heard 1991; WDNR 2005, 2006a)
Sockeye salmon	*Oncorhynchus nerka*	01, 03–05, 07–11, 16, 19–22, 25–33, 35–37, 40, 41, 44–50	5, 8, 14	**General Information (Habitats and Feeding/Life-history Types)** NOAA Fisheries recognizes seven ESUs of sockeye salmon in Washington: (1) Snake river; (2) Ozette Lake; (3) Baker river; (4) Okanogan River; (5) Quinault Lake; (6) Lake Pleasant; and (7) Lake Wenatchee. WDFW recognizes an additional sockeye salmon stock in the Big Bear Creek drainage of Lake Washington. Kokanee (landlocked sockeye) occur in many lakes, with the larger populations in Banks and Loon lakes in eastern Washington and Lake Whatcom and Lake Washington-Sammamish in western Washington. Juveniles feed on zooplankton, and adults primarily feed on fish, euphausiids, and copepods. **Reproduction/Life History** Spawn in shallow, gravelly habitat in rivers and lakes during August to October. Juvenile sockeye rear in lakes for 1–2 years before migrating to the ocean. Emergence occurs within 3–5 months. (Gustafson et al. 1997; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Steelhead	*Oncorhynchus mykiss*	01, 03–05, 07–12, 14, 15, 17–41, 44–50	All	**General Information (Habitats and Feeding)** NOAA Fisheries recognizes 15 Distinct Population Segments (DPSs) of steelhead, seven of which occur in Washington. During their ocean phase, steelhead are generally found within 10 and 25 miles of the shore; steelhead remain in the marine environment 2–4 years before returning to fresh water to spawn. Most steelhead spawn at least twice in their lifetimes. Escape cover, such as logs, undercut banks, and deep pools, is important for adult and young steelhead in the freshwater systems. The coastal west-side streams typically support more winter steelhead populations. **Reproduction** A summer spawning run enters fresh water in August and September, and a winter run occurs from December through February. Summer steelhead usually spawn farther upstream than winter populations and dominate inland areas such as the Columbia Basin. Spawning occurs from March to April for both winter and summer run steelhead. After hatching and emergence (approximately 3 months), 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. (Busby et al. 1996; McKinnell et al. 1997; WDNR 2006a; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Coastal cutthroat trout	*Oncorhynchus clarki clarki*	01–05, 07–30	All	**General Information (Habitats and Feeding/Life-history Types)** NOAA Fisheries has recognized three ESUs in Washington: (1) Puget Sound; (2) Olympic Peninsula; (3) Southwestern Washington/Columbia River. USFWS has assumed sole jurisdiction for this species. No coastal cutthroat trout DPSs are listed under the ESA in Washington. Coastal cutthroat trout exhibit varied life-history forms including: • Resident (stays in streams after rearing in their natal streams) – Resident coastal cutthroat trout utilize small headwater streams for all of their life stages. • Fluvial (migrates to larger rivers after rearing in their natal streams). • Adfluvial (migrates to lakes after rearing in their natal streams). • Anadromous (utilizes estuaries and nearshore habitat but has been caught offshore). Juveniles of all life forms feed primarily on aquatic invertebrates but are opportunistic feeders; adults tend to feed on smaller fish, amphibians, and crustaceans while foraging within the nearshore environment. **Reproduction/Life History** Coastal cutthroat trout are repeat spawners, and juveniles typically rear in the natal streams for up to 2 years. Spawning occurs from late December to February, with incubation lasting approximately 2–4 months. Emergence occurs after 4 months. (Johnson et al. 1999; Pauley et al. 1988; WDNR 2006a)
Redband trout	*Oncorhynchus mykiss gardnerii*	37–40, 45–49, 54–57	NA	**General Information (Habitats and Feeding)** Redband trout is a subspecies of rainbow trout found east of the Cascade Mountains, which prefer cool water that is less than 70°F (21°C), and occupy streams and lakes with high amounts of dissolved oxygen. Their food primarily consists of Daphnia and chironomids as well as fish eggs, fish, and insect larvae and pupae. **Reproduction/Life History** Spawn in streams with clean, small gravel from March through May. Incubation takes approximately 1–3 months, with emergence occurring between June and July. (USFS 2007)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Westslope cutthroat trout	*Oncorhynchus clarki lewisii*	37–39, 44–55, 58–62	NA	**General Information (Habitats and Feeding/Life-history Types)** Cutthroat trout tend to thrive in streams with extensive pool habitat and cover. The westslope is a subspecies of cutthroat trout with three possible life forms: • Adfluvial (migrates to lakes) • Fluvial (migrates to larger rivers) • Resident (stays in streams). The headwater tributaries used by resident cutthroat are typically cold, nutrient-poor waters that result in slow growth. Fluvial and adfluvial forms can exhibit more growth due to warmer water temperatures and nutrient availability. Fry feed on zooplankton, and fingerlings feed on aquatic insect larvae. Adults feed on terrestrial and aquatic insects. **Reproduction/Life History** Spawning: all three life forms spawn in small gravel substrates of tributary streams in the spring (March to July) when water temperature is about 50°F (10°C); incubation occurs during April to August, and emergence occurs from May through August. Fry spend 1–4 years in their natal stream before migrating to their ultimate habitat. (Liknes and Graham 1988; Shepard et al. 1984; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Bull trout	*Salvelinus confluentus*	01, 03–05, 07–23, 26, 27, 29–41, 44–55, 57–62	All	**General Information (Habitats and Feeding/Life-History Types)** Widely distributed in Washington; exhibit four life-history types: • Resident (stays in streams after rearing in their natal streams) • Fluvial (migrates to larger rivers after rearing in their natal streams) • Adfluvial (migrates to lakes after rearing in their natal streams) • Anadromous (bull trout in the nearshore ecosystem rely on estuarine wetlands and favor irregular shorelines with unconsolidated substrates). Young of the year occupy side channels, with juveniles in pools, runs, and riffles; adults occupy deep pools. Juvenile diet includes larval and adult aquatic insects; subadults and adults primarily feed on fish. **Reproduction/Life History** The migratory forms of bull trout, such as anadromous, adfluvial, and fluvial, move upstream by early fall to spawn in September and October (November at higher elevations). Although resident bull trout are already in stream habitats, they move upstream looking for suitable spawning habitat. They prefer clean, cold water (50°F [10°C]) for spawning. Colder water (36–39°F [2–4°C]) is required for incubation. Preferred spawning areas often include groundwater infiltration. Extended incubation periods (up to 220 days) make eggs and fry particularly susceptible to increases in fine sediments. Bull trout typically rear in natal streams for 2–4 years, although resident fish may remain in these streams for their entire lives; multiple life-history forms may occur in the same habitat environments. (Goetz et al. 2004; WDNR 2005, 2006a; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Dolly Varden	*Salvelinus malma*	01, 03, 05, 07, 17–22, 24	6–10, 14–17	**General Information (Habitats and Feeding/Life-History Types)** Species restricted to coastal areas and rivers that empty into them. Juveniles extensively use instream cover; while in the marine systems, they use beaches of sand and gravel. Prefer pool areas and cool temperatures. Feed opportunistically on aquatic insects, crustaceans, salmon eggs, and fish. Closely related to bull trout and exhibit the same life-history traits. Four life-history types occur: • Resident (stays in streams after rearing in their natal streams) • Fluvial (migrates to larger rivers after rearing in their natal streams) • Adfluvial (migrates to lakes after rearing in their natal streams) • Anadromous (migrates to marine waters after rearing in their natal streams). **Reproduction/Life History** Spawn and rear in streams from mid-September through November. Incubation lasts approximately 130 days. Juveniles can spend 2–4 years in their natal streams before migration to marine waters. (Leary and Allendorf 1997; WDNR 2005; Wydoski and Whitney 2003)
Pygmy whitefish	*Prosopium coulteri*	08, 19, 39, 47, 49, 53, 55, 58, 59, 62	NA	**General Information (Habitats and Feeding)** 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 only nine. They occur most often in deep, oligotrophic lakes with temperatures less than 50°F (10°C), where they feed on zooplankton, such as cladocerans, copepods, and midge larvae. **Reproduction/Life History** Pygmy whitefish spawn in streams or lakes from July through November. They prefer pools, shallow riffles, and pool tail-outs when spawning in streams. Lake spawning by pygmy whitefish occurs at night. Spawning occurs by scattering their eggs over coarse gravel. Incubation and emergence timing are unknown, but eggs are believed to hatch in the spring. (Hallock and Mongillo 1998; WDNR 2005, 2006a; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Olympic mudminnow	*Novumbra hubbsi*	08–24	NA	**General Information (Habitats and Feeding)** Occur in the southern and western lowlands of the Olympic Peninsula, the Chehalis River drainage, lower Deschutes River drainage, south Puget Sound lowlands west of the Nisqually River, and in King County. They are generally found in quiet water with mud substrate, preferring bogs and swamps with dense aquatic vegetation. Mudminnows feed on annelids, insects, and crustaceans. **Reproduction/Life History** Adults spawn from November through June (peaking in April and May). Females deposit eggs onto vegetation where fry remain firmly attached for approximately 1 week after hatching. Incubation lasts approximately 8-10 days. (Harris 1974; Mongillo and Hallock 1999; WDNR 2005, 2006a)
Lake chub	*Couesius plumbeus*	48, 61; other locations unknown	NA	**General Information (Habitats and Feeding)** Bottom dwellers inhabiting a variety of habitats in lakes and streams, but are known to prefer small, slow streams. In Washington, they are known only from the northeastern part of the state (small streams and lakes in Okanogan and Stevens counties). Juveniles feed on zooplankton and phytoplankton, whereas adults primarily feed on insects. **Reproduction/Life History** Lake chub move into shallow areas on rocky and gravelly substrates in tributary streams of lakes or lakeshores during the spring to spawn when water temperatures are between 55 and 65°F (13 and 18°C). The eggs are broadcast over large rocks and then settle into the smaller substrate, hatching after approximately 10 days. (WDNR 2005; Wydoski and Whitney 2003)
Leopard dace	*Rhinichthys falcatus*	25–31, 37–41, 44–50	NA	**General Information (Habitats and Feeding)** In Washington, leopard dace inhabit the bottoms of streams and small to mid-sized rivers, specifically the Columbia, Snake, Yakima, and Simikameen Rivers, with velocities less than 1.6 ft/sec (0.5 m/sec); prefer gravel and small cobble substrate covered by fine sediment with summer water temperatures ranging between 59 and 64°F (15 and 18°C). Juveniles feed primarily on aquatic insects; adult leopard dace consume terrestrial insects. **Reproduction/Life History** Breeding habitat for dace generally consists of the gravel or cobble bottoms of shallow riffles; leopard dace breed in slower, deeper waters than the other dace species. The spawning period for dace is from May through July. The eggs adhere to rocky substrates. Fry hatch approximately 6–10 days after fertilization, and juveniles spend 1–3 months rearing in shallow, slow water. (WDNR 2005, 2006a; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Margined sculpin	*Cottus marginatus*	32, 35	NA	**General Information (Habitats and Feeding)** Endemic to southeastern Washington (smaller tributary streams of the Walla Walla and Tucannon River drainages) where habitat is in deeper pools and slow-moving glides in headwater tributaries with silt and small gravel substrate. They prefer cool water less than 68°F (20°C) and avoid high-velocity areas. Food includes immature aquatic insects, invertebrates, small fish, and eggs. **Reproduction/Life History** Spawning occurs in May and June primarily under rocks, root wads, or logs. The female deposits a mass of adhesive eggs in the nest, which is guarded by the male. Incubation duration unknown. (Mongillo and Hallock 1998; WDNR 2005; Wydoski and Whitney 2003)
Mountain sucker	*Catostomus platyrynchus*	25–35, 37–41, 44–50	NA	**General Information (Habitats and Feeding)** Distribution restricted to Columbia River system. Found in clear, cold mountain streams less than 40 ft wide and in some lakes; prefer deep pools in summer with moderate current. Food consists of algae and diatoms. Juveniles prefer slower side channels or weedy backwaters. **Reproduction/Life History** Males reach sexual maturity in 2–3 years and females in 4 years. Spawning in June and July when water temperatures exceed 50°F (10°C). Spawning occurs in gravelly riffles of small streams when suckers move into those reaches to feed on algae. Spawning likely occurs at night when water temperatures are in a range of 51–66°F (10.5–19°C). Fertilized eggs fall into and adhere to the spaces between the gravel composite. Incubation period lasts approximatley 8-14 days. (Wydoski and Whitney 2003)
Umatilla dace	*Rhinichthys umatilla*	31, 36–41, 44–50, 59–61	NA	**General Information (Habitats and Feeding)** Umatilla dace are benthic fish found in relatively productive, low-elevation streams with clean substrates of rock, boulders, and cobbles in reaches where water velocity is less than 1.5 ft/sec (0.5 m/sec). Feeding is similar to that described for leopard dace. Juveniles occupy streams with cobble and rubble substrates, whereas adults occupy deeper water habitats. **Reproduction/Life History** Spawning behaviors are similar to those described for leopard dace, with spawning primarily occurring from early to mid-July. (WDNR 2005, 2006a; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Pacific lamprey	*Lampetra tridentata*	01, 03–05, 07–35, 37–40, 44–50	All	**General Information (Habitats and Feeding)** Found in most large coastal and Puget Sound rivers and Columbia, Snake, and Yakima river basins. The larvae are filter feeders, residing in mud substrates and feeding on algae and other organic matter for at least 5 years. **Reproduction/Life History** From July through October, maturing Pacific lamprey enter fresh water and gradually move upstream to spawn the following spring. The nest usually consists of a shallow depression built in gravel and rock substrates. Eggs hatch in 2–4 weeks, with newly hatched larvae remaining in the nest for 2–3 weeks before moving downstream as larvae (ammocoetes). Juveniles migrate to the Pacific Ocean 4–7 years after hatching and attach to fish in the ocean for 20–40 months before returning to rivers to spawn. (WDNR 2005; Wydoski and Whitney 2003)
River lamprey	*Lampetra ayresi*	01, 03, 05, 07–16, 20–40	1–9, 11–17	**General Information (Habitats and Feeding)** Detailed distribution records are not available for Washington, but they are known to inhabit coastal rivers, estuaries, and the Columbia River system. They have also been observed in Lake Washington and its tributaries. In the marine system, river lamprey inhabit nearshore areas. Adults are anadromous living in the marine system as parasites on fish. Adult river lamprey are believed to occupy deep portions of large river systems. The larvae feed on microscopic plants and animals. **Reproduction/Life History** Adults migrate back into fresh water in the fall. Spawning occurs in winter and spring. Eggs hatch in 2–3 weeks after spawning. Juveniles are believed to migrate from their natal rivers to the Pacific Ocean several years after hatching; adults spend 10–16 weeks between May and September in the ocean before migrating to fresh water. (WDNR 2005; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Western brook lamprey	*Lampetra richardsoni*	01, 03, 05, 07–14, 16, 20–40	NA	**General Information (Habitats and Feeding)** Found in small coastal and Puget Sound rivers and lower Columbia and Yakima river basins; spends entire life in fresh water. Adults are found in cool water (52–64°F [11–17.8°C]) on pebble/rocky substrate. Larvae (ammocoetes) are filter feeders, consuming primarily diatoms. Adults do not feed and die within a month of spawning. **Reproduction/Life History** Spawning generally occurs from April through July, with adults creating nests in coarse gravel at the head of riffles. Eggs hatch after about 10 days in water between 50 and 60°F (10 and 16°C). Within 30 days of hatching, ammocoetes emerge from the nests and move to the stream margin, where they burrow into silty substrates. Larvae remain in the stream bottom—apparently moving little—for approximately 4–6 years. (Wydoski and Whitney 2003)
Green sturgeon	*Acipenser medirostris*	22, 24, 28	All	**General Information (Habitats and Feeding)** NOAA Fisheries recognizes two DPSs of green sturgeon, both of which can be found in Washington. The southern DPS is listed as threatened and the northern DPS is a species of concern. Habits and life history not well known. Washington waters with green sturgeon populations include the Columbia River, Willapa Bay, and Grays Harbor, in addition to marine waters. They spend much of their life in marine nearshore waters and estuaries feeding on fishes and invertebrates. **Reproduction/Life History** Spawning generally occurs in spring in deep, fast-flowing sections of rivers. Spawning habitat includes cobble or boulder substrates. Green sturgeon move upstream during spring to spawn and downstream during fall and winter. Large eggs sink to bottom. (Adams et al. 2002; Emmett et al. 1991; Kynard et al. 2005; Nakamoto and Kisanuki 1995; Wydoski and Whitney 2003)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
White sturgeon	*Acipenser transmontanus*	01, 03, 05–22, 24–37, 40–42, 44–61	All	**General Information (Habitats and Feeding)** Found in marine waters and major rivers in Washington, including the Columbia River, Snake River, Grays Harbor, Willapa Bay, Puget Sound, and Lake Washington. In marine environments, adults and subadults use estuarine and marine nearshore habitats, including some movement into intertidal flats to feed at high tide. Some landlocked populations exist behind dams on the Columbia River. Juveniles feed on mysid shrimp and amphipods; large fish feed on variety of crustaceans, annelid worms, mollusks, and fish. **Reproduction/Life History** Spawn in deep, fast-flowing sections of rivers (prefer swift [2.6–9.2 ft/sec (0.8–2.8 m/sec)] and deep [13–66 ft (4–20 m)] water) on bedrock, cobble, or boulder substrates. Spawning occurs from April through July, with incubation lasting approximately 7 days and emergence following in another 7 days. (Emmett et al. 1991; WDNR 2005; Wydoski and Whitney 2003)
Eulachon	*Thaleichthys pacificus*	01–29 (mouths of major rivers)	14–17	**General Information (Habitats and Feeding)** Eulachon occur from northern California to southwestern Alaska in offshore marine waters. They are plankton-feeders, eating crustaceans such as copepods and euphausiids; larvae and post larvae eat phytoplankton and copepods. They are an important prey species for fish, marine mammals, and birds. **Reproduction/Life History** Spawn in tidal portions of rivers in spring when water temperature is 40–50°F (4–10°C), generally from March through May; use a variety of substrates, but sand and gravel are most common. Eggs stick to substrate and incubation ranges from 20–40 days (dependent on temperature). Larvae drift downstream to salt water where juveniles rear in nearshore marine areas. (Howell et al. 2001; Langer et al. 1977; Lewis et al. 2002; WDFW 2001; WDNR 2005; Willson et al. 2006)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Longfin smelt	*Spirinchus thaleichthys*	01–03, 05–17, 22 and 24	1–9, 15–17	**General Information (Habitats and Feeding)** Marine species that spawns in streams not far from marine waters. They are anadromous, with some populations in Lake Washington that spawn in tributaries, including the Cedar River. Juveniles use nearshore habitats and a variety of substrates; juveniles feed on zooplankton. Adults feed on copepods and euphausiids. Most adults die after spawning. **Reproduction** Spawn in coastal rivers from October through December. Lake Washington populations spawn from January through April. Eggs hatch in approximately 40 days and the larvae drift downstream to salt water. (Gotthardt 2006; WDNR 2005; Wydoski and Whitney 2003)
Pacific sand lance	*Ammodytes hexapterus*	NA	All	**General Information (Habitats and Feeding)** Widespread in Puget Sound, Strait of Juan de Fuca, and coastal estuaries. Schooling plankton feeders. Adults feed during the day and burrow into the sand at night. **Reproduction/Life History** Spawn on sand and beaches with gravel up to 1-inch in diameter at tidal elevations of +4–5 ft (+1.5 meters) to approximately the mean higher high water (MHHW) line from November through February. Emergence occurs from January to April. Larvae and young rear in bays and nearshore areas. (Garrison and Miller 1982; Nightingale and Simenstad 2001b; NRC 2001; Penttila 2000; Penttila 2001; WDFW 1997a)
Surf smelt	*Hypomesus pretiosus*	NA	All	**General Information (Habitats and Feeding)** Schooling plankton-feeding forage fish. They feed on a variety of zooplankton, planktonic crustaceans, and fish larvae. Adult surf smelt are pelagic but remain in nearshore habitats. Juveniles rear in nearshore areas, and adults form schools offshore; feed on planktonic organisms. Also an important forage fish. **Reproduction/Life History** Spawning occurs year-round in north Puget Sound, fall and winter in south Puget Sound, and summer along the coast. They spawn at the highest tides during high slack tide on coarse sand and pea gravel. Incubation is 2–5 weeks. Emergence varies with season: 27–56 days in winter, 11–16 days in summer. (Nightingale and Simenstad 2001b; NRC 2001; Penttila 2000; Penttila 2001; WDFW 1997c)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Pacific herring	*Clupea harengus pallasi*	NA	1, 2, 4, 5, 8–13, 16, 17	**General Information (Habitats and Feeding)** Eighteen separate stocks in Puget Sound. Widely distributed throughout Puget Sound and coastal wetlands and estuaries. Pacific herring adults feed on small fish, copepods, decapod crab larvae, and euphausiids. Juveniles feed primarily on euphausiids, copepods, and small crustacean larvae. Are also an important forage fish. **Reproduction/Life History** Utilize intertidal and subtidal habitats (between 0 and -40 ft [0 and -12.2 m] mean lower low water [MLLW]) for spawning and juvenile rearing; spawning also occurs above MLLW. Spawning occurs from late January to early April. Eggs are adhered to eelgrass, kelp, seaweed, and sometimes on pilings. Eggs hatch after approximately 10 days. Larvae are pelagic. (Nightingale and Simenstad 2001b; Penttila 2000; Simenstad et al. 1979; WDFW 1997b)
Lingcod	*Ophiodon elongatus*	NA	All	**General Information (Habitats and Feeding)** The lingcod is a large top-level carnivore fish found throughout the West Coast of North America. Adult lingcod have a relatively small home range. Juveniles prefer sand habitats near the mouths of bays and estuaries, while adults prefer rocky substrates. Larvae and juveniles are generally found in upper 115 ft (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; and adults on fish, squid, and octopi. **Reproduction/Life History** Spawn in shallow water and intertidal zone from January through late March. Egg masses adhere to rocks, and incubation is from February to June. Larvae spend 2 months in pelagic nearshore habitat. (Adams and Hardwick 1992; Emmett et al. 1991; Giorgi 1981; NMFS 1990; NRC 2001)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Pacific cod	*Gadus macrocephalus*	NA	All	**General Information (Habitats and Feeding)** Pacific cod are widely distributed in relatively shallow marine waters throughout the northern Pacific Ocean (Washington's inland marine waters are considered the southern limit of populations). Adults and large juveniles are found over clay, mud, and coarse gravel bottoms; juveniles use shallow vegetated habitats such as sand-eelgrass. Feed opportunistically on invertebrates (worms, crabs, shrimp) and fishes (sand lance, pollock, flatfishes). Larvae feed on copepods, amphipods, and mysids. **Reproduction/Life History** Broadcast spawners during late fall through early spring. Eggs sink and adhere to the substrate. Incubate for 1–4 weeks, and larvae spend several months in the water column. Juvenile cod metamorphose and settle to shallow vegetated habitats. (Albers and Anderson 1985; Bargmann 1980; Dunn and Matarese 1987; Garrison and Miller 1982; Hart 1973; Nightingale and Simenstad 2001b; NMFS 1990; NRC 2001)
Pacific hake	*Merluccius productus*	NA	All	**General Information (Habitats and Feeding)** Pacific hake are schooling fish. The coastal stock of hake is migratory; Puget Sound stocks reside in estuaries and rarely migrate. Larvae feed on calanoid copepods; juveniles and small adults feed on euphasiids; adults eat amphipods, squid, herring, and smelt. **Reproduction/Life History** Puget Sound spawning occurs from March through May at mid-water depths of 50–350 ft (15–90 m); may spawn more than once per season. Eggs and larvae are pelagic. (Bailey 1982; McFarlane and Beamish 1986; NMFS 1990; NRC 2001; Quirollo 1992)
Walleye pollock	*Theragra chalcogramma*	NA	All	**General Information (Habitats and Feeding)** Widespread species in northern Pacific. Washington is the southern end of their habitat. Larvae and small juveniles are found at 200-ft (60-m) depth; juveniles use nearshore habitats of a variety of substrates. Juveniles feed on small crustaceans, adults feed on copepods, euphausiids, and young pollock. **Reproduction/Life History** Broadcast spawning occurs from February through April. Eggs are suspended at depths ranging from 330–1,320 ft (100–400 m). Pelagic larvae settle near the bottom and migrate to inshore, shallow habitats for their first year. (Bailey et al. 1999; Garrison and Miller 1982; Livingston 1991; Miller et al. 1976; NRC 2001)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Black rockfish	*Sebastes melanops*	NA	All	**General Information (Habitats and Feeding)** Adults prefer deep and shallow rock substrates in summer, deeper water in winter. Kelp and eelgrass are preferred habitat for juveniles that feed on nekton and zooplankton. Adults feed on amphipods, crabs, copepods, and small fish. **Reproduction/Life History** Spawning occurs from February through April; ovoviviparous incubation as with other rockfish species. Larvae are planktonic for 3–6 months, where they are dispersed by currents, advection, and upwelling. They begin to reappear as young-of-the-year fish in shallow, nearshore waters. (Kramer and O'Connell 1995; WDNR 2006a)
Bocaccio rockfish	*Sebastes paucispinis*	NA	All	**General Information (Habitats and Feeding)** Adults semidemersal in shallow water over rocks with algae, eelgrass, and floating kelp. Larvae feed on diatoms; juveniles feed on copepods and euphausiids. **Reproduction/Life History** Ovoviviparous spawning occurs year-round, with incubation lasting 40–50 days. Larvae and juveniles are pelagic. (Garrison and Miller 1982; Hart 1973; Kramer and O'Connell 1995; MBC Applied Environmental Sciences 1987; NRC 2001; Sumida and Moser 1984)
Brown rockfish	*Sebastes auriculatus*	NA	All	**General Information (Habitats and Feeding)** Utilize shallow-water bays with natural and artificial reefs and rock piles; estuaries used as nurseries; can tolerate water temperatures to at least 71°F (22°C); eat small fishes, crabs, and isopods. **Reproduction/Life History** Spawning occurs from March through June. Larvae are released from the female into the pelagic environment in May and June (ovoviviparous incubation). Larvae live in the upper zooplankton layer for up to 1 month before they metamorphose into pelagic juveniles. The pelagic juveniles spend 3–6 months in the water column as plankton. They then settle in shallow water nearshore, later migrating to deeper water. (Eschmeyer et al. 1983; Kramer and O'Connell 1995; Love et al. 1990; NRC 2001; Stein and Hassler 1989)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Canary rockfish	*Sebastes pinniger*	NA	All	**General Information (Habitats and Feeding)** Adults use sharp drop-offs and pinnacles with hard bottoms; often associated with kelp beds; feed on krill and occasionally on fish. Adults are mostly found at depths of 260–660 ft (80–200 meters) (with two recorded at 2,750 ft [838 meters]), tending to collect in groups around pinnacles and similar high-relief rock formations, especially where the current is strong. Young canary rockfish live in relatively shallow water, moving to deeper water as they mature. Juveniles feed on small crustacea such as krill larvae (and eggs), copepods, and amphipods, while adults eat krill and small fish. **Reproduction/Life History** Spawning is ovoviviparous and occurs from January through March. Larvae and juveniles are pelagic. (Boehlert 1980; Boehlert and Kappenman 1980; Boehlert et al. 1989; Hart 1973; Kramer and O'Connell 1995; Love et al. 1990; NRC 2001; Sampson 1996)
China rockfish	*Sebastes nebulosis*	NA	All	**General Information (Habitats and Feeding)** Occur inshore and on open coast in sheltered crevices. Feed on crustacea (brittle stars and crabs), octopi, and fish. Juveniles are pelagic, but the adults are sedentary associating with rocky reefs or cobble substrates. **Reproduction/Life History** Spawning occurs from January through July; ovoviviparous incubation as with other rockfish species. Individual China rockfish spawn once a year. Larvae settle out of the plankton between 1 and 2 months after release. (Eschmeyer et al. 1983; Kramer and O'Connell 1995; Love et al. 1990; NRC 2001; Rosenthal et al. 1988)
Copper rockfish	*Sebastes caurinus*	NA	All	**General Information (Habitats and Feeding)** 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 mollusks. **Reproduction/Life History** Spawning occurs from March through May, with ovoviviparous incubation from April to June. Larvae are pelagic in deeper water before moving inshore. Newly spawned fish begin settling near the surface around large algae canopies or eelgrass, when available, or closer to the bottom when lacking canopies. (Eschmeyer et al. 1983; Haldorson and Richards 1986; Kramer and O'Connell 1995; Matthews 1990; NRC 2001; Stein and Hassler 1989)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Greenstriped rockfish	*Sebastes elongates*	NA	All	**General Information (Habitats and Feeding)** Adults found in benthic and mid-water columns. They live at between 330 and 825 ft (100 and 250 m). As they age, greenstriped rockfish move to deeper water. They are solitary and are often found resting on the seafloor and living among cobble, rubble, or mud. Adults feed on euphausiids, small fish, and squid. **Reproduction/Life History** From 10,000 to over 200,000 eggs are produced by the females each season by ovoviviparous spawning. Greenstriped rockfish release one brood of larvae in Washington. Larval release varies, occurring generally from January through July, depending on geographic location. (Eschmeyer et al. 1983; Kramer and O'Connell 1995; Love et al. 1990; NRC 2001)
Quillback rockfish	*Sebastes maliger*	NA	All	**General Information (Habitats and Feeding)** Shallow-water benthic species in inlets near shallow rock piles and reefs. Juveniles use eelgrass, sand, and kelp beds. Feed on amphipods, crabs, and copepods. **Reproduction/Life History** Ovoviviparous spawning from April through July, with larval release from May to July. (Kramer and O'Connell 1995; WDNR 2006a)
Redstripe rockfish	*Sebastes proriger*	NA	All	**General Information (Habitats and Feeding)** Adults found from 330- to 1,000-ft (100- to 300-m) depths, and young often found in estuaries in high- and low-relief rocky areas. Juveniles feed on copepods and euphausiids; adults eat anchovies, herring, and squid. **Reproduction/Life History** Spawning is ovoviviparous, occurring from January through March. Larvae and juveniles are pelagic. (Garrison and Miller 1982; Hart 1973; Kendall and Lenarz 1986; Kramer and O'Connell 1995; NRC 2001; Starr et al. 1996)
Tiger rockfish	*Sebastes nigrocinctus*	NA	All	**General Information (Habitats and Feeding)** Semidemersal to demersal species occurring at depths ranging from shallows to 1,000 ft (305 m); larvae and juveniles occur near surface and range of depth; adults use rocky reefs, canyons, and headlands; generalized feeders on shrimp, crabs, and small fishes. **Reproduction/Life History** Ovoviviparous spawning peaks in May and June. Juveniles are pelagic. (Garrison and Miller 1982; Kramer and O'Connell 1995; Moulton 1977; NRC 2001; Rosenthal et al. 1988)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Widow rockfish	*Sebastes entomelas*	NA	All	**General Information (Habitats and Feeding)** Adults found from 330- to 1,000-ft (100- to 300-m) depths near rocky banks, ridges, and seamounts; adults feed on pelagic crustaceans, Pacific hake, and squid; juveniles feed on copepods and euphausiids. **Reproduction /Life History** Ovoviviparous spawning occurs from October through December. One brood of 95,000 to 1,113,000 eggs are produced by female widows per year. The season of larval release occurs earlier in the southern parts of their range than in the northern regions, likely January through April in Washington waters. (Eschmeyer et al. 1983; Kramer and O'Connell 1995; Laroche and Richardson 1981; NMFS 1990; NRC 2001; Reilly et al. 1992)
Yelloweye rockfish	*Sebastes ruberrimus*	NA	All	**General Information (Habitats and Feeding)** Adults are found from depths of 80–1,800 ft (24–550 m), near reefs and cobble bottom. Juveniles prefer shallow, broken-bottom habitat. Juveniles often hide in rock crevices; adults are demersal and solitary, tending to remain localized and not making extensive migrations. Adults feed on other rockfish species, sand lance, herring, shrimp, rock crabs, and snails. **Reproduction/Life History** Ovoviviparous spawning in late fall or early winter, with the larvae released from May to July. (Eschmeyer et al. 1983; Hart 1973; Kramer and O'Connell 1995; NRC 2001; Rosenthal et al. 1988)
Yellowtail rockfish	*Sebastes flavidus*	NA	All	**General Information (Habitats and Feeding)** Adults found from 165- to 1,000-ft (50- to 300-m) depths; adults semipelagic or pelagic over steep-sloping shores and rocky reefs. Juveniles occur in nearshore areas. Adults are opportunistic feeders on pelagic animals including hake, herring, smelt, squid, krill, and euphausiids. **Reproduction/Life History** Ovoviviparous spawning from October through December. Incubation is between January and March. Larvae and juveniles are pelagic swimmers. (Eschmeyer et al. 1983; Kramer and O'Connell 1995; Love et al. 1990; NRC 2001; O'Connell and Carlile 1993)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Olympia oyster	*Ostrea lurida*	NA	1–14, 17	**General Information (Habitats and Feeding)** 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. They occupy nearshore ecosystem on mixed substrates with solid attachment surfaces and are found from 1 ft (0.3 m) above MLLW to 2 ft (0.6m) below MLLW. Intolerant of siltation. **Reproduction/Life History** Reproduce spring to fall when water temperatures are between 54 and 61°F (12.5 and 16°C) by broadcast spawning. After 8–12 days, larvae develop into free-swimming larvae. Larvae are free-swimming for 2–3 weeks before they settle onto hard substrate, such as oyster shells and rocks. (Baker 1995; Couch and Hassler 1990; West 1997)
Northern abalone	*Haliotis kamtschatkana*	NA	10	**General Information (Habitats and Feeding)** Also known as pinto abalone. Presence in Washington is limited to the Strait of Juan de Fuca and the San Juan Islands. Occupies bedrock and boulders from extreme low water to 100 ft (30 m) below MLLW; usually associated with kelp beds. The abalone is completely vegetarian and uses its radula to scrape pieces of algae from the surface of rocks. **Reproduction/Life History** Broadcast spawners that release pelagic gametes that develop into free-swimming larvae using cilia to propel themselves. After up to a week, the larvae settle to the bottom, shed their cilia, and start growing a shell to begin sedentary adult life on crustose coralline algae. (Gardner 1981; NMFS 2007a; WDNR 2006b; West 1997)
Newcomb's littorine snail	*Algamorda subrotundata*	NA	14–17	**General Information (Habitats and Feeding)** Found in Grays Harbor and Willapa Bay on Washington coast; current distribution uncertain. Algae feeder occupying narrow band in *Salicornia* salt marshes above MHHW and is not considered a true marine gastropod. **Reproduction/Life History** Broadcast spawning in salt marshes. Other reproductive information unknown. (Larsen et al. 1995)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Giant Columbia River limpet	*Fisherola nuttalli*	35, 36, 40, 45, 47–49	NA	**General Information (Habitats and Feeding)** Also known as the shortface lanx, it occupies fast-moving and well-oxygenated streams. It is found in the Hanford Reach segment of the Columbia River, Wenatchee, Deschutes (OR), Okanogan, Snake, and Methow rivers. Prefers shallow, rocky areas of cobble to boulder substrates and diatom-covered rocks, and feeds by grazing on algae attached to rocks. **Reproduction/Life History** Broadcast external fertilization. Reproduction timing is unknown. (Neitzel and Frest 1989; Neitzel and Frest 1990; Pacific Biodiversity Institute 2007)
Great Columbia River spire snail	*Fluminicola columbiana*	35, 45, 48, 49; other locations unknown	NA	**General Information (Habitats and Feeding)** Also known as the Columbia pebblesnail and ashy pebblesnail, its current range is restricted to rivers, streams, and creeks of the Columbia River basin. It requires clear, cold streams with highly oxygenated water and is generally found in shallow water (less than 5 inches [13 cm] deep) with permanent flow on cobble-boulder substrates. Spire snails live on and under rocks and vegetation in the slow to rapid currents of streams where they graze on algae and small crustaceans. **Reproduction/Life History** They are short-lived, usually reaching sexual maturity within a year, at which time they breed and die**.** Unknown reproduction timing. (Neitzel and Frest 1989; Neitzel and Frest 1990; Pacific Biodiversity Institute 2007)
California floater (mussel)	*Anodonta californiensis*	30, 36, 37, 40, 42, 47–49, 52–54, 58–61	NA	**General Information (Habitats and Feeding)** In Washington, it is known to occur in the Columbia and Okanogan rivers and several lakes. Freshwater filter feeder requiring clean, well-oxygenated water for survival that is declining throughout much of its historical range. California floater mussels are intolerant of habitats with shifting substrates, excessive water flow fluctuations, or seasonal hypoxia. **Reproduction/Life History** Spring spawning occurs after adults reach 6–12 years in age. Fertilization takes place within the brood chambers of the female mussel. Fertilized eggs develop into a parasitic stage called glochidia, which attach to species-specific host fish during metamorphosis. After reaching adequate size, juvenile mussels release from the host and attach to gravel and rocks. (Box et al. 2003; Frest and Johannes 1995; Larsen et al. 1995; Nedeau et al. 2005; Watters 1999; WDNR 2006b)

Table 5-1 (continued). Range of occurrence of the HCP species and their habitat requirements.

Common Name	Scientific Name	Water Resource Inventory Area[a]	Tidal Reference Area[b]	Habitat Requirements and Reproduction Timing
Western ridged mussel	*Gonidea angulata*	01, 03–05, 07–11, 13, 21–42, 44–55, 57–62	NA	**General Information (Habitats and Feeding)** Specific information on this species is generally lacking; reside on substrates ranging from firm mud with the presence of some sand, silt, or clay to coarse gravel in creeks, streams, and rivers. They require constant, well-oxygenated flow, and shallow water (<10 ft [3 m] depth). This species may tolerate seasonal turbidity but is absent from areas with continuous turbidity and is sensitive to water quality changes such as eutrophication or presence of heavy metals. **Reproduction/Life History** During breeding, males release sperm into the water and females must bring this into their shell for fertilization to occur. Larvae called glochidia are released by the female and attach to the gills of fish for 1–6 weeks; postlarval mussels hatch from cysts as free-living juveniles to settle and bury in the substrate. (COSEWIC 2003; WDNR 2006b)

Source: Modified from (Jones & Stokes 2006).

[a] Water Resource Inventory Areas (WRIAs) are administration and planning boundaries for watershed areas, as established and managed by the Washington State Department of Ecology (Ecology). WRIA designations were formalized under WAC 173-500-040 and authorized under the Water Resources Act of 1971, Revised Code of Washington (RCW) 90.54. For WRIA boundary locations and related information, see URL = http://www.ecy.wa.gov/services/gis/maps/wria/wria.htm.

[b] Tidal Reference Areas as follows (from WAC 220-110-240): 1 = Shelton, 2 = Olympia, 3 = South Puget Sound, 4 = Tacoma, 5 = Seattle, 6 = Edmonds, 7 = Everett, 8 = Yokeko Point, 9 = Blaine, 10 = Port Townsend, 11 = Union, 12 = Seabeck, 13 = Bangor, 14 = Ocean Beaches, 15 = Westport, 16 = Aberdeen, 17 = Willapa Bay.

6.0 Conceptual Framework for Assessing Impacts

The subactivities covered in this white paper modify the bed and banks of riverine, lacustrine, and marine environments. Alteration of these environments by dredging, gravel mining, sediment capping, and channel creation will affect, to varying degrees, the physical and biological processes that create and sustain aquatic ecosystems within these environments. Furthermore, some activities covered by this white paper will result in additional uses of the aquatic ecosystems in riverine, lacustrine, and marine environments. The conceptual framework used in this white paper to assess impacts on HCP species and their habitats begins with a definition of the impacts associated with the activities authorized under an HPA for a channel modification project. The impact will exert varying degrees of effect on controlling factors within the ecosystem (Williams and Thom 2001). Controlling factors are those 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**" along which alterations to the environment associated with HPA-authorized activities can lead to impacts on the ecological function of the habitat used by HCP species. **Impact mechanisms** are the alterations to any of the conceptual framework components along the impact pathway that can result in an impact on ecological function and therefore on HCP species. Figure 6-1 illustrates the conceptual framework used in this white paper to define channel modification impacts on HCP species and their habitats.

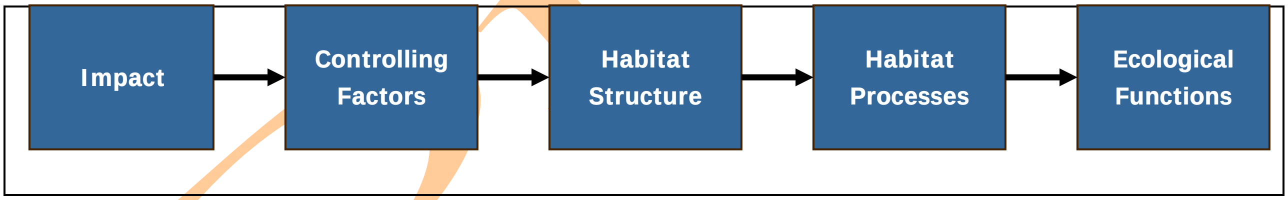

Figure 6-1. Conceptual framework for assessing impacts (Williams and Thom 2001).

Table 6-1 identifies the **mechanisms of impact** that are known to be associated with dredging, gravel mining, sediment capping, and channel creation. These mechanisms of impact are sorted by the environment (marine, riverine, and lacustrine, as appropriate) in which they occur, as the environment plays a fundamental role in the manner by which these mechanisms manifest themselves. In addition, the activity (e.g., dredging) may vary significantly depending on whether it is located in a river, lake, or ocean. This white paper presents what is known about the effects of these mechanisms on those species being considered for coverage under a WDFW multispecies HCP. By identifying these impacts and the nature of the risks these impacts exert on HCP species, measures can be implemented to avoid and, if avoidance is not possible, minimize harmful impacts on these species and the habitats that support their growth and survival.

Table 6-1. Impact mechanisms and submechanisms associated with dredging, gravel mining, sediment capping, and channel creation.

Environment	Impact Mechanism	Submechanisms
Marine	Construction and Maintenance	Noise-related disturbances (materials placement) Noise-related disturbances (vessel operation) Burial
	Dredging Equipment Operation	Bed disturbance from grounding, anchoring, and prop wash Temporary ambient light modification Bank, channel, and shoreline disturbances Water quality degradation Noise-related disturbances (vessel and equipment operation) Entrainment
	Hydraulic and Geomorphic Modifications	Altered wave energy Altered current velocities Altered nearshore circulation patterns Altered sediment supply Altered substrate composition and stability
	Aquatic Vegetation Modifications	Altered autochthonous production Altered habitat complexity
	Water Quality Modifications	Altered temperature regime Altered dissolved oxygen Altered suspended sediments and turbidity Nutrient and pollutant loading
	Ecosystem Fragmentation	Habitat loss and fragmentation
Lacustrine	Construction and Maintenance	Noise-related disturbances (materials placement) Noise-related disturbances (vessel operation) Burial
	Dredging Equipment Operation	Bed disturbance from grounding, anchoring, and prop wash Temporary ambient light modification Bank, channel, and shoreline disturbances Water quality degradation Noise-related disturbances (vessel and equipment operation) Entrainment
	Hydraulic and Geomorphic Modifications	Altered wave energy Altered current velocities Altered nearshore circulation patterns Altered sediment supply Altered substrate composition and stability
	Aquatic Vegetation Modifications	Altered autochthonous production Altered habitat complexity
	Water Quality Modifications	Altered temperature regime Altered dissolved oxygen Altered suspended sediments and turbidity Nutrient and pollutant loading
	Ecosystem Fragmentation	Habitat loss and fragmentation

Table 6-1 (continues). Impact mechanisms and submechanisms associated with dredging, gravel mining, sediment capping, and channel creation.

Environment	Impact Mechanism	Submechanisms
Riverine	Construction and Maintenance	Dewatering, flow bypass, and fish handling Channel rewatering Construction equipment operation Noise-related disturbances (materials placement) Noise-related disturbances (vessel operation) Burial Bank, channel, and shoreline disturbances
	Dredging Equipment Operation	Bed disturbance from grounding, anchoring, and prop wash Temporary ambient light modification Bank, channel, and shoreline disturbances Water quality degradation Noise-related disturbances (vessel and equipment operation) Entrainment
	Hydraulic and Geomorphic Modifications	Altered channel geometry Altered flow regime Altered sediment supply Altered substrate composition and stability Altered groundwater-surface water interactions Altered hyporheic flow/exchange
	Riparian Vegetation Modifications	Altered riparian shading and ambient air temperature regime Altered stream bank stability Altered allochthonous input Altered habitat complexity Altered groundwater-surface water interactions
	Aquatic Vegetation Modifications	Altered autochthonous production Altered habitat complexity
	Water Quality Modifications	Altered temperature regime Altered dissolved oxygen Altered suspended sediments and turbidity Nutrient and pollutant loading
	Ecosystem Fragmentation	Altered longitudinal connectivity Altered river-floodplain connectivity Altered groundwater-surface water interactions Habitat loss and fragmentation

The identification of impact mechanisms associated with HPA-authorized activities that affect habitat is based on a model described by Williams and Thom (2001). For analyzing risk of take and refining the impact analysis as it pertains directly to listed species or species that will be addressed in the HCP, the “exposure-response” model developed by USFWS was used (National Conservation Training Center 2004). Each of these models is discussed in more detail below.

The Williams and Thom model provides the framework for analysis based on the literature search. The goals of this framework are to:

- Elucidate impacts associated with each HPA activity.
- Determine how those impacts manifest themselves in effects on habitat and habitat functions utilized by the species that will be addressed in the HCP.
- Develop recommendations for impact avoidance, minimization, and mitigation measures that target the identified impacts.

The analysis begins with an impact which, in this case, would consist of activities authorized under an HPA for a channel modification project. The impact will exert varying degrees of effect on controlling factors within the ecosystem (Williams and Thom 2001). Controlling factors are those physical processes or environmental conditions (e.g., flow conditions or sediment transport) that control local habitat structure (e.g., substrate). Habitat structure is linked to habitat processes (e.g., sediment transport), which are linked to ecological functions (e.g., salmon spawning habitat). These linkages form the "**impact pathway**" in which alterations to the environment associated with HPA-authorized activities can lead to impacts on the ecological function of the habitat for HCP species. **Impact mechanisms** are the alterations to any of the conceptual framework components along the impact pathway that can result in an impact on ecological function(s) and therefore on HCP species. For each HPA-authorized activity addressed in this white paper, several principal impact mechanisms were identified for each subactivity type, from a geomorphological, engineering, hydrologic, and biological perspective.

This impact analysis serves to identify the direct and indirect impacts that could potentially affect federally listed species and those species that will be addressed in the HCP. To further refine the analysis in each white paper, the exposure-response model (National Conservation Training Center 2004) was incorporated into the impact analysis. The exposure-response model evaluates the likelihood that adverse effects may occur as a result of species exposure to one or more stressors. This model takes into account the effects of exposure for all life-history forms likely to experience stressor exposure, and characterizes the resultant effects across all life-history stages.

The exposure-response model was incorporated as a series of matrices, presented in Appendix A, with results synthesized in Section 7 (*Direct and Indirect Impacts*) of this white paper. In these species-specific exposure-response matrices, each mechanism and submechanism was initially examined and evaluated to:

- Identify and characterize specific impacts or stressors

- Evaluate the potential for exposure (potential for species to be exposed = identification of stressor timing/duration/frequency/life-history, form, and presence coincident with an impact)
- Identify the species' anticipated response to a stressor
- Identify measures that could reduce exposure
- Identify performance standards if appropriate
- Characterize the resulting effects of specific impacts on the various species.

With regard to exposure, standard language was used to indicate when an impact occurs, and for how long and how frequently the stressor or impact occurs. Definitions of the terms used in this analysis are listed in Table 6-2.

Based on life-history information, an analysis of potential exposure was completed for each HCP species. This included an analysis of the direct and indirect impacts (associated with each of the impact mechanisms) on the different lifestages of each species and the likely responses of each species to these stressors. Impact minimization measures to reduce or avoid submechanism impacts were also identified. A final conclusion regarding the overall effect of the submechanism/stressor on a species is also presented in the Appendix A matrices.

Where information was available, the cumulative effects associated with the major impact mechanisms were also identified (see Section 8).

The information generated by the exposure response analysis is used to summarize the overall risk of take associated with the impact mechanisms produced by each subactivity type. The summary risk of take analysis is presented in Section 9, which presents the risk of take associated with each subactivity type using: (1) a narrative discussion of the risk of take associated with each subactivity type by the specific associated submechanism of impact; and (2) risk of take assessment matrices (Appendix A) that rate the risk of take resulting from each subactivity by impact mechanism and environment type. The risk of take ratings presented in the text and matrices in Section 9 are based upon the rating criteria defined in Table 6-3.

Based on the identification of impacts and risk of take analysis, additional recommendations (e.g., conservation, management, protection, BMPs) for minimizing project impacts or risk of take were developed.

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Table 6-2. Definitions of terms used in the exposure-response analysis for this white paper.

Parameter	Description	Exposure	Definition
When	The timing during which stressor exposure occurs (e.g., time of day, season, associated with operations or maintenance)	—	Defined flexibly as appropriate for each stressor.
Duration	The length of time the receptor is expected to be exposed to the stressor	Permanent	Stressor is permanent (e.g., conversion of habitat to built environment)
		Long-term	Stressor will last for greater than five years to decades (e.g., time required for complete riparian recovery)
		Intermediate-term	Stressor will last from 6 months to approximately 5 years (e.g., time required for beach substrate to recover from construction equipment)
		Short-term	Stressor will last from days to 6 months (e.g., time required for invertebrate community to recolonize following dewatering)
		Temporary	Stressor associated with transient action (e.g., pile driving noise)
Frequency	The regularity with which stressor exposure is expected to occur and/or the time interval between exposure	Continuous	Stressor is ongoing and occurs constantly (e.g., permanent modification of habitat suitability)
		Intermittent	Stressor occurs routinely on a daily basis
		Daily	Stressor occurs once per day for extended periods (e.g., daytime structural shading)
		Common	Stressor occurs routinely (i.e., at least once per week or several times per month)
		Seasonal	Stressor occurs for extended periods during specific seasons (e.g., temperature effects occurring predominantly in winter and summer)
		Annual	Stressor occurs for an extended period annually for a short period of time
		Interannual–decadal	Stressor occurs infrequently (e.g., pile driving associated with project construction and maintenance)

Table 6-3. Definitions of the terminology used for risk of take determinations in this white paper.

Risk of Take Code	Potential for Take	Definition*
H	High	Stressor exposure is likely to occur with high likelihood of individual take in the form of direct mortality, injury, and/or direct or indirect effects on long-term survival, growth, and fitness potential due to long-term or permanent alteration of habitat capacity or characteristics. Likely to equate to a Likely to Adversely Affect (LTAA) finding.
M	Moderate	Stressor exposure is likely to occur causing take in the form of direct or indirect effects potentially leading to reductions in individual survival, growth, and fitness due to short-term to intermediate-term alteration of habitat characteristics. May equate to an LTAA or a Not Likely to Adversely Affect (NLTAA) finding depending on specific circumstances.
L	Low	Stressor exposure is likely to occur causing take in the form of temporary disturbance and minor behavioral alteration. Likely to equate to an NLTAA finding.
I	Insignificant	Stressor exposure may potentially occur, but the likelihood is discountable and/or the effects of stressor exposure are insignificant. Likely to equate to an NLTAA finding.
N	No Risk	No risk of take ratings apply to species with no likelihood of stressor exposure because they do not occur in habitats that are suitable for the subactivity type in question, or the impact mechanisms caused by the subactivity type will not produce environmental stressors.
?	Unknown	Unknown risk of take ratings apply to cases where insufficient data are available to determine the probability of exposure or to assess stressor response.

*LTAA = Likely to Adversely Affect.
NLTAA = Not Likely to Adversely Affect.

7.0 Direct and Indirect Impacts

Each of the four subactivity types identified and considered in this white paper under channel modification (i.e., dredging, gravel mining and bar scalping, sediment capping, and channel creation and alignment) will alter the natural flow regime and therefore affect species, habitats, and ecological processes. This section reviews and synthesizes what is known about the potential impacts of each of the identified impact mechanisms (as identified in Section 6 [*Conceptual Framework for Assessing Impacts*]) on HCP species. It reflects the literature findings on both direct and indirect impacts of activities associated with channel modification activities. The exposure-response matrices (included in Appendix A) provide a synthesis of each of the HCP species (or species groupings). The matrix structure differs slightly from the text below to provide consistency with the Exposure-Response Matrices presented in other WDFW white papers [e.g., (Herrera 2007a)]. The matrix structure also differs slightly from the text primarily in that the matrices define impacts with respect to different environments (i.e., riverine, lacustrine, marine), whereas the text below may discuss these environments collectively for some of the impact mechanisms.

7.1 Dredging

Dredging occurs in marine, riverine, and lacustrine environments. Marine dredging is performed primarily for vessel navigation in ports and marinas. It is uncertain whether estuarine HPAs would be considered marine or riverine based upon the geomorphic definition used herein; however, it is clear that estuarine dredging activities will likely have an impact on marine environments, particularly the broadcast of fine sediments to the nearshore zone (Hossain et al. 2004).

Freshwater dredging occurs primarily in large rivers and reservoirs to allow the passage of deep-draft vessels in channels and marinas. Maintenance dredging to increase conveyance for flood and erosion control occurs primarily in relatively smaller channels at bridge and culvert crossings, in roadside and irrigation ditches, and in sediment traps constructed for this purpose. Hydraulic suction dredging used specifically for vegetation management in freshwater environments is also discussed in this section.

7.1.1 Dredging Equipment Operation

There are two major types of dredging equipment:

- **Mechanical dredges** include clamshell, dipper, and ladder dredges. Mechanical dredges remove material through direct force and are used both for new and maintenance projects. Mechanical dredges cause more sediment resuspension when dredging occurs in fine, loose, or noncohesive substrates.

- **Hydraulic dredges** include cutterheads, dustpans, hoppers, hydraulic pipelines, plain suction, and sidecasters. Hydraulic dredges remove material in slurries and are generally used for maintenance projects. Hydraulic dredges are generally faster than mechanical dredges. Although hydraulic dredges create less resuspension of sediment than mechanical dredges, considerable resuspension can occur (Figure 7-1). Additionally, hydraulic dredging entrains considerably more water from the dredge site than mechanical dredging. Equipment type varies by project. Smaller, shallower dredging projects typically use different equipment than that required for deep water dredging projects.

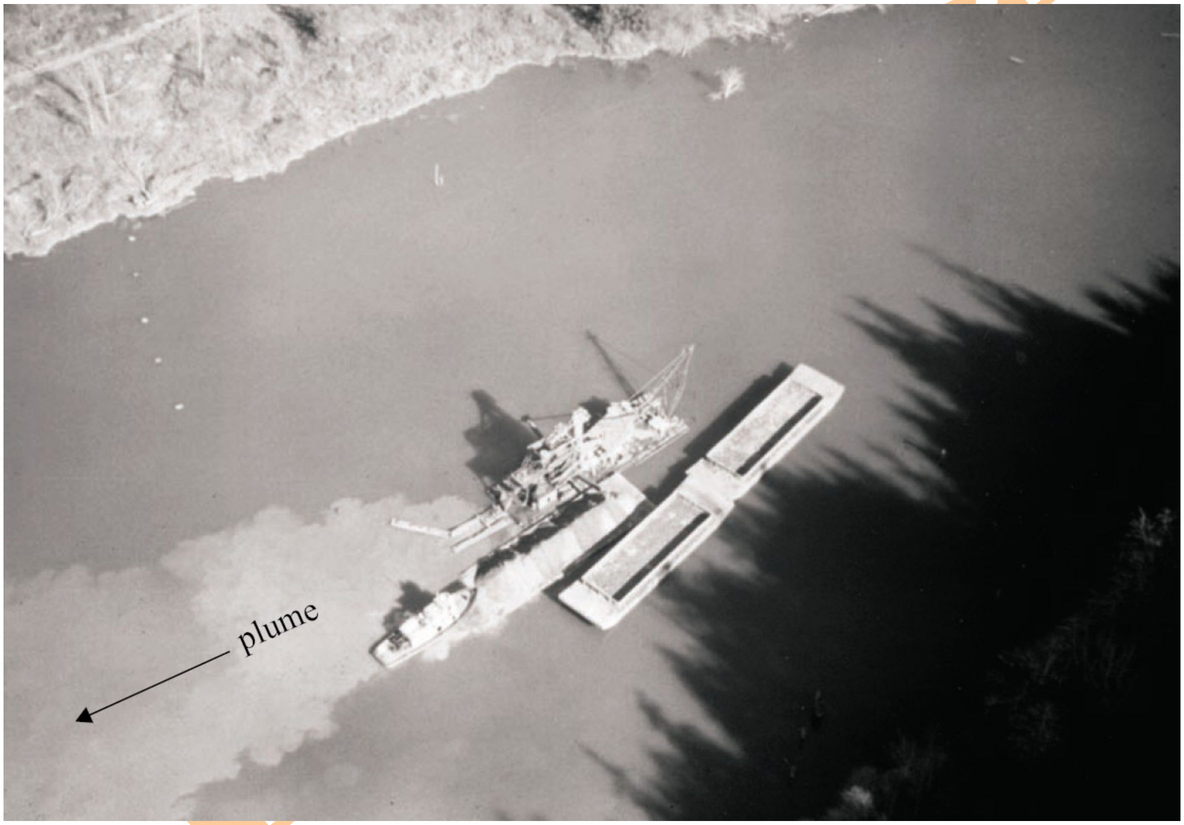


Figure 7-1. A suction gravel dredge and barges on the Chehalis River in the mid-1960s, showing a suspended-sediment plume moving downstream (Norman et al. 1998).

The techniques and equipment used for navigational dredging in marine environments are generally the same as those employed for navigational dredging in riverine and lacustrine environments. As a result, navigational dredging in freshwater environments affects organisms through many of the same mechanisms of impact identified for marine environments. The primary difference between dredging in marine and freshwater environments has to do with the physical effects of the activity on habitat-forming processes in a unidirectional channel and the attendant biological effects on freshwater species. In contrast with large-scale navigational dredging conducted from a vessel or barge, small-scale navigational dredging may be performed from land using a clamshell bucket operated from a crane. The maintenance dredging of streams, ditches, and sediment traps is typically conducted from land using heavy equipment (such as a backhoe or excavator) or a suction dredge.

In terms of construction activities, this section provides information regarding the primary dredging itself. Discussions regarding underwater structure construction impacts associated with disposal operations are included in the sediment cap section because sediment capping often accompanies dredging disposal operations, and the techniques used to dispose of dredge spoils at sea are similar to those used in sediment capping technology. Therefore, the effects of dredge spoil disposal are covered in Section 7.1 (*Dredging*). The remaining two construction impact submechanisms, dredging equipment operation and entrainment of organisms during the dredging activity, are addressed here. Note: some of the information presented in this white paper is reproduced from previously prepared white papers addressing the effects from dredging and overwater structures in marine environments (Nightingale and Simenstad 2001a, 2001b).

7.1.1.1 Submechanisms of Impact

The operation of dredging equipment during construction presents several potential stressors (i.e., submechanisms of impact):

- Bed disturbances from grounding, anchoring, and prop wash
- Temporary ambient light modification
- Bank, channel, and shoreline disturbances
- Water quality degradation
- Noise-related disturbances
- Entrainment

The first two stressors are addressed in detail in the *Facility Operation and Vessel Activities* section of the Marinas and Shipping/Ferry Terminals white paper (Herrera 2007a). In general, bed disturbances from vessel operation can result in several stressors, namely benthic disturbance and turbidity, eelgrass and macroalgae disturbance, and freshwater aquatic vegetation disturbance (Eriksson et al. 2004; Haas et al. 2002; Kennish 2002; Yousef et al. 1980). Temporary ambient light from dredging operations have been found to affect fish migration behavior and place some species at risk of increased predation (Fields 1966; Johnson et al. 1998; Prinslow et al. 1979; Ratte and Salo 1985; Tabor et al. 2001). Bank, channel, and shoreline disturbances are addressed below in the Channel Creation and Alignment portion of this white paper in Section 7.4.1.1.2 (*Bank, Channel, and Shoreline Disturbances*). The water quality impacts are addressed in detail below in Section 7.1.6 (*Water Quality Modifications*). The two remaining stressors, noise and entrainment, are addressed below.

7.1.1.1.1 Noise-Related Disturbances (Elevated Underwater Noise)

Dredging operations can produce underwater noise through a variety of mechanisms. These mechanisms include construction-related noise impacts from impulsive sources (i.e., short duration, high intensity noise from sources such as dredging bucket impact or materials placement), and continuous noise sources (e.g., vessel or equipment operation). The discussion presented in this section provides the noise-related analytical basis for the development of the exposure-response matrixes (Appendix A) and the risk of take analysis (Section 9).

This section summarizes existing information on the sources of underwater noise, existing and proposed effects thresholds, and the magnitude of noise stressors associated with typical project construction and maintenance activities. This discussion is derived in part from a summary of the current science on the subject developed by WSDOT (2006).

Measurement of Underwater Noise

Underwater sound levels are measured with a hydrophone, or underwater microphone, which converts sound pressure to voltage, which is then converted back to pressure, expressed in pascals (Pa), pounds per square inch (psi), or decibel (dB) units. Derivatives of dB units are most commonly used to describe the magnitude of sound pressure produced by an underwater noise source, with the two most commonly used measurements being the instantaneous peak sound pressure level (dB_{PEAK}) and the root mean square (dB_{RMS}) pressure level during the impulse, referenced to 1 micropascal (re: 1µ Pa) (Urick 1983). The dB_{PEAK} measure represents is the instantaneous maximum sound pressure observed during each pulse. The RMS level represents the square root of the total sound pressure energy divided by the impulse duration, which provides a measure of the total sound pressure level produced by an impulsive source. The majority of literature uses dB_{PEAK} sound pressures to evaluate potential injury to fish. However, USFWS and NOAA Fisheries have used both dB_{PEAK} (for injury) dB_{RMS} (for behavioral effects) threshold values to evaluate adverse effects on fish, marine mammals, and diving birds (Stadler 2007; Teachout 2007). dB_{RMS} values are used to define disturbance thresholds in fish species, meaning the sound pressure level at which fish noticeably alter their behavior in response to the stimulus (e.g., through avoidance or a “startle” response). dB_{PEAK} values are used to define injury thresholds in salmonids, meaning the sound pressure level at which injury from barotraumas may occur (i.e., physical damage to body tissues caused by a sharp pressure gradient between a gas or fluid-filled space inside the body and the surrounding gas or liquid). Unless otherwise noted, all sound pressure levels cited herein are in dB_{PEAK} or dB_{RMS} re: 1µPa.

Noise behaves in much the same way in air and in water, attenuating gradually over distance as the receptor moves away from the noise source. However, underwater sound exhibits a range of behaviors in response to environmental variables (Urick 1983). For example, sound waves bend upward when propagated upstream into currents and downward when propagated downstream in the direction of currents. Sound waves will also bend toward colder, denser water. Haloclines and other forms of stratification can also influence how sound travels. Noise shadows created by bottom topography and intervening land masses or artificial structures can, under certain circumstances, block the transmission of underwater sound waves. In freshwater systems, sound propagation is often influenced by depth and channel morphology. Underwater noise does not transmit as effectively when water depths are less than 3 feet due to the amplitude of the sound pressure wave (Urick 1983). Because underwater sound does not travel around obstructions, bends in a river or large changes in gradient will truncate sound propagation. This will limit the physical extent of noise related impacts.

Underwater noise attenuation, or transmission loss, is the reduction of the intensity of the acoustic pressure wave as it propagates, or spreads, outward from a source. Propagation can be categorized using two models, spherical spreading and cylindrical spreading. Spherical (free-field) spreading occurs when the source is free to expand with no refraction or reflection from boundaries (e.g., the bottom or the water surface). Cylindrical spreading applies when sound energy spreads outward in a cylindrical fashion bounded by the sediment and water surface. Because neither model applies perfectly in any given situation, most experts agree that a combination of the two best describes sound propagation in real-world conditions (Vagle 2003).

Currently, USFWS and NOAA Fisheries are using a practical spreading loss calculation, which accommodates this view (Stadler 2007; Teachout 2007). This formula accommodates some of the complexity of underwater noise behavior, but it does not account for a number of other factors that can significantly affect sound propagation. For example, decreasing temperature with depth can create significant shadow zones where actual sound pressure levels can be as much as 30 dB lower than calculated because sound bends toward the colder deeper water (Urick 1983). Haloclines, current mixing, water depth, acoustic wavelength, sound flanking (i.e., sound transmission through bottom sediments), and the reflective properties of the surface and the bottom can all influence sound propagation in ways that are difficult to predict.

Given these complexities, characterizing underwater sound propagation inherently involves a large amount of uncertainty. An alternative calculation approach, known as the Nedwell model (not used by USFWS or NOAA Fisheries), indirectly accounts for some of these factors. Nedwell and Edwards (2002) and Nedwell et al. (2003) measured underwater sound levels associated with pile driving close to and at distance from the source in a number of projects in English rivers. They found that the standard geometric transmission loss formula used in the practical spreading loss model did not fit well to the data, most likely because it does not account for the aforementioned factors that affect sound propagation. They developed an alternative model based on a manufactured formula that produced the best fit to sound attenuation rates measured in the field. This model thereby accounts for uncharacterized factors that affect noise attenuation, but does not explicitly identify each factor or its specific effects. Because there is considerable uncertainty regarding how to model the many factors affecting underwater noise propagation, and this would require site-specific information that cannot practically be obtained in many instances, the Services (i.e., USFWS and NOAA Fisheries) use the more conservative practical spreading loss model in ESA consultations (Stadler 2007; Teachout 2007).

Vessel and Equipment Operation

The underwater noise produced by an HPA permitted project, either during construction or operation, is defined by the magnitude and duration of underwater noise above ambient noise levels. The action area for underwater noise effects in ESA consultations is defined by the distance required to attenuate construction noise levels to ambient levels as calculated using the practical spreading loss calculation or other appropriate formula provided in evolving guidance from USFWS and NOAA Fisheries on this subject.

In a review of underwater sounds produced by a variety of dredges, Clarke et al. (2002) found that sound intensity, periodicity, and spectra vary by type of dredge. Bucket dredges have repetitive sequences of sounds, including winch, bucket impact, bucket closing, and bucket emptying. Cutterhead dredges have relatively continuous sounds made by the cutterhead rotating through the substrate. Hopper dredges produce a combination of sounds from the engine/propeller and from the draghead in contact with substrate. The transmission of underwater sound depends on the type of substrate, ambient suspended sediment loads (which tend to scatter and attenuate sound), bathymetry of the waterway, hydrodynamic conditions, condition of the equipment, and the skill of the dredge operator. The Clarke et al. (2002) review noted that the sound of bucket impact with the substrate was at the limit of detection by a low-noise hydrophone and hydrophone audio amplifier at 7 km from the impact point. Cutterhead sounds peaked at 100-110 dB_{PEAK} in the frequency range of 70-1000 Hz and were inaudible at about 500 meters from the source. The hopper dredge sound peaked at 120-140 dB_{PEAK} and fell within a frequency range of 70-1000 Hz. In a study at Cook Inlet, Alaska, the sound of the bucket striking a mixed sand and/or gravel substrate was the most intense sound generated from all aspects of bucket dredge operations and was measured up to 3000 meters from the dredging site (Dickerson et al. 2001). Peak sound levels were 124.0 dB_{PEAK} at a frequency of 162.8 Hz measured at 150 meters from the bucket strike location, 50.8 dB_{PEAK} above peak ambient conditions. Noise levels for a 2001 Fisheries Impact Assessment to determine potential fish effects of pile driving for the San Francisco-Oakland Bay Bridge construction were 29 times higher than the Cook Inlet dredge measurement [based on calculations from Shaw et al. (1999)]. Even accounting for attenuation, the root mean square impulse during pile driving (199-201 dB_{RMS}) was more intense than sound from dredging operations (124.0 dB_{RMS}).

7.1.1.1.2 Entrainment

Entrainment occurs when an organism is trapped in the uptake of sediments and water being removed by dredging machinery (Reine and Clarke 1998). Benthic infauna are particularly vulnerable to being entrained by dredging uptake, but motile epibenthic and demersal organisms such as burrowing shrimp, crabs, and eggs, or rearing larvae and juveniles of many fish species also can be susceptible to entrainment. Entrainment rates are usually described by the number of organisms entrained per cubic yard (cy) of sediment dredged (Armstrong et al. 1982).

Demersal fish, such as sand lance, sculpins, and sticklebacks, are hypothesized to have the highest rates of entrainment as they reside on or in the bottom substrates, with life-history strategies of burrowing or hiding in the bottom substrate. This is also true in freshwater environments. For example, lamprey ammocoetes likely have a high risk of vulnerability to dredging due to the lengthy time of residence in freshwater sediments in their early life-history stages. In general, larval fish that have little or no swimming capacity to avoid direct dredge impacts are also at significant risk of entrainment in dredge sites. Of particular concern for the purpose of this analysis, are the HCP groundfish (lingcod, rockfish, Pacific cod, pollock, hake) and the forage fishes (herring, sand lance, and surf smelt), which all have larval or juvenile life-history stages with low-motility. The juvenile life-history stage of the groundfish species typically rear in shallow nearshore habitats, where dredging is likely to occur. Due to their demersal nature and limited motility, they face a higher risk of dredging entrainment.

Larger fish may also be susceptible to entrainment. Armstrong et al. (1982) found that larger fish were not necessarily able to avoid the hopper dredge, with the largest specimen being a 9.2-in (234-mm) tomcod. Tests of excluders mounted on the draghead of a hopper dredge showed that 66 percent fewer fishes (mostly flatfish and gunnels in the study) were entrained through use of the device (Shaw 1996).

Buell (1992) found entrainment of juvenile white sturgeon (11.8–19.6 in [300–500 mm]) at a rate of 0.015 fish/cy. In another study, juvenile salmonids and eulachons were the dominant entrained taxa due to the dredge location in a constricted waterway, making it more difficult for salmonids to avoid the dredge operation (Larson and Moehl 1990; McGraw and Armstrong 1990).

Bivalve larvae, such as larval oysters, are assumed to suffer 100 percent mortality when entrained during dredging due to sediment smothering, anoxia, starvation, or mechanical injury. However, the population level effects of these stressors may be relatively limited. For example, mortality of larval Chesapeake Bay oysters from suction dredge entrainment was identified as a potential issue affecting population viability during the 1980s. To address this concern, Lunz (1985) developed a population model to evaluate potential dredging effects in the context of natural mortality rates. He estimated that entrainment-related mortality would typically range between 0.005 and 0.3 percent of total larval abundance, which is an insignificant effect relative to natural recruitment variability (i.e., natural larval mortality). Many species, particularly marine fish and invertebrates, have planktonic larval life-history stages that suffer naturally high mortality rates (in some cases exceeding 99 percent), so the small mortality rate that results from dredging will not have a significant effect on recruitment.

7.1.1.2 Direct and Indirect Effects on Fish and Invertebrates

Dredging vessel and equipment operation is likely to generate continued sound for long periods of time. Direct effects associated with these noises include temporary impacts on hearing ability or behavioral responses such as startling or scattering, ultimately reducing the fitness and survival of the affected species. Indirect effects include masking of ambient noises in the aquatic environment that fish would ordinarily use to identify prey and predators, subsequently reducing foraging success and increasing vulnerability to predation. Other indirect effects include stress competition from displacement and behavioral avoidance.

Most fish sense sounds, vibrations, and other displacements of water in their environment through their inner ear and with the lateral line running the length of each side of the fish and on the head. The lateral line is a mechano-sensory system that plays an indirect role in hearing through its sensitivity to pressure changes at close range. The hearing organs and lateral line system are collectively referred to as the acoustico-lateralis system. The hearing thresholds of different fish species varies depending on the structure and sensitivity of this system. Those families of fish known as hearing specialists include cyprinids (dace [e.g., Umatilla and leopard dace], minnows and carp), catastomids (suckers [e.g., mountain sucker]), and ictalurids (catfish), which collectively belong to Ostariophysan taxonomic grouping of fishes. These fish possess a physical connection between the swim bladder and the inner ear, with the swimbladder acting as an amplifier that transforms the pressure component of sound into particle velocity component, to which the inner ear is sensitive (Moyle and Cech 1998). The hearing capacity of salmonids, on the other hand, is limited both in bandwidth and intensity threshold. The Atlantic salmon, for example, is functionally deaf at sound pressure wavelengths above 380 hertz (Hz) (Hawkins and Johnstone 1978). In these fish, the swimbladder does not likely enhance hearing.

Noise sources, such as pile driving that produce high intensity sound pressure waves, can result in direct effects on fish that include effects as limited as temporary stress and behavioral avoidance, temporary or permanent injury in multiple organ systems (including hearing, heart, kidney, swim bladder, and other vascular tissue), and direct mortality (Popper and Fay 1973, 1993). Another potential effect includes masking of existing ambient noise reducing the ability of fish to sense predators or prey. These activities may also have indirect effects such as reducing the foraging success of these fish by affecting the distribution or viability of potential prey species. Numerous studies have examined the effects on fish associated with underwater noise and are discussed more fully below.

In general, injury and mortality effects from underwater noise are caused by rapid pressure changes, especially on gas-filled spaces in the body. Rapid volume changes of the swim bladder may cause it to tear, resulting in a loss of hearing sensitivity and hydrostatic control. Intense noise may also damage the tissue in hearing organs, as well as the heart, kidneys, and other highly vascular tissue. Susceptibility to injury is variable and depends on species-specific physiology, auditory injury, and auditory thresholds (Popper and Fay 1973, 1993). While species-specific data are limited, the available information indicates variable effects related to physiology, size, and age, as well as the intensity, wavelength, and duration of sound exposure.

Hardyniec and Skeen (2005) and Hastings and Popper (2005) summarized available information on the effects of pile driving-related noise on fish. Pile driving effects observed in the studies reviewed ranged broadly from brief startle responses followed by habituation to instantaneous lethal injury. The difference in effect is dependent on a number of factors, including: piling material, the type and size of equipment used, and mitigation measures; site-specific depth, substrate, and water conditions; and the species, size, and life-history stage of fish exposed.

Popper et al. (2005) exposed three species of fish to high-intensity percussive sounds from a seismic air gun at sound levels ranging between 205 and 209 $\mathrm{dB_{Peak}}$, intending to mimic exposure to pile driving. Subject species included a hearing generalist (broad whitefish), a hearing specialist (lake chub), and a species that is intermediate in hearing (northern pike). They found that the broad whitefish suffered no significant effects from noise exposure, the lake chub demonstrated a pronounced temporary threshold shift in hearing sensitivity (i.e., hearing loss), and the northern pike showed a significant temporary hearing loss but less than that of the lake chub. The hearing sensitivity of lake chub and northern pike returned to their respective normal thresholds after 18 to 24 hours. High-intensity sounds can also permanently damage fish hearing (Cox et al. 1987; Enger 1981; Popper and Clarke 1976).

Enger (1981) found that pulsed sound at 180 dB was sufficient to damage the hearing organs of codfish (genus *Gadus*), resulting in permanent hearing loss. Hastings (1995) found that goldfish exposed to continuous tones of 189, 192, and 204 dB_{peak} at 250 Hz for 1 hour suffered permanent damage to auditory sensory cells. Injury effects may also vary depending on noise frequency and duration. Hastings et al. (1996) found destruction of sensory cells in the inner ears of oscars 4 days after exposure to continuous sound for 1 hour at 180 dB_{peak} at 300 Hz. In contrast, when the two groups of the same species were exposed to continuous sound at 180 dB_{peak} at 60 Hz for 1 hour, and to impulsive sound at 180 dB_{peak} at 300 Hz repeatedly over 1 hour, they showed no apparent injury. Susceptibility to injury may also be life-history specific. Banner and Hyatt (1973) demonstrated increased mortality of sheepshead minnow eggs and embryos when exposed to broadband noise approximately 15 dB above the ambient sound level. However, hatched sheepshead minnow fry were unaffected by the same exposure.

Even in the absence of injury, noise can produce sublethal effects. Behavioral responses to sound stimuli are well established in the literature for many fish species. For example, Moore and Newman (1956) reported that the classic fright response of salmonids to instantaneous sound stimuli was the "startle" or "start" behavior, where a fish rapidly darts away from the noise source. Knudsen et al. (1992) found that in response to low-frequency (10 Hz range) sound, salmonids 1.6–2.4 in (40–60 mm) in length exhibited an initial startle response followed by habituation, while higher frequency sound caused no response even at high intensity. In a study of the effects of observed pile driving activities on the behavior and distribution of juvenile pink and chum salmon, Feist et al. (1992) found that pile-driving operations were associated with changes in the distribution and behavior of fish schools in the vicinity. Fish schools were two-fold more abundant during normal construction days in comparison to periods when pile driving took place. Blaxter et al. (1981) found Atlantic herring to exhibit an avoidance response to both continuous pulsed sound stimuli with habituation to more continuous stimuli occurring over time, and Schwarz and Greer (1984) found similar responses on the part of Pacific herring. Sound has also been shown to affect growth rates, fat stores, and reproduction (Banner and Hyatt 1973; Meier and Horseman 1977).

Prolonged underwater noise can also reduce the sensitivity of fish to underwater noise stimuli, with potentially important effects on survival, growth, and fitness. The fish auditory system is likely one of the most important mechanisms fish use to detect and respond to prey, predators, and social interaction (Amoser and Ladich 2005; Fay 1988; Hawkins 1986; Kalmijn 1988; Myrberg 1972; Myrberg and Riggio 1985; Nelson 1965; Nelson et al. 1969; Richard 1968; Scholik and Yan 2001; Scholik and Yan 2002; Wisby et al. 1964). Scholik and Yan (2001) studied the auditory responses of the cyprinid fathead minnow to underwater noise levels typical of human-related activities (e.g., a 50-horsepower outboard motor). They found that prolonged exposure decreased noise sensitivity, increasing the threshold level required to elicit a disturbance response for as long as 14 days after the exposure. Amoser and Ladich (2005) reported similar findings in common carp in the Danube River, noting that auditory ability in this hearing specialist species was measurably masked in environments with higher background noise. They reported similar but far less pronounced responses in hearing generalist species such as perch. These data suggest that elevated ambient noise levels have the potential to impair hearing ability in a variety of fish species, which may in turn adversely affect the ability to detect prey and avoid predators, but that this effect is variable depending on the specific sensitivity of the species in question. Feist et al. (1992) similarly theorized that it was possible that auditory masking and habituation to loud continuous noise from machinery may decrease the ability of salmonids to detect approaching predators.

In general, information on the effects of underwater noise on invertebrates is limited, indicating that additional research on the subject is needed. What little data are available suggest some sensitivity to intense percussive underwater noise. In a study completed by Turnpenny et al. (1994), mussels, periwinkles, amphipods, squid, scallops, and sea urchins were exposed to high air gun and slow-rise-time sounds at between 217 and 260 dB, analogous to extremely loud pile driving. One scallop suffered a split shell following exposure to 217 dB, suggesting the potential for serious injury when percussive underwater noise exceeds these levels.

No research has been identified regarding the effects of lower intensity continuous underwater noise on invertebrates. However, operational noise is typically associated with sound pressures well below levels that have been observed to cause injury in shellfish, suggesting that HCP invertebrate species might not be subject to these effects. Because HCP invertebrates with the potential for stressor exposure are either filter feeders or grazers and are essentially non-motile, these species are unlikely to be subject to auditory masking effects that would limit the ability to sense predators and prey. Some potential may exist for disturbance induced interruption of feeding behavior, but more research on this subject is necessary to determine this definitively and this subject is considered a data gap.

In addition to noise-related disturbances, entrainment during dredging can have direct and indirect effects on HCP species. The direct and indirect effects associated with dredging entrainment include injury or mortality of fish and invertebrate species. Indirect effects include alteration of food web configuration or dynamics that could affect overall species survival or fitness.

7.1.2 Riparian Vegetation Modifications

Dredging in marine and lacustrine environments generally occurs from a barge (USACE 1983). It is extremely unlikely that operations would be conducted from on-land and would require the removal of riparian vegetation. Therefore, provided that disposal of dredged material does not harm riparian vegetation (i.e., riparian vegetation is buried during disposal), impacts on fish and invertebrates associated with riparian vegetation modifications will likely be negligible as a result of most marine and lacustrine dredging. Modifications to riparian vegetation and associated impacts on fish and invertebrates could occur as a result of sloughing caused by nearshore dredging that destabilizes vegetated banks.

In contrast, small-scale navigational dredging and maintenance dredging are typically conducted from land and thus have the potential to modify riparian vegetation. Therefore, this section addresses impacts from dredging in freshwater environments.

7.1.2.1 Submechanisms of Impact

Modifications to riparian vegetation resulting from land-based dredging operations include the following stressors (i.e., submechanisms of impact):

- Altered shading and an altered ambient air temperature regime
- Altered stream bank stability
- Altered allochthonous input
- Altered habitat complexity
- Altered groundwater-surface water interactions

7.1.2.1.1 Altered Riparian Shading and Ambient Air Temperature Regime

Removal of riparian vegetation as part of land-based dredging affects water temperature in riverine environments through a number of mechanisms. The dominant mechanism is the effect of reduced shading on solar radiation exposure. The influence of shade 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; Murphy and Meehan 1991; Poole and Berman 2001a; Quinn 2005). Alternatively, riparian vegetation removal and alteration can also cause surface waters to gain or lose heat more rapidly because the ability to regulate ambient temperatures is reduced (Bolton and Shellberg 2001; Knutson and Naef 1997; Murphy and Meehan 1991; Poole and Berman 2001a; Quinn 2005).

In addition to the effects of shading, a broad array of research has shown that alterations of riparian vegetation can strongly affect temperatures even when adequate stream shading is still provided. Riparian vegetation restricts air movement, providing an insulating effect that regulates ambient air temperatures. Alterations of the riparian buffer width and vegetation composition can degrade this insulating effect, leading to greater variability in ambient air temperatures that in turn influence water temperatures (AFS and SER 2000; Bartholow 2002; Barton et al. 1985; Beschta 1991, 1997; Beschta et al. 1988; Beschta and Taylor 1988; Brosofske et al. 1997; Brown 1970; Chen et al. 1992, 1993, 1995; Chen et al. 1999; Johnson and Jones 2000; MacDonald et al. 2003; May 2003; Murphy and Meehan 1991; Spence et al. 1996; Sridhar et al. 2004; Sullivan et al. 1990; Theurer et al. 1984; USFS et al. 1993). For example, Chen et al. (1995) found that maximum air temperatures at the margins of old-growth forest stands are elevated 3–29°F (2–16°C) relative to interior temperatures. Riparian buffer widths of 100 to 300 feet may be necessary to provide full ambient temperature regulation (AFS and SER 2000; Brosofske et al. 1997).

7.1.2.1.2 Altered Stream Bank Stability

Many HPA-permitted activities involve the temporary or permanent modification of riparian vegetation structure. Riparian vegetation is an important component of the aquatic ecosystem that serves a variety of important functions for habitat structure, water quality, and biological productivity. The specific nature of these functions varies depending on the type of environment, but increasing bank cohesion plays an important role in regulating channel width and substrate.

The root structure supporting riparian vegetation naturally resists the shear stresses created by flowing water and thus retards bank erosion by stabilizing stream banks and shorelines and by maintaining cover habitat along stream margins. By dissipating the erosive energy of flood waters, wind and rain, and by filtering sheet flows, riparian vegetation limits the amount of fine sediment entering river and stream systems (Brennan and Culverwell 2004; Knutson and Naef 1997; Levings and Jamieson 2001). If riparian vegetation is removed as part of an HPA-permitted activity, stream banks and shorelines will likely be exposed to the erosive effects of wind, rain, and current. The removal of riparian trees and understory can dramatically alter stream bank stability and the filtering of sediments from overland flow (Kondolf and Curry 1986; Shields 1991; Shields and Gray 1992; Simon 1994; Simon and Hupp 1992; Waters 1995), resulting in increased erosion and increased inputs of fine sediment (Bolton and Shellberg 2001).

7.1.2.1.3 Altered Allochthonous Input

Riparian detritus and other externally derived (allochthonous) materials are the primary source of organic fodder in headwater streams, forming the basis of the food chain (MacBroom 1998). This material includes terrestrial macroinvertebrates along with leaves, branches, and other vegetative materials, the latter providing food sources for benthic macroinvertebrates (Bilby and Bisson 1998; Knutson and Naef 1997; Murphy and Meehan 1991). As rivers increase in order and grow in size, these materials are processed and recycled by an increasing diversity of organisms (Vannote et al. 1980). Without allochthonous inputs, the forage detritus available for benthic macroinvertebrates is compromised, also diminishing the habitat and species diversity of these prey items (Murphy and Meehan 1991). Removal of freshwater riparian vegetation as part of HPA-permitted activities would cause an incremental decrease in the input of externally derived (allochthonous) materials to the nearby aquatic environment and food web.

7.1.2.1.4 Altered Habitat Complexity

Impacts on habitat complexity from riparian vegetation loss and/or removal will be variable and will depend on the type and extent of dredging activities. Reductions in large woody debris loading to a riverine system from the loss of riparian functions (i.e., recruitment) may contribute to a loss of habitat complexity. Processes that homogenize habitat also diminish ecological health and habitat diversity (Jacobson 2006). The loss of large woody debris may result in the loss of pools and alterations of channel geometry.

Instream large woody debris may be disturbed or removed from the channel as part of dredging operations. In addition, the potential recruitment of large woody debris may be adversely impacted as a result of vegetation removal from channel banks and bars during construction access and staging. Woody debris in freshwater streams controls channel morphology, regulates the storage and transport of sediment and particulate organic matter, and creates and maintains hydraulic complexity that contributes to fish habitat (Murphy and Meehan 1991; Naiman et al. 2002). Fish use complex environments and the structure of the LWD itself for cover and refuge (Cederholm et al. 1997; Everett and Ruiz 1993; Harvey et al. 1999).

7.1.2.1.5 Altered Groundwater-Surface Water Interactions

Alteration or removal of riparian vegetation would appreciably change the interface between plants, soil, and water on and near the bank surface. Riparian vegetation also acts as a filter for groundwater, removing sediments and taking up nutrients (Knutson and Naef 1997). In conjunction with upland vegetation, riparian vegetation also moderates streamflow 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 streamflows during low rainfall periods (Knutson and Naef 1997).

HPA-permitted activities that create a physical barrier between the bank and hyporheic flow may prevent water exchange between the bank and with the aquatic ecosystem. (The hyporheic zone is the zone of ecological connectivity between surface water and groundwater.) The interface between flow within the hyporheic zone and the stream channel is an important buffer for stream temperatures (Poole and Berman 2001b), 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 2001b).

7.1.2.2 Direct and Indirect Effects on Fish and Invertebrates

Loss or degradation of the shading and ambient temperature regulation functions provided by riparian vegetation can lead to increased water temperatures in summer, when solar radiation exposure and ambient air temperatures are highest. In winter, loss or degradation of the insulating capacity of riparian vegetation can lead to decreased water temperatures and increased incidence of ice scour. Increased stream temperatures in the summer can also cause a concomitant decrease in dissolved oxygen levels, an additional stressor with additive deleterious effects. Numerous studies of such effects in the field have documented the deleterious effects on fish species of changes in the temperature regime in freshwater stream systems. Additional effects of temperature on water quality are described in Sections 7.1.6.1.1 (*Altered Temperature Regime*) and 7.1.6.2 (*Direct and Indirect Effects on Fish and Invertebrates*) under Section 7.1.6 (*Water Quality Modifications*).

Bank instability caused by the loss of riparian vegetation can also impact HCP species through two primary stressors. First, slope instability can increase turbidity by delivering an excess amount of fine-grained sediment to a river, affecting water quality and habitat conditions. The effects associated with turbidity are discussed in Section 7.1.6 (*Water Quality Modifications*). Second, slumping of unstable banks caused by a loss of riparian vegetation can bury invertebrates. Although some specifics are known for marine invertebrate species (Hinchey et al. 2006), it is unknown what tolerance limits the HCP freshwater mollusks may have with respect to burial.

A reduction in allochthonous food sources to rivers caused by riparian vegetation modifications diminishes the ability of the system to support higher trophic organisms. This would extend to most of the freshwater HCP species.

Activities that alter groundwater dynamics in riverine systems can directly affect fish and invertebrates in the short-term by influencing water quality and habitat suitability or availability. In the long-term, changes to groundwater exchange can generate indirect effects on fish and invertebrate species by affecting low flow conditions (i.e., increasing the magnitude of periods of drought resulting in reduced habitat availability and suitability, potential stranding or desiccation), and by affecting water quality through warmer stream temperatures and decreased organic and nutrient inputs.

Activities that alter habitat complexity can directly affect fish and invertebrates. In a study of Smith Creek in northwest California, Harvey et al. (1999) found that tagged adult coastal cutthroat trout moved more frequently from pools without large woody debris than from pools with large woody debris. They hypothesized that the habitat created by wood attracts fish, and once fish establish territory within the desirable habitat, they remain there longer. A study by Cederholm et al. (1997) in a tributary of the Chehalis River found that wood additions caused an increase in winter populations of juvenile coho salmon and age-0 steelhead populations.

7.1.3 Aquatic Vegetation Modifications

A special case of freshwater dredging is the use of a hydraulic suction dredge for the specific goal of vegetation management in freshwater environments. The suction dredge is typically used to remove invasive aquatic vegetation; however, the technique is not plant-specific and can entrain aquatic vegetation that is beneficial to HCP species.

Dredging operations directly entrain and eliminate aquatic vegetation from the dredged site. Aquatic vegetation plays a key role in the trophic support of marine and freshwater ecosystems. Dredging operations present several potential stressors in both marine and freshwater (riverine and lacustrine) environments.

7.1.3.1 Marine Environments

7.1.3.1.1 Submechanisms of Impact

Altered Autochthonous Production

A potential threat from dredging is the burial of aquatic vegetation in adjacent areas due to increased sedimentation (Wilber and Clarke 2001). Dredging operations broadcast fine sediments over a broad area, the extent of which depends on tidal currents and basin geometry (Hossain et al. 2004). Burial of the submerged aquatic vegetation community in marine environments can lead to decreased primary and secondary productivity, which in turn may affect overall food-web productivity.

Another threat to aquatic vegetation is sedimentation from open-sea or nearshore beach nourishment disposal sites. Although open-sea disposal has been demonstrated to be protective of aquatic vegetation when disposal rates are regulated to produce low rates (less than 1 inch) of sedimentation over the course of the project (Simonini et al. 2005), the extreme sensitivity of eelgrass to burial makes it vulnerable even in areas that are distant from the disposal site (Mills and Fonseca 2003).

Altered Habitat Complexity

Aquatic vegetation, in particular eelgrass, is important cover for juvenile fish and invertebrates (Phillips 1984). Eelgrass also provides a necessary structural surface for a community of epibenthic organisms, making eelgrass communities one of the most productive ecotones in the Pacific Northwest (Ferraro and Cole 2007).

7.1.3.1.2 Direct and Indirect Effects on Fish and Invertebrates

Marine littoral vegetation is important for the colonization of organisms that are important prey resources for HCP species, such as Newcomb’s littorine snail, Pacific sand lance, Pacific herring, Pacific cod, northern abalone, surf smelt, steelhead and coastal cutthroat trout, salmon (pink, chum, coho, and Chinook), Olympia oyster, bull trout, rockfish, longfin smelt, eulachon; and walleye pollock (Chambers et al. 1999; Gardner 1981; Goetz et al. 2004; Johnson et al. 1999; Larsen et al. 1995; Myers et al. 1998; Pauley et al. 1988; WDNR 2006a, 2006b; West et al. 1994).

In studies on outmigrating juvenile chum in Hood Canal, Simenstad et al. (1980) found juvenile chum fry (1.2–1.8 in [30–45 mm]) feeding extensively upon small, densely distributed harpacticoid copepods, selecting the largest copepods available. Similarly, Miller et al. (1976) reported that juvenile chum fed predominantly on epibenthic harpacticoid copepods. As the fish grew in size, their diet content was composed more of larger epibenthos and pelagic crustaceans. Consistent with other studies, the highest densities of harpacticoid copepods occurred in magnitudes 4–5 times higher in eelgrass stands than in sand habitat without eelgrass. Specific habitat needs vary across species and life-history stages.

Similarly, in a study of the Drayton Harbor marina, Thom et al. (1989) reported that juvenile salmon density was the highest at the eelgrass habitat site that also supported the highest salmon prey density and epibenthos density. Total fish density increased dramatically immediately following a peak in maximum epibenthos and the most rapid increase in *Zostera* (eelgrass) biomass (Thom et al. 1989). These epibenthic prey assemblages of copepods, such as the harpacticoids, are known to feed on bacteria, epiphytes, plant detritus, and diatoms. It is consistently documented that vegetation assemblages associated with eelgrass, in particular, support increased magnitudes of juvenile salmonid epibenthic prey (Cordell 1986; Simenstad et al. 1980; Thom et al. 1989).

The limitation of habitat for key prey resources likely affects migration patterns and the survival of many juvenile fish species. For smaller fish less than 1.97 in (50 mm) in length, residence times along particular shorelines are thought to be a function of prey abundance (Simenstad et al. 1980).

Eelgrass also plays a role in protecting invertebrates from both fish and avian predators (Bostrom and Mattila 1999). It is uncertain what role eelgrass plays in the protection of HCP invertebrate species, but the existing science suggests that a loss of eelgrass would result in increased predation of those species.

7.1.3.2 Riverine and Lacustrine Environments

7.1.3.2.1 Submechanisms of Impact

Altered Habitat Complexity

Aquatic primary producers, such as benthic algae, macrophytes, and phytoplankton, play key roles in the trophic support of stream ecosystems. In general, benthic algae occur in the form of microscopic unicellular algae, forming thin layers or assemblages called periphyton. Macrophytes include angiosperms rooted in the stream bottom, along with mosses, and other bryophytes. These include many forms such as rooted plants with aerial leaves, floating attached plants with submerged roots, floating unattached plants, and rooted submerged plants (Murphy 1998). A small algal biomass in a stream can support a much larger biomass of consumers due to the rapid turnover in biomass (Hershey and Lamberti 1992; Murphy 1998). Although aquatic primary production is sometimes underrated due to the small amount of algae and plants present in many streams, it is a basic energy source for freshwater ecosystems.

7.1.3.2.2 Direct and Indirect Effects on Fish and Invertebrates

The loss of aquatic vegetation in riverine environments poses both direct and indirect effects on HCP species that depend on aquatic vegetation for any one of their life-history stages or any prey that depend on aquatic vegetation. HCP species affected by the loss of aquatic vegetation in settings where dredging is likely to occur would therefore include green and white sturgeon, California floater and western ridged mussels, mountain sucker, giant Columbia River limpet, pygmy whitefish, leopard and umatilla dace, bull trout, and Pacific salmon (Frest and Johannes

1995; Hughes and Peden 1989; Mongillo and Hallock 1998; Mongillo and Hallock 1999; Watters 1999).

The uptake of carbon, nitrogen, and phosphorous by aquatic vegetation provides important nutrients to fish and invertebrate consumers. This aquatic primary production is the source of autochthonous organic matter and part of the source of allochthonous matter in each stream reach. Invertebrate grazing of these primary producers by snails, caddisflies, isopods, minnows, and other grazers is an important pathway of energy flow. For stream herbivores, for example, benthic diatoms are the most nutritious and easily assimilated food source (Lamberti et al. 1989). The availability of algae regulates the distribution, abundance, and growth of invertebrate scrapers (Hawkins and Sedell 1981), an important food source for fish. Juvenile salmonids, as drift-feeders, focus on food from autochthonous pathways. Invertebrate scrapers and collector–gatherers are known to be most frequently eaten by salmonids (Bilby and Bisson 1992; Hawkins et al. 1983; Murphy and Meehan 1991). Although terrestrial and adult aquatic insects are important (Bjornn and Reiser 1991), juvenile salmon in streams have been found to be primarily supported by autochthonous organic matter (Bilby and Bisson 1992).

Freshwater macrophytes are also known to modify their physiochemical environment by slowing water flow, trapping sediments, and altering temperature and water chemistry profiles. Through the trapping of particles by plant fronds, they also change the nature of the surrounding sediments by increasing the organic matter content and capturing smaller grain size sediment than typically occurs in uncolonized areas (Carrasquero 2001).

The summer density of coho salmon fry has been found to be directly related to the abundance of algae. A high density of fry can result from smaller feeding territories (Dill et al. 1981) due to increased invertebrate prey (Hawkins et al. 1983; Murphy et al. 1981). Increases in vertebrate production have been found to occur primarily in the spring and early summer, coincident with the primary production cycle of benthic algae (Murphy 1998). Therefore, removal of or permanent disturbance to algal communities could have an adverse effect on local freshwater ecosystems and the HCP species that depend upon these ecosystems. In the case of coho salmon fry, the reduction in prey area (i.e., smaller feeding territories) results in a direct effect on the fitness, growth, and survival of the affected fry.

7.1.4 Hydraulic and Geomorphic Modifications

The purpose of dredging is to modify hydraulic and geomorphic conditions to maintain navigation, alleviate flooding, and increase conveyance. Dredging operations present several potential stressors in both marine and freshwater (riverine and lacustrine) environments.

7.1.4.1 Riverine Environments

Riverine hydraulics distribute water, sediment, and organic materials along a lineal path toward lower elevations. Fishes and invertebrates depend upon the diversity of habitats created by the hydraulic forces that scour, transport, and deposit diverse sediments along the river profile

(Montgomery et al. 1999). HCP species, such as sturgeon, char, bull trout, salmonids, and freshwater mussels, depend on particular riverine sediment types and habitats. If the flow becomes too strong, reaches of rivers can be made impassable to various fish species or life-history stages, or unsuitable for invertebrates. In short, the reproduction, growth, and survival of these HCP species depend on particular hydraulic regimes to maintain suitable habitats. Alterations to river hydraulics that change the flow of water and the ability of the water to move sediments and nutrients can have direct and indirect effects on HCP species.

7.1.4.1.1 Submechanisms of Impact

Dredging alters riverine hydraulics through morphologic changes in the channel geometry and substrate composition. Dredging operations in riverine environments present the following stressors:

- Altered channel geometry
- Altered flow regime
- Altered sediment supply
- Altered substrate composition and stability
- Altered hyporheic flow/exchange.

Altered Channel Geometry

Dredging activities modify the channel geometry by removing substrate from the system. These changes result in a channel geometry that is out of equilibrium with natural sediment transport and channel processes. Changes in riverine hydraulics and velocities that alter the entrainment, transport, and deposition of sediment and woody debris could have deleterious effects on fish and invertebrates both at the dredge site and in areas adjacent to it. Changes in substrate can adversely affect the growth of aquatic vegetation.

Altered Flow Regime

Dredging activities may alter the current velocity in riverine environments through changes in the channel geometry that include deepening, narrowing, or straightening. Dredging activities that modify riparian vegetation can increase the flow velocity through a reduction in hydraulic roughness compared to pre-disturbance or vegetated conditions (Millar and Quick 1998). Geomorphic alterations can also reduce velocities elsewhere in the channel. These flow reductions could encourage the deposition of fine sediment (silt and clay: (Miller et al. 1977), particularly near the sources of such material [i.e., in large rivers: (Downing 1983)]. Sediment removal and lowering of the bed elevation can decrease natural transport rates and thereby disconnect downstream channel reaches from important sources of sediment, nutrients, woody debris, and organic nutrients.

Altered Sediment Supply

The effects of dredging are similar to gravel mining (see Section 7.2, *Gravel Mining and Scalping*) in that they alter the supply of sediment to downstream reaches through the removal of bedload material and the disruption of the sediment budget (Jacobson 2006; Kondolf 1997).

Altered Substrate Composition and Stability

Because the rate and caliber of sediment supplied to a channel can influence the substrate size (Dietrich et al. 1989), changes in sediment supply can alter the composition of substrate used by HCP species. Dredging activities that increase the current velocity can increase the potential for scour and substrate coarsening. Dredging can also result in burial at the dredge site as sediment is replenished by natural sediment transport and depositional processes. The placement of dredge spoils along the banks (which is typically done along small streams and irrigation/drainage ditches) can result in additional channelization and provide a local source of fine sediment for recruitment back into the channel.

Altered Hyporheic Flow/Exchange

Lowering of the bed-surface and water-surface elevations caused by riverine dredging may lower the water table because the channel determines the level down to which the local alluvial groundwater drains (Galay 1983). Lowering of the water table can result in the loss of groundwater storage and the loss of summer base flow (Kondolf et al. 2002) and hyporheic groundwater upwelling zones (Stanford and Ward 1993).

7.1.4.1.2 Direct and Indirect Effects on Fish and Invertebrates

Fish and invertebrates inhabiting riverine environments require certain flow velocities for spawning, rearing, and foraging. For example, increases in flow velocities could present potential barriers to fish migration or could exceed thresholds for certain life-history stages of some HCP species. For instance, leopard and Umatilla dace inhabit riverine environments where the velocities are less than 1.6 ft/sec (Wydoski and Whitney 2003). Exceeding this velocity as a result of hydrogeomorphic modification from dredging would render the habitat unsuitable for these species. Likewise, fish and invertebrates require a range of substrate conditions in riverine environments for various life-history stages. These conditions rely on the replenishment of suitably sized substrates to offset natural sediment transport processes that remove sediment.

Fish and invertebrates require a range of substrate conditions in riverine environments for various life-history stages. Alteration of the substrate composition through coarsening or fining of the bed can have direct and indirect effects on HCP species. Substrate conditions rely on the replenishment of suitably sized substrates to offset natural sediment transport processes that remove sediment. In one California study, the primary cause for the decline of salmon in the Sacramento River was linked to the loss of spawning gravels normally derived from bank erosion before the installation of riprap bank stabilization (Buer et al. 1984).

The ecological effects of substrate coarsening and fining on salmonids and trout in riverine environments are well known. Large substrates, exceeding the maximum size mobilized by spawning salmonids, are typically avoided during redd building (Kondolf and Wolman 1993). Field observations have shown that salmonids can build redds where the average substrate size (D_{50}) is up to 10 percent of the average body length (Kondolf and Wolman 1993). The optimal range of spawning gravels for salmonids is listed in Table 7-1. Bed scour and substrate coarsening are often accompanied by an increase in the interlocking strength of bed particles and the threshold force necessary for bed mobility (Church et al. 1998; Konrad 2000; Lane 1955).

Table 7-1. Spawning gravel criteria for salmonids.

Gravel bed criteria	Small-bodied Salmonids <13.8 in (<35 cm)	Large-bodied Salmonids >13.8 in (>35 cm)
Dominant substrate particle size	0.3–2.5 in (8–64 mm)	0.6–5 in (16–128 mm)
Minimum gravel patch size	10.8 ft^2 (1 m^2)	21.5 ft^2 (2 m^2)

Adapted from (Schuett-Hames et al. 1996).
Note: Small-bodied salmonids include cutthroat trout; large-bodied salmonids include coho and Chinook salmon and steelhead trout.

Substrates preferred by other HCP species vary widely, and may differ from those preferred by salmonids in many cases. For example, sturgeon have clear preferences for different types of substrate during spawning and juvenile rearing, ranging from sand to gravel, to large cobble (Brannon 1984; Golder Associates 2005; Kynard and Parker 2005; Kynard et al. 2005; Nguyen and Crocker 2006; Peake 1999; Young and Scarnecchia 2005)

Substrate fining can adversely affect salmonids and trout by clogging spawning gravels with fine sediment (Zimmermann and Lapointe 2005). Embryo mortality has been found to occur from poor water circulation and lack of oxygenation associated with the filling of intergravel pore spaces by fine sediment (Bennett et al. 2003; Chapman 1988; Cooper 1965; Lisle and Lewis 1992). In a study of spawning chum salmon in low-gradient, gravel-bed channels of Washington and Alaska, Montgomery et al. (1996) found that minor increases in the depth of scour caused by bed fining and a reduction in hydraulic roughness significantly reduced embryo survival. The deposition of fine sediment can also adversely impact invertebrates (Wantzen 2006). Fine sediment particles may clog biological retention mechanisms such as the filtering nets of caddisfly larvae, or the filtering organs of mollusks. Additionally, overburden from increased deposition has been shown to adversely affect invertebrates having low motility (Hinchey et al. 2006).

The effects of altered hyporheic flow caused by dredging are essentially the same as those described above for riparian vegetation modification in Section 7.1.2.1.5 (*Altered Groundwater-Surface Water Interactions*).

7.1.4.2 Marine Environments

The immediate change in bathymetry caused by dredging modifies the relationship between topography and wave energy and results in a shoreline that is out of equilibrium with natural shoreline processes (Komar 1998). This redistributes wave energy and sediment transport along the shoreline, causing a number of hydraulic and geomorphic modifications that could have deleterious effects on fish and invertebrates both at the dredge site and adjacent to it.

7.1.4.2.1 Submechanisms of Impact

Dredging operations present the following stressors in marine environments:

- Altered wave energy
- Altered current velocities
- Altered nearshore circulation patterns
- Altered sediment supply

<u>Altered Wave Energy</u>

Dredging changes the response of the incoming wave field to the shoreline (Demir et al. 2004; Work et al. 2004). As a result, wave energy artificially accumulates in some areas and is diminished in others (Komar 1998). This redistribution of wave energy can result in changes in substrate and water-column characteristics.

Substrate is an important factor for the growth of aquatic vegetation in Puget Sound (Koch 2001) and the conditions for fish spawning in intertidal waters (typically forage fish). Increased wave energy intensifies bed shear stress; if some of the coarsest material is not mobilized, a generally coarser substrate or lag deposit may form (Komar 1998). However, the degree to which this occurs depends on the available substrate and geologic setting. On the outer coast, for example, substrate is loose, deep, sandy, and unconsolidated. In protected, previously glaciated areas, the basin topography is complex and the coarse nature of the substrate slows down erosion dramatically (Nordstrom 1992). In these locales, a lag deposit can transform a sandy, gravelly shoreline to a near bedrock-like shoreline [e.g., Foulweather Beach (Finlayson 2006)]. This process is similar to what has occurred on the urbanized shorelines throughout the Great Lakes (Chrzastowski and Thompson 1994).

The loss of sediment to a drift cell can also result in a coarsening of the substrate as fine-grained sediment is lost to deep portions of the basin by resuspension (Finlayson 2006). However, because some drift cells can be extremely long [e.g., more than 20 miles long in the drift cell that extends between Seattle and Mukilteo on the northeastern shore of the main basin of Puget Sound (Terich 1987)], the effects of a modification can extend well beyond the primary activity area.

Water-column characteristics depend heavily on wave motion for mixing of the upper portion of the water column (Babanin 2006) and for producing high shear stresses near the bed (Lamb et al.

2004). Wave energy is the dominant source of fluid mechanical energy in the nearshore in most Washington waters (Finlayson 2006). The attenuation of waves can increase water column stratification in marine waters and lead to dissolved oxygen reduction and temperature anomalies (Qiao et al. 2006); see Section 7.1.6 (*Water Quality Modifications*) for details. Surficial mixing and circulation also play an important role in primary productivity, particularly near large river mouths [e.g., Willapa Bay (Roegner et al. 2002)].

Altered Current Velocities

In altering the pattern of a wave breaking alongshore, dredged borrow pits and disposal placements (discussed in the Section 7.3, *Sediment Capping*) change wave-driven currents, such as rip currents (Demir et al. 2004; Work et al. 2004). Altering current strength and placement can have significant impacts on both aquatic vegetation and the substrate that it is embedded in. The relationship between flow velocity and a change in substrate is related to a quantity, known as the boundary shear stress (Miller et al. 1977). Substrate and aquatic vegetation are removed if a critical shear stress is exceeded. Again, these impacts are comparable to those discussed for *Altered Wave Energy* (above).

Geomorphic alterations can also reduce velocities elsewhere. These reductions could encourage the deposition of fine sediment (silt and clay: Miller et al. 1977), particularly near sources of fine sediment [i.e., large rivers: Downing 1983)]. These effects are similar those discussed for *Altered Wave Energy* (above).

Altered Nearshore Circulation

Nearshore circulation is a generic phrase that describes the flux of salt, water, and sediment in association with tidal and wave motion near the shoreline. In more exposed, sandy settings, nearshore circulation is dominated by the mechanics of wave breaking (Komar 1998). These effects are generally insignificant in Puget Sound because wave breaking occurs entirely within the swash zone (Finlayson 2006), but nearshore circulation can be altered when swell is present because it changes the approaching wave field in profound ways (Demir et al. 2004). In Puget Sound and near the mouth of large rivers (e.g., the Columbia), tidal currents and freshwater input can also play an important role in nearshore currents.

In Puget Sound and near the mouth of large rivers (e.g., the Columbia), tides and freshwater input play a more important role in nearshore currents. Repeated dredging operations have been demonstrated to alter tidal prisms by altering the mechanics of estuarine exchange in the Columbia River (Sherwood et al. 1990) and elsewhere (da Silva and Duck 2001). Tidal motions are rarely sufficient to mobilize sediment typical of Puget Sound beaches [material of gravel size or larger (Finlayson 2006)] but they can mobilize fine sediments (i.e., silt and clay), particularly in areas of high sediment supply [e.g., (Nittrouer and Sternberg 1975)].

Altered Sediment Supply

By interrupting littoral transport and nearshore circulation, dredging activities affect hydraulic and geomorphic processes in a manner similar to breakwaters (Demir et al. 2004; Work et al. 2004; Herrera 2007c). Alteration of sediment transport patterns can present potential barriers to 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 (Haas et al. 2002; Penttila 2000; Thom and Shreffler 1996; Thom et al. 1994). These impacts primarily manifest as a change in substrate, the impacts of which are similar to the effects of altered wave energy.

7.1.4.2.2 Direct and Indirect Effects on Fish and Invertebrates

Substrate Stressors

The effects of substrate coarsening on fish and invertebrates as a result of increased wave energy are similar to what has occurred on the urbanized shorelines throughout the Great Lakes (Chrzastowski and Thompson 1994). These changes have produced pronounced ecological changes within recent years in the Great Lakes (Meadows et al. 2005), causing the elimination of native species and enabling invasives (zebra mussels) to dominate the nearshore ecosystem (Marsden and Chotkowski 2001). Changing substrate can adversely affect the growth of aquatic vegetation. For instance, eelgrass is incapable of growing in dominantly gravelly substrates (Koch 2001). For details regarding the effects on fish and invertebrates as a result of aquatic vegetation disturbances, see Section 7.1.3 (*Aquatic Vegetation Modifications*).

The primary direct effect on fish and invertebrates from changes in drift cell characteristics is to alter the degree of turbidity in the nearshore environment (Bash et al. 2001; Berry et al. 2003). (See Section 7.1.6.1.3, *Altered Suspended Sediments and Turbidity*, for a full discussion of the effects of turbidity.)

Nearshore circulation patterns are a dominant characteristic that shapes the suitability of nearshore habitats for a range of HCP species. Specifically, fish and invertebrate species that are planktonic breeders have been shown to produce spatially variable spawn that relies on the combination of wave motion, ambient currents, and circulation patterns for transport to and retention in productive nursery areas (Hernandez-Miranda et al. 2003; Rooper et al. 2006; Sinclair 1992). While specific studies on HCP species are lacking, virtually all of the purely marine HCP species have a planktonic egg and/or larval life-history stage dependent on rearing habitat transport and retention dynamics. Developing eggs or larvae that are transported into areas unfavorable for rearing face a high likelihood of starvation and predation or, in the case of schooling pelagic species, may be permanently isolated from their spawning population (Sinclair 1992).

Although there have been few experimental studies on the effects of sediment loss on forage fishes, damage to surf smelt spawning areas have been documented in the presence of shoreline hardening (i.e., bulkheads) in Hood Canal (Penttila 1978; Thom et al. 1994). Typical spawning substrates consist of fine gravel and coarse sand, characteristic of the pebble veneer found throughout Puget Sound (Finlayson 2006), 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, changing the wave environment may change the survivability of surf smelt spawn. The importance of substrate to spawning has also been empirically demonstrated in the closely related Japanese surf smelt (Hirose and Kawaguchi 1998).

Pacific sand lance also rely on sandy substrates for burrowing at night. Pacific sand lance spawn in the high intertidal zone on substrates varying from sand to sandy gravel. As with surf smelt, sand lance spawning is susceptible to the deleterious effects of littoral alterations because sand lance rely on a certain beach profile and specific substrate compositions (Penttila 1995).

Shoreline habitats are used extensively by a range of salmonid species, including Chinook, chum, and pink salmon; bull trout and Dolly Varden; and cutthroat trout. Coho salmon and steelhead also use these environments but are not as dependent on the shallow water margins. Fresh (2006) examined nearshore habitats used by juvenile salmonids and concluded that the conversion of sandy, mobile substrates, such as those on natal deltas, to deeper and harder substrates would produce a greater impact on salmonid rearing than those on naturally immobile shorelines. Because Puget Sound shorelines are diverse in terms of sediment mobility (Finlayson 2006), the effect on juvenile salmonids from shoreline hardening is highly site specific and could be small in places where the shoreline is naturally immobile.

While the loss of sediment to a drift cell can detrimental to HCP species, deposition of large amounts of fine sediment can kill aquatic vegetation vital to nearshore HCP species. Recent work has shown that burying eelgrass at depths as little as 25 percent of the total plant height could decrease productivity and increase the mortality of eelgrass (Mills and Fonseca 2003). For more information about the effects of aquatic vegetation on fish and invertebrates, see Section 7.1.3 (*Aquatic Vegetation Modifications*). Eelgrass can also be discouraged from colonizing new areas with a high clay content as a result of recent sediment deposition (Koch 2001).

Water Column Stressors

In addition to the aforementioned substrate stressors, water-column stressors from altered wave energy can also impact HCP species. Increased shear stresses near the bed caused by increased wave energy can prove harmful to both aquatic vegetation and the fish and invertebrates that use and consume it. The effects of dissolved oxygen reduction and temperature anomalies on fish and invertebrates are discussed in Section 7.1.6 (*Water Quality Modifications*). The disruption of surficial mixing may have effects on the primary productivity and ultimately on any marine species through food-web interactions.

Wave energy also plays a role in the distribution of aquatic vegetation used by salmonids and other nearshore fishes, particularly in energetic environments. High wave energy has shown to inhibit the colonization and growth of some seagrasses [e.g., eelgrass (Fonseca and Bell 1998); see Section 7.1.3 (*Aquatic Vegetation Modifications*) for details], although in more recent work in Puget Sound, no correlation was found between eelgrass prevalence and wave characteristics

(Finlayson 2006). High shear stresses associated with waves can also dislodge kelp (Kawamata 2001).

Fish that are planktonic breeders have been shown to produce spatially variable spawn that relies on the combination of wave motion and ambient currents to be transported to appropriate and productive nursery areas (Hernandez-Miranda et al. 2003; Rooper et al. 2006). Waves produce motions and induce transport both in the water column and near the seabed that are capable of transporting particulates large distances (Liang et al. 2007; McCool and Parsons 2004). Altering these mechanical processes alters transport rates (Liang et al. 2007; McCool and Parsons 2004). While no specific studies have analyzed this effect in any of the HCP species, it is possible that changes in wave-induced transport could transport spawn and larvae to less desirable areas and, therefore, contribute to mortality of the larvae of planktonic-breeding species.

Many fish species, such as herring, rockfish, pollock, and cod, have planktonic larvae that are dependent on wave and current patterns for transport to and/or retention in areas favorable for rearing. Developing larvae that are transported away from areas favorable for rearing before they are ready for life in open water face an increased risk of starvation and predation or, in the case of schooling pelagic species, may be permanently isolated from their spawning population (Sinclair 1992).

Invertebrates that cannot tolerate extremely high shear stress or burial may be directly affected by altered wave energy. While experimental evidence of the mortality limits of large shear stresses on mollusks or other invertebrates is nonexistent, Olympia oysters have been shown to be intolerant of siltation and do best in the absence of fine-grained materials (WDNR 2006b). The burial of mollusks and the related stress or mortality resulting from partial and complete burial have been addressed empirically (Hinchey et al. 2006). Results of these studies indicate that species-specific responses vary as a function of motility, living position, and inferred physiological tolerance of anoxic conditions. Burial is particularly detrimental, owing to the large suspended sediment concentrations produced by dredging operations (Wilber and Clarke 2001).

HCP species can also be impacted by altered current velocities. Nearshore currents, even those in heavily altered environments, do not exceed the threshold for adult salmonid navigation, but high velocities have been shown to exclude some small fishes (e.g., juvenile salmonids and forage fishes) from navigating nearshore waters (Michny and Deibel 1986; Schaffter et al. 1983). This would cause the fragmentation of habitat for these species (see Section 7.1.5 [*Ecosystem Fragmentation] for details*).

Eelgrass and many other species of aquatic vegetation (e.g., bull kelp) require some water motion for survival (Fonseca et al. 1983). The degree of sensitivity is species-specific and also dependent on other factors such as pollutant loading. Similar to the effects associated with alterations in wave energy, alterations in velocity in the water column could alter transport and increase the mortality of planktonic spawn (e.g., Pacific herring).

Fish and invertebrates inhabiting riverine environments require certain flow velocities for spawning, rearing, and foraging. For example, increases in flow velocities could present potential barriers to fish migration, exceed thresholds for certain life-history stages of some HCP species, or otherwise make habitat conditions unsuitable. For instance, juvenile white sturgeon are able to tolerate a broad range of riverine flow velocities, but preferentially select deepwater habitats with sand substrate in the thalweg (Young and Scarnecchia 2005). Altered flow velocities may extend conditions outside the range preferred by this species, or may lead to changes in substrate conditions that render the habitat unsuitable.

Alterations to nearshore circulation can reduce the tidal prism. The reduction of the tidal prism, as documented from dredging activities on the Columbia River (Sherwood et al. 1990) can eliminate the exposure of entire habitats from tidal action. The impact of the loss of lagoonal habitats on HCP species is discussed in depth in Section 7.1.5 (*Ecosystem Fragmentation*). In addition to stranding areas from marine influence, a reduction in tidal motions can increase stratification and limit the vertical mobility of nutrients and dissolved oxygen (Mickett et al. 2004). This type of behavior has been observed elsewhere (Perillo et al. 2005). Recent work has shown that there is a complex interplay between these phenomena and the primary productivity of nearshore waters on the Washington outer coast (Roegner et al. 2002). However, more dramatic consequences could occur in the naturally mixing-limited waters of Puget Sound (Warner 2001). Changes in nearshore circulation could also alter the transport of planktonic spawn, increasing the mortality of those species. Effects on invertebrates would be associated with removal or burial.

Increasing tidal prisms, as documented in Europe (da Silva and Duck 2001), can expose previously dry, polluted sediments to marine influence. See Section 7.1.6 (*Water Quality Modifications*) for a more detailed account of these effects. Increased tidal fluxes could also produce velocities sufficient to exclude small nearshore fishes (e.g., sand lance and surf smelt) from potential breeding and nursery areas. For details, see Section 7.1.5 (*Ecosystem Fragmentation*).

7.1.4.3 Lacustrine Environments

Lacustrine ecosystems, pertaining to lakes, are generally defined by non-flowing inland waters impounded in a topographic depression either by natural or anthropogenic processes without a direct connection to the sea. Physical characteristics such as wave energy, circulation and mixing, sediment types, and water properties (temperature, turbidity, nutrient levels, and dissolved oxygen content) are important habitat-controlling factors in lacustrine environments. As these factors determine the distribution of species in these systems, changes in these factors can directly and indirectly affect the successful reproduction, growth, and survival of the diverse fish and invertebrate species endemic to these habitats.

Human-operated reservoirs present other special issues. Reservoirs are morphologically, biologically, and hydrologically dissimilar from natural lakes. Morphologically, lakes are often deepest near the middle, while reservoirs are typically deepest at the downstream end. This difference has implications for current strength and direction. The extent of shoreline development is much greater than in natural lakes because annual drawdown exposes a larger area to shore processes (Baxter 1977). The location and nature of depositional forms are highly variable with reservoir morphometry, incoming sediment load, and reservoir operation. Reservoirs are also subject to density or turbidity currents resulting from differences in temperature or sediment concentration between inflows and reservoir waters (Snyder et al. 2006). Mixing zones between the water sources influence the usage of reservoir areas by fishes.

Reservoir environments can lack natural habitat due to the loss of riparian forest as a result of flooding, siltation of rocky shorelines, and a paucity of aquatic vegetation resulting from fluctuating water levels (Prince and Maughan 1978). Depending on reservoir operations, drawdown and filling cycles can re-entrain silty deposits in littoral areas.

7.1.4.3.1 Submechanisms of Impact

The submechanisms of impact of dredging in lacustrine environments are essentially the same as described for marine environments, albeit on a different suite of species. In both environments, wave energy and sediment recruitment and transport are altered. However, in lakes these impacts are often exacerbated by differences in human-controlled water-level variability (in the case of reservoirs) and natural lake limnology (Wilcox et al. 2002). This inherent variability makes the differences between natural lakes and reservoirs less pronounced with respect to nearshore processes. However, there are other geomorphic differences with pronounced effects on habitat (discussed at length below).

Systematic studies of impacts on the habitat in western Washington lakes are extremely limited (Jones & Stokes 2006). Some analysis of habitat types and species distributions has been prepared as part of the development of various shoreline master programs [e.g., (The Watershed Company 2006)], but these typically only catalog species and activity types and do not provide information about their relation to one another. Therefore, the physical processes discussed in depth in Section 7.1.4.2 (*Marine Environments*) are considered to be relevant here, recognizing that some differences occur (mostly apparent from previous work performed in the Great Lakes). To summarize, the four most important differences between marine and lacustrine environments are the following:

- *Nearshore circulation and water column characteristics*. Nearshore circulation on a lakeshore is fundamentally different than in marine environments. First, wave energy is so small that wave-induced nearshore circulation is negligible (see below); however, wind does play an important role in driving wholesale circulation of the lake (Rao and Schwab 2007). Temperature is the dominant factor in maintaining stratification (unlike in the marine environment, where salinity is typically the most important water column constituent). Finally, the absence of tides means that water level on the time scale of hours to days is stable, and the distribution of wave energy on the shoreline is discrete.

- *Groundwater input*. Because lakes are fundamentally connected to upland environments, the limiting nutrients in a lake (typically phosphorus) are different than in a marine environment (typically nitrogen). Just as in marine environments, benthic productivity and diversity have been linked to groundwater effluent (Hagerthey and Kerfoot 2005; Hunt et al. 2006). However, lacustrine seeps have high productivity but low species diversity (Hagerthey and Kerfoot 2005; Hunt et al. 2006) as opposed to marine seeps which are both productive and diverse (Kelley et al. 2002).

- *Short-period waves*. Because lakes are confined, all of their wave energy must be generated from local winds. This makes all of the waves fetch-limited (Komar 1998). Fetch-limited waves have extremely short periods and small wave heights compared to their open water, marine counterparts. In this sense, lacustrine littoral processes are similar to those found in Puget Sound (Finlayson 2006).

- *Lack of buffering capacity*. The dispersion of suspended sediment from dredging operations in lacustrine environments typically has a more pronounced effect on lake water quality because of the relative lack of nearshore circulation in lake waters. See Section 7.1.6 (*Water Quality Modifications*) for details.

7.1.4.3.2 Direct and Indirect Effects on Fish and Invertebrates

The primary impacts associated with hydraulic and geomorphic modifications from dredging in lacustrine environments are similar to those discussed in Section 7.1.4.2 (*Marine Environments)* and include changes in wave energy, circulation and mixing, substrate type, and turbidity. Reservoirs are subject to density or turbidity currents resulting from differences in temperature or sediment concentrations between inflows and reservoir waters (Snyder et al. 2006). Dredging can cause both short-term and long-term effects on habitat conditions. In the short term, increased suspended sediment concentrations can cause localized turbidity currents that affect the suitability of nearshore habitats for spawning, rearing, and foraging. Sockeye salmon, an HCP species, use lacustrine beaches for spawning. Alteration of nearshore substrate, wave action, and groundwater inflow conditions can reduce spawning habitat suitability, restricting the range of available habitat.

Changes in bathymetry can cause broader long-term effects on current and circulation patterns, with similar potential for adverse effects on habitat suitability. For example, Karp and Mueller (2002) found that mixing zones and shallow water littoral habitat were the preferred habitats used by razorback sucker in Lake Powell, Utah. This species primarily used shallow, vegetated habitats in side canyons, and since these areas represent <1 percent of the available habitat, species productivity is highly sensitive to water level fluctuations and temperature gradients that can fragment these habitats (for example, Mueller et al. (2000) found that temperature gradients caused the razorback sucker to abandon preferred inshore habitat in Lake Mohave, Arizona). Changes in current conditions and mixing zone dynamics induced by dredging can alter temperature gradients in lacustrine systems. While the razorback sucker is not an HCP species, its habits and habitat use are similar to mountain sucker, leopard and spotted dace, and other species that use shallow water littoral habitats in lacustrine environments. This suggests similar potential for effects on habitat suitability from dredging.

7.1.5 Ecosystem Fragmentation

The impacts of dredging operations can fragment various marine and freshwater ecosystems. The collective effects of dredging in marine and freshwater environments can disconnect crucial habitats and limit fish accessibility and ecosystem functions.

7.1.5.1 Marine and Lacustrine Environments

Dredging operations can limit the accessibility of fish through changes in both the structure and characteristics of marine and lacustrine shorelines (e.g., linear and barren versus undulating and covered in large woody debris). This can take the form of complete removal of habitats, such as the elimination of marine lagoon habitats due to changes in alongshore sediment transport patterns or the tidal prism.

7.1.5.1.1 Habitat Loss and Fragmentation

Dredging operations could lead to a loss or fragmentation of existing habitat. Dredging in lacustrine environments can alter the wave energy reaching the shoreline and thereby alter the local recruitment and transport of sediment. Consequently, dredging has a tendency to fragment the nearshore ecosystem. Due to a number of hydrogeomorphic changes detailed in Section 7.1.4 (*Hydraulic and Geomorphic Modifications*), coastal lagoons could be made inaccessible by reducing the tidal prism (Sherwood et al. 1990).

7.1.5.1.2 Direct and Indirect Effects on Fish and Invertebrates

Lagoons provide important rearing habitat for juvenile salmonids, including Chinook (Busby and Barnhart 1995) and coho (Minakawa and Kraft 2005) as well as Pacific herring (Saiki and Martin 2001), and can be lost due to changes in the tidal prism (Sherwood et al. 1990). Lagoons, sometimes referred to as pocket estuaries, have declined both in terms of size and number due to human modifications to lowland coastal areas in Puget Sound (Beamer et al. 2005). In fact, access to high-quality lagoon habitat has been shown to be the critical path in the restoration of Chinook runs in the Skagit River system (Beamer et al. 2005). The primary impact of a loss of lagoon habitat would be to expose juvenile salmonids and forage fish to increased risk of predation (Hood 2006; Wagner and Austin 1999). Shallow water marginal habitats in the nearshore environment are similarly important to a variety of salmon species (Fresh 2006). Loss or fragmentation of these habitats can have significant effects on the survival, growth, and fitness of dependent species.

The loss of shallow water and lagoon habitats can also affect invertebrate species. The Olympia oyster also uses lagoons, therefore the species could be susceptible to losses due to changes in tidal prism (Baker 1995). Lake shorelines represent crucial spawning habitat for sockeye (Burgner 1991; Scheuerell and Schindler 2004). Consequently, altering the wave energy reaching the shoreline can lead to a loss or fragmentation of existing spawning habitat for sockeye salmon.

Juvenile Chinook salmon also use lacustrine littoral zones (Sergeant and Beauchamp 2006). Sergeant and Beauchamp (2006) have shown that although substrate preferences for juvenile Chinook are weak, they prefer fine substrates with cover. Because the wave energy caused by bathymetric changes due to dredging could change the local shoreline substrate, it possibly also changes both the distribution and continuity of spawning and rearing areas, increasing the potential for predation.

7.1.5.2 Riverine Environments

By altering the channel and floodplain form, dredging activities will change how water, organisms, and food resources are transferred through the mosaic of habitat patches that constitute the river-floodplain system. Dredging activities that alter habitat connectivity in riverine environments can lead to habitat loss and fragmentation.

7.1.5.2.1 Submechanisms of Impact

Altered Longitudinal Connectivity

Hydromodification of riverine environments by dredging reduces the structural complexity of instream habitat by changing the channel geometry and influencing the recruitment, transport, and retention of sediments and LWD. Woody debris in freshwater streams controls the channel morphology, regulates the storage and transport of sediment and particulate organic matter, and creates and maintains hydraulic complexity that contributes to fish habitat (Murphy and Meehan 1991; Naiman et al. 2002). Woody debris increases the hydraulic roughness and impounds sediment behind logjams (Keller and Swanson 1979; Harvey et al. 1987; Shields and Gippel 1995; Gippel et al. 1996; Montgomery et al. 1996; Buffington and Montgomery 1999; Manga and Kirchner 2000). Local aggradation behind stable logjams can raise the bed-surface elevation of channels and increase the potential for floodplain inundation and lateral channel migration (Abbe and Montgomery 2003). Consequently, changes in wood loading and the age structure and composition of riparian forests can dramatically influence channel dynamics and the potential for lateral channel migration in unconfined river systems (Brummer et al. 2006).

Within channels, 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) and Sedell et al. (1985) found that approximately 80 percent of the pools in several small streams in southwest Washington and Idaho were 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 the formation of backwater pools along margins of the mainstem (Naiman et al. 2002). The hydraulic complexity created by LWD encourages the capture and sequestration of other allochthonous inputs, making these materials more available to the food chain through grazing and decomposition (Knutson and Naef 1997; Murphy and Meehan 1991; Naiman et al. 2002; Quinn 2005).

LWD accumulation creates habitat through two primary mechanisms. First, the wood itself provides cover and creates local scour pool habitat; second, wood in channels promotes lateral and vertical energy transfer, thus altering the composition and/or abundance of accessible food sources for HCP species and creating more accessible habitat for foraging and rearing. The impact of LWD on vertical and lateral connectivity is addressed above; below is a discussion of how LWD creates and modifies in-channel habitat.

LWD itself serves as a substrate for algal growth and macroinvertebrate habitat (Bowen et al. 1998). In German streams, Hoffman (2000) showed an intimate connection between LWD and all life-history stages of the lepidostomatid caddisfly, *Lasiocephala basalis*. In contrast, Hilderbrand et al. (1997) noted no change in macroinvertebrate populations following a wood addition experiment in Virginia, and Spanhoff et al. (2006) noted a net negative impact of wood addition on stream macroinvertebrates. Despite these findings, other studies have shown that wood in channels and on shorelines can serve as a substrate for both algal growth (Bowen et al. 1998) and macroinvertebrate habitat (Rolauffs et al. 2001; Warmke and Hering 2000).

Altered River-Floodplain Connectivity

Dredging in riverine environments to improve navigation, and in smaller channels to increase conveyance, lowers the bed elevation. In doing so, dredging can disconnect off-channel habitats from the river and smaller channels. Dredging therefore has the potential to decrease lateral connectivity with side-channel, slough, and floodplain ponds. Side channels create refugia for juvenile fish (Jungwirth et al. 1993), while floodplain ponds and backwater sloughs create zones of high retention and productivity that provide vital rearing habitat (Hall and Wissmar 2004; Sommer et al. 2005) and important sources of organic material for the channel (Tockner et al. 1999). The loss of connectivity between the river and these habitats can result in a decrease in organic matter recruitment (Tockner et al. 1999; Valett et al. 2005) and reduced access to valuable foraging and rearing habitat (Henning et al. 2006). It has been estimated that in the Skagit Valley, 41 percent of sloughs and 31 percent of small tributary habitat has been lost to channelization for agricultural purposes (Beechie et al. 1994). Floodplains have been shown to act as nutrient sinks and carbon sources for adjacent channels (Tockner et al. 1999; Valett et al.

2005). Consequently, floodplain–channel connection augments allochthonous carbon budgets in restored channels and engages habitat that would otherwise be inaccessible.

The presence of LWD within channels has been shown to promote floodplain connection during storm flow conditions by increasing flow resistance within the channel (Dudley et al. 1998). Increased channel roughness promotes backwater conditions that locally connect floodplain and channel habitat. As noted previously, LWD also promotes floodplain connection by diverting flow into side channels (Abbe and Montgomery 1996; Brummer et al. 2006).

Altered Groundwater-Surface Water Interactions

The effects of dredging on this component of ecological connectivity are essentially the same as those discussed above for riparian vegetation modifications in Section 7.1.2.1.5 (*Altered Groundwater-Surface Water Interactions*).

7.1.5.2.2 Direct and Indirect Effects on Fish and Invertebrates

Floodplain connectivity creates fish forage and refuge habitat for several of the HCP species (Feyrer et al. 2006; Henning 2004). Chinook that rear on floodplains have been shown to grow faster than those rearing in adjacent channels (Sommer et al. 2001). Additionally, in a 2004 study of the Sacramento splittail (Ribeiro et al. 2004), fishes rearing in floodplain habitat were healthier and longer. Swales and Levings (1989) found that off-channel habitat in the Coldwater River, British Columbia were vital rearing areas for coho, while juvenile Chinook, steelhead, and Dolly Varden were most abundant in floodplain ponds.

The complex environments created by LWD increase the access for aquatic species to floodplain habitat. Fish use LWD for cover and refuge (Cederholm et al. 1997; Everett and Ruiz 1993; Harvey et al. 1999). In a study of Smith Creek in northwest California, Harvey et al. (1999) found that tagged adult coastal cutthroat trout moved more frequently from pools without LWD than from pools with LWD. They hypothesized that the habitat created by LWD attracts fish, and once fish establish territory within the desirable habitat, they remain there longer. A study by Cederholm et al. (1997) on a tributary of the Chehalis River found that LWD additions caused an increase in winter populations of juvenile coho salmon and age-0 steelhead populations. Based on these studies, it follows that the loss of LWD to a channel would reduce floodplain–channel resource exchange and habitat accessibility, which would likely adversely impact the 52 HCP species, especially those that favor floodplain habitat.

7.1.6 Water Quality Modifications

Dredging in marine and freshwater environments produces large amounts of suspended sediment by exposing fine sediments, resuspending those sediments intended to be removed but lost and, if the disposal occurs in marine and freshwater environments, through the direct disposal of dredged materials (USACE 1983). Although increased turbidity is the principal water quality modification, the indirect impacts of hydraulic and geomorphic modifications can combine to increase stratification and reduce vertical mixing (Fischer et al. 1979). Also, dredging has the potential to release toxic compounds to the water column including ammonium, cyanide, lead, and arsenic (Spadaro et al. 1993).

7.1.6.1 Submechanisms of Impact

In general, water quality impacts from dredging operations are not environment specific. The indirect modifications to water quality alter four primary water quality variables in marine and freshwater environments: temperature, dissolved oxygen, suspended sediments and turbidity, and nutrient and pollutant loading.

7.1.6.1.1 Altered Temperature Regime

Temperature is a primary metric of aquatic ecosystem health, and aquatic organisms have adapted to live within specific thermal regimes. Alterations to these thermal regimes occur to the detriment of the local, adjusted population. In marine environments, dredging activities have been shown to alter tidal prisms and estuarine mixing (Hossain et al. 2004). These changes would alter the thermal profile of the estuary (Fischer et al. 1979) and could affect fish and invertebrates.

7.1.6.1.2 Altered Dissolved Oxygen

Dissolved oxygen (DO) content is critical to the growth and survival of all 52 HCP species. The amount of oxygen dissolved in water is dependent on temperature, physical mixing, respiration, photosynthesis and, to a lesser degree, atmospheric pressure. These parameters can vary diurnally and seasonally and depend on activities such as daytime photosynthetic oxygen inputs and night-time plant respiration processes that deplete dissolved oxygen levels. Dredging activities have been shown to alter the underlying physical processes (Perillo et al. 2005), but it has also been linked directly to lowering dissolved oxygen levels caused by increased sedimentation (Hossain et al. 2004). Dissolved oxygen concentration is temperature dependent; as temperatures rise, the gas-absorbing capacity of the water decreases and the dissolved oxygen saturation level decreases. Reduced dissolved oxygen levels can be due to increased temperature (Snoeyink and Jenkins 1980), organic or nutrient loading (Ahearn et al. 2006), increased benthic sedimentation (Welch et al. 1998), or the chemical weathering of iron and other minerals (Schlesinger 1997).

7.1.6.1.3 Altered Suspended Sediments and Turbidity

Several of the studies cited in this white paper present information in turbidity level units in the place of suspended sediment concentrations to infer effects thresholds. Turbidity is commonly used as a surrogate for suspended sediment concentrations, but the relationship between these measures is site specific. Where available, the equivalent suspended sediment concentration is provided, otherwise the turbidity value is provided. Because this complicates the interpretation of this information, a brief discussion of the relationship between turbidity and suspended sediment concentrations is provided here.

The International Standards Organization (ISO) defines turbidity as the 'reduction of transparency of a liquid caused by the presence of undissolved matter' (Lawler 2005), as measured by turbidimetry or nephelometry. Turbidity can be caused by a wide range of suspended particles of varying origin and composition. These include inorganic materials like silt and clay, and organic materials such as tannins, algae, plankton, micro-organisms and other organic matter. The term suspended sediments refers to inorganic particulate materials in the water column. Suspended sediments can range in size from fine clay to boulders, but the term applies most commonly to suspended fines (i.e., sand size or finer material). Because suspended sediments are a component of turbidity, turbidity is commonly used as a surrogate measure for this parameter. However, the accuracy of the results is dependent on establishing a clear correlation between turbidity and suspended sediment concentrations to account for the influence of organic materials. This correlation is site specific, given the highly variable nature of organic and inorganic material likely to occur in a given setting.

It has been well documented that inefficiencies in the dredging activity can produce both high levels of turbidity at the project site, but also at some distance away from the project (Erftemeijer and Lewis 2006; Hossain et al. 2004; Perillo et al. 2005; USACE 1983, 2005). In general, the response of aquatic biota to elevated suspended solids concentrations is highly variable and dependent upon life-history stage, species, background suspended solids concentrations, and ambient water quality. Appendix A provides summary tables of the research that has been conducted on the effects of suspended solids on fish and invertebrates. The following sections provide detailed information on some of those findings.

7.1.6.1.4 Nutrient and Pollutant Loading

Dredging activities can alter nutrient and pollutant loading indirectly by modifying and restricting nearshore circulation. There are numerous incidences of dredging affecting tidal circulation and estuarine stratification (Hossain et al. 2004; Perillo et al. 2005; Sherwood et al. 1990). For a complete discussion of how this occurs, see Section 7.1.4 (*Hydraulic and Geomorphic Modifications*). Dredging activities in Puget Sound have also been shown to resuspended previously contaminated sediments, which could contribute toxic compounds, such as lead, arsenic, ammonium and cyanide into the marine environment (Spadaro et al. 1993).

The processing and retention of sediment, nutrients, and pollutants in aquatic systems is also accelerated by the presence of aquatic vegetation (Clarke 2002). Numerous studies have shown that macrophytes and algae in marine environments act to reduce ambient concentrations of suspended sediment (Abdelrhman 2003; Moore 2004), nutrients (Moore 2004), and metals (Fritioff and Greger 2003). Seagrasses have also been linked to improved water quality. For example, Moore (2004) noted decreased nutrient concentrations and turbidity levels in seagrass beds relative to areas outside the beds along the littoral zone of the Chesapeake Bay National Estuarine Research Reserve. Aquatic vegetation not only reduces nutrient and sediment concentrations, the plants themselves can sequester harmful trace metal pollutants and are frequently planted in wetland treatment systems with this intended function. In a comparative study of heavy metal uptake in terrestrial, emergent, and submerged vegetation, Fritioff and

Greger (2003) noted that submerged vegetation was efficient at removing zinc, copper, cadmium, and lead from influent stormwater.

Any activity that mechanically removes or by other means affects aquatic vegetation will reduce the sediment, nutrient, and pollutant retention and reduction capabilities of the system. With this reduction comes increased pollutant loading to receiving waters, which could exacerbate eutrophic conditions and/or metals toxicity. (For more information on metal toxicity, see Section 7 (*Direct and Indirect Impacts*) of the Shoreline Modifications white paper [Herrera 2007c.])

Any activity that affects riparian or nearshore areas will degrade the buffering capability of the terrestrial–aquatic ecotone. Numerous studies have shown that wide stream buffers are effective at attenuating nutrients (Feller 2005; Mayer et al. 2005), herbicides (Gay et al. 2006), and sediment loading (Jackson et al. 2001). Riparian vegetation acts to retard overland flow, promote infiltration, and assimilate shallow groundwater nutrients. When this vegetation is removed through any HPA activity, nutrients and pollutants will be more efficiently transported from upland sources to downgradient water bodies. Forested buffers have been shown to effectively remove nutrients in shallow groundwater. In a study of a forested buffer in Alabama, it was found that a 33-ft (10-m) buffer reduced the groundwater nitrate concentration by 61 percent (Schoonover and Williard 2003). In a subsequent study of a forested wetland buffer, it was found that a buffer averaging 125 ft (38 m) wide reduced nitrate concentration by 78 percent and total phosphorus by 66 percent (Vellidis et al. 2003).

7.1.6.2 Direct and Indirect Impacts on Fish and Invertebrates

The majority of research on temperature impacts on aquatic species has focused on salmonids. Most salmonids prefer the same temperature ranges during most of their life-history stages. The primary exception to this is that char (bull trout and Dolly Varden) require lower temperatures for optimal incubation, growth, and spawning (Richter and Kolmes 2005). An optimal temperature matrix is presented in Table 7-2; different species have different requirements at various life-history stages. These same temperature ranges have been adopted by Ecology and are incorporated into the state water quality standards (WAC 173-201A; Finlayson 2006). Table 7-3 presents the highest 7-day average maximum thresholds as promulgated in the state standards.

Each of the HCP species is ectothermic (cold-blooded); consequently, temperature is a resource that organisms use for energetic means. With organism metabolism dependent on water temperature, thermal regime may be the single-most important habitat feature controlling aquatic organisms.

Thermal stress can occur through multiple direct and indirect pathways in fish and invertebrates. These include direct mortality, altered migration and distribution, increased susceptibility to disease and toxicity, and altered development, spawning, and swimming speeds (Sullivan et al. 2000). Motile organisms have the ability to avoid or evacuate those areas of extreme temperature, but even then the stress induced from periodic exposure and resulting habitat avoidance can affect organism health and contribute to decreased survival, growth, and fitness (Groberg et al. 1978).

Table 7-2. Estimates of thermal conditions known to support various life-history stages and biological functions of bull trout (a species extremely intolerant of warm water) and anadromous (ocean-reared) salmon[a].

Consideration	Anadromous Salmon	Bull Trout
Temperature of common summer habitat use	10–17°C (50–63°F)	6–12°C (43–54°F)
Lethal temperatures (1-week exposure)	Adults: >21–22°C (70–72°F)	—
	Juveniles: >23–24°C (73–75°F)	Juveniles: 22–23°C (72–73°F)
Adult migration	Blocked: >21–22°C (70–72°F)	Cued:10–13°C (50–55°F)
Swimming speed	Reduced: >20°C (68°F)	—
	Optimal: 15–19°C (59–66°F)	—
Gamete viability during holding	Reduced: >13–16°C (55–61°F)	—
Disease rates	Severe: >18–20°C (64–68°F)	—
	Elevated: 14–17°C (57–63°F)	—
	Minimized: <12–13°C (54–55°F)	—
Spawning	Initiated: 7–14°C (45–57°F)	Initiated:<9°C (48°F)
Egg incubation	Optimal: 6–10°C (43–50°F)	Optimal: 2-6°C (36–43°F)
Optimal growth	Unlimited food: 13–19°C (55–66°F)	Unlimited food: 12–16°C (54–61°F)
	Limited food: 10–16°C (50–61°F)	Limited food: 8–12°C (46–54°F)
Smoltification	Suppressed: >11–15°C (52–59°F)	—

Source: (Poole et al. 2001).

[a] 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).

Table 7-3. Aquatic life temperature criteria in fresh water[a].

Category	Highest 7-DADMax
Char spawning	9°C (48.2°F)
Char spawning and rearing	12°C (53.6°F)
Salmon and trout spawning habitat	13°C (55.4°F)
Core summer salmonid habitat	16°C (60.8°F)
Salmonid spawning, rearing, and migration	17.5°C (63.5°F)
Salmonid rearing and migration Only	17.5°C (63.5°F)
Non-anadromous interior redband trout	18°C (64.4°F)
Indigenous warm water species	20°C (68°F)

Source: (WAC 173-201A; Finlayson 2006) Table 200 (1)(c).

[a] Aquatic life temperature criteria. Except where noted, water temperature is measured by the 7-day average of the daily maximum temperatures (7-DADMax). Table 200 (1)(c) lists the temperature criteria for each of the aquatic life use categories.

Elevated water temperatures can impair migratory behavior and dispersal. In salmonids, for example, adult migration blockages occur consistently when temperature exceed 69.8–71.6°F (21–22°C) (Poole and Berman 2001a). Selong et al. (2001) demonstrated that temperatures exceeding the optimal growth range of bull trout and other salmonid species constitute an effective barrier to migration and dispersal to rearing and foraging habitat. More broadly, elevated temperature regimes can affect fish and invertebrate species by altering behavior and reducing resistance to disease and toxic substances. Studies have indicated that under chronic thermal exposure conditions, aquatic organism susceptibility to toxic substances may increase. Because elevated temperatures increase metabolic processes, gill ventilation also rises proportionately (Heath and Hughes 1973). Black et al. (1991) showed that an increase in water flow over the gills, which results from increased gill ventilation at increased temperature, resulted in rapid uptake of toxicants, including metals and organic chemicals, via the gills. Salmonids also become more susceptible to infectious disease at elevated temperatures (57–68°F [14–20°C]) because immune systems are compromised (Harrahy et al. 2001), while bacterial and viral activity is accelerated (Tops et al. 2006). In nearshore areas where temperature (as well as pollutant levels) may be elevated, the combined effect of thermal and water pollution may be a primary driver of salmonid decline.

Considerably less research exists defining thermal criteria for invertebrates, although marine invertebrates can generally withstand higher temperatures. Gagnaire et al. (2006) noted that elevated temperatures caused blood cell mortality in Pacific oysters but not until temperatures exceeded 104°F (40°C), which is unlikely even in altered settings. It is unclear, however, what sublethal effect(s) may represent a significant factor for invertebrate populations.

In addition to temperature, the majority of research on dissolved oxygen impacts on aquatic species has focused on salmonids. Juvenile salmon are highly sensitive to low dissolved oxygen concentrations (USFWS 1986) and, consequently, are among the more vulnerable HCP species with regard to dissolved oxygen impairment. Salmon generally require dissolved oxygen levels of greater than 6 ppm for optimal survival and growth, with lethal one-day minimum concentrations of around 3.9 ppm (Ecology 2002). Different organisms at different life-history stages require different levels of dissolved oxygen to thrive. Table 7-4 lists the minimum recommended dissolved oxygen concentrations for salmonids and stream-dwelling macroinvertebrates (Ecology 2002). The dissolved oxygen thresholds presented in this table were derived from more than 100 studies representing over 40 years of research.

It should be noted that recommendations are presented in Table 7-4 for dissolved oxygen thresholds in categories other than lethality. Fish are motile organisms and, where possible, will avoid dissolved oxygen levels that would cause direct mortality. However, this avoidance behavior in and of itself can affect fishes. Stanley and Wilson (2004) found that fish aggregate above the seasonal hypoxic benthic foraging habitat in the Gulf of Mexico, while Eby et al. (2005) found that fish in the Neuse River estuary (North Carolina) were restricted by hypoxic zones to shallow, oxygenated areas, where in the early part of the summer about one-third fewer prey resources were available. Studies such as these reveal how dissolved oxygen can change fish distributions relative to habitat, and potentially exclude fishes from reaching foraging and rearing areas. Sublethal dissolved oxygen levels can also cause increased susceptibility to infection (Welker et al. 2007) and reduced swim speeds (Ecology 2002), both of which may cause indirect impacts on HCP fish species.

Table 7-4. Summary of recommended dissolved oxygen levels for full protection (approximately less than 1 percent lethality, 5 percent reduction in growth, and 7 percent reduction in swim speed) of salmonid species and associated macroinvertebrates.

Life-history Stage or Activity	Oxygen Concentration (ppm)	Intended Application Conditions
Incubation through emergence	≥9.0–11.5 *(30 to 90-DADMin)* and No measurable change when waters are above 52°F (11°C) (weekly average) during incubation.	Applies throughout the period from spawning through emergence Assumes 1-3 ppm will be lost between the water column and the incubating eggs
Growth of juvenile fish	≥8.0–8.5 *(30-DADMin)* and ≥5.0-6.0 *(1-DMin)*	In areas and at times where incubation is not occurring
Swimming performance	≥8.0-9.0 *(1-DMin)*	Year-round in all salmonid waters
Avoidance	≥5.0-6.0 *(1-DMin)*	Year-round in all salmonid waters
Acute lethality	≥3.9 *(1-DMin)* ≥4.6 *(7 to 30-DADMin)*	Year-round in all salmonid waters
Macroinvertebrates *(stream insects)*	≥8.5-9.0 *(1-DMin or 1-DAve)*	Mountainous headwater streams
	≥7.5-8.0 *(1-DMin or 1-DAve)*	Mid-elevation spawning streams
	≥5.5-6.0 *(1-DMin or 1-DAve)*	Low-elevation streams, lakes, and nonsalmonid waters
Synergistic effect protection	≥8.5 *(1-DAve)*	Year-round in all salmonid waters to minimize synergistic effect with toxic substances

Source: Ecology 2002.
1-DMin = annual lowest single daily minimum oxygen concentration.
1-DAve = annual lowest single daily average concentration.
7-, 30-, 90-DADMin = lowest 7-, 30- or 90-day average of daily minimum concentrations during incubation period, respectively.

Little consensus exists concerning low dissolved oxygen criteria for macroinvertebrates, and tolerances to hypoxic conditions that are taxonomically specific. Many invertebrates are adapted to live in benthic low-energy environments where dissolved oxygen concentrations are naturally low; consequently, these organisms can withstand hypoxic conditions. Other taxa, including Hirudinea, Decapoda, and many aquatic insects, tolerate dissolved oxygen levels below 1.0 ppm (Hart and Fuller 1974; Nebeker et al. 1992). Kaller and Kelso (2007) found benthic macroinvertebrate density, including mollusks, greatest in low dissolved oxygen areas of a Louisiana wetland, while a literature review by Gray et al. (2002) found that in marine environments, invertebrates were not affected by low dissolved oxygen until concentrations fell below 1–2 ppm. Benthic dissolved oxygen levels can seasonally drop below this threshold in productive systems that receive high biochemical oxygen demand (BOD) loadings. For instance, depressed benthic dissolved oxygen levels in Hood Canal, Washington, have been associated with spot shrimp decline (Peterson and Amiotte 2006). This dissolved oxygen decline has in turn been linked to BOD loadings from leaking or improperly functioning onsite wastewater disposal systems. These conditions in Puget Sound highlight the importance of reducing anthropogenically generated BOD. While most BOD increases can be attributed to other human activities, the reduction of tidal flushing due to dredging can exacerbate these inherent problems (Hossain et al. 2004).

The effects of suspended sediments and turbidity on fish can be divided into four categories: lethal, sublethal, behavioral, and habitat effects. Although juveniles of many fish species thrive in rivers and estuaries with naturally high concentrations of suspended solids, studies have shown that high concentrations of suspended solids (as well as the duration of exposure) can be lethal to salmonid populations (McLeay et al. 1987; Newcombe and MacDonald 1991; Servizi and Martens 1987). Lake and Hinch (1999) found concentrations in excess of 40,000 ppm suspended solids to elicit stress responses in juvenile coho salmon. Suspended solids concentrations this high would likely only be associated with construction activities. However, other studies have shown lethal effects at much lower concentrations.

Servizi and Martens (1991) exposed juvenile coho salmon to natural Fraser River suspended solids and found a 96-hour LC_{50} (the concentration at which 50 percent population mortality was observed) of only 22,700 ppm. Using the identical apparatus and sediment source, juvenile sockeye salmon had a 96-hour LC_{50} of 17,600 ppm (Servizi and Martens 1987), and juvenile Chinook salmon had an LC_{50} of 31,000 ppm (Servizi and Gordon 1990). With lethal effects at concentrations as low as 17,600 ppm, it is obvious that, for at least some species, the sublethal effects of suspended solids occur at even lower concentrations.

Stress induced in fish from moderate concentrations of suspended solids can have sublethal effects. Studies on a variety of fishes, including sockeye and Chinook (Newcomb and Flagg 1983), coho, four-spine stickleback, cunner, and sheepshead minnow (Noggle 1978), attribute chronic and acute impacts from high suspended solids to reduced oxygen uptake (Wilber and Clarke 2001). Fish must keep their gills clear for oxygen exchange. In the presence of high loadings of suspended solids, they engage a cough reflex to perform that function. Due to increased metabolic oxygen demand with increased temperatures and the need to keep respiratory pathways free of sediments for oxygen uptake, increased temperature and reduced oxygen levels combine to reduce the ability of fish to cough and maintain ventilation rates. The stress induced by these conditions can lead to compromised immune defenses and reduced growth rates (Au et al. 2004).

Elevated concentrations of suspended solids can also cause behavioral effects in fish. Sigler et al. (1984), Aksnes and Utne (1997), Mazur and Beauchamp (2003), and Vogel and Beauchamp (1999) all report that suspended solids at sublethal concentrations have been shown to affect fish functions such as avoidance responses, territoriality, feeding, and homing behavior. Sigler et al. (1984) observed reduced growth rates in juvenile steelhead and coho salmon at suspended solids concentrations as low as 100 ppm, while Servizi and Martens (1992) reported increased cough frequency in juvenile coho at concentrations of approximately 240 ppm. Feeding success was found to be linked to turbidity levels, with higher turbidity levels reducing prey capture success. Wildish and Power (1985) reported avoidance of suspended solids by rainbow smelt and Atlantic herring at 20 ppm and 10 ppm, respectively.

In studies of coho behavior in the presence of short-term pulses of suspended solids, Berg and Northcote (1985) found that territorial, gill flaring, and feeding behaviors were disrupted. At turbidity levels of between 30 and 60 nephelometric turbidity units (NTUs), social organization broke down, gill flaring occurred more frequently, and only after a return to a turbidity of 1–20 NTUs was the social organization re-established. Similarly, feeding success was also found to be linked to turbidity, with higher turbidity levels reducing prey capture success. In a study of dredging impacts on juvenile chum in Hood Canal, Salo et al. (1980) found that juvenile chum salmon showed avoidance reactions to high turbidity levels. These behavioral thresholds vary across species and life-history stages. Consistent with their early reliance on nearshore estuarine habitats with relatively high turbidities compared to pelagic or freshwater habitats, juvenile chum are classified as turbidity tolerant compared to other fishes (Salo et al. 1980).

In contrast with the above studies, it also appears that under certain circumstances elevated suspended solids may benefit salmonids by providing cover (Gregory and Levings 1998) or by triggering a sense of predation cover for salmonids (Gregory 1993). The studies of Gregory and Northcote (1993) indicated that when suspended solids concentrations exceeded 200 ppm, juvenile salmon increase their feeding rates while demonstrating pronounced behavioral changes in prey reaction and predator avoidance.

Recent studies have shown that the size and shape of suspended sediments and the duration of exposure are important factors in determining the extent of adverse effects of increased turbidity on salmonids (Martens and Servizi 1993; McLeay et al. 1987; Northcote and Larkin 1989; Servizi and Martens 1987, 1991; Newcombe and MacDonald 1991). Dredging activities suspend all sediments that are dredged, and often release easily suspendible clays into the water column, which are similar to the bothersome angular particulates reported on in these studies.

Elevated suspended sediments can also affect aquatic habitat. For example, increased turbidity is known to compromise submerged aquatic vegetation (Parkhill and Gulliver 2002; Terrados et al. 1998) such as eelgrass (Erftemeijer and Lewis 2006), which is associated with important rearing habitats for a suite of marine fishes including Pacific cod, Pacific salmon, rockfish, Pacific herring, and walleye pollock (Nightingale and Simenstad 2001a; Simenstad et al. 1999).

Elevated concentrations of suspended solids can also affect invertebrates. As with dissolved oxygen, invertebrates tend to thrive across a wide range of suspended solids concentrations. Negative impacts on eastern oyster egg development have been shown to occur at 188 ppm total suspended solids (Cake 1983). Hardshell clam eggs appear to be more resilient, with egg development affected only after total suspended solids concentrations exceeded 1,000 ppm (Mulholland 1984). Mulholland (1984) showed that suspended solids concentrations of <750 ppm allowed for continued larval development but higher concentrations for durations of 10–12 days showed lethal effects for both clams and oysters.

For bivalves, when suspended solids concentrations rise above their filtering capacities, their food becomes diluted (Widdows et al. 1979). Studies have shown that the addition of silt, in relatively low concentrations in environments with high algal concentrations, can be marked by the increased growth of mussels (Kiorboe et al. 1981), surf clams (Mohlenberg and Kiorboe 1981), and eastern oysters (Urban and Langdon 1984). Bricelj and Malouf (1984), however, found that hardshell clams decreased their algal ingestion with increased sediment loads, and no growth rate differences were observed between clams exposed to algal diets alone and clams with added sediment loads (Bricelj et al. 1984). Urban and Kirchman (1992) reported similarly ambiguous results concerning suspended clay. Suspended clay (20 ppm) interfered with juvenile eastern oyster ingestion of algae, but it did not reduce the overall amount of algae ingested. Grant et al. (1990) found that the summer growth of European oysters was enhanced at low levels of sediment resuspension and inhibited with increased deposition. It was hypothesized that the chlorophyll in suspended solids may act as a food supplement that could enhance growth, but higher levels may dilute planktonic food resources, thereby, suppressing food ingestion. Changes in behavior in response to sediment loadings were also noted for soft-shelled clams in sediment loads of 100–200 ppm, with changes in their siphon and mantles over time (Grant and Thorpe 1991).

Collectively, these studies show no clear pattern of sublethal effects from elevated concentrations of suspended solids and thereby turbidity that could be generally applied across aquatic mollusks. This uncertainty is further complicated by the fact that many of the HCP invertebrate species are poorly studied. This indicates the need for directed studies on the sensitivity of these species before effects thresholds can be set. In the absence of this information, however, it is useful to consider that HCP invertebrates are all bottom-dwelling mollusks that have evolved to live in dynamic environments under conditions of variable turbidity. Therefore, sensitivity to turbidity-related stressors would be expected to occur only when conditions exceed the range of natural variability occurring in their native habitats.

In a study of the impact of sedimentation on seagrass in southeast Asia, Terrados et al. (1998) noted approximately a 50 percent decline in the number of seagrass species and a 150 percent decline in seagrass biomass with a 15 percent increase in clay content of the sediments. Numerous studies have shown increased biomass within seagrass beds for invertebrates (Cardoso et al. 2007; Seitz et al. 2005) and vertebrate species (Ferraro and Cole 2007; Pihl et al. 2006); thus, sedimentation-related negative impacts on seagrass arising from dredging activities would likely affect the HCP species by decreasing the available nearshore habitat.

Nutrient and pollutant loading cause eutrophication when limits to vegetative growth are reduced. In marine waters, iron preferentially binds with sulfide, and the associated phosphorus is released; this creates conditions of nitrogen limitation (Blomqvist et al. 2004). When nutrient limitations are eliminated, vegetative growth increases. This process accelerates carbon fixation; the additional carbon loading to the aquatic system increases respiration as heterotrophs use carbon for energy. Through the process of carbon oxidation, oxygen is converted to carbon dioxide (CO_2), and ambient dissolved oxygen levels decrease. Eutrophication-induced hypoxia is a nationwide problem (Scavia and Bricker 2006). In Washington, low dissolved oxygen episodes in Hood Canal have resulted in widespread fish and invertebrate kills (Peterson and

Amiotte 2006). These low dissolved oxygen episodes have been linked to excess carbon loading due to nutrient enrichment. The resultant algal blooms may not only impact dissolved oxygen levels but also, if certain species flourish, may contribute to paralytic shellfish poisoning (Horner 1998). The ramifications of low dissolved oxygen on HCP species are addressed in Section 7.1.6.1.2 (*Altered Dissolved Oxygen*) above and in Section 9 (*Potential Risk of Take*).

7.2 Gravel Mining and Scalping

Gravel is extracted for use as base material in the construction of roads, highways, and railroads and as aggregate mix in the construction of roads and buildings. Gravel sources include active river sediments and glacial sediments deposited during the Pleistocene by meltwater streams. Sources are ideally located close to markets to reduce transportation costs and maximize profits. Gravel extraction methods are illustrated in Figure 7-2 and include the following (Kondolf et al. 2002):

- Dry-pit mining is the excavation of gravel within the active channel on dry intermittent or ephemeral streams beds.
- Wet-pit mining is the excavation of gravel within the riverine floodplain below the groundwater table, requiring the use of a dragline or hydraulic excavator.
- Bar scalping or "skimming" is the extraction of gravel from the surface of gravel bars above the low-flow water level.
- Bar excavation involves pit excavation at the downstream end of the gravel bar for gravel extraction.
- Gravel traps are channel-spanning hydraulic controls that promote ponding and sediment deposition. The collected sediment is then extracted during low-flow conditions.
- Channel-wide instream mining occurs in rivers with variable flow regimes and involves the excavation of gravel across the entire active channel width during the dry season.
- Floodplain and terrace-pit mining is similar to wet-pit mining but includes dewatering of the pit to work in the dry.

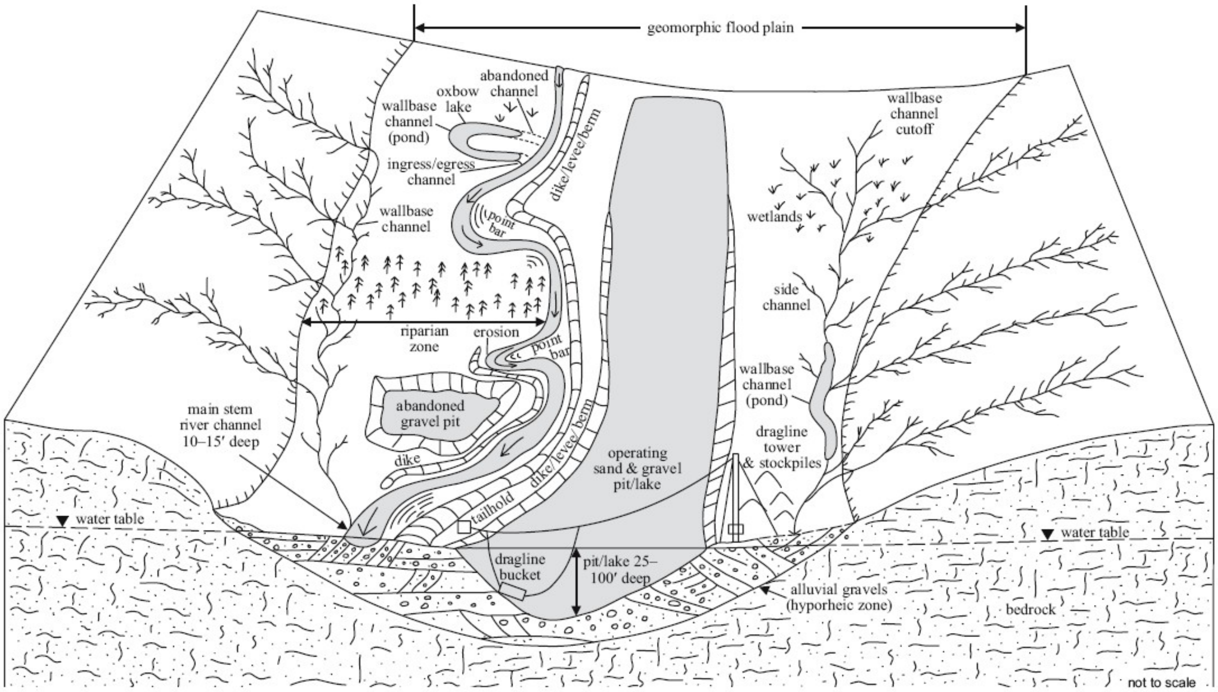


Figure 7-2. Schematic illustration of typical gravel extraction methods within the active floodplain (Norman et al. 1998).

Gravel-mining activities impact habitat by disturbing the channel bed and banks (including increasing suspended solids, and clearing or disturbing aquatic and riparian vegetation). Gravel mining activities can entrain burrowing animals and fill habitat areas with substrate different in nature than the endemic substrate. Long-term effects resulting from gravel mining activities can also pose risks of direct and indirect effects to fishes and invertebrates in affected freshwater and saltwater environments through modifications of hydraulic conditions, sediment supply, water quality, and riparian and aquatic vegetation. The effects of gravel mining activities are described below.

7.2.1 Construction and Maintenance

Construction impacts from gravel mining are due to construction equipment operation and the disturbance and dewatering of the area during gravel extraction.

7.2.1.1 Submechanisms of Impact

Direct and indirect impacts on the HCP species are summarized below for each of these submechanisms based on the literature review and subsequent analysis.

7.2.1.1.1 Dewatering, Flow Bypass, and Fish Handling

In many cases, gravel mining may require the exclusion of streamflows or even the dewatering of the work area to protect aquatic life and/or provide a suitable environment for construction. These activities have the potential to cause direct and indirect effects on HCP species. Fish exclusion and dewatering involve the placement of barriers (e.g., block nets, temporary berms, cofferdams) around a work area and the capture and removal of fish and other aquatic life within the work area. Electrofishing is a common practice used for fish capture in freshwater environments, as is the use of minnow traps, hand nets, beach seines, and other net-based capture methods.

7.2.1.1.2 Channel Rewatering (Elevated Turbidity)

Installation, operation, and removal of a stream bypass system to rewater a channel can increase turbidity. The in-water installation and removal work poses the highest risk of disturbing the stream bank and substrate, thereby resuspending sediments and increasing turbidity. Fish may experience short-term, adverse effects as a result of increased turbidity.

7.2.1.1.3 Construction Equipment Operation

The operation of construction equipment during gravel-mining operations presents several different stressors including: (1) entrainment during bar scalping and pit excavation, (2) increased turbidity, and (3) underwater noise exceeding ambient levels. The first two stressors are addressed in Section 7.1.1.1.2 (*Entrainment*) and Section 7.1.6.1.3 (*Altered Suspended Sediments and Turbidity*), respectively, under Section 7.1 (*Dredging*). Gravel mining operations are not expected to include pile driving. The effects of underwater noise from non-pile driving activities are discussed in Section 7.1.1.1.1 (*Noise-Related Disturbance*) under Section 7.1 (*Dredging*).

7.2.1.2 Direct and Indirect Effects on Fish and Invertebrates

The direct effects of fish exclusion and dewatering include:

- Direct mortality, injury, and stress from electrical field exposure (i.e., electrofishing)
- Capture by netting, leading to direct mortality, injury, and stress

- Physical and thermal stress and possible trauma associated with handling and transfer during capture and transfer between temporary holding containers and release locations
- Stranding and asphyxiation
- Entrainment or impingement in block nets, dewatering pumps, and bypass equipment
- Increased stress, predation exposure, and habitat and forage competition once relocated
- Increased competition for aquatic species forced to compete with relocated animals.
- Temporary barriers to migratory fish species associated with exclusion areas.

Of the various methods used for dewatering and fish handling, the majority of research has been conducted on incidental mortality and injury rates associated with electrofishing. Much of this research has focused on adult salmonids greater than 12 inches in length (Dalbey et al. 1996). The relatively few studies that have been conducted on juvenile salmonids suggest spinal injury rates lower than those observed for large fish, perhaps because juvenile fish generate less total electrical potential along a shorter body length (Dalbey et al. 1996; Sharber and Carothers 1988; Thompson et al. 1997). Electrofishing-related injury rates are variable, reflecting a range of factors from fish size and sensitivity, individual site conditions, to crew experience and the type of equipment used, with the equipment type being a particularly important factor (Dalbey et al. 1996; Dwyer and White 1997; Sharber and Carothers 1988). Electrofishing equipment typically uses continuous direct current (DC) or low-frequency pulsed DC equipment. The use of low-frequency DC (equal to or less than 30 Hz) is the recommended electrofishing method because it is associated with lower spinal injury rates (Ainslie et al. 1998; Dalbey et al. 1996; Fredenberg 1992). Even with careful selection of equipment, observed injury rates can vary. For example, one study in the Yakima River basin (McMichael et al. 1998) observed a 5.1 percent injury rate for juvenile steelhead captured using 30 Hz pulsed DC equipment. Ainslie et al. (1998) reported injury rates of 15–39 percent in juvenile rainbow trout using continuous and pulsed DC equipment, and found that while pulsed DC equipment produced injury more frequently, these injuries were less severe in nature.

It is notable that electrofishing capture typically has a low direct mortality rate, but it is reasonable to conclude that injuries induced by electrofishing could have long-term effects on survival, growth, and fitness. The few studies that have examined this question found that few juvenile salmonids die as a result of electrofishing-induced spinal injury (Ainslie et al. 1998; Dalbey et al. 1996). However, fish with more injuries demonstrated a clear decrease in growth rates, and in some cases growth was entirely arrested (Dalbey et al. 1996). In the absence of additional supporting information, it is reasonable to conclude that these same effects would affect many of the HCP fish species, but this conservative assumption may not be universally accurate. Studies of the effects of electrofishing on other fish species are more limited, but available data indicate that at least some HCP species may be less sensitive to injury-related effects. Holliman et al. (2003) exposed a threatened cyprinid (minnow) species, to electrofishing techniques in the laboratory and found that the typical current and voltage parameters used to minimize adverse effects on salmonid species produced no evidence of injury. This suggests that other cyprinids such as leopard and spotted dace, lake chub, and suckers may also be less sensitive.

Beyond the effects of electrofishing, the act of capture and handling demonstrably increases physiological stress in fishes (Frisch and Anderson 2000). Primary contributing factors to handling-induced stress and death include exposure to large changes in water temperatures and dissolved oxygen conditions (caused by large differences between the capture, holding, and release environments); duration of time held out of the water; and physical trauma (e.g., due to net abrasion, squeezing, accidental dropping). Even in the absence of injury, stress induced by capture and handling can have a lingering effect on survival and productivity. One study found that handling stress impaired predator evasion in salmonids for up to 24 hours following release and caused other forms of mortality (Olla et al. 1995).

Use of a bypass system is a common means of creating exclusion areas via dewatering and flow reduction. Partial dewatering is a technique used to reduce the volume of water in the work area to make capture methods more efficient. In riverine habitats, this method is used to move fish out of affected habitats to reduce the number of individuals exposed to capture and handling stress and potential injury and mortality. NOAA Fisheries has estimated that 50–75 percent of fish in an affected reach will volitionally move out of an affected reach when flows are reduced by 80 percent (NMFS 2006). However, volitional movement will lead to concentration of fish in unaffected habitats, increasing competition for available space and resources.

Failure to capture and remove fish or invertebrates from work areas must also be considered. Organisms left in the exclusion area would potentially be directly exposed to stranding and asphyxiation during dewatering or, if left inundated, to mechanical injury and/or high intensity noise, turbidity and other pollutants. Many species of fish, such as salmonids and larval lamprey, are highly cryptic and can avoid being detected even when using multiple pass electrofishing because they hide in large interstices or are buried in sediments (Peterson et al. 2005; Peterson et al. 2004; Wydoski and Whitney 2003).

NOAA Fisheries has estimated incidental take resulting from dewatering and fish handling associated with stream crossing projects. In calculating incidental take from these activities, the agency applied an estimated stranding rate of 8 percent for ESA-listed salmonids (which equates to 8 percent mortality) (NMFS 2006), based on expected 45 percent capture efficiency using three pass electrofishing (Peterson et al. 2004), and assuming a 25 percent injury rate. The effects of increased turbidity during rewatering are the same as those discussed for dredging in Section 7.1.6.1.3 (*Altered Suspended Sediments and Turbidity*).

As noted, research on fish injury and mortality associated with dewatering has focused predominantly on salmonids, relatively large fish species that respond well to this exclusion technique. Other species may have non-motile or cryptic life-history stages (e.g., lamprey ammocoetes buried in fine sediments, great Columbia River spire snail) or life-history stages that can not easily move to adjust to changes in flow or are not easily captured and relocated (e.g., adhesive eggs of eulachon, juvenile rockfish and lingcod). In freshwater environments, examples of species and life-history stages that are sensitive to dewatering impacts include incubating salmonid eggs and aelvins, lamprey ammocoetes, the adhesive eggs of eulachon, sturgeon, great Columbia River spire snail, and other species. These life-history stages are relatively immobile and also difficult to capture and relocate efficiently. Therefore, they face a higher likelihood of exposure to stranding or entrainment in dewatering pumps, which would be expected to lead to mortality. In marine environments, the larval and juvenile life-history stages of rockfish, lingcod, Pacific cod, hake, pollock, herring, smelt, and sand lance are similarly immobile and difficult to capture and therefore vulnerable to the same effects.

Rewatering of the exclusion area following construction is generally expected to result in a temporary increase in turbidity. The in-water installation and removal work poses the highest risk of disturbing the stream bank and substrate, thereby resuspending sediments and increasing turbidity. Fish may experience short-term, adverse effects as a result of increased turbidity.

HCP invertebrate species demonstrate different sensitivity to the effects of dewatering and relocation than fish, with many species being relatively insensitive to the effects of handling, at least during adult life-history stages. For example, Krueger et al. (2007) studied the effects of suction dredge entrainment on adult western ridged and western pearlshell mussels in the Similkameen River (Washington State) and found no evidence of mortality or significant injury. Suction dredge entrainment is expected to be a more traumatic stressor than removal and relocation by hand. These findings suggest that careful handling would be unlikely to cause injury. However, the authors cautioned that these findings were limited to adult mussels, and the potential for injury and mortality in juveniles remains unknown.

The sensitivity of other HCP invertebrate species, such as giant Columbia River limpet and great Columbia River spire snail, is somewhat less certain. Adults may be easily removed and relocated during dewatering, but juveniles and eggs may be difficult to locate and remove effectively. This suggests the potential for mortality from stranding.

While handling-related injury and mortality are relatively unlikely, relocation may lead to significant nonlethal effects. For example, scattering of closely packed groups of adult mussels may affect reproductive success. Female mussels filter male gametes from the water column, and successful fertilization is thereby density dependent for species that occur in flowing water environments (Downing et al. 1993).

Failure to locate and remove small or cryptic invertebrate species or life-history stages may result in stranding or concentrated exposure to other stressors within the exclusion area. Stranding caused by operational water level fluctuations was associated with mass mortality of

California floater and western ridged mussels in Snake River reservoir impoundments (Nedeau et al. 2005).

7.2.2 Hydraulic and Geomorphic Modifications

Gravel mining results in hydraulic and geomorphic modifications to the channel bed. These changes in the channel geometry modify the relationship between channel topography and sediment transport and result in conditions that are out of equilibrium with natural channel processes.

7.2.2.1 Submechanisms of Impact

The hydraulic and geomorphic modification impacts resulting from gravel mining operations include four submechanisms of impact: (1) altered channel geometry, (2) altered flow regime, (3) altered sediment supply, and (4) altered groundwater-surface water interactions.

7.2.2.1.1 Altered Channel Geometry

The removal of gravel from the active channel alters the channel geometry. For example, bar scalping, which typically removes gravel from the top of the bar to just above the water level, effectively eliminates the confinement of flow during low-flow conditions and can lead to channel widening. This alters the flow regime and channel stability. Coarse sediment that was previously transported through the reach may now be deposited (Kondolf et al. 2002). In addition, in areas where bar scalping has occurred, studies have shown that it contributes to the loss of side channel habitat (Weigand 1991). Bar scalping on the Puyallup, Carbon and White Rivers resulted in a mean reduction in side channel riffle habitat, and mean side-channel glide and pool habitat area over a one-year period by lowering the channel-bed and water-surface elevations (Weigand 1991).

Pit mining within the floodplain presents the risk of an avulsion into the pit or pit "capture" (Figure 7-2). River avulsions during large flood events have been document at numerous floodplain gravel mining sites in Washington (Norman et al. 1998). The capture of excavation pits by the channel can alter the ambient bed profile by steepening the gradient at the entry to the pit and forming a nick point (Collins 1997; Collins and Dunne 1990; Kondolf 1997; Kondolf et al. 2002). This steep gradient can cause the nick point to propagate upstream through headcut erosion. Channel incision during headcut propagation decreases the channel gradient and destabilizes the banks (Kondolf et al. 2002; Sandecki 1989). Bank erosion can increase the local supply of fine sediment and result in channel instability upstream of the excavation pits (Sear 1995). Alterations in channel geometry caused by both in-channel and pit mining can therefore result in the loss of floodplain and channel complexity through the creation of a wide, shallow channel or through channel incision and bank instability (Kondolf et al. 2002).

Bar scalping creates a wide flat cross section, then eliminates confinement of the low-flow channel, and results in a thin sheet of water at baseflow. Scalping can also remove the armor layer from gravel bars, leaving the finer subsurface particles vulnerable to entrainment (erosion) at lower flows. A related effect is that bar scalping lowers the overall elevation of the bar surface and may reduce the threshold water discharge at which sediment transport occurs. Salmon redds downstream are thus susceptible to the deposition of displaced alluvium.

7.2.2.1.2 Altered Flow Regime

Both in-channel gravel mining and gravel bar scalping may alter river currents and velocities. These alterations arise from changes in the channel gradient resulting from gravel extraction. One study conducted in the Puyallup River by Pauley et al. (1989) documented higher velocities and scour in riffles upstream of a skimmed bar due to the reach-scale channel steepening associated with the lower downstream hydraulic control. Dunne et al. (1981) noted that bar scalping has the potential to cause the channel to take a steeper path across the inside of the bar or the meander cut-off. Rempel and Church (2003) found that bar scalping resulted in deeper water and higher velocity over gravel bars during the summer months, which includes the period of fish rearing. As noted earlier, the capture of excavation pits by the channel can alter the ambient bed profile by first steepening the gradient at the entry to the pit and then decreasing the channel gradient as the headcut propagates upstream (Kondolf et al. 2002; Sandecki 1989), thereby increasing and decreasing current velocities.

7.2.2.1.3 Altered Sediment Supply

Gravel mining alters the supply of sediment to downstream reaches through the removal of bedload material and the disruption of the sediment budget (Kondolf 1997; Jacobson 2006). Dunne et al. (1981) determined that bar scalping results in a diminished supply of sand and gravel to downstream bars and causes a decrease in bar size downstream of the scalped bar. Pit capture can reduce the sediment supply by trapping large amounts of bedload in the pit. Because the rate and size of sediment supplied to a channel can influence the substrate size (Dietrich et al. 1989), changes in sediment supply can alter the composition of substrate used by HCP species.

In areas where velocities may increase after mining activities (from channel incision and increases in the water energy), sediment once suitable for spawning may subsequently be transported downstream. In addition, upstream mining activities may generate an abundant amount of fine sediment that fills and covers the gravel substrate and results in a loss of suitable spawning habitat (Carling and Reader 1982).

7.2.2.1.4 Altered Groundwater-Surface Water Interactions

Channel incision caused by the extraction of gravel typically lowers the water table because the channel determines the level down to which the local alluvial groundwater drains (Galay 1983). Lowering of the water table can result in the loss of groundwater storage and the loss of summer baseflow (Kondolf et al. 2002) and hyporheic groundwater upwelling zones (Stanford and Ward 1993).

7.2.2.2 Direct and Indirect Effects on Fish and Invertebrates

Changes in channel geometry in the area of the mining activity may affect the post-mining use of a particular area by fish and invertebrates. Rempel and Church (2003) examined the short-term impacts on fish and invertebrates at the reach scale following scalping of Harrison Bar on the lower Fraser River in British Columbia. The study found that scalping from the highest portions of the bar resulted in a reduction in the available area of shallow water used by juvenile fish for refugia during a typical spring freshet. Although they found that salmon representation was higher in the short term after bar scalping due to increased topographic complexity remaining on the bar surface, two of the seven invertebrate taxa examined (Chironomidae and Oligochaeta) showed a significant reduction. In contrast, the abundance of the common mayfly increased after scalping. In general, Rempel and Church (2003) attributed the significant decrease in invertebrate density to increased sediment transport across the bar and subsequent burial during the first freshet. Although some studies have indicated that biotic communities recover quickly (i.e., within a few weeks) from bed disturbances (Merz and Chan 2005; Tikkanen et al. 1994), other studies have indicated that habitat disturbance from in-channel work can impact biota for several years (Laasonen et al. 1998).

Alterations to the existing flow regime through changes in velocity may affect fish use within the area mined. Changes in velocities may change the lifestage use of an area from the pre-mining condition. Some invertebrates may be absent when velocities are persistently high (Norman et al. 1998). Changes in flow velocity and substrate that result from channelization may change benthic macroinvertebrate populations (Brookes 1989). The direct and indirect effects of altered current and velocity on fish and invertebrates are essentially the same as the effects discussed for dredging in Section 7.1.4.1 (*Riverine Environments*).

Fish and invertebrates require a range of substrate sizes and conditions in riverine environments for various life-history stages. These conditions rely on the replenishment of suitably sized substrates to offset natural sediment transport processes that remove sediment. Instream and bar scalping gravel mining can disrupt the transport and deposition of sediment within a system. The direct and indirect effects of altered sediment supply and substrate composition are essentially the same as those effects discussed for dredging in the *Altered Substrate Composition and Stability* subsection of Section 7.1.4.1.1 (*Submechanisms of Impact*).

The effects of altered hyporheic flow caused by gravel mining are the same as those described above for riparian vegetation modifications caused by dredging in Section 7.1.2.1.5 (*Altered Groundwater-Surface Water Interactions*).

7.2.3 Water Quality Modifications

Gravel mining can alter water quality as a consequence of modifications to groundwater input, hyporheic flow, and through the surface and groundwater exchanges between the river and gravel pits. Bar scalping disturbs the channel bed and can release fine sediment into the water column. The resulting changes in water temperature and turbidity can affect dissolved oxygen.

7.2.3.1 Submechanisms of Impact

Gravel mining has the potential to alter three primary water quality variables: temperature, turbidity, and dissolved oxygen.

7.2.3.1.1 Altered Temperature Regime

Instream gravel mining creates wide and shallow flow that lacks shading from vegetation, which maximizes exposure to the sun. The removal of riparian and bar vegetation during gravel mining activities further reduces shading and thereby increasing water temperatures, particularly on smaller rivers (Kondolf et al. 2002; Norman et al. 1998). Channel incision and floodplain disconnection can reduce the temperature-moderating effects of hyporheic zone interactions (Stanford and Ward 1993). Gravel pits convert formerly lotic (flowing) habitats into lentic (stillwater) habitats. Surface water temperatures in pits may rise during the spring and summer due to the longer periods of sunlight and the stagnant water (Norman et al. 1998). Off-channel pits that heat up in the summer provide habitat for warm-water fish that prey on juvenile salmonids. The warm, lentic waters from gravel pits following pit capture may lower water quality by increasing the downstream water temperature of the receiving waters.

7.2.3.1.2 Suspended Sediments and Turbidity

In-channel gravel mining activities increase the suspension of fine sediment and fine organic material (Weigand 1991). In general, the response of aquatic biota to elevated suspended solids concentrations is highly variable and dependent upon life-history stage, species, background suspended solids concentrations, and ambient water quality. Appendix A provides tables summarizing the research that has been conducted on the effects of suspended solids on fish and invertebrates.

7.2.3.1.3 Altered Dissolved Oxygen

The amount of oxygen dissolved in water is dependent on temperature, physical mixing, respiration, photosynthesis, and, to a lesser degree, atmospheric pressure. The primary controls on dissolved oxygen content are well documented and are described for dredging in Section 7.1.6.1.2 (*Altered Dissolved Oxygen*). In general, gravel mining activities that increase water temperature and suspended solids will tend to decrease the dissolved oxygen content. For example, captured gravel pits in the Naugatuck River, Connecticut function as lakes throughout most of the year with seasonally stagnant water and depressed dissolved oxygen levels (MacDonald 1988).

7.2.3.2 Direct and Indirect Effects on Fish and Invertebrates

The effects on fish and invertebrate species of altered water temperature, altered dissolved oxygen, and altered suspended sediment and turbidity are well documented and described above for dredging in Section 7.1.6 (*Water Quality Modifications*).

7.2.4 Ecosystem Fragmentation

Gravel mining activities can limit the accessibility of fish through changes in the structure of instream and off-channel habitat. This occurs primarily through channel incision caused by the removal of gravel from the sediment budget and from the incorporation of excavation pits into the channel. Hydromodifications of riverine environments by gravel mining activities could therefore result in a loss or fragmentation of existing habitat through alterations in the longitudinal connectivity and river-floodplain connectivity. Due to a number of hydrogeomorphic changes detailed in Section 7.2.2 (*Hydraulic and Geomorphic Modifications*), floodplain and off-channel habitat can be made inaccessible by channel incision induced by the removal of aggregate or by pit capture. Pit capture can also result in the fragmentation and loss of spawning and rearing habitats (Norman et al. 1998). Levees constructed to isolate pits from the active channel reduce habitat complexity and dynamic channel migration.

<u>Direct and Indirect Effects on Fish and Invertebrates</u>

Captured pits become lakes within the river and transform lotic environments into lentic environments. The incorporation of off-channel pits by river capture exposes juvenile salmonids to heavy predation by exotic, warm-water fish. For example, McMichael et al. (1999) showed that predation on juvenile salmonids by predaceous warm-water fishes in the Lower Yakima River is substantial. Smallmouth bass were estimated to consume about 0.5 million salmon smolts per year, resulting in an annual loss of about 1,350 adult salmon.

The effects of altered longitudinal and river-floodplain connectivity on fish and invertebrates caused by gravel mining is similar to the effects described for dredging in Section 7.1.5 (*Ecosystem Fragmentation*).

7.2.5 Aquatic Vegetation Modifications

Modifications to existing aquatic vegetation may occur from in-channel gravel mining and bar scalping. Changes to aquatic vegetation and the effects on fish and invertebrates would be similar to those described for dredging in Section 7.1.3 (*Aquatic Vegetation Modifications*).

7.2.6 Riparian Vegetation Modifications

Gravel mining activities alter the distribution of riparian vegetation both directly through the removal or disturbance of riparian vegetation during mining activities and indirectly through the conversion of riparian areas to open pits. The loss of riparian vegetation caused by gravel mining can reduce the supply and retention of LWD. The mechanisms of impact and effects on fish and invertebrates for the modification of riparian vegetation caused by gravel mining are similar to the mechanisms of impact described for freshwater dredging in Section 7.1.2 (*Riparian Vegetation Modifications*).

7.3 Sediment Capping

In-situ sediment capping refers to the placement of a subaqueous covering or cap of clean material over contaminated sediment to isolate contaminated sediment, and to decrease biota exposure to contaminants. Sediment caps are generally constructed of clean sediment, sand, or gravel, but can also include geotextiles, liners, or the addition of material such as organic carbon, to attenuate the flux of contaminants into the overlying water. Depending on the contaminants and sediment conditions present, a cap is generally designed to reduce risk through the following primary functions:

- Physical isolation of the contaminated sediment sufficient to reduce exposure due to direct contact and to reduce the ability of burrowing organisms to move contaminants to the cap surface
- Stabilization of contaminated sediment and erosion protection of sediment and the cap sufficient to reduce resuspension and the transport of contaminants into the water column
- Chemical isolation of contaminated sediment sufficient to reduce exposure from dissolved contaminants that may be transported into the water column.

Sediment capping has primarily been practiced in large rivers, lakes, estuaries, and coastal marine environments (Palermo et al. 1998; RETEC 2002). Of these environments, capping has occurred most frequently in marine settings.

The techniques and equipment used for sediment capping are generally not specific to marine or freshwater environments. As a result, sediment capping in freshwater environments affects organisms through many of the same mechanisms of impact identified for marine environments. The primary difference between sediment capping in marine and freshwater environments has to do with the physical effects of the activity on habitat-forming processes in a unidirectional channel (for riverine environments) and the biological effects on freshwater species.

If performed correctly, sediment capping is effective at reducing biotic exposure to pollution, but the placement of the cap and other indirect effects will have an impact on biota. This section addresses those mechanisms of impact.

7.3.1 Construction and Maintenance

Impacts associated with construction activities will be highly variable and dependent upon the project scale and capping technique. In-situ capping will generally not involve the use of retaining walls to stabilize the cap, but capping of dredge spoils is sometimes associated with the use of a confined aquatic disposal (CAD) cell. These cells are frequently constructed using piles and other treated wood products (addressed in Section 7.3.5, *Water Quality Modifications*). Consequently, there are potential impacts associated with pile driving noise and leaching of contaminants from treated wood. Nearly all sediment capping projects will entail the use of barges and other vessels during construction and maintenance of the cap (Palermo et al. 1998). Operation of these vessels will increase ambient noise levels which may impact biota. However, the greatest impact by far to fish and invertebrates will come from burial with the capping material and from elevated contaminant and suspended solids levels during construction.

7.3.1.1 Submechanisms of Impact

Elevated suspended solid and contaminants are addressed in the *Water Quality Modifications* section (Section 7.3.5), while this section addresses pile driving impacts, vessel noise, and burial of the benthic organisms.

7.3.1.1.1 Noise-Related Disturbances

Sediment capping operations can produce underwater noise through a variety of mechanisms. These mechanisms include construction-related noise impacts from impulsive sources (i.e., short duration, high intensity noise from sources such as pile driving or materials placement), and continuous noise sources (e.g., vessel or equipment operation). The discussion presented in this section provides the noise-related analytical basis for the development of the exposure-response matrixes (Appendix A) and the risk of take analysis (Section 9).

This section summarizes existing information on the sources of underwater noise, existing and proposed effects thresholds, and the magnitude of noise stressors associated with typical project construction and maintenance activities. This discussion is derived in part from a summary of the current science on the subject developed by WSDOT (2006). A summary of underwater noise behavior and how underwater noise is measured is presented in Section 7.1.1.1.1 (*Noise-Related Disturbances*).

The underwater noise produced by sediment capping activities is defined by the magnitude and duration of underwater noise above ambient noise levels. The extent of underwater noise effects is defined by the distance required to attenuate construction noise levels to ambient levels, as calculated using the practical spreading loss calculation or other appropriate formula provided in evolving guidance from USFWS and NOAA Fisheries on this subject.

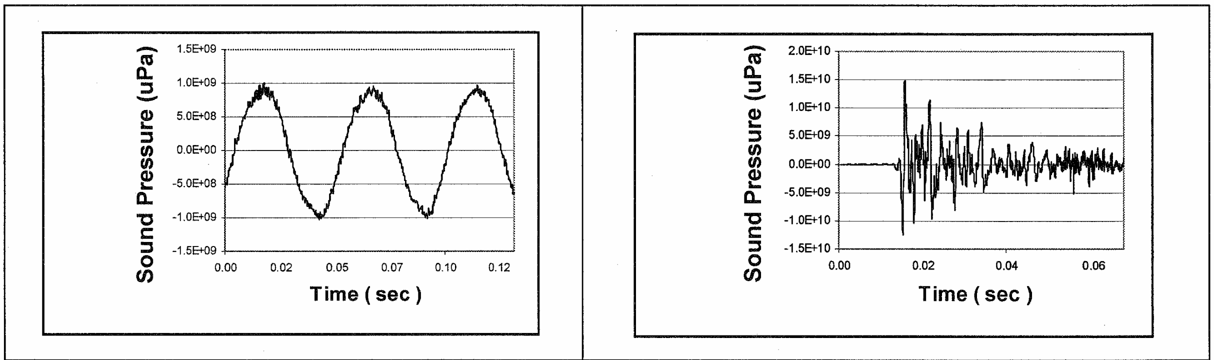
Although there are many sources of noise in the underwater environment, the following are typical sources of underwater noise associated with sediment capping operations:

- Materials placement
- Vessel operation.

<u>Materials Placement</u>

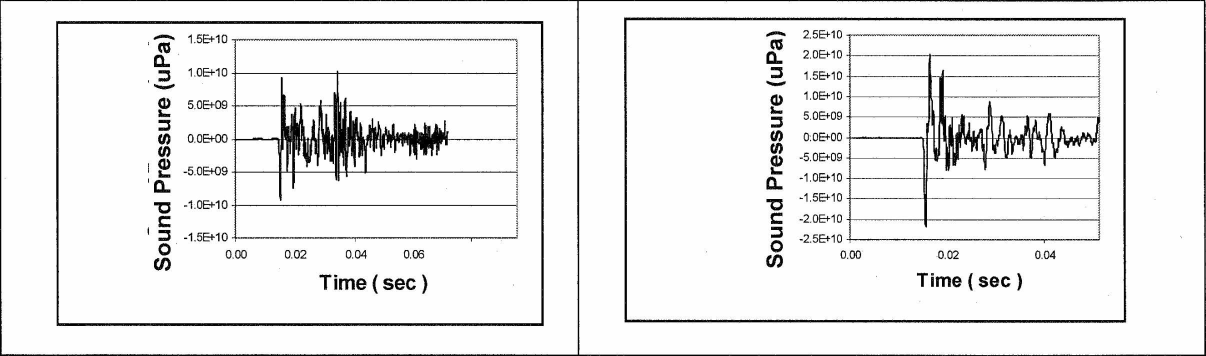
Of the potential sources of construction-related noise, pile driving has received the most scrutiny because it produces the highest intensity stressors capable of causing noise related injury. Other sources of underwater noise, such as the dumping of large rock or underwater tool use have received less study. Therefore, available data on noise levels associated with pile driving are presented here as a basis for comparison.

Two major types of pile driving hammers are in common use, vibratory hammers and impact hammers. There are four kinds of impact hammers: diesel, air or steam driven, hydraulic, and drop hammer (typically used for smaller timber piles). Vibratory hammers produce a more rounded sound pressure wave with a slower rise time. In contrast, impact hammers produce sharp sound pressure waves with rapid rise times, the equivalent of a punch versus a push in comparison to vibratory hammers. The sharp sound pressure waves associated with impact hammers represent a rapid change in water pressure level with greater potential to cause injury or mortality in fish and invertebrates. Because the more rounded sound pressure wave produced by vibratory hammers produces a slower increase in pressure, the potential for injury and mortality is reduced. (Note that while vibratory hammers are often used to drive piles to depth, load-bearing piles must be "proofed" with some form of impact hammer to establish structural integrity.) The changes in pressure waveform generated by these different types of hammers are pictured in Figure 7-3.



Vibratory Hammer wave form—set duration

Air or steam-driven hammer wave form—single strike



Diesel hammer wave form—single strike

Hydraulic hammer wave form—single strike

Figure 7-3. Changes in pressure or underwater waveform generated by hammer type (WSDOT 2006).

Piling composition also influences the nature and magnitude of underwater noise produced during pile driving. Driven piles are typically composed of one of three basic material types: timber, concrete, or steel (although other special materials such as plastic may be used). Steel piles are often used as casings for pouring concrete piles. Noise levels associated with each of these types of piles are summarized in Table 7-5. Reference noise levels are denoted in both dB_{PEAK} and dB_{RMS} values, at the specified measurement reference distance.

Table 7-5. Reference noise levels, by structure type.

Material Type and Size	Impact Hammer Type	Reference Noise Levels[a]		Environment Type	Source
		dB_{PEAK}	dB_{RMS}		
12-inch timber	Drop	177 @ 10 m	165 @ 10 m	Marine	(Illingworth and Rodkin 2001)
24-inch concrete piles	Unspecified	188 @ 10 m	173 @ 10 m	Unspecified	[DesJardin 2003, personal communication cited by WSDOT (2006)], (Hastings and Popper 2005)
Steel H-piles	Diesel	190 @10 m	175 @ 10 m	Marine	(Hastings and Popper 2005; Illingworth and Rodkin 2001)
12-inch steel piles	Diesel	190 @10 m	190 @ 10 m	Marine	(Illingworth and Rodkin 2001)
14-inch steel piles	Hydraulic	195 @ 30 m	180 @ 30 m	Marine	(Reyff et al. 2003)
16-inch steel piles	Diesel	198 @ 10 m	187 @ 9 m	Freshwater	(Laughlin 2004)
24-inch steel piles	Diesel	217 @ 10 m	203 @ 10 m	Unspecified	(WSDOT 2006)
24-inch steel piles	Diesel	217 @ 10 m	203 @ 10 m	Unspecified	(Hastings and Popper 2005)
30-inch steel piles	Diesel	208 @ 10 m	192 @10 m	Marine	(Hastings and Popper 2005)
66-inch steel piles	Hydraulic	210 @ 10 m	195 @ 10 m	Marine	(Reyff et al. 2003)
96-inch steel piles	Hydraulic	220 @ 10 m	205 @ 10 m	Marine	(Reyff et al. 2003)
126-inch steel piles	Hydraulic	191 @ 11 m	180–206 @ 11 m	Marine	(Reyff et al. 2003)
150-inch steel piles	Hydraulic	200 @ 100 m	185 @ 100 m	Marine	(Reyff et al. 2003)

[a] Metric distances are listed as they were provided in the source material; 9 m = 29.5 ft; 10 m = 32.8 ft; 11 m = 36 ft; 30 m = 98 ft; 100 m = 328 ft.

Vessel Operation

Construction vessel operation during sediment capping operations may generate continuous noise for longer periods than pile driving, with the effect of elevating ambient noise levels or the masking of ambient noises in the aquatic environment that fish would ordinarily use to identify prey and predators. For example, large vessel engines can produce underwater sound up to 198 dB, and depth sounders can produce noise in excess of 180 dB (Buck 1995; Heathershaw et al. 2001). Hazelwood and Connelly (2005) monitored fishing vessel noise over a broad octave range from 10 Hz–40 kHz and documented noise levels ranging from 140–185 dB_{peak}, with the loudest noise occurring at the lower end of the octave range. Commercial sonar devices operating in a frequency range of 15–200 kHz can produce underwater noise ranging from 150–215 dB at maximum levels (Stocker 2002).

Ambient underwater noise levels serve as the baseline for measuring the disturbance created by project construction or maintenance. Both natural environmental noise sources and mechanical or human-generated noise contribute to the ambient or baseline noise conditions within and surrounding a project site. Therefore, these noise measurements, particularly those recorded in the vicinity of ferry terminals and other high-activity locations, are indicative of the level of noise that could be produced by vessel operation during sediment capping activities.

Ambient noise levels have been measured in several different marine environments on the West Coast and are variable depending on a number of factors, such as site bathymetry and human activity. For example, measured ambient levels in Puget Sound are typically around 130 dB_{peak} (Laughlin 2005). However, ambient levels at the Mukilteo ferry terminal reached approximately 145 dB_{peak} in the absence of ferry traffic (WSDOT 2006). Ambient underwater noise levels measured in the vicinity of the Friday Harbor ferry terminal project ranged between 131 and 136 dB_{peak} (Laughlin 2005). Carlson et al. (2005) measured the underwater baseline for the Hood Canal and found it to range from 115 to 135 dB_{RMS}. Heathershaw et al. (2001) reported open-ocean ambient noise levels to be between 74 and 100 dB_{peak} off the coast of central California. Note, however, that these ambient noise levels are typical conditions, and typical conditions can be punctuated by atypical natural events. For example, lightning strikes can produce underwater noise levels as high as 260 dB_{peak} in the immediate vicinity (Urick 1983).

Limited data are available on ambient noise levels in freshwater environments, but it is reasonable to conclude that they vary considerably based on available information. For example, high-gradient rivers, fast-flowing rivers, and large rivers and lakes with significant human activity are likely to produce more noise than lakes and slow-flowing rivers in more natural environments. Burgess and Blackwell (2003) measured ambient sounds in the Duwamish River in Seattle, Washington, (averaged over 20 seconds to 5 minutes) and found the sound to vary between 110 to 130 dB continuous sound exposure level (SEL) (SEL provides a measure of total sound pressure exposure and is expressed as dB re: $1\mu Pa^2$/second). Amoser and Ladich (2005) measured ambient noise levels in the mainstem Danube River, a smaller, fast-flowing tributary stream, a small lake, and a quiet river backwater. The river and stream represented fast-flowing habitats, the lake and backwater quiet, slow-flowing habitats. Sound behavior was complex. They found that ambient noise levels ranged from as low as 60 to as high as 120 dB_{peak} in the fast-flowing habitats, depending on the sound frequency (lower frequency sound was typically louder). Ambient noise in the slackwater habitats was considerably lower, ranging from 40 to 80 dB_{peak} across the frequency range (again with lower frequency sounds being loudest).

7.3.1.1.2 Burial

Rapid burial of the benthos will occur in every sediment capping project. Non-motile organisms will not have the ability to evacuate the work site and will be buried. Numerous studies of dredge spoil deposits have shown that when thin layers of sediment are distributed over the benthos there is little impact on benthic organisms (Simonini et al. 2005; Wilber et al. 2007).

Smith and Rule (2001) found that dredge spoils spread over a wide area in the Solitary Islands Marine Park, NSW, Australia had no measurable effect on benthic organisms because motile macrofauna had the opportunity to migrate upwards between passes of the barge. Because sediment caps are typically on average 3 to 4 feet thick (USACE 1991a), upward migration will generally not occur. Consequently, 100 percent mortality of benthic organisms is expected during the placement of a sediment cap (Qian et al. 2003).

Little is known about recolonization of the benthos subsequent to sediment capping. The one existing peer reviewed study indicates that recovery could be on the order of years (Qian et al. 2003). Qian et al. (2003) monitored recovery of benthic organisms following a capping project in the Pearl River Estuary, China. They found that the project area did not fully recover from the disturbance of capping until between 3.5 and 6.5 years (depending upon the study plot) after completion of the project. This study indicates that burial will be a significant impact mechanism which organisms may take years to recover from.

7.3.1.2 Direct and Indirect Effects on Fish and Invertebrates

The direct and indirect effects of noise-related disturbances on fish and invertebrates from sediment capping operations are the same as those discussed for dredging operations in Section 7.1.1.2 (*Direct and Indirect Effects on Fish and Invertebrates*).

Burial is not expected to be a major impact mechanism for most fish, because most will be able to evacuate the project area at the onset of capping. Burial could potentially affect some of the same species that are likely to be entrained by dredging operations. Demersal fish, such as sand lance, sculpins, and sticklebacks, are hypothesized to have the highest rates of burial, as they reside on or in the bottom substrates, with life-history strategies of burrowing or hiding in the bottom substrate. Larval fish that have little or no swimming capacity are also at significant risk of burial at sediment capping sites.

Burial will be the primary impact mechanism for invertebrates. Evidence from Eagle Harbor, Washington suggests that the sediment cap has improved benthic habitat six years after project completion (Zisette 2007), primarily because the contaminated sediment was an organic-rich contaminated mud and the cap is a well-aerated sand. But, the research of Qian et al. (2003) suggests that this recovery may take years. This indicates that any invertebrate species affected by a sediment capping project will, in the short term, be highly impacted. It should be noted however, that only two of the three listed HCP marine invertebrate species inhabit marine environments where sediment capping would occur. They include the Northern abalone and the Olympia oyster. Sediment capping in freshwater environments could potentially affect three listed HCP freshwater invertebrate species. They include the California floater (mussel), Great Columbia River spire snail, and the Western ridged mussel. Olympia oysters have been shown to be intolerant of siltation and do best in the absence of fine-grained materials (WDNR 2006b). The burial of mollusks and related stress or mortality resulting from partial and complete burial have been addressed empirically (Hinchey et al. 2006). Results of these studies indicate that species-specific responses vary as a function of motility, living position, and inferred physiological tolerance of anoxic conditions. Mechanical and physiological adaptations contribute to this tolerance.

7.3.2 Hydraulic and Geomorphic Modifications

Sediment capping modifies hydraulic and geomorphic conditions of the seafloor, river bed, or lake bottom through the placement of sediment in "lifts" or layers over the contaminated site. In general, the stressors associated with hydraulic and geomorphic modifications resulting from sediment capping are not environment-specific.

7.3.2.1 Submechanisms of Impact

Sediment capping present several potential stressors in both marine and freshwater (riverine and lacustrine) environments:

- Altered channel geometry
- Altered flow regime
- Altered wave energy
- Altered nearshore circulation patterns
- Altered substrate composition and stability.

7.3.2.1.1 Altered Channel Geometry

Sediment capping modifies the channel geometry in riverine environments. These changes result in a channel geometry that is out of equilibrium with natural sediment transport and channel processes. These changes to channel geometry and the effects of these changes are similar to those described for dredging in the *Altered Channel Geometry* subsection of Section 7.1.4.1.1 (*Submechanisms of Impact*).

7.3.2.1.2 Altered Flow Regime

Sediment capping alters the current velocity (primarily in riverine environments) through changes in local bathymetry. Sediment caps reduce the water depth and can increase the local flow velocity compared to conditions before capping. These changes are similar to those described for dredging in the *Altered Flow Regime* subsection of Section 7.1.4.1.1 (*Submechanisms of Impact*).

7.3.2.1.3 Altered Wave Energy

Nearshore sediment capping alters the incoming wave energy in marine and lacustrine environments in much the same way as beach nourishment (for more information, see the Habitat Modifications white paper [Herrera 2007b]. Generally speaking, the steeper the beach, the more reflective it is (Komar 1998). Sediment capping will alter the slope of the nearshore and thus change the wave reflection and energy. The degree to which this occurs is strongly site dependent. In many instances, the effects will be insignificant but where a sediment cap drapes a previously armored shoreline, the potential for the restoration of a pre-development wave environment is possible. If a CAD cell is used to contain dredge spoils, wave energy may be drastically altered in much the same way that a submerged breakwater will alter wave energy. For impacts associated with breakwaters see the *Breakwaters* subsection of the Shoreline Modifications white paper (Herrera 2007c).

7.3.2.1.4 Altered Nearshore Circulation

The addition of material will alter incoming and reflected wave energy in marine and lacustrine environments; however, it is expected that these alterations will be insignificant. For shorelines that presently do not possess wave-driven nearshore circulation due to shoreline armoring, but could have had wave-driven nearshore circulation under pre-development conditions [i.e., those in the Strait of Juan de Fuca or the outer coast (Komar 1998)], the return of a mobile substrate has the potential to restore a more natural circulation pattern that could be beneficial to fish. If a CAD cell is used to contain dredge spoils, nearshore circulation may be drastically altered in much the same way that a submerged breakwater will alter nearshore circulation. Breakwaters have a number of effects on nearshore circulation, including producing potentially damaging changes in water quality (Bordalo 2003). For details about the way breakwaters affect nearshore circulation, and their effects on fish and invertebrates, see the *Breakwaters* subsection of the Shoreline Modifications white paper (Herrera 2007c).

7.3.2.1.5 Altered Substrate Composition and Stability

The objective of sediment capping is to create a relatively immobile substrate; consequently, coarse sands are frequently used to cover contaminated silt and mud substrates. In studies of impacts associated with beach nourishment, the coarsening of shorelines through nourishment activities has been shown to reduce invertebrate numbers (Peterson et al. 2006), and has been discouraged by other studies (Speybroeck et al. 2006). This would indicate that sediment capping may not only bury resident organisms but may discourage their return by altering the substrate particle size. If a CAD cell is used to contain dredge spoils, nearshore circulation may be drastically altered in much the same way that a submerged breakwater will alter nearshore circulation. Breakwaters have been shown to disrupt littoral transport of sediments by cutting off down-drift shorelines to the sediment supply (Bowman and Pranzini 2003; Sane et al. 2007; Thomalla and Vincent 2003). For more details about the effects on fish and invertebrates from altered sediment supply due to artificial reefs, see the *Breakwaters* subsection of the Shoreline Modifications white paper (Herrera 2007c).

7.3.2.2 Direct and Indirect Effects on Fish and Invertebrates

If a CAD cell is constructed to contain dredge spoils and the sediment cap, then the impacts on fish and invertebrates will be essentially the same as the effects discussed for dredging in Section 7.1.4 (*Hydraulic and Geomorphic Modifications*). Additionally, in-situ sediment capping operations may have the potential to create nearshore spawning habitat. Loose, mobile materials are spawning habitat for a number of HCP forage fish species (Penttila 1978; Penttila 1995). It follows that if the sediment capping could potentially attract forage fish, predator (i.e., salmonid) numbers may also increase. The coarsening of the substrate occurring in the majority of sediment-capping projects may discourage the return of the benthic infauna which inhabited the pre-project site (Speybroeck et al. 2006) but, as stated previously, only the Olympia Oyster is likely to be affected because Newcomb's littorine snail and the northern abalone do not inhabit sediment capping areas.

7.3.3 Ecosystem Fragmentation

Sediment capping projects can limit fish movement and accessibility to various habitats through changes in both the structure of the shoreline and its characteristics. If a CAD cell is used, ecosystem fragmentation impacts will be similar to those associated with submerged breakwaters (see the *Breakwaters* subsection of the Shoreline Modifications white paper [Herrera 2007c]); these impacts primarily center on food web alterations induced by the attraction of piscivorous fish to the hard habitat of the CAD structure. Otherwise, impacts will be similar to those associated with beach nourishment projects (see the Beach Nourishment discussion in the Habitat Modifications white paper [Herrera 2007b]), that is primarily alteration of nearshore circulation patterns.

7.3.3.1 Direct and Indirect Effects on Fish and Invertebrates

The direct and indirect effects of habitat loss and fragmentation in marine environments are essentially the same as the effects discussed for dredging in Section 7.1.5.1.1 (*Habitat Loss and Fragmentation*).

7.3.4 Aquatic Vegetation Modifications

The primary potential impact on aquatic vegetation from sediment capping is burial. Eelgrass, the dominant seagrass in marine waters of western Washington, is sensitive to large sedimentation rates (Mills and Fonseca 2003). If there is eelgrass present near the activity site, it is possible that the activity will cause an aquatic vegetation loss. Because eelgrass is a crucial component to the life history of several HCP species (Phillips 1984), these activities would likely limit or reverse gains in fish populations from the addition of loose, mobile foreshore.

7.3.4.1 Direct and Indirect Effects on Fish and Invertebrates

The direct and indirect impacts of aquatic vegetation modification on fish and invertebrates associated with sediment capping are identical to those of dredging (see Section 7.1.3, *Aquatic Vegetation Modifications*).

7.3.5 Water Quality Modifications

The degree to which water quality is impacted from a sediment capping project is dependent upon the scale and type of project. If a CAD cell is used, water quality impacts will be similar to those associated with submerged breakwaters (see the *Breakwaters* subsection of the Shoreline Modifications white paper [Herrera 2007c]). If in-situ capping is conducted, the primary water quality impact will be associated with increased suspended solids during construction. Finally, there is the impact associated with the entrainment of contaminated sediments during the placement of the cap. The water quality modifications of sediment capping are not environment specific.

7.3.5.1 Submechanisms of Impact

7.3.5.1.1 Altered Suspended Sediments and Turbidity

Monitoring of suspended solids concentrations during sediment cap emplacement has been conducted in only a few studies. In general, the suspended solids concentrations which will occur during sediment capping will be lower than concentrations which will occur during dredging. This is due to the fact that the sediment used in capping is usually a coarse sand, while dredged sediments can be of a finer grain and thus more easily entrained (Lyons et al. 2006). However, there is concern that contaminated sediments may be suspended during cap emplacement and so researchers have closely monitored suspended solids concentrations during multiple capping projects.

Hamblin et al. (2000) monitored benthic suspended solids concentration with an acoustic Doppler profiler in Hamilton Harbor, Lake Ontario. They found that maximum suspended solids concentrations reached 140 ppm shortly after each pass of the sediment barge. They also found that these concentrations quickly returned to background levels (10 ppm) until the next pass of the barge. This indicates that when coarse sand is used as a capping material, rapid particle settling prevents long duration increases in suspended solids. This same pattern of short-term increase in suspended solids was noted by Fredette et al. (2002) on the Palos Verdes Shelf, California. Consequently, it does not appear that elevated suspended solids during capping is an important impact mechanism.

7.3.5.1.2 Nutrient and Pollutant Loading

As previously noted, there is the potential for the entrainment of contaminated sediments during cap placement. Capped sediments are most frequently contaminated with polychlorinated biphenyls **(**PCBs), polycyclic aromatic hydrocarbons (PAHs) and metals (Hull et al. 1999). Entrainment of these pollutants will be a function of the capping technique with pump down techniques generating little disturbance and point dump techniques creating more (Palermo et al. 1998). To study how much contaminated sediment was entrained during point dump capping, Lyons et al. (2006) collected water samples during the Boston Harbor and Eagle Harbor capping projects. The sampling indicated that total PCB and total PAH concentrations spiked to levels as high as 84 ppb and 5.2 ppm, respectively. These pulses exceeded acute water quality standards (WAC 173-201A), but where of a relatively short duration. This, one of the only studies to monitor water quality during cap emplacement, indicates that techniques which minimize benthic disturbance should be used whenever possible. There are no available studies that have monitored ambient metals concentrations during placement of a cap, so this impact stands as a data gap.

7.3.5.2 Direct and Indirect Effects on Fish and Invertebrates

The direct and indirect effects of elevated suspended sediments and turbidity associated with sediment capping are identical to those of dredging presented in Section 7.1.6.2 (*Direct and Indirect Effects on Fish and Invertebrates*).

PCBs and PAHs impact fish species through multiple pathways. One of these pathways which has been studied in the Pacific Northwest is immunosuppression. McCain et al. (Mccain et al. 1990) reported that juvenile Chinook salmon from the Duwamish estuary are exposed to both elevated levels of PCBs and PAHs. Arkoosh et al. (2001) found that the immune response in juvenile Chinook salmon from the Duwamish was lower than that of cohorts from a nonurban estuary and those from the hatcheries that released into those systems. In a subsequent study, Jacobson et al. (2003) exposed juvenile Chinook to 20 percent of the LD_{50} for Aroclor 1254 (a common PCB) and to bacterial exposure. They found that fish exposed to both bacterial and contaminant stressors had a greater negative effect on salmon health than either stressor alone.

Outside of immune system impairment, Chinook exposed to elevated PCB levels in the Duwamish estuary have also shown reduced growth rates (Varanasi et al. 1993). If Chinook, and presumably other fish species, are in the immediate vicinity of a sediment capping project, the increased PCB levels will contribute to these immune and metabolic impacts. The effects of elevated PAH levels on fish has been previously addressed by a number of studies and are presented in Table 7-6, as adapted from Anchor (2006) and Stratus (2005).

Table 7-6. Effects thresholds for PAHs in surface water on fish species.

Organism	Exposure Source	Toxicity	Concentration (ppb)	Reference
Pacific herring	PAHs leaching from 40-year old pilings	24 hr lethal concentration of a chemical within a medium that kills 50% of sample population	50	(Vines et al. 2000)
Pacific herring	PAHs leaching from 40-year old pilings	Significant reduction in hatching success and increased abnormalities in surviving larvae	3	(Vines et al. 2000)
Trout	Commercial creosote added to microcosms	Lowest observable effects concentration for immune effects	0.6	(Karrow et al. 1999)

Sources: Jones & Stokes (2006); Stratus (2005); ppb = parts per billion.

The effect of elevated PCB and PAH concentrations on invertebrate species has been well studied. In a literature review by Fuchsman et al. (2006) it was reported that 50 percent lethal concentrations for Aroclor 1254 ranged from 6.1 ppb for grass shrimp to 20,000 ppb for hydra over a 96 hour exposure period. Their research, however, did not include any of the HCP invertebrate species. Similarly, there is no research which has directly addressed PAH impacts on HCP invertebrate species. Despite this, a number of studies have addressed PAH toxicity for other invertebrate species. Table 7-7 depicts the effect thresholds for PAHs in surface water for zooplankton, mysids, and marine amphipods. In marine waters these impacts will only be relevant to the invertebrate species which reside in areas where sediment capping occurs. The only HCP marine invertebrate species that would inhabit sediment capping areas is the Olympia oyster.

Table 7-7. Effects thresholds for PAHs in surface water on invertebrate species.

Organism	Exposure Source	Toxicity	Concentration (ug/L)	Reference
Mysid (*Mysidopsis bahia*)	Elizabeth River, Virginia, sediment extracts	24 hr lethal concentration of a chemical within a medium that kills 50% of sample population	180	(Padma et al. 1999)
Amphipod (*Rhepoxynius abronius*)	Eagle Harbor WA sediment extracts	96-hour 24 hr lethal concentration of a chemical within a medium that kills 50% of sample population	1,800	(Swartz 1989)
Zooplankton	PAHs leaching from pilings placed in microcosms	No observable effects concentration	11.1	(Sibley et al. 2004)
Zooplankton	Commercial creosote added to microcosms	No observable effects concentration	3.7	(Sibley et al. 2001)
Zooplankton	Commercial creosote added to microcosms	Concentration of a chemical within a medium that kills 50% of sample population	2.9	(Sibley et al. 2001)

Sources: Jones & Stokes (2006); Stratus (2005)

7.4 Channel Creation and Alignment

This subactivity type is reserved for projects that involve the relocation, straightening, or meandering of an existing channel or the creation of a new channel where none existed before. Those activities performed primarily for purposes of creating off-channel habitat in side channels and sloughs and those activities that promote in-channel habitat complexity such as the placement of large woody debris are addressed in the Habitat Modifications White Paper (Herrera 2007b).

Channel relocation changes the location of the channel while preserving or recreating other characteristics, such as the overall channel profile, pattern, cross-section, and bed elevation. A primary purpose of channel creation and alignment activities is to relocate the alignment of a waterway away from an eroding bank. Relocation may also be used where a significant building or road is directly threatened by erosion. Channel relocation is often a means to solve problems of channel encroachment and/or confinement, and to foster the development of a new, stable channel with healthy riparian buffers. A channel can be entirely relocated to a new alignment, or simply moved laterally within the existing alignment. Flow deflection techniques such as groins and bank bars are discussed in the Shoreline Modifications White Paper (Herrera 2007c).

The subactivity types described in this section occur primarily in riverine environments but may also include the creation of tidal channels in estuarine environments. The mechanisms of impact for this subactivity type focus primarily on riverine settings and include references to marine settings, where appropriate. Because channel creation activities involve many of the same mechanisms of impact as those described previously in this white paper for the other subactivity types, the reader is referred to previous sections when appropriate.

7.4.1 Construction and Maintenance

Channel creation and alignment can be a major undertaking involving the reconstruction of the channel bed, habitat features, channel banks, and floodplain. The impacts associated with construction activities will be highly dependent on the specific relocation or realignment project.

7.4.1.1 Submechanisms of Impact

This section addresses the impact from equipment operation, temporary dewatering, and altered stream bank and shoreline stability.

7.4.1.1.1 Construction Equipment Operation

In general, in-channel work will be associated with a greater risk of take than off-channel work. The operation of construction equipment during in-channel work presents stressors including increased turbidity and underwater noise exceeding ambient levels. Increased turbidity is addressed for dredging in Section 7.1.6.1.3 (*Altered Suspended Sediments and Turbidity*). Channel creation may include pile driving; and the effects of underwater noise from pile driving and non-pile driving activities are discussed for sediment capping in Section 7.3.1.1.1 (*Noise-related Disturbances*).

7.4.1.1.2 Bank, Channel, and Shoreline Disturbances

Impacts associated with construction activities will vary widely depending on how the work is conducted. The most common method of channel creation is to work in a dry, off-channel area and then connect the new channel or realigned reach to the main channel once the work is completed. This approach minimizes work in an active channel and reduces construction related impacts. In general, in-channel work will have a much greater impact on the bank and channel when compared with off-channel work. Channel realignment and bank regrading will destroy bank and bed habitat in the active channel and will temporarily lead to elevated suspended sediment concentrations. This may result in the downstream burial of invertebrates, elevated suspended solids, and habitat destruction. Although some studies have indicated that biotic communities recover quickly (i.e., within a few weeks) from these disturbances (Merz and Chan

2005; Tikkanen et al. 1994), other studies have indicated that habitat disturbance from in-channel restoration work can impact biota for several years (Laasonen et al. 1998). This is primarily the result of projects that were incorrectly designed and resulted in structural failures (Babcock 1986; Frissell and Nawa 1992).

7.4.1.1.3 Temporary Dewatering and Flow Bypass

In many instances, channel creation and alignment will involve temporary dewatering. A discussion of the stressors associated with dewatering and fish handling is provided for gravel mining in Section 7.2.1.1.1 (*Dewatering, Flow Bypass, and Fish Handling*) and Section 7.2.1.1.2 (*Channel Rewatering [Elevated Turbidity]).*

7.4.1.1.4 Channel Dewatering

Once the barriers isolating the newly excavated channel are breached, it will fill by drawing surface water from existing surface water. This will create a potential dewatering and stranding hazard as well as the potential for entrainment into the new channel environment. In marine and larger lacustrine systems, the dewatering and stranding hazard is likely limited because the volume of the new channel will be relatively insignificant. In contrast, in riverine environments the creation of the new channel may redirect the entire surface flow leading to dewatering of the existing channel.

7.4.1.2 Direct and Indirect Effects on Fish and Invertebrates

The short-term effects of bank, channel, and shoreline disturbance on HCP species during construction can vary widely depending on construction techniques and whether work is conducted in the wetted channel or in a dry, off-channel area prior to rewatering. There are numerous studies indicating that salmonid densities in restored channels that emulate natural conditions increase after project completion (Fuller 1990; Jungwirth et al. 1993; Roni et al. 2006).

Aquatic species trapped in rapidly dewatering habitats face the risk of mortality from stranding, particularly non-motile species and life-history stages. Motile species that are able to avoid stranding will be displaced from existing habitats and forced to relocate within disturbed and/or occupied habitat that may present limited foraging opportunities. This could limit their survival, growth, and fitness.

The effects of channel creation and alignment on invertebrates are not well known. Laasonen et al. (1998) found that macroinvertebrate abundance in restored streams in Finland was lowest in streams that were restored one month prior to sampling. They also found that there was no difference in macroinvertebrate populations between channelized reaches and reaches restored 0-16 years prior to sampling. Likewise, Suren and McMurtrie (2005) found that invertebrate communities did not improve following riparian planting and channel modifications in urban New Zealand streams due to hypothesized sediment loading and urban runoff pollution. Other studies have shown more positive results concerning macroinvertebrate response to channel alterations (Nakano and Nakamura 2006). Regardless, the impact will not be certain and each project must be considered on a case-by-case basis.

7.4.2 Hydraulic and Geomorphic Modifications

A primary purpose of channel creation and alignment activities is to modify the channel hydraulics and morphology to minimize the risks of flooding, erosion, and encroachment on adjacent property. These changes in the channel geometry can modify the relationship between channel topography and sediment transport and result in conditions that are out of equilibrium with natural channel processes. The hydraulic and geomorphic modifications resulting from channel creation and alignment activities include two submechanisms of impact: altered channel geometry and altered substrate composition and stability. These impact mechanisms and attendant effects on HCP species are essentially the same as for the conveyance dredging of streams using heavy equipment (see Section 7.1.4, *Hydraulic and Geomorphic Modifications*).

Another potential impact is related to the loss of floodplain habitat due to the loss of opportunities. “Lost opportunity impacts” result from projects that adversely alter natural fluvial processes important to the ongoing creation of fish and wildlife habitats (WDFW 2003). The following quote from WDFW (2003) provides a definition of lost opportunity impacts:

> *“Preventing a channel from naturally migrating across the floodplain usually eliminates sources of woody debris, sediment, and side channels; these losses are defined as “lost opportunities.” Natural channels evolve over time and migrate across their floodplains. When a channel naturally moves to a new alignment, it leaves behind vital habitat such as floodplain sloughs and side channels. Those habitats have a finite productive longevity, some likely less than 20 years. If the natural fluvial processes of a stream are restricted or interrupted, these side-channel habitats will diminish in productivity and will not be replaced. These habitats cannot be mitigated by the design of a project. They are lost when a channel is fixed in a specific location, regardless of the bank-protection technique. Lost-opportunity impacts last as long as channel migration is halted.”*

7.4.3 Ecosystem Fragmentation

By altering the channel and floodplain form, channel creation and alignment activities can change how water, organisms, and food resources are transferred through the mosaic of habitat patches that constitute the river-floodplain system. The impact mechanisms of channel creation and alignment leading to ecosystem fragmentation include altered longitudinal connectivity, altered river-floodplain connectivity, and altered hyporheic flow and exchange. These impact mechanisms and attendant effects on HCP species are the same as those described for the conveyance dredging of streams using heavy equipment (see Section 7.1.5, *Ecosystem Fragmentation*).

7.4.4 Aquatic Vegetation Modifications

Aquatic vegetation will initially be destroyed by channel creation and alignment activities. Studies of gravel augmentation show that this vegetation recovers quickly following minor disturbances (Merz et al. 2004). Elevated nutrient levels during the growing season will accelerate primary production and post-project vegetation recovery. Consequently, initial impacts on aquatic vegetation may only be ephemeral and thus the associated impact on HCP species will be minimal. The loss of aquatic vegetation as part of channel creation and alignment includes altered autochthonous production and altered habitat complexity. These impact mechanisms and resulting effects are the same as those described for the conveyance dredging of streams using heavy equipment (see Section 7.1.3, *Aquatic Vegetation Modifications*).

7.4.5 Riparian Vegetation Modifications

Channel creation and alignment activities can modify existing riparian vegetation due to bank disturbances during construction, channel migration through a riparian buffer, or as a consequence of relocating a channel to a new alignment lacking riparian vegetation. In riverine environments, a dominant effect of vegetation removal is the loss of shading and increase in solar radiation exposure (Knutson and Naef 1997; Murphy and Meehan 1991; Poole and Berman 2001a; Quinn 2005). Riparian vegetation also stabilizes banks against erosive forces. The removal of riparian trees and understory can dramatically alter stream bank stability and the filtering of sediments from overland flow (Kondolf and Curry 1986; Shields 1991; Shields and Gray 1992; Simon 1994; Simon and Hupp 1992; Waters 1995), resulting in increased erosion and increased inputs of fine sediment (Bolton and Shellberg 2001). These sediments may clog spawning gravels and temporarily increase suspended sediment concentrations.

The loss of riparian vegetation as part of channel creation and alignment includes a number of mechanisms and effects that are the same as those described for the conveyance dredging of streams with heavy equipment (see Section 7.1.2, *Riparian Vegetation Modifications*). These mechanisms of impact include the following:

- Altered riparian shading
- Altered ambient air temperature regime
- Altered stream bank stability
- Altered allochthonous inputs
- Altered habitat complexity
- Altered groundwater-surface water interactions.

7.4.6 Water Quality Modifications

Channel creation and alignment can alter water quality as a consequence of natural adjustments to a modified channel geometry, which can release fine sediment into the water. Channel creation and alignment activities can also alter water temperature and nutrient loading through changes in groundwater input, hyporheic flow, altered shading from riparian vegetation, and through the loss of instream woody debris. These changes in water quality can also affect the concentration of dissolved oxygen. Channel creation and alignment activities have the potential to alter four primary water quality variables: temperature regime, suspended sediments and turbidity, dissolved oxygen, and the presence of toxic substances. These water quality impacts and their effects on HCP species are essentially the same as for dredging and are discussed in Section 7.1.6 (*Water Quality Modifications*).

8.0 Cumulative Effects

Increasing evidence indicates that the most devastating environmental effects are most likely not the direct effects of a particular action, but the combination of individually minor effects of multiple actions over time (CEQ 1997). In general, as the number of channel modifications increases in a given area, impacts will accrue producing a net loss in riverine, lacustrine, and/or marine habitat. The type and extent of each of these alterations depends on specific site characteristics and the subactivity types.

8.1 Dredging

The cumulative effects of dredging have been documented by a number of studies (Byrnes et al. 2004; Cooper et al. 2007; Erftemeijer and Lewis 2006). These studies have documented that repeated dredging reduces the prevalence of seagrasses and macroinvertebrates; however, impacts on invertebrates conditioned for disturbance can respond quickly and recover significant populations of benthic invertebrates (Bolam and Rees 2003; Robinson et al. 2005). However, even in the most optimistic studies, the major cumulative impact of dredging is lower seabed productivity and diversity (Robinson et al. 2005).

Dredging from the lower Columbia River since at least 1904 has had cumulative effects on the sediment budget of the river and the littoral cell extending 160 km (100 miles) along the Pacific coast, from Point Grenville, Washington, to Tillamook Head, Oregon. The coast along this cell has experienced accelerated erosion, with recent coastal erosion in the Westport area alone costing $30 million in repairs (Kondolf et al. 2002).

8.2 Gravel Mining and Scalping

The greatest effects of instream gravel mining, bar scalping, and pit mining may be considered as cumulative because they may become obvious only over time and extend beyond the limits of the mining site itself (Kondolf 1997). Moreover, the effects of one mining activity may interact with nearby mining, yielding a net cumulative effect not apparent from a single mining action (Kondolf et al. 2002). Individually subtle effects of gravel mining can become more visible and serious through the propagation of channel incision upstream and downstream of such activities (often for distances of kilometers) on mainstem and tributaries and through the coalescing of incision effects.

Channel incision caused by the cumulative effects of gravel mining causes lowered alluvial groundwater tables, desiccation of riparian and floodplain vegetation, reduced channel-floodplain interactions, and the elimination of processes of channel migration and the consequent creation of habitat. Any extraction of gravel from the channel bed or floodplain interrupts sediment transport continuity and represents a net loss in the sediment transport budget, thereby inducing channel instability and reducing the volume of downstream bars (Dunne et al. 1981).

Because the direct and indirect effects of bar scalping are far-reaching, the cumulative effects of numerous bar-scalping operations can result in long-term habitat degradation. For example, Dunne et al. (1981) documented cases in which the current channel was abandoned and a former channel adopted following bar scalping. Bar scalping has also been shown to eliminate side channels, which are important habitats for juvenile salmonids (Pauley et al. 1989; Weigand 1991). Bar scalping on the Puyallup, Carbon, and White rivers from 1987 to 1988 reduced the mean side-channel riffle habitat area from 1350 to 930 cubic yards and mean side-channel glide and pool habitat area from 1550 to 0 yards at treatment sites, while the representative habitat areas increased or remained unchanged at control sites (Weigand 1991).

Small-scale extractions are often viewed as having only small, insignificant impacts. However, a small extraction on a small stream can take a large fraction of the annual sediment load, and multiple small extractions on a larger stream can add up to be equivalent to a large proportion of the total load. Even when the extractions are small, they can add up to have a significant cumulative effect on channel form, especially in small channels, where the sediment load would be naturally low (Kondolf et al. 2002).

8.3 Sediment Capping

Although numerous sediment capping projects are seldom performed in any one area, they are typically performed in marine and freshwater harbors that have been impacted by previous industrial activities. Sediment capping activities can therefore contribute to the cumulative effects of numerous, related types of industrial cleanup activities. These cumulative effects could include the loss of nearshore habitats, habitat fragmentation, and the displacement of endemic species as a result of large-scale modifications to substrate composition and bathymetry. Some of the cumulative effects of sediment capping can be observed from studies examining the cumulative effects of multiple beach nourishment projects. Beach nourishment (discussed in the Habitat Modifications white paper [Herrera 2007b]) involves the rapid deposition of large quantities of sand and because of this, the impacts associated with the work are similar to those impacts that are associated with sediment capping.

Peterson et al. (2006) documented the loss of benthic macroinvertebrates on a stretch of beach in North Carolina from a number of small beach nourishment projects. Several earlier studies have shown that invertebrates can be harmed by nourishment projects (Diaz et al. 2004; Peterson et al. 2006; Rakocinski et al. 1996), but (Peterson et al. 2006) was the first show that the cumulative damage could occur due to multiple ongoing projects, and overcome the rapid recolonization typical of invertebrates. This same process of reburial before invertebrate recolonization could occur if a sediment cap was successively maintained or if multiple caps were placed adjacent to one another.

8.4 Channel Creation and Alignment

Although numerous stream restoration and channel creation projects have been completed over the past decade, the cumulative effects of these projects has not been adequately assessed by the scientific community. In general, the cumulative effects of multiple channel creation and alignment projects that fall short of rehabilitating degraded conditions are likely to result in the loss of native habitat for many HCP species. For instance, the listing of several salmon populations as threatened or endangered under the Endangered Species Act has been linked to (among other things) the widespread loss of spawning and rearing habitat resulting from channel modifications throughout the region (Montgomery et al. 2003).

9.0 Potential Risk of Take

Channel modification activities are typically designed with the intent of modifying channel or bed morphology characteristics to promote human uses of the aquatic environment for various purposes, including navigation, flood control, pollution management, and landscape conversion. In modifying the aquatic environment to suit these purposes, these types of projects lead to a fundamental alteration of ecological process characteristics, imposing effects on the environment through an array of impact mechanisms. The resulting alteration of the environment in turn imposes ecological stressors that may persist well after project construction is completed. The magnitude of these stressors will vary depending on the scale of the project in question and the degree to which it modifies ecological conditions and processes.

This section provides a narrative and tabular summary of the risk of take resulting from exposure to impact mechanisms and related ecological stressors associated with the construction and operation of channel modifications. For the purpose of this analysis, channel modification includes the following four subactivity types: dredging; gravel mining and scalping; sediment caps; and channel creation and alignment. The summary presented for each subactivity type is supported by a risk of take matrix, identifying the overall risk of take for each of the 52 HCP species (Tables 9-1 through 9-4, presented at the end of this narrative). These matrices provide an individual risk of take for each species by impact mechanism category and environment type (i.e., riverine, marine and lacustrine).

This summary is derived from the impact mechanism and stressor specific risk of take ratings developed for the 52 HCP species in the exposure response matrices, which are presented in Appendix A. The risk of take assessment presented in Appendix A and summarized here was developed based on the likelihood of exposure, for each of these 52 species, to the impact mechanisms and stressors imposed by each subactivity type as well as the sensitivity of exposed life-history stages to these stressors.

The risk of take is rated by impact mechanism for each species using the criteria presented in Table 6-3. As noted, the risk of take rating criteria are based on the following assumptions:

- **High risk of take (H)** ratings are associated with:
    - ☐ Stressor exposure is likely to occur with high likelihood of individual take in the form of direct mortality, injury, and/or direct or indirect effects on long-term survival, growth, and fitness potential due to long-term or permanent alteration of habitat capacity or characteristics. Likely to equate to an LTAA finding.

- **Moderate risk of take (M)** ratings are associated with:
    - ☐ Stressor exposure is likely to occur causing take in the form of direct or indirect effects potentially leading to reductions in individual survival, growth, and fitness due to short-term to intermediate-term alteration of habitat characteristics. May equate to an LTAA or an NLTAA finding depending on specific circumstances.
- **Low risk of take (L)** ratings are associated with:
    - ☐ Stressor exposure is likely to occur, causing take in the form of temporary disturbance and minor behavioral alteration. Likely to equate to an NLTAA finding.
- **Insignificant or discountable risk of take (I)** ratings apply to:
    - ☐ Stressor exposure may potentially occur, but the likelihood is discountable and/or the effects of stressor exposure are insignificant. Likely to equate to an NLTAA finding.
- **No risk of take (N)** ratings apply to species with no likelihood of stressor exposure because they do not occur in habitats that are suitable for the subactivity type in question, or the impact mechanisms caused by the subactivity type will not produce environmental stressors.
- **Unknown risk of take (?)** ratings apply to cases where insufficient data are available to determine the probability of exposure or to assess stressor response.

The risk-of-take summary is organized by subactivity, impact mechanism category, and environment type. In cases where the physical effects and related risk of take are similar between environment types, the risk of take discussion is grouped to avoid redundancy. In the following subsections, a general description of the risk of take associated with each subactivity type is provided by impact mechanism category and, where appropriate, by submechanism. The summary risk of take presented in the narrative and the matrices for each impact mechanism category represents the greatest overall risk of take from each of the submechanism of impact in that category.

9.1 Dredging

Dredging is a subactivity type that, broadly speaking, involves the removal of substrate to change bathymetry or channel configuration to promote human uses of the water body or the surrounding landscape, or to protect property and infrastructure. The nature and scale of an individual dredging activity can vary widely depending on its specific purpose and the environment in which it is implemented. For example, dredging in marine and lacustrine environments, as well as large rivers such as the Columbia, is most often intended to establish and maintain navigation channels in shipping lanes used by commercial and/or recreational vessel traffic, as well as approaches and berths for marinas and terminals. These activities are typically conducted from a barge or other type of floating or suspended platform, with dredge spoils disposed at an approved aquatic disposal site.

In contrast, dredging activities also commonly occur in smaller rivers and streams to remove accumulated sediment for the purpose of protecting critical infrastructure (e.g., bridge foundations) or to improve the flood conveyance capacity of the channel. These activities are often conducted directly from the bank using a trackhoe, excavator, or similar heavy equipment. This activity may involve the on-site disposal of dredge spoils in the floodplain or upland environment.

Because dredging projects can occur in such a wide range of environment types, a broad range of HCP species face the potential for stressor exposure. The risk of take resulting from dredging related impact mechanisms is described in further detail in the following sections. Because the nature and scale of dredging activities and the life-history stages exposed vary depending on environment type, this discussion has been divided into marine and riverine and lacustrine environments where significant differences in the nature of stressor exposure are likely. Species-specific risk of take ratings for dredging operations are presented by impact mechanism in Table 9-1 (presented at the end of the narrative portion of Section 9). The species level risk of take ratings are conditioned based on the nature of the stressor exposure anticipated in each environment type.

9.1.1 Dredging Equipment Operation

The construction component of a dredging activity is typically temporary to short-term in duration, lasting from days to weeks, and recurring at interannual to decadal frequencies. Exceptions may occur with larger projects (such as Columbia River navigation channel dredging) that may extend over several months of continuous activity. Stressors associated with dredging activities include visual, physical, and noise related disturbance from vessel and equipment operation, and entrainment of organisms in the dredge mechanism. This latter stressor is associated with a high probability of injury or mortality.

The risk of take associated with these stressors varies depending on the nature of the exposure and the sensitivity of species and life-history stages exposed. For example, motile fish species and life-history stages are most likely able to avoid entrainment, and would therefore only be exposed to visual, physical and noise related disturbances. Therefore, these species may face a moderate risk of take resulting from behavioral avoidance, stress, and habitat displacement. In contrast, species or life-history stages with limited motility face a higher potential for injury or mortality through entrainment, which equates to a high risk of take. Fish eggs and demersal or planktonic larvae and juveniles, as well as the HCP invertebrate species, are effectively non-motile and vulnerable to entrainment.

In addition to the specific submechanisms and related stressors addressed here, dredging activities will produce water quality related stressors that impose an additional risk of take. Specifically, dredging activities cause increased suspended solids (turbidity) and may potentially result in the introduction of toxic substances to the environment through accidental spills. In specific cases, dredging may cause the disturbance and resuspension of contaminated sediments, potentially reintroducing or exacerbating a pathway for HCP species exposure to toxic substances. Risk of take associated with these impact mechanisms is discussed below under Section 9.1.6 (*Water Quality Modifications*).

9.1.1.1 Physical, Visual, and Noise Related Disturbance

Dredging activities will result in physical, visual, and noise related disturbance in the marine environment. Visual and physical disturbance during construction would be expected to alter fish behavior, causing temporary avoidance and startle responses, compelling individuals to move out of the affected habitats or to assume a cryptic posture. Such disturbances will increase stress and exertion, may alter spawning and foraging behavior, or increase the risk of predation if fish are startled away from protective habitat. These effects may lead to decreased survival, growth, fitness, and spawning success, which equates to a moderate risk of take.

Noise related disturbance may occur in the form of acute spikes in underwater sound pressure levels from equipment impacts (e.g., a dredge bucket striking a steel vessel hull or hard substrate), and continuous noise created by vessel engines, generators, and dredge operation. These effects will alter the ambient noise environment.

Specific information on the risk of take associated with underwater noise is relatively limited for the majority of HCP species. For the purpose of ESA consultation, most available research has focused on the effects of pile driving related underwater noise on fish. This subject has received the most scrutiny because pile driving is a relatively common activity that produces noise stressors of sufficient magnitude to cause observed injury and mortality in fish by a number of mechanisms (e.g., cardiovascular and other tissue damage, hearing organ damage). A sufficient base of information has been assembled to establish effects thresholds for disturbance and injury in the HCP salmonid species.

Until recently, NOAA Fisheries and USFWS recognized underwater noise levels of 150 dB_{RMS} and 180 dB_{peak} as thresholds for disturbance and injury, respectively, of federally listed salmonid species (Stadler 2007; Teachout 2007). While the disturbance threshold still stands, on April 30, 2007, NOAA Fisheries established the following dual criteria to evaluate the onset of physical injury to fishes exposed to underwater noise from impact hammer pile driving (NMFS 2007b):

> ***SEL:*** *A fish receiving an accumulated Sound Exposure Level (SEL) at or above 187 dB re: one micropascal squared-second during the driving of piles likely results in the onset*

> *of physical injury; a simple accumulation method shall be used to sum the energy produced during multiple hammer strikes.*
>
> ***Peak SPL:*** *A fish receiving a peak sound pressure level (SPL) at or above 208 dB re: one micropascal (which equates to dB$_{peak}$) from a single hammer strike likely results in the onset of physical injury.*

Exceeding either criterion equals injury. The effects thresholds established for pile driving provide a useful basis for qualitative estimation of the effects of other sources of underwater noise. While data on other sources of underwater noise are limited, what data are available indicate that these noise sources associated with dredging are unlikely to exceed established salmonid injury thresholds or noise levels associated with injury in fish and invertebrates subjected to experimental noise exposure.

However, noise stressors produced by dredging operations are likely to exceed levels sufficient to cause disturbance and behavioral modification (e.g., startle or avoidance responses), or to cause other physiological responses detrimental to survival, growth and fitness. Behavioral modification and habitat displacement from stressor exposure may lead to increased exertion, alteration of feeding behavior, and increased predation exposure. Auditory masking effects caused by protracted alteration of the ambient noise environment (e.g., from extended vessel and motorized equipment operation) may affect their ability to detect predators and prey. Behavioral and auditory masking effects would generally be temporary to short-term in nature, lasting for the duration of the dredging activity. Prolonged exposure to elevated ambient noise levels may also cause temporary changes in hearing sensitivity in certain fish species. These hearing threshold effects may last for some period after activities are completed (e.g., hours to days). Collectively, these effects may limit the survival, growth, and fitness of individuals exposed to these stressors. Because these stressors are short-term in nature, stressor exposure equates to a moderate risk of take.

9.1.1.2 Entrainment

Entrainment is essentially the unintentional capture of organisms within the dredged material or the surrounding water column, and the unintentional removal of these organisms from the environment. Entrainment is a likely occurrence regardless of equipment type if non-motile species or life-history stages are present during dredging activities. Exposure to this stressor is likely to cause mortality through mechanical injury, smothering, or stranding. Species with one or more non-motile life-history stages that occur in environments suitable for dredging activities face a high risk of take from this subactivity type.

9.1.2 Riparian Vegetation Modifications

Dredging activities in marine and lacustrine environments are expected to take place from floating platforms, barges/vessels, and/or existing overwater structures. Therefore, no modification of the riparian environment would be expected to occur and there will be no related risk of take.

Dredging projects in riverine environments with the potential to result in riparian vegetation modification are expected to take place primarily on small to moderate sized streams and rivers that cannot practically be accessed from a floating dredge platform. Examples include modified stream channels in agricultural and urban settings that rapidly accumulate sediment and lose flood conveyance capacity. Some of these systems may incorporate sediment traps that are subject to routine maintenance dredging. Dredging activities in stream systems of this type can lead to extensive modification of riparian vegetation over a significant length of channel. Riparian recovery may be retarded if dredging activities occur at a high frequency (e.g., annually or biennially), meaning that the stressor exposure will occur over an extended duration.

9.1.2.1 Altered Riparian Shading and Altered Ambient Air Temperature Regime

Removal of riparian vegetation can demonstrably affect the temperatures of streams and lower order river environments, producing a range of potential effects on fish and wildlife species. In smaller stream systems where flood conveyance dredging may occur routinely along lengths of the channel equivalent to hundreds of channel widths, these effects can become pronounced. Increased stream temperatures can lead to a variety of unfavorable effects on HCP species occurring in these environment types. Due to their potential to occur over an extended duration, these effects are equated with a high risk of take.

Dredging projects in larger river systems are typically implemented from bridges, barges, or other suspended or floating platforms. Thus, there is little potential for riparian vegetation modification in these systems. Risk of take for HCP species limited to these environment types is rated accordingly.

9.1.2.2 Altered Stream Bank Stability

Removal of riparian vegetation can affect shoreline stability through the reduction in root cohesion and the loss of large woody debris (LWD) inputs that affect localized erosion and scour conditions. As noted in the previous section, these effects may become pronounced in smaller stream systems where riparian modification effects are imposed over a considerable length of channel relative to the overall size of the stream. In the worst-case scenario, this type of riparian vegetation modification could result in decreased stream bank and shoreline stability, leading to erosion and elevated turbidity along the length of affected channel. These effects will be pronounced during seasonal high-flow conditions. Risk of take associated with this stressor varies depending on species-specific sensitivity to increased turbidity and dependence on the habitat structure provided by intact stream banks. Again, when a worst case scenario perspective is applied, these effects can become chronic and intermediate- to long-term in nature. Therefore, these effects equate to a high risk of take.

9.1.2.3 Altered Allochthonous Inputs

Riparian vegetation is an important source of nutrient input to the aquatic environment, strongly influencing the productivity of the aquatic food chain. Allochthonous nutrient inputs include sources such as insect-fall, leaf litter and other organic debris, and LWD inputs that contribute both organic material and habitat complexity. However, the importance of allochthonous inputs to riverine food web productivity decreases along a downstream gradient as rivers grow in size and the contributions of autochthonous production and nutrient cycling to the food web increase.

In a worst-case scenario, a permitted dredging activity that repeatedly alters an extensive length of riparian zone relative to channel size may lead to chronic reduction in allochthonous inputs. In such cases, a localized reduction in food web productivity might result, leading to decreased foraging opportunities, decreased overall habitat suitability, and decreased growth and fitness. This equates to a high risk of take for a range for species that are dependent on riverine rearing conditions.

9.1.2.4 Altered Habitat Complexity

The influence of riparian vegetation on riverine habitat complexity is broadly recognized. Modification of riparian vegetation alters habitat complexity in a number of ways, primarily through the loss of undercut banks, root structure, and LWD inputs to the channel. The hydraulic and geomorphic effects of riparian vegetation modification can lead to further alterations in habitat complexity. This impact mechanism presents potential risk of take for a broad range of species dependent on riverine aquatic ecosystems through a variety of species-specific stressors. Depending on the particular life history of the affected species, alteration in habitat complexity may limit the availability of suitable spawning, resting, and rearing habitat, and may alter foraging opportunities and predation exposure. In general, fish species that are dependent on habitats potentially affected through this mechanism of impact by dredging projects are likely to experience decreased spawning success and/or decreased survival, growth, and fitness due to an overall reduction in suitable habitat area. This equates to a high risk of take for those HCP fish and invertebrate species occurring in environment types where this level of effect is likely to occur.

9.1.2.5 Altered Groundwater-Surface Water Interactions

The influence of riparian vegetation on hyporheic exchange is well documented as an important component of ecosystem health. Alteration of riparian vegetation can in turn lead to an alteration of surface water and groundwater exchange, with important effects on the riverine ecosystem. This submechanism is most likely to occur in smaller streams and rivers where routine maintenance dredging activities result in chronic degradation of riparian vegetation. This distribution of impacts limits the potential exposure of related stressors to a narrower range of species and species life-history stages, but the potential risk of take caused by this mechanism is nonetheless significant. For example, many salmonid species preferentially spawn in locations where groundwater inflow contributes to improved spawning gravel quality (i.e., high interstitial DO and low substrate fines). For rearing salmonids and other temperature-sensitive species, groundwater inflow may provide thermal refuges important for survival during summer rearing periods. Hyporheic connectivity is also an important component of food web productivity. Therefore, this impact mechanism has the potential to affect juvenile and/or adult survival, growth, and fitness, and in some cases the spawning productivity of a range of species. Applying a worst-case scenario perspective, routine dredging projects that cause chronic degradation of riparian vegetation may permanently alter groundwater-surface water interactions. This level of stressor exposure would impose a high risk of take on those HCP species dependent on this habitat characteristic.

9.1.3 Aquatic Vegetation Modifications

Stressors imposed by aquatic vegetation modification occur through two primary submechanisms: reduction in autochthonous productivity provided by the plant community; and the changes in habitat structure imposed by the removal of vegetation. Autochthonous production by submerged aquatic vegetation is a source of primary and secondary production in the aquatic food web of the marine littoral zone. A diversity of species feed directly on live and fragmented submerged aquatic vegetation, forming the basis of the food web for a number of other species. The contribution of submerged aquatic vegetation to habitat structure in nearshore marine environments is well recognized. Numerous species use these habitats for cover and rearing during larval and juvenile life-history stages. Of specific interest, Pacific herring are (primarily) effectively obligate spawners on submerged aquatic vegetation in the low intertidal and subtidal zone.

The risk of take associated with alteration of aquatic vegetation varies depending on the environment type. For example, aquatic vegetation plays a key role in the productivity of the nearshore marine ecosystem. In contrast, it plays a limited role in the productivity of cold water streams and rivers, where native aquatic vegetation is quite limited.

9.1.3.1 Marine Environment

Dredging activities in the marine environment are most likely to be permitted only if they can demonstrate that losses of aquatic vegetation will be substantially limited and mitigated. However, in a worst case scenario a dredging project could result in the loss of a substantial amount of aquatic vegetation habitat with extensive localized losses of autochthonous productivity and habitat structure. Because local bathymetry and substrate conditions are usually altered in the process, reduced habitat suitability may limit the potential for natural recovery following project completion.

Alteration of marine littoral vegetation caused by marina/terminal projects may in some cases lead to localized shifts in food web productivity, possibly affecting foraging opportunities for dependent species and life-history stages. This translates to a high risk of take resulting from decreased growth and fitness.

Alterations of the submerged aquatic vegetation community through reduction in aerial extent or conversion to other habitat types (e.g., conversion of eelgrass habitat to algae and kelp) can reduce the productivity of these habitats for dependent life-history stages. This translates to a high risk of take for species dependent on these habitats through reduced survival, spawning success, or growth and fitness (see Table 9-1).

9.1.3.2 Riverine and Lacustrine Environments

The effects of dredging aquatic vegetation modification and related stressors on HCP species in riverine and lacustrine habitats varies considerably depending on the scale of the activity, the nature of the affected habitat, and the sensitivity of the species exposed to the resulting ecological stressors. In most river systems in the Pacific Northwest, particularly in coldwater streams, aquatic vegetation plays a relatively small ecological role. Therefore, changes in autochthonous production and habitat complexity imposed by alteration of aquatic vegetation may have relatively minor effects on the majority of HCP species occurring in these environments relative to the effects of dredging on hydraulic and geomorphic conditions. In contrast, vegetation plays a more significant role in lacustrine habitats, where emergent and submerged aquatic vegetation are often abundant in the photic zone and play a larger role in habitat structure and food web productivity. It is notable that dredging is used to manage aquatic vegetation in lakes, particularly for controlling invasive species.

Due to the variable sensitivity of HCP species to modification of aquatic vegetation, the risk of take in riverine and lacustrine habitats varies. Species specific risk of take is determined by the relative dependence of the species in question on the aquatic vegetation in these environment types.

9.1.4 Hydraulic and Geomorphic Modifications

Dredging activities, by their very nature, impose significant changes in the hydraulic and geomorphic characteristics of the project area and the surrounding environment. These modifications can in turn significantly alter the suitability of the affected habitats for HCP species adapted to the unmodified environment. The submechanisms through which these impacts manifest are manifold and complex, even before considering the complexity of the responses of HCP species to stressor exposure. Therefore, for the purpose of this analysis, the risk of take associated with these submechanisms is viewed in a holistic fashion.

The species-specific risk of take ratings resulting from dredge-related hydraulic and geomorphic modifications presented in Table 9-1 reflect this holistic perspective. The basis for these ratings is discussed by submechanism in the following sections.

9.1.4.1 Riverine Environment

Dredging in riverine environments may range in scale from excavation of accumulated sediments from small managed channels or instream sediment traps using a track hoe operated from the bank to multi-year maintenance dredging projects on the Columbia River employing ships, barges, or other floating platforms to clear navigation channels for oceangoing vessels. The risk of take ratings presented in this section are therefore applicable across a broad range of environment types, and the species specific ratings for riverine habitats presented in Table 9-1 reflect the potential for exposure across a range of habitat types.

9.1.4.1.1 Altered Channel Geometry, Flow Regime, and Substrate Composition and Stability

Flow regime, channel geometry, and substrate composition and stability are dominant factors determining aquatic habitat structure in riverine environments. Alteration of any of these habitat components can change the suitability of the habitat for various life-history stages of HCP species. These habitat alterations are essentially permanent and continuous, and can lead to changes in the productivity of the habitat for spawning, forage, rearing, and refuge. In a worst-case scenario, these effects are in turn likely to lead to reduced spawning success, as well as reduced survival, growth, and fitness for species and life-history stages dependent on the affected habitat.

Dredging fundamentally modifies these environmental characteristics by altering channel geometry and removing substrate from the system. These alterations are in turn likely to change local channel hydraulics and sediment transport and stability. Experience has broadly demonstrated the effects of these individual submechanisms on the survival, growth, and fitness of many of the HCP species that occur in riverine environments. Using the criteria defined for the purpose of this white paper, the effects on survival, growth, fitness, and productivity caused by long-term alteration of environmental and habitat characteristics equates to a high risk of take.

9.1.4.1.2 Altered Hyporheic Flow/Exchange

Dredging operations can lead to the alteration of groundwater exchange in riverine environments through changes imposed on channel geometry. Increased flood conveyance may lead to reduced water surface elevations, and reduced connectivity between the river and the floodplain during peak flows. This is likely to lead to changes in hyporheic exchange with detrimental effects on ecological productivity.

Hyporheic exchange is an important component of ecosystem function (including water quality moderation) in riverine environments. Therefore, this impact mechanism has the potential to affect juvenile and/or adult survival, growth, and fitness, and in some cases the spawning productivity of a range of species. Using the criteria defined for the purpose of this white paper, the effects on survival, growth, fitness, and productivity caused by long-term alteration of environmental and habitat characteristics equates to a high risk of take.

Species with a moderate risk of take include those with life-history stages that are dependent on hyporheic exchange for its beneficial effects on water temperature and dissolved oxygen levels. For example, most salmonids preferentially spawn in areas with groundwater-induced upwelling, which promotes oxygenation of spawning gravels. Alteration of hyporheic exchange in environments suitable for spawning could potentially affect egg survival and reduce the availability of suitable spawning habitat, resulting in reduced spawning success. Similarly, groundwater inflow can provide important thermal refugia for migrating adult and rearing juvenile salmonids during periods with high water temperatures. A reduction in the amount of thermal refugia may negatively affect survival during these life-history stages. Similar effects would be expected for other coldwater fish species with low thermal tolerance thresholds, such as pygmy whitefish. More generally, hyporheic exchange also plays a key role in nutrient cycling and food web productivity in alluvial bed rivers. Activities resulting in significant alteration of hyporheic exchange could adversely affect food web productivity, limiting foraging opportunities for fish and invertebrate species dependent on these types of environments.

9.1.4.2 Marine and Lacustrine Environments

Dredging activities in the marine environment will unavoidably modify hydraulic and geomorphic conditions in and around the project area, resulting in the imposition of several impact mechanisms and related stressors. Risk of take resulting from these impact mechanisms is strongly linked to species-specific dependence on the affected nearshore environment.

9.1.4.2.1 Altered Wave Energy, Altered Current Velocities, and Altered Nearshore Circulation Patterns

Wave energy, current velocities, and circulation patterns are all important determinants governing nearshore marine habitat characteristics. These factors determine habitat suitability for a number of species-specific life-history processes. For example, wave energy conditions, currents, and circulation patterns will have a strong influence on nearshore water temperatures and on the sorting and transport of sediments. Many fish species selectively spawn in locations where current and circulation patterns promote the settling of planktonic larvae in favorable environments for rearing. Alteration of these patterns can cause larvae to be transported to unfavorable environments. Similarly, juvenile fish rearing in nearshore environments selectively choose environments with suitable wave energy and current conditions. These impact mechanisms can fundamentally alter habitat suitability for these uses, leading to decreased survival, growth, and fitness. This translates to a high risk of take for those HCP species that are dependent on these habitats during some phase of their life history.

9.1.4.2.2 Altered Sediment Supply and Altered Substrate Composition

Sediment supply and substrate composition are fundamental components of nearshore ecosystem structure. The physical alteration of the nearshore environment that accompanies dredging activities can lead to alterations in sediment supply and substrate conditions through alteration of wave energy conditions, as well as the interruption or alteration of longshore sediment transport. This can lead to changes in substrate conditions that may be beneficial or detrimental to individual species. Because substrate composition is an important determinant of community structure in the nearshore environment, these habitat changes can fundamentally alter community structure and habitat suitability for species dependent on the original habitat condition. This translates to a moderate risk of take for those HCP species that are dependent on these habitats due to effects on the survival, growth, and productivity of exposed lifestages.

9.1.5 Ecosystem Fragmentation

Ecosystem fragmentation is an impact mechanism that incorporates the collective effects of habitat modification in the footprint of the structure, the resulting effects on the migration and dispersal of organisms, hydraulic modification, the transport, distribution, and biogeochemical processing of LWD, other organic material, nutrients, and pollutants, and the impact mechanisms imposed by hydraulic and geomorphic modifications. As with hydraulic and geomorphic modifications, this impact mechanism is a multifaceted component of the effects that dredging imposes on the aquatic environment.

The species specific risk of take associated with ecosystem fragmentation caused by dredging is presented by environment type in Table 9-1.

9.1.5.1 Marine and Lacustrine Environments

Dredging activities in marine and lacustrine environments are capable of causing ecosystem fragmentation in the marine environment. The magnitude of this impact submechanism and the related risk of take are driven by the scale of the project in question, with larger projects having the most potential for adverse effects.

9.1.5.1.1 Habitat Loss and Fragmentation

Depending on their siting and configuration, dredging activities can present a significant potential for habitat loss and fragmentation in marine and lacustrine environments. In estuarine environments, dredging projects remove shallow bars at the riverine and marine interface, potentially accelerating the flow of water from estuaries into open ocean waters. Altering bathymetry and flow conditions may in turn lead to changes in salinity, tidal exchange, and circulation patterns within the estuarine and nearshore environment, altering habitat conditions and potentially eliminating certain desirable habitat types. Dredging projects in nearshore environments may cause the conversion of shallow water to deeper water habitats, reducing the suitability of these habitats for certain species. For example, many salmonid species typically migrate as juveniles in shallow water along marine and lacustrine shorelines. The fragmentation of shallow water habitat along the shoreline may increase predation exposure and reduce foraging opportunities.

As discussed in Section 9.1.4 (*Hydraulic and Geomorphic Modifications*), dredging can alter wave energy, current, and circulation patterns in the nearshore and offshore environment. These effects can in many cases result in habitat fragmentation through various pathways. Alteration of these habitat characteristics may render productive habitats less suitable for a given species or, in the case of organisms with a planktonic life-history stage, may hinder the dispersal and retention of eggs and larvae in areas suitable for rearing. Collectively, this can result in take through effects on survival, growth, and fitness of affected populations, which equates to a moderate risk of take for exposed species.

9.1.5.2 Riverine Environments

9.1.5.2.1 Altered Longitudinal Connectivity

Hydromodification of riverine environments by dredging reduces the structural complexity of instream habitat by changing channel geometry and influencing the recruitment, transport, and retention of sediments and LWD. Complex channels capture and retain LWD and sediment, which promotes the formation of pools and other hydraulically complex features. This hydraulic complexity in turn encourages the sorting and deposition of sediments and organic material in diverse patches, supporting food web productivity, and providing spawning and rearing habitat for a diverse array of species. This diversity of habitat patches supports a biologically diverse community. Dredging promotes simplification of the riverine environment, reducing the longitudinal distribution and frequency of these habitat patches across the riverine landscape. This reduction in habitat complexity leads to reduced food web productivity, and the reduced availability of habitats suitable for HCP species that occur in these environments. Because these effects are extensive and long lasting, this impact mechanisms equates to a high risk of take for these species.

Using the criteria defined for the purpose of this white paper, the effects on survival, growth, fitness, and productivity caused by the long-term alteration of environmental and habitat characteristics imposed by altered longitudinal connectivity equates to a high risk of take.

9.1.5.2.2 Altered River-Floodplain Connectivity

By altering channel geometry and local hydraulic conditions, dredging can lead to decreased connectivity between the riverine environment and floodplain and terrestrial habitats. The intended purpose of dredging activities in smaller rivers and streams is often to improve flood conveyance capacity, limiting floodplain connectivity during high flow events. Localized changes in water surface elevation may lead to decreased inundation of off-channel and side channel habitats during high flow events.

This lateral habitat connectivity is an important feature of riverine environments that contributes to their productivity. As discussed in the Habitat Modifications white paper (Herrera 2007b), the implications of this degraded connectivity are significant for ecosystem productivity. A number of HCP species are dependent on off-channel and floodplain habitats during one or more life-history stages. Reduction in the availability of suitable habitat will lead to increased competition for available habitat, decreased growth and fitness, increased exposure to predation, and potentially decreased availability of suitable spawning sites. While these effects primarily concern fish, invertebrate species such as mussels could also be affected due to reduced productivity of host fish populations.

Using the criteria defined for the purpose of this white paper, the effects on survival, growth, fitness, and productivity caused by long-term alteration of environmental and habitat characteristics imposed by altered river-floodplain connectivity equates to a high risk of take.

9.1.5.2.3 Altered Groundwater-Surface Water Interactions

The effects of dredging on this component of ecological connectivity and related risk of take are discussed above in Section 9.1.4.1.2 (*Altered Hyporheic Flow/Exchange*) under Section 9.1.4 (*Hydraulic and Geomorphic Modifications*).

9.1.6 Water Quality Modifications

Dredging activities can lead to water quality modifications through a number of submechanisms. The majority of these are construction related and temporary. However, the hydraulic and geomorphic effects of dredging can also lead to water quality effects that are longer lasting in duration.

The species specific risk of take ratings associated with water quality modifications connected with dredging activities are presented by environment type in Table 9-1.

9.1.6.1 Altered Temperature Regime

Dredging projects can result in an alteration of the temperature regime in marine and lacustrine settings, primarily through changes in current circulation and stratification induced by wave energy, current circulation and vertical mixing, and other hydraulic and geomorphic effects. Any alteration in temperature regime attributable to dredging is unlikely to be of sufficient magnitude to cause acute mortality, but may cause increased stress leading to decreased survival, growth, and fitness. Motile species may also exhibit behavioral avoidance of affected areas, increasing competition for available suitable habitats with attendant effects on survival, growth, and fitness. Ultimately, the suitability of the habitat for a range of species may be affected. Applying a worst-case scenario perspective, these effects are likely to lead to a high risk of take because dredging can cause long-term changes in the ecological factors that contribute to temperature regime changes.

9.1.6.2 Altered Dissolved Oxygen

Dredging can lead to altered dissolved oxygen levels through a variety of mechanisms, including changes in water temperature regime (discussed directly above), hydraulic and geomorphic effects leading to altered nutrient cycling and eutrophication, and chemical weathering of substances in substrate exposed by dredging activities. These effects vary in duration from short-term to long-term and their magnitude is dependent on site specific conditions. Similar to the effects of altered temperature regime, altered dissolved oxygen levels attributable to the effects of dredging are unlikely to lead to acute mortality, but may cause increased stress leading to decreased survival, growth, and fitness. Motile species may also exhibit behavioral avoidance of affected areas, increasing competition for available suitable habitats with attendant effects on survival, growth, and fitness. Applying a worst-case scenario perspective, these effects are likely to lead to a high risk of take because dredging can cause long-term changes in the ecological factors that contribute to dissolved oxygen levels.

9.1.6.3 Altered Suspended Sediments and Turbidity

Channel bed and bank disturbance during dredging are likely to result in a short-term increase in suspended sediment levels in the aquatic environment. The subsequent geomorphic effects of dredging may lead to increased erosion or changes in wave energy that may cause chronic elevation in suspended sediment loading as the system adjusts to the new hydraulic and hydrologic regime imposed by changes in channel geometry or local bathymetry. The effects of elevated suspended sediment levels vary depending on the magnitude of the stressor and the sensitivity of the species or life-history stage exposed to the stressor.

Non-motile species or life-history stages exposed to pulses of high concentrations of suspended sediment may suffer direct mortality, injury, or extreme physiological stress from burial and smothering or gill irritation and injury, while motile species may be able to avoid these stressors. Chronic elevation in suspended sediment levels caused by hydraulic and geomorphic adjustments would be less likely to reach levels sufficient to cause direct mortality, but may be sufficient to affect growth and fitness over the intermediate-term by limiting ecological productivity and the ability to detect prey species.

On balance, the long-term risk of take from changes in suspended sediment concentrations and turbidity caused by dredging will be variable depending on the specific site conditions. However, given the potential for short-term injury or mortality resulting from elevated suspended sediment levels associated with this activity, a high risk of take must be assumed for this submechanism for those HCP species that occur in suitable riverine environments.

9.1.6.4 Nutrient and Pollutant Loading

Dredging can induce changes in nutrient and pollutant loading through a number of mechanisms. In the marine environment in particular, dredging activities have been associated with changes in estuarine tidal dynamics, which fundamentally affects the processing and distribution of nutrients and pollutants. Similarly the effects of dredging on marine aquatic vegetation can lead to changes in nutrient cycling and pollutant sequestration. Dredging in Puget Sound has often been associated with the resuspension of contaminated sediments, creating new exposure pathways for organisms in the water column. In riverine environments, fragmentation of floodplain habitats may affect the riparian buffering capacity and limit the contribution of floodplain habitats to nutrient cycling, leading to detrimental changes in water quality. Dredging operations in any environment type present the potential for the introduction of toxic substances from accidental spills from equipment used during the dredging activity.

Depending on the nature and concentration of the contaminant, toxic substance exposure can cause a range of adverse effects in exposed species. In extreme cases, these effects can include direct mortality (e.g., exposure of immobile lamprey ammocoetes buried in bottom substrates, fish exposed to accidental vessel spills in enclosed embayments). Even in the absence of mortality, exposure to a variety of contaminants can cause physiological injury and/or contaminant bioaccumulation, leading to decreased growth and fitness. Changes in nutrient loading may lead to detrimental changes in food web community structure, which may be limiting to growth and fitness.

Because some contaminant exposure and changes in nutrient loading induced by dredging may be intermediate-term to long-term in duration, these stressors are equated with a high risk of take in riverine, marine, and lacustrine environment types.

9.2 Gravel Mining and Scalping

Gravel mining and bar scalping operations are expected to impose impact mechanisms and related ecological stressors similar to those caused by dredging in riverine environments. Specifically, this subactivity type is anticipated to occur only in alluvial bed rivers where the desirable substrate resources are abundant. Therefore, the risk of stressor exposure and resulting risk of take are limited to this environment type and are considered to be essentially the same as those described in Section 9.1 for dredging activities in smaller riverine environments. Species specific risk of take ratings for gravel mining and scalping operations are presented by impact mechanism in Table 9-2 (presented at the end of the narrative portion of Section 9). The specific stressors and related risk of take from impact mechanisms caused by this subactivity type are described in the following subsections.

9.2.1 Construction and Maintenance

Construction and maintenance related submechanisms of impact, stressors, and related risk of take associated with gravel mining and bar scalping are similar to those discussed for *Dredging Equipment Operation* in Section 9.1.1, with the impacts limited to riverine environments where this type of activity is likely to take place.

9.2.2 Hydraulic and Geomorphic Modifications

The submechanisms of impact, stressors, and related risk of take from hydraulic and geomorphic modifications associated with gravel mining and bar scalping are similar to those discussed in Section 9.1.4 (*Hydraulic and Geomorphic Modifications*) for dredging in riverine environments. The effects of the remaining submechanisms and related risk of take are otherwise similar.

9.2.3 Ecosystem Fragmentation

The submechanisms of impact, stressors, and related risk of take from ecosystem fragmentation associated with gravel mining and bar scalping are similar to those discussed in Section 9.1.5 (*Ecosystem Fragmentation)* for dredging in riverine environments.

9.2.4 Aquatic Vegetation Modifications

Gravel mining and scalping operations may lead to the modification or loss of aquatic vegetation in the project footprint and within the zone of hydraulic and geomorphic effects imposed by the modified footprint structure. Due to the fact that aquatic vegetation plays a lesser role in the function of riverine ecosystems where gravel mining and scalping operations are likely to take place, the risk of take associated with altered autochthonous production and habitat complexity is expected to be low to moderate, except in specific cases where species are known to be dependent on aquatic vegetation (e.g., Olympic mudminnow).

9.2.5 Riparian Vegetation Modifications

The submechanisms of impact, stressors, and related risk of take from riparian vegetation modification associated with gravel mining and bar scalping are similar to those discussed in Section 9.1.2 (*Riparian Vegetation Modifications)* for dredging in smaller riverine environments. Downstream impacts are predominantly driven by the hydraulic and geomorphic effects of the activity on channel hydraulics and hyporheic exchange.

9.2.6 Water Quality Modifications

Sources of water quality modification resulting from gravel mining and bar scalping include altered suspended sediments and turbidity and the introduction of toxic substances. The risk of take associated with these submechanisms of impact is similar to that described for dredging in Sections 9.1.6.3 (*Altered Suspended Sediments and Turbidity*) and 9.1.6.4 (*Nutrient and Pollutant Loading*), respectively.

9.3 Sediment Capping

Sediment caps are used primarily as a means of sequestering contaminated substrate material, isolating these materials from the aquatic environment and limiting potential exposure pathways for toxic substances. These types of projects are usually implemented using a barge or similar floating platform to place a layer of clean sediment on top of the contaminated material. The clean substrate layer is typically configured to be appropriate for the wave energy and current conditions at the site, and is usually sufficiently thick to limit the potential for release of contaminants from bioturbation (i.e., disturbance by burrowing organisms or other forms of biological activity), grounding, or anchor scour.

Predominantly employed in the marine environment, sediment caps are occasionally used in lacustrine environments and in riverine environments in depositional settings where scour of the cap is unlikely to occur. These environments are most commonly found in estuarine reaches, which for the purpose of this white paper are considered to be part of the marine environment. Species specific risk of take ratings for sediment cap development and maintenance are presented by impact mechanism in Table 9-3 (presented at the end of the narrative portion of

Section 9). The specific stressors and related risk of take from impact mechanisms caused by this subactivity type are described in the following subsections.

9.3.1 Construction and Maintenance

Construction and maintenance related submechanisms of impact, stressors, and related risk of take associated with sediment cap development are similar to those discussed in Section 9.1.1 (*Dredging Equipment Operation*).

9.3.2 Hydraulic and Geomorphic Modifications

Sediment caps have the potential to alter local hydraulic and geomorphic conditions in the vicinity of the site, imposing effects that may potentially extend beyond the footprint of the structure. In general, the impact mechanisms and related risk of take for these types of projects are expected to be similar to those described for dredging in Section 9.1.4 (*Hydraulic and Geomorphic Modifications*). The magnitude of these effects can be highly variable, and dependent on the nature of the project and the surrounding environmental context. The risk of take resulting from stressors caused by this impact mechanism will similarly vary widely and in many cases will be lower than the estimates presented here, which are based on a worst-case scenario perspective.

9.3.3 Ecosystem Fragmentation

The submechanisms of impact, stressors, and related risk of take from ecosystem fragmentation caused by sediment cap development are considered to be similar to those discussed in Section 9.1.5 (*Ecosystem Fragmentation*) for dredging. These effects are imposed primarily through the hydraulic and geomorphic modifications of the local environment. The effects of the remaining submechanisms and related risk of take are otherwise similar.

9.3.4 Aquatic Vegetation Modifications

Sediment caps can lead to modification of the aquatic vegetation community through burial of existing communities and alteration of the habitat characteristics necessary to support the establishment of vegetation through stressors imposed by hydraulic and geomorphic modifications. For example, sediment caps may alter substrate conditions, reducing the suitability of the substrates for rooted vegetation or the availability of hard substrates for encrusting vegetation or kelp holdfasts. The resulting risk of take associated with these stressors varies based on the sensitivity of the HCP species and the environment type in which stressor exposure occurs, but is considered to be similar to that described for dredging in Section 9.1.3 (*Aquatic Vegetation Modifications*), except that these impacts are not expected to occur in riverine environments.

9.3.5 Water Quality Modifications

Sources of water quality modification associated with sediment caps include increased suspended sediments and the potential introduction of toxic substances during project construction, and the effects of riparian and hydraulic and geomorphic modifications on stream temperatures. Risk of take associated with these submechanisms is discussed in the following sections.

9.3.5.1 Altered Suspended Sediments and Turbidity

The effects of this construction related stressor and related risk of take are similar to those described for dredging in Section 9.1.6.3 (*Altered Suspended Sediments and Turbidity*). However, the species exposed to the risk of take include both freshwater and marine HCP species that occur in environments potentially suitable for this subactivity type.

9.3.5.2 Nutrient and Pollutant Loading

Risk of take associated with this submechanism is similar to that discussed in Section 9.1.6.4 (*Nutrient and Pollutant Loading*), under dredging. However, the species exposed to the risk of take include both freshwater and marine HCP species that occur in environments potentially suitable for this subactivity type.

9.4 Channel Creation/Alignment

Artificial or realigned channels are extensive hydromodifications specifically designed to reconfigure the aquatic environment to promote human uses. Channel realignment projects conducted for the primary purpose of habitat restoration are discussed in the Habitat Modifications White Paper (Herrera 2007b). Extensive in size and pervasive in effect, this subactivity type imposes a number of ecological stressors on the environment through essentially permanent alteration of habitat and water quality conditions. These types of channel modifications are commonly accompanied by dike and levee development and may be maintained by maintenance dredging, structures, and activities that impose their own risk of take. HCP species occurring in environments modified by this type of project will typically experience a high risk of take from one or more impact mechanisms.

Species specific risk of take ratings for channel creation or alignment are presented by impact mechanism in Table 9-4 (presented at the end of the narrative portion of Section 9). The specific stressors and related risk of take from impact mechanisms caused by this subactivity type are described in the following subsections.

9.4.1 Construction and Maintenance

Channel creation or realignment is a significant construction effort involving the use of heavy machinery, extensive dredging and/or excavation, and the removal of riparian vegetation throughout the length of the modification. These submechanisms are capable of imposing a variety of short-term stressors on the aquatic environment. In addition to the immediate effects of construction, maintenance of these structures may include routine upkeep of associated dikes and levees, and dredging to maintain navigability.

Artificial channels can be constructed by dredging combined with excavation, or by excavation of the new channel "in the dry" on existing floodplain habitat until connection to the existing channel is necessary. The impact mechanisms imposed by dredging and related risk of take are discussed in Section 9.1 (*Dredging*). Therefore this discussion of risk of take specifically addresses the impact mechanisms imposed by the construction of artificial channels in the dry, and the effects of connection to the existing channel.

9.4.1.1 Equipment Operation and Materials Placement

The operation of heavy construction equipment to excavate an artificial channel and connect it to the existing channel imposes stressors in the form of physical and visual disturbance of bank and channel habitat and, potentially, increased underwater noise from in-water equipment use and materials placement and excavation. The magnitude of these stressors will vary widely, depending on the scale of the modification and the specific construction measures used. Applying a "worst-case-scenario" perspective, the magnitude of these stressors can be significant.

The literature on underwater noise levels produced by heavy equipment use is quite limited, and this subject is considered a data gap. In general however, noise produced by heavy equipment during the in-water operation of heavy equipment is unlikely to exceed established injury thresholds but may well exceed disturbance thresholds. Therefore, projects involving some element of in-water work are expected to result in a moderate risk of take from underwater noise. Visual disturbance during construction would have similar effects. Physical disturbance is similarly expected to produce only a moderate risk of take due to temporary disturbance and displacement for most species exposed to this stressor. In-contrast, sessile or otherwise non-motile species or life-history stages are an exception, as they will be unable to escape or avoid physical disturbance. Therefore, they are at increased risk of mechanical injury from crushing or burial during construction, which constitutes a high risk of take.

9.4.1.2 Bank/Channel/Shoreline Disturbance

Bank, channel, and/or shoreline disturbance during the construction and maintenance of artificial channels involves significant disturbance and alteration of stream banks and lacustrine and marine shorelines. This disturbance causes short-term water quality impacts, and long-term (essentially permanent) modification of hydraulic and geomorphic conditions and ecosystem connectivity. The short-term water quality effects of channel and bed disturbance may lead to behavioral and physiological stress on species or life-history stages exposed to the disturbance, or may limit the availability and suitability of habitats for sensitive life-history stages during critical periods. Non-motile species exposed to these stressors may face immediate effects on survival if occupied habitats are eliminated, or may experience injury or mortality from related water quality effects. These effects would be equated with a moderate to high risk of take, depending on species specific sensitivity.

9.4.1.3 Temporary Dewatering and Flow Bypass

Temporary dewatering and flow bypass with fish removal and relocation from work areas may be required during artificial channel creation. Even when dewatering is not required for construction and maintenance, exclusion areas are often created around the work sites to contain sediments and other pollutants and to reduce the magnitude of stressor exposure. This construction and maintenance activity poses a relatively high risk of take. Well-designed protocols and trained personnel are necessary to avoid high levels of mortality. Even with appropriate protocols and experienced field crews, high levels of mortality can result. For example, NOAA Fisheries evaluated take associated with dewatering and fish handling in a recent biological opinion. They estimated that salmonid mortality rates in the range of 8 to as high as 20 percent may occur even when trained personnel are used, and have assumed an injury rate of 25 percent (NMFS 2006).

Mortality rates may be even higher in areas with complex substrate and bathymetry. During the egg, larval, or juvenile life-history stage of many species, individuals may be too small or too cryptic to collect and relocate effectively (e.g., juvenile salmonids hiding in cobble interstices, river lamprey ammocoetes buried in fine substrate, larval or juvenile dace). Mortality is the expected outcome for any individuals stranded within the exclusion area. Even in the absence of mortality, fish handling and relocation may result in stress and injury, as well as increased competition for forage and refuge in the relocation habitat. Moreover, the act of capture, handling, or forced behavioral modification of an ESA-listed species constitutes harassment, which is considered a form of take. Thus, the permitting of channel and work area dewatering poses a high risk of take of varying levels of severity depending on habitat and species-specific factors.

In addition to these effects, the act of dewatering the stream and redirecting flow may pose a barrier to fish migration. Delays in migration can lead to adverse effects on spawning fitness, can increase exposure to predation and poaching, and can deny juvenile fish access to rearing habitats during critical periods. These effects also constitute a moderate risk of take of HCP species with migratory life-history stages.

9.4.1.4 Channel Dewatering

Once the barriers isolating the newly excavated channel are breached, it will fill by drawing surface water from existing surface water, creating a potential dewatering and stranding hazard as well as potential entrainment into the new channel environment. In marine and larger lacustrine systems, the dewatering and stranding hazard is likely limited, because the volume of the new channel will be relatively insignificant. In contrast, in riverine environments the creation of the new channel may redirect the entire surface flow leading to dewatering of the existing channel. Aquatic species trapped in rapidly dewatering habitats face risk of mortality from stranding, particularly non-motile species and life-history stages. Motile species able to avoid stranding will be displaced from existing habitats and forced to relocate within disturbed and/or occupied habitat that may present limited foraging opportunities, which could limit survival, growth, and fitness. It is generally presumed that care will be taken during channel connection to dewater slowly, reducing stranding risk. Consistent with a worst-case scenario approach however, this activity must be associated with a high risk of take, particularly for non-motile species and life-history stages that may be exposed to this stressor.

9.4.2 Hydraulic and Geomorphic Modifications

Channel creation and realignment represent significant alterations of the aquatic environment. Many of the habitat effects of this subactivity type manifest through modification of hydraulic and geomorphic processes in the affected environment. These effects are significant and become effectively permanent, given the longevity of these structures and the associated development that occurs in association with them. Risk of take associated with this impact mechanism is described in the following sections.

9.4.2.1 Altered Flow Regime

Artificial channels and channel realignments, when the primary purpose is not for habitat restoration, alter flow conditions in riverine environments by simplifying the channel geometry, often by straightening the channel and changing (increasing) the stream gradient. This tends to concentrate high flows in the stream channel, accelerating flow velocity and erosive forces. The effects of this stressor on HCP species are complex and variable, depending on the position of the hydromodification in the riverine environment and how the affected habitats are used by HCP species. Applying a worst-case scenario perspective, these pervasive long-term effects would be expected to reduce habitat suitability for species utilizing the affected environment, limiting individual survival, growth, and fitness and overall population productivity. This equates to a high risk of take.

9.4.2.2 Altered Channel Geometry, Altered Substrate Composition/Stability

Artificial or reconfigured channels change the channel geometry by design. A side effect of changes in flow regime and channel configuration is subsequent changes in substrate composition and stability, either by design or through effect. These structures are often created in conjunction with dikes and levees to accelerate the flow of water through the landscape, facilitating conversion of this land to human uses. Channel geometry typically becomes more simplified, and substrate composition and stability is altered through the loss of sources of sediment recruitment and altered sediment transport capacity imposed by channel simplification and alteration of the normal flow regime.

Channel geometry and substrate composition and stability are dominant factors determining aquatic habitat structure in riverine environments. Alteration of any of these habitat components can change the suitability of the habitat for various life-history stages of HCP species. These habitat alterations are essentially permanent and continuous, and can lead to changes in the productivity of the habitat for spawning, forage, rearing, and refuge. In a worst-case scenario, these effects are in turn likely to lead to reduced spawning success, as well as reduced survival, growth, and fitness for species and life-history stages dependent on the affected habitat. This equates to a high risk of take for species with exposure to these impact mechanisms.

9.4.3 Ecosystem Fragmentation

Channel creation/realignment will often unavoidably lead to ecosystem fragmentation. The submechanisms of impact, related ecological stressors, and risk of take associated with ecosystem fragmentation operate in a slightly different fashion between riverine, and lacustrine and marine habitats. Discussion of the risk of take occurring in these environment types is provided in the following sections.

9.4.3.1 Altered Longitudinal Connectivity

Hydromodification of riverine environments by artificial channels reduces the structural complexity of instream habitat by changing channel geometry and influencing the recruitment, transport, and retention of sediments and LWD. Complex channels capture and retain sediment which promotes the formation of pools and other hydraulically complex features. This hydraulic complexity in turn encourages the sorting and deposition of sediments and organic material in diverse patches, supporting food web productivity, and providing spawning and rearing habitat for a diverse array of species. This diversity of habitat patches supports a biologically diverse community. Hydromodification promotes simplification of the riverine environment, reducing the longitudinal distribution and frequency of these habitat patches across the riverine landscape. This reduction in habitat complexity leads to reduced food web productivity, and the reduced availability of habitats suitable for HCP species that occur in these environments. Because these effects are extensive and effectively permanent, this impact mechanisms equates to a high risk of take for the HCP species.

9.4.3.2 Altered River-Floodplain Connectivity

Artificial or reconfigured channels purposefully simplify channel structure, disconnecting floodplain and off-channel habitats from the riverine ecosystem. This form of ecosystem fragmentation limits the extent to which river flows interact with the floodplain and terrestrial riparian ecosystem, disconnecting the stream channel from important sources of organic matter and nutrients, and from important sinks for pollutants. This in turn may limit food web productivity, affecting the survival, growth, and fitness of any species dependent on the riverine environment for rearing. In addition, this loss of connectivity may limit the availability of important habitat types for HCP species. For example, side channel habitats are preferentially selected by various species of salmonids (e.g., sockeye salmon) for spawning. These habitats also provide key winter rearing and storm refuge habitats for coho salmon, steelhead, spring Chinook, native char (bull trout and Dolly Varden), and other species. Floodplain wetlands are also highly productive refuge habitats for a variety of species, such as coho salmon, during high winter flows. The reduction in suitable refuge and foraging habitat area caused by ecosystem fragmentation increases competition for remaining habitat, predation risk, and risk of displacement to habitats unfavorable for rearing. Collectively, these long-term ecological stressors pose a high risk of take for HCP species that occur in the affected riverine environment.

9.4.3.3 Altered Hyporheic Flow/Exchange

The modification of hydraulic, geomorphic, and riparian conditions imposed by artificial or reconfigured channels is likely to influence and alter groundwater and surface water exchange in the project area and downstream. This hyporheic exchange is an important component of ecosystem function (including water quality moderation) in riverine environments. Therefore, this impact mechanism has the potential to affect juvenile and/or adult survival, growth, and fitness, and in some cases the spawning productivity of a range of species. Because this effect will be pervasive and essentially permanent, this mechanism is generally equated with a high risk of take for species exposed to this stressor, depending on species-specific, life-history characteristics.

Species facing high risk of take include those with life-history stages that are dependent on hyporheic exchange for its beneficial effects on water temperature and dissolved oxygen levels. For example, most salmonids preferentially spawn in areas with groundwater-induced upwelling, which promotes oxygenation of spawning gravels. Alteration of hyporheic exchange in environments suitable for spawning could potentially affect egg survival and reduce the availability of suitable spawning habitat, resulting in reduced spawning success. Similarly, groundwater inflow can provide important thermal refugia for migrating adult and rearing juvenile salmonids during periods with high water temperatures. A reduction in the amount of thermal refugia may negatively affect survival during these life-history stages. Similar effects would be expected for other coldwater fish species with low thermal tolerance thresholds, such as pygmy whitefish. More generally, hyporheic exchange also plays a key role in nutrient cycling and food web productivity in alluvial bed rivers. Channel modifications resulting in significant alteration of hyporheic exchange could adversely affect food web productivity, limiting foraging opportunities for fish and invertebrate species dependent on these types of environments.

9.4.4 Aquatic Vegetation Modifications

Channel creation/realignment projects can lead to modification of the aquatic vegetation community, resulting in the imposition of potential stressors. The resulting risk of take associated with these stressors varies based on the sensitivity of the HCP species and the environment type in which stressor exposure occurs.

9.4.4.1 Altered Autochthonous Production

Modification of the submerged aquatic vegetation community in lakes and rivers can lead to decreased primary and secondary productivity, which in turn may affect overall food web productivity. In systems where the aquatic vegetation community is an important component of food web productivity, this can lead to a high risk of take through long-term, indirect effects on foraging success, growth, and fitness of species and life-history stages that depend on forage in the nearshore environment. As noted however, a high risk of take would only apply to those species adapted to habitats with naturally abundant aquatic vegetation. Otherwise, only a moderate risk of take would be expected.

9.4.4.2 Altered Habitat Complexity

Submerged aquatic vegetation provides habitat structure in nearshore environments, creating vertical dimension and overhead cover. Alteration of habitat complexity can decrease the availability of suitable rearing habitat for species and life-history stages dependent on the nearshore environment, leading to increased predation risk and increased competition for suitable space, leading to long-term effects on survival, growth, and fitness. This equates to a high risk of take for species dependent on aquatic vegetation functions in these environments. As noted however, a high risk of take would only apply to species adapted to habitats with naturally abundant aquatic vegetation. Otherwise, only a moderate risk of take would be expected.

9.4.5 Riparian Vegetation Modifications

Channel creation/realignment projects can result in extensive modification of riparian vegetation along a significant length of stream channel or marine or lacustrine shoreline. These effects are often particularly pronounced in riverine environments by virtue of the channel simplification and fragmentation of floodplain habitats that accompanies this type of project. Riparian vegetation is often removed to create dikes and levees around the reconfigured channel. The risk of take associated with stressors resulting from these impact mechanisms is discussed in the following sections by submechanism.

9.4.5.1 Altered Riparian Shading and Altered Ambient Air Temperature Regime

Loss of riparian shading can demonstrably affect the temperature of streams and lower order river environments, producing a range of potential effects on fish and wildlife species. In higher order river environments, this effect is far less pronounced. Water temperatures in systems of this nature are less influenced by localized shading and ambient air temperature than by the combined effects of basin conditions in upstream areas. In smaller rivers and streams, the removal of vegetation to accommodate the dikes and levees that support the realigned channel, and the effects of structure on ecosystem connectivity and channel morphology, compound the potential temperature effects caused by loss of shading and ambient temperature regulation. Through these pathways, channel realignment can lead to unfavorable alterations in stream temperature conditions for HCP species adapted to the native river environment.

Using the worst case scenario perspective, the effects of altered stream temperatures must be equated with a high risk of take due to the long-term nature of the habitat alteration and the potential effects on survival, growth, and fitness of HCP species.

9.4.5.2 Altered Stream Bank Stability

While removal of riparian vegetation can lead to bank instability, realigned channels are typically hardened with dike and levee structures to increase bank stability and prevent erosion. The level of bank stability provided by the structures is undesirable from an ecological perspective if it prevents natural channel migration processes and limits the recruitment of sediment and woody debris. The risk of take associated with these undesirable effects of altered stream bank stability is discussed in Section 9.4.2 (*Hydraulic and Geomorphic Modifications*).

9.4.5.3 Altered Allochthonous Inputs

Riparian vegetation is an important source of nutrient input to the aquatic environment, strongly influencing the productivity of the aquatic food chain. Allochthonous nutrient inputs include sources such as insect-fall, leaf litter, and other organic debris, and LWD inputs that contribute both organic material and habitat complexity. The importance of allochthonous inputs to riverine food web productivity decreases along a downstream gradient. However, as rivers grow in size, the contributions of autochthonous production and nutrient cycling to the food web increase. As noted in Section 9.4.3.1 (*Altered Longitudinal Connectivity*), channel realignment projects alter the transport and cycling of autochthonous nutrients through simplification of channel structure, and fragmenting longitudinal connectivity. This has been shown to affect food web productivity in downstream reaches.

The magnitude of this impact mechanism varies depending on the amount of riparian vegetation modified or disconnected from the channel by the dike/levee project, and the effects of channel simplification on nutrient cycling. In lower order streams, allochthonous inputs are more important to food web productivity, while they provide a minor contribution in the lower reaches of large river systems. On this basis, the loss of allochthonous production from a channel realignment project near the mouth of a large river will produce related stressors of potentially lower magnitude than an extensive realignment in a smaller river or higher in the watershed of larger systems. In such cases, a localized reduction in food web productivity might result, leading to decreased foraging opportunities, decreased overall habitat suitability, and decreased growth and fitness. Due to the long-term nature of these effects, this equates to a high risk of take for a range of HCP species that are dependent on riverine rearing conditions.

9.4.5.4 Altered Habitat Complexity

The influence of riparian vegetation on riverine habitat complexity is broadly recognized. Modification of riparian vegetation alters habitat complexity in a number of ways, primarily through the loss of undercut banks, root structure, and LWD inputs to the channel. The hydraulic and geomorphic effects of riparian vegetation modification can lead to further alterations in habitat complexity. This impact mechanism presents a potential risk of take for a broad range of species dependent on riverine aquatic ecosystems through a variety of species-specific stressors. Depending on the particular life history of the affected species, alteration in habitat complexity may limit the availability of suitable spawning, resting, and rearing habitat, and may alter foraging opportunities and predation exposure. In general, fish species that are dependent on habitats potentially affected through this mechanism of impact by channel realignment are likely to experience decreased spawning success and/or decreased survival, growth, and fitness due to an overall reduction in suitable habitat area. Due to the long-term nature of this submechanism, this equates to a high risk of take, which applies broadly to all species that utilize riparian habitats.

9.4.5.5 Altered Groundwater-Surface Water Interactions

Riparian modification associated with channel realignment may further influence hyporheic exchange, causing a cascading effect in downstream reaches. Risk of take associated with altered groundwater-surface water interactions is similar to that discussed for dredging in Section 9.1.4.1.2 (*Marine and Lacustrine Environments*) under Section 9.1.4 (*Hydraulic and Geomorphic Modifications*).

9.4.6 Water Quality Modifications

Sources of water quality modification associated with channel creation/realignment projects include increased suspended sediments, the potential introduction of toxic substances during project construction, and the effects of riparian and hydraulic and geomorphic modifications on stream temperatures. Risk of take associated with these submechanisms is discussed in the following sections.

9.4.6.1 Altered Temperature Regime

Channel creation/realignment projects can lead to long-term alteration of the aquatic temperature regime through a variety of mechanisms. In riverine environments, the predominant factors are the reduction in riparian shading and change in groundwater-surface water interactions that occur in the modified environment type. In lacustrine and marine environments, alteration of nearshore current and circulation patterns induced by artificial channels may lead to changes in stratification patterns with significant localized effects on temperature conditions.

In either case, these effects will persist for the life of the structure and have the potential to affect the survival, growth, and fitness of HCP species. Therefore, this impact mechanism equates to a high risk of take.

9.4.6.2 Altered Suspended Sediments and Turbidity

The effects of this construction-related stressor and related risk of take are similar to those described for dredging in Section 9.1.6.3 (*Altered Suspended Sediments and Turbidity*).

However, the species exposed to the risk of take include both freshwater and marine HCP species that occur in environments potentially suitable for this subactivity type.

9.4.6.3 Introduction of Toxic Substances

Risk of take associated with this submechanism is similar to that discussed in Section 9.1.6.4 (*Nutrient and Pollutant Loading*) under dredging.

Table 9-1. Species- and habitat-specific risk of take for mechanisms of impacts associated with dredging.

	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Ecosystem Fragmentation			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications		
Species	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**
Chinook salmon	H	M	M	H	H	H	H	H	H	H	N	N	M	H	M	H	M	M
Coho salmon	H	M	M	H	H	H	H	H	H	H	N	N	M	H	M	H	M	M
Chum salmon	H	M	I	H	H	I	H	H	I	H	N	N	M	H	I	H	M	I
Pink salmon	H	M	I	H	H	I	H	H	I	H	N	N	M	H	I	H	M	I
Sockeye salmon	H	M	M	H	H	H	H	H	H	H	N	N	M	H	M	H	M	M
Steelhead	H	M	M	H	?	H	H	?	H	H	?	N	M	?	M	H	?	M
Coastal cutthroat trout	H	M	M	H	H	H	H	H	H	H	N	N	M	H	M	H	M	M
Redband trout	H	N	M	H	N	H	H	N	H	H	N	N	M	N	M	H	N	M
Westslope cutthroat trout	H	N	M	H	N	H	H	N	H	H	N	N	M	N	M	H	N	M
Bull trout	H	M	M	H	H	H	H	H	H	H	N	N	M	H	M	H	M	M
Dolly Varden	H	M	M	H	H	H	H	H	H	H	N	N	M	H	M	H	M	M
Pygmy whitefish	H	N	M	H	N	H	H	N	H	H	N	N	M	N	M	H	N	M
Olympic mudminnow	H	N	N	H	N	H	H	N	H	H	N	N	H	N	N	H	N	N
Lake chub	H	N	M	H	N	H	H	N	H	H	N	N	M	N	M	H	N	H
Leopard dace	H	N	M	H	N	H	H	N	H	H	N	N	M	N	M	H	N	H
Margined sculpin	H	N	N	H	N	H	H	N	N	H	N	N	M	N	N	H	N	N
Mountain sucker	H	N	M	H	N	H	H	N	H	H	N	N	M	N	M	H	N	H
Umatilla dace	H	N	M	H	N	H	H	N	H	H	N	N	M	N	M	H	N	H
Pacific lamprey	H	I	H	H	N	H	H	H	H	H	N	N	M	I	M	H	L	H
River lamprey	H	M	H	H	N	H	H	H	H	H	N	N	M	H	M	H	M	H
Western brook lamprey	H	N	H	H	N	H	H	N	H	H	N	N	M	N	M	H	N	H
Green sturgeon	N	M	N	N	N	N	N	?	N	N	N	N	N	?	N	N	L	N
White sturgeon	H	M	H	H	N	H	H	?	H	H	N	N	H	?	H	H	L	H

Table 9-1 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with dredging.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Ecosystem Fragmentation			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications		
	Riverine	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**
Eulachon	H	H	N	H	N	N	H	H	N	M	N	N	I	H	N	H	H	N
Longfin smelt	H	H	H	H	N	H	H	H	N	M	N	N	I	H	H	H	H	N
Pacific sand lance	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Surf smelt	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Pacific herring	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Lingcod	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Pacific cod	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Pacific hake	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Walleye pollock	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Black rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Bocaccio rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Brown rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Canary rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
China rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Copper rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Greenstriped rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Quillback rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Redstripe rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Tiger rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Widow rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Yelloweye rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Yellowtail rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Olympia oyster	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N

Table 9-1 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with dredging.

Species	**Construction & Maintenance Activities**			**Hydraulic and Geomorphic Modifications**			**Ecosystem Fragmentation**			**Riparian Vegetation Modifications**			**Aquatic Vegetation Modifications**			**Water Quality Modifications**		
	Riverine	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**
Northern abalone	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Newcomb's littorine snail	N	N	N	N	H	N	N	H	N	N	N	N	N	N	N	N	H	N
Giant Columbia River limpet	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Great Columbia River spire snail	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
California floater (mussel)	H	N	H	H	N	H	H	N	H	H	N	N	M	N	M	H	N	H
Western ridged mussel	H	N	H	H	N	H	H	N	H	H	N	N	M	N	M	H	N	H

Risk of Take Ratings: **H** = High, **M** = Moderate; **L** = Low; **I** = Insignificant or Discountable; **N**= No Risk of Take; **?** = Unknown Risk of Take.
Shaded cells indicate environment types in which the species in question does not occur; therefore, there is no risk of take from the impact mechanism in question.

Table 9-2. Species- and habitat-specific risk of take for mechanisms of impacts associated with gravel mining and scalping.

	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Ecosystem Fragmentation			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications		
Species	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**
Chinook salmon	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Coho salmon	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Chum salmon	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Pink salmon	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Sockeye salmon	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Steelhead	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Coastal cutthroat trout	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Redband trout	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Westslope cutthroat trout	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Bull trout	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Dolly Varden	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Pygmy whitefish	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Olympic mudminnow	H	N	N	H	N	N	H	N	N	H	N	N	H	N	N	H	N	N
Lake chub	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Leopard dace	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Margined sculpin	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Mountain sucker	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Umatilla dace	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Pacific lamprey	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
River lamprey	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Western brook lamprey	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Green sturgeon	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

Table 9-2 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with gravel mining and scalping.

	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Ecosystem Fragmentation			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications		
Species	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**
White sturgeon	H	N	N	H	N	N	H	N	N	H	N	N	H	N	N	H	N	N
Eulachon	H	N	N	H	N	N	H	N	N	M	N	N	I	N	N	H	N	N
Longfin smelt	H	N	N	H	N	N	H	N	N	M	N	N	I	N	N	H	N	N
Pacific sand lance	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Surf smelt	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Pacific herring	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Lingcod	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Pacific cod	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Pacific hake	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Walleye pollock	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Black rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Bocaccio rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Brown rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Canary rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
China rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Copper rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Greenstriped rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Quillback rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Redstripe rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Tiger rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Widow rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Yelloweye rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

Table 9-2 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with gravel mining and scalping.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Ecosystem Fragmentation			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications		
	Riverine	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**
Yellowtail rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Olympia oyster	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Northern abalone	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Newcomb's littorine snail	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Giant Columbia River limpet	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Great Columbia River spire snail	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
California floater (mussel)	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Western ridged mussel	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N

Risk of Take Ratings: **H** = High, **M** = Moderate; **L** = Low; **I** = Insignificant or Discountable; **N**= No Risk of Take; **?** = Unknown Risk of Take.

Shaded cells indicate environment types in which the species in question does not occur; therefore, there is no risk of take from the impact mechanism in question.

Table 9-3. Species- and habitat-specific risk of take for mechanisms of impacts associated with sediment caps.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Ecosystem Fragmentations			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications		
	Riverine	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**
Chinook salmon	N	M	M	N	H	H	H	H	H	N	N	N	N	H	M	N	M	M
Coho salmon	N	M	M	N	H	H	H	H	H	N	N	N	N	H	M	N	M	M
Chum salmon	N	M	I	N	H	I	H	H	I	N	N	N	N	H	I	N	M	I
Pink salmon	N	M	I	N	H	I	H	H	I	N	N	N	N	H	I	N	M	I
Sockeye salmon	N	M	M	N	H	H	H	H	H	N	N	N	N	H	M	N	M	M
Steelhead	N	M	M	N	?	H	H	?	H	N	?	N	N	?	M	N	?	M
Coastal cutthroat trout	N	M	M	N	H	H	H	H	H	N	N	N	N	H	M	N	M	M
Redband trout	N	N	M	N	N	H	H	N	H	N	N	N	N	N	M	N	N	M
Westslope cutthroat trout	N	N	M	N	N	H	H	N	H	N	N	N	N	N	M	N	N	M
Bull trout	N	M	M	N	H	H	H	H	H	N	N	N	N	H	M	N	M	M
Dolly Varden	N	M	M	N	H	H	H	H	H	N	N	N	N	H	M	N	M	M
Pygmy whitefish	N	N	M	N	N	H	N	N	N	N	N	N	N	N	M	N	N	M
Olympic mudminnow	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Lake chub	N	N	M	N	N	H	N	N	H	N	N	N	N	N	M	N	N	H
Leopard dace	N	N	M	N	N	H	H	N	H	N	N	N	N	N	M	N	N	H
Margined sculpin	N	N	N	N	N	H	N	N	N	N	N	N	N	N	N	N	N	N
Mountain sucker	N	N	M	N	N	H	H	N	H	N	N	N	N	N	M	N	N	H
Umatilla dace	N	N	M	N	N	H	H	N	H	N	N	N	N	N	M	N	N	H
Pacific lamprey	N	I	H	N	N	H	H	H	H	N	N	N	N	I	M	N	L	H
River lamprey	N	M	H	N	N	H	H	H	H	N	N	N	N	H	M	N	M	H
Western brook lamprey	N	N	H	N	N	H	N	N	H	N	N	N	N	N	M	N	N	H
Green sturgeon	N	M	N	N	N	N	N	?	N	N	N	N	N	?	N	N	L	N

Table 9-3 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with sediment caps

	Construction & Maintenance Activities			**Hydraulic and Geomorphic Modifications**			**Ecosystem Fragmentations**			**Riparian Vegetation Modifications**			**Aquatic Vegetation Modifications**			**Water Quality Modifications**		
Species	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**
White sturgeon	N	M	H	N	N	H	H	?	H	N	N	N	N	?	H	N	L	H
Eulachon	N	H	N	N	N	N	H	H	N	N	N	N	N	H	N	N	H	N
Longfin smelt	N	H	H	N	N	H	H	H	H	N	N	N	N	H	H	N	H	N
Pacific sand lance	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Surf smelt	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Pacific herring	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Lingcod	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Pacific cod	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Pacific hake	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Walleye pollock	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Black rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Bocaccio rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Brown rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Canary rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
China rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Copper rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Greenstriped rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Quillback rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Redstripe rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Tiger rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Widow rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Yelloweye rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N

Table 9-3 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with sediment caps

	Construction & Maintenance Activities			**Hydraulic and Geomorphic Modifications**			**Ecosystem Fragmentations**			**Riparian Vegetation Modifications**			**Aquatic Vegetation Modifications**			**Water Quality Modifications**		
Species	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**
Yellowtail rockfish	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Olympia oyster	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Northern abalone	N	H	N	N	N	N	N	H	N	N	N	N	N	H	N	N	H	N
Newcomb's littorine snail	N	N	N	N	H	N	N	H	N	N	N	N	N	N	N	N	H	N
Giant Columbia River limpet	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Great Columbia River spire snail	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
California floater (mussel)	N	N	H	N	N	H	H	N	H	N	N	N	N	N	M	N	N	H
Western ridged mussel	N	N	H	N	N	H	H	N	H	N	N	N	N	N	M	N	N	H

Risk of Take Ratings: **H** = High, **M** = Moderate; **L** = Low; **I** = Insignificant or Discountable; **N**= No Risk of Take; **?** = Unknown Risk of Take.

Shaded cells indicate environment types in which the species in question does not occur; therefore, there is no risk of take from the impact mechanism in question.

Table 9-4. Species- and habitat-specific risk of take for mechanisms of impacts associated with channel creation and alignment.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Ecosystem Fragmentation			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications		
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine
Chinook salmon	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Coho salmon	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Chum salmon	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Pink salmon	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Sockeye salmon	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Steelhead	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Coastal cutthroat trout	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Redband trout	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Westslope cutthroat trout	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Bull trout	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Dolly Varden	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Pygmy whitefish	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Olympic mudminnow	H	N	N	H	N	N	H	N	N	H	N	N	H	N	N	H	N	N
Lake chub	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Leopard dace	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Margined sculpin	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Mountain sucker	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Umatilla dace	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Pacific lamprey	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
River lamprey	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Western brook lamprey	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Green sturgeon	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

Table 9-4 (continued). **Species- and habitat-specific risk of take for mechanisms of impacts associated with channel creation and alignment.**

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Ecosystem Fragmentation			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications		
	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine	Riverine	Marine	Lacustrine
White sturgeon	H	N	N	H	N	N	H	N	N	H	N	N	M	N	N	H	N	N
Eulachon	H	N	N	H	N	N	H	N	N	M	N	N	I	N	N	H	N	N
Longfin smelt	H	N	N	H	N	N	H	N	N	M	N	N	I	N	N	H	N	N
Pacific sand lance	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Surf smelt	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Pacific herring	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Lingcod	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Pacific cod	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Pacific hake	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Walleye pollock	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Black rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Bocaccio rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Brown rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Canary rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
China rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Copper rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Greenstriped rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Quillback rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Redstripe rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Tiger rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Widow rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

Table 9-4 (continued). Species- and habitat-specific risk of take for mechanisms of impacts associated with channel creation and alignment.

Species	Construction & Maintenance Activities			Hydraulic and Geomorphic Modifications			Ecosystem Fragmentation			Riparian Vegetation Modifications			Aquatic Vegetation Modifications			Water Quality Modifications		
	Riverine	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**	**Riverine**	**Marine**	**Lacustrine**
Yelloweye rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Yellowtail rockfish	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Olympia oyster	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Northern abalone	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Newcomb’s littorine snail	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Giant Columbia River limpet	H	N	N	H	N	N	H	N	N	H	N	N	H	N	N	H	N	N
Great Columbia River spire snail	H	N	N	H	N	N	H	N	N	H	N	N	H	N	N	H	N	N
California floater (mussel)	H	N	N	H	N	N	H	N	N	H	N	N	H	N	N	H	N	N
Western ridged mussel	H	N	N	H	N	N	H	N	N	H	N	N	H	N	N	H	N	N

Risk of Take Ratings: **H** = High, **M** = Moderate; **L** = Low; **I** = Insignificant or Discountable; **N**= No Risk of Take; **?** = Unknown Risk of Take.

Shaded cells indicate environment types in which the species in question does not occur; therefore, there is no risk of take from the impact mechanism in question.

10.0 Data Gaps

This section identifies data gaps, as well as what information is needed to fill those gaps, for each of the impact mechanisms associated with the construction and maintenance of channel modification activities.

10.1 Dredging

Although the sources of turbidity generation due to dredging are well known, the connection of this source to a measurable biological response is a crucial data gap. Adequate data do not exist to quantify the biological response in terms of threshold sediment dosages and exposure durations that can be tolerated by various organisms. The existing data indicate that responses to suspended sediments are highly species-specific, with some species having lethal effects at several hundred parts per million (ppm) in 24 hours and others having no effect at concentrations above 10,000 ppm for 7 days. Studies on east coast species have identified lethal concentration levels, and Newcombe and Jensen (1996) have developed a predictive model for defining lethal and sublethal fish injury threshold levels for suspended solids concentrations in streams and estuaries. However, threshold studies for the temporary impacts of suspended sediment levels specific to aquatic environments in the Pacific Northwest are lacking. Additionally, although dredging of drainage channels for agriculture is widespread throughout the state, the extent of the impacts and effects on HCP species remains essentially undocumented.

There are numerous studies of impacts on aquatic species from dredging activities (Cooper et al. 2007; Erftemeijer and Lewis 2006; Newell et al. 2004). However these impacts have been shown to be site and species specific (Byrnes et al. 2004), with “opportunistic” species (e.g., mollusks) being much less affected than those that have long life histories (e.g., rockfish) (Newell et al. 2004). Considering the diversity of environments present in Washington, there exist a number of data gaps with respect to specific HCP species, most particularly with the effects on rockfish of adjacent dredging operations. A data gap exists with regard to appropriate turbidity thresholds to use in monitoring programs that have been successful elsewhere to limit adverse effects on aquatic species (Thorkilsen and Dynesen 2001).

No research has been identified regarding the effects of lower intensity, continuous underwater noise on invertebrates. However, operational noise is typically associated with sound pressures well below levels that have been observed to cause injury in shellfish, suggesting that HCP invertebrate species would not be subject to these effects. Because HCP invertebrates with the potential for stressor exposure are either filter feeders or grazers and are essentially non-motile, these species are unlikely to be subject to auditory masking effects that would limit their ability to sense predators and prey. Some potential may exist for disturbance induced interruption of feeding behavior, but more research on this subject is necessary to definitively determine this and this subject is considered a data gap.

10.2 Gravel Mining and Scalping

Although considerable advances have been made in the understanding of fluvial geomorphology and aquatic and riparian ecology in recent decades, there are still relatively few studies directly addressing the impacts of gravel mining in its various forms (e.g., wet and dry pit mining, bar scalping) and ecological restoration after mining. Most of the case studies of the geomorphic effects of mining have involved large extraction rates over a decade or more, resulting in large, measurable changes in channel form (Norman et al. 1998). Studies of long-term, indirect, and cumulative effects of mining up the food chain stand as a data gap. Such studies designed to measure mining-induced changes would require the collection of baseline data, which is seldom performed prior to gravel mining activities.

Food-web impacts of gravel mining are not well understood. Predation on juvenile salmon by introduced warm water species (such as those that thrive in the artificial habitats created by floodplain pits) has been documented in California, but no such studies are known to have been undertaken in Washington. The food-web implications of disrupting or eliminating shallow gravel riffle habitats, and reducing the abundance of large woody debris in the channel as a consequence of instream mining, have not been directly measured in the field.

10.3 Sediment Capping

When compared with dredging, sediment capping is a relatively new practice and consequently there are a number of data gaps concerning the impacts on HCP species. Nearly all of the literature regarding sediment capping is oriented toward the physical and biogeochemical properties of sediment caps and the impact of capping on benthic macroinvertebrates. Consequently, data gaps exist concerning the use of capped areas as fish nesting and foraging habitat. Despite this data gap, insight into how capped areas may be used by fish can be found by reviewing the information which exists regarding fish colonization of nourished beach habitat.

There is substantial anecdotal evidence that forage fishes use placed materials for spawning. For instance, a beach nourishment project in Silverdale Waterfront Park continues to be used by surf smelt. Shorelines cut into man-made fill in Commencement Bay have also been designated forage fish spawning areas (Penttila 2007). Developing this anecdotal evidence into a peer-reviewed article should be a target of future research considering the novelty and applicability of the work to both beach nourishment and sediment capping projects.

Additional studies regarding cap longevity would also be useful. As more sediment caps are applied and studied, our knowledge of how capping materials and techniques affect project longevity will improve. With this knowledge, a more accurate assessment of impact on biota can be made.

Lastly, there is substantial evidence that invertebrate communities can rapidly recolonize an area after sediment capping, but all of this research has been conducted in marine waters. Capping of nutrient-laden sediments in small lakes practiced primarily in Japan (see Palermo et al. 1998) may have different impacts on invertebrates. Lateral recolonization, which has been found to be a factor in marine waters (Qian et al. 2003), may occur more rapidly near tributary inlets, but as of yet there is no evidence to indicate that recolonization would occur at different rates in marine, lacustrine, or riverine environments.

10.4 Channel Creation and Alignment

Restoring the ecological integrity of rivers, streams, and tidal channels requires an understanding of pre-disturbance conditions at the time of earliest Euro-American settlement in the mid-19th century. Unfortunately, documentation of these conditions is limited. Archival investigations, field studies, and geographic information systems and remote sensing analyses (such as those undertaken by the Puget Sound River History Project at the University of Washington) are needed to understand the historical landscape to address regional problems of resource management, restoration, and planning.

Straightening and dredging of drainage channels for agriculture is widespread throughout the state but remains essentially undocumented in its extent or impacts. The need for additional studies of this common practice stands as a data gap for channel creation and alignment.

Although it is recognized that lost-opportunity impacts must be mitigated to achieve no loss of habitat (WDFW 2003), currently there are no tools for universal and consistent application of the concept. Tools are needed to assess the lost opportunities associated with channel creation and alignment activities to ensure that appropriate mitigation is provided.

11.0 Habitat Protection, Conservation, Mitigation, and Management Strategies

The Endangered Species Act requires that impacts on listed species or designated critical habitat be avoided or, if unavoidable, minimized to the maximum extent practicable.

11.1 Dredging

A number of techniques have been developed that may be used to mitigate the effects of dredging on sensitive ecosystems (Smits 1998). However, many of these require a trade-off with regard to dredging efficiency and impacts on organisms. For example, in hydraulic dredging, the dredging rate can be adapted by increasing the amount of water pumped up relative to the amount of sediment that is dredged, which can help to reduce the extent of turbidity plumes, although the possibility of entrainment increases (Erftemeijer and Lewis 2006). Other examples of environmentally sensitive dredging equipment have been cited by Erftemeijer and Lewis (2006):

- Encapsulated bucket lines for bucket chain dredgers
- Closed clamshells for grab dredgers
- Auger dredgers
- Disc cutters
- Scoop dredgers and sweep dredgers.

In muddy environments that are underlain by sand, suction of material from below without exposing dredged material to the water column is also possible with new technology (RBW 2007). In this case, if implemented correctly, the effects to fish and invertebrates associated with entrainment and water-column turbidity could be virtually eliminated.

Measures to mitigate the destruction of aquatic resources found by Erftemeijer and Lewis (2006) include: confined land-disposal, turbidity modeling (plume prediction), turbidity thresholds, limits to allowable reduction in aquatic species productivity, minimizing the duration of dredging, seasonal restrictions to avoid fish use and aquatic flowering periods, limiting over-dredge quantities, use of silt screens, prohibiting dredging near eelgrass areas, stopping dredging when turbidity thresholds are exceeded, and adoption of legislation banning the use of certain (clamshell) dredging methods.

Contractual requirements have also been used to constrain the impacts on aquatic wildlife associated with dredging (Erftemeijer and Lewis 2006). In the bridge project to connect Denmark to Sweden, two major tools were introduced to ensure that dredging-induced turbidity was kept below the limits necessary to fulfill the environmental objectives and criteria of the project: (1) the contractor was held responsible through his contract for keeping the spill below specified limits varying in time and space, taking into consideration environmentally sensitive periods and areas; (2) a monitoring program was implemented to identify dispersal of significant turbidity occurrences, and documenting key variables related to the most sensitive benthic communities. Dredging was stopped temporarily during peak tidal currents on twenty occasions to keep within these environmental restrictions (Thorkilsen and Dynesen 2001). These measures helped to ensure that there were no significant impacts from dredging and construction of this major infrastructure project.

Although a common practice in Washington State, the installation of physical barriers such as silt screens has not always proved as successful in practice (USACE 2005). Enclosure of dredging equipment with a silt screen is restricted mainly to use with stationary dredgers using pipeline discharge methods, and is always accompanied by some degree of leakage underneath. Protection of an environmentally sensitive area with silt screens may in some cases be viable, but only if the physical conditions of the site (especially waves and currents) allow their effective use (USACE 2005). As a result, a rigorous monitoring program is recommended to accompany any barrier method, such as silt screens.

Dredged spoils disposal presents another challenge to protect aquatic species. USACE (1983) classifies disposal into three categories: open water, confined (either in upland areas or at sea), and habitat development (usually beach nourishment in Washington State). Open ocean disposal of clean materials have been shown to have little effect on benthic invertebrate populations when strict procedures regarding release have been followed (Simonini et al. 2005). Typically, confined land disposal is more preferable when sediments are contaminated (USACE 1983). However, care should be used when disposing of sediments on land. Runoff from confined disposal sites have been shown to be a source of pollution (Peijnenburg et al. 2005). Beach nourishment of dredged materials presents its own challenges and is discussed at length in the Habitat Modifications white paper (Herrera 2007b).

11.2 Gravel Mining and Scalping

The ecological impacts and effects on HCP species of instream and pit mining can be significantly reduced or eliminated if future management of gravel mining emphasizes incentives to use alternative sources of construction aggregate such as glacial outwash deposits, reservoir deltas, quarries, and recycled concrete rubble.

If gravel mining is to occur in a riverine environment, several steps can be taken to minimize impacts on HCP species. To reduce the impacts of gravel mining on substrate conditions, Collins and Dunne (1989) recommended limiting instream gravel extraction rates to the ambient rate at which sediment is replenished by natural bedload transport processes. Additionally, quantitative site assessments should be performed to measure and document habitat changes and habitat use and preferences of salmonids before and after bar scalping activities, using both scalped and control sites.

Norman et al. (1998) offer several recommendations for planning and siting floodplain gravel mines. Wherever possible, large gravel mines should be located in uplands away from the river valley bottom. A poor second choice is to locate mining on terraces high above the active (100-year) floodplain. In Washington, upland glacial deposits offer ample rock supplies. Mining these deposits eliminates the potential for stream capture or river avulsion. Furthermore, pits in these locations have a good potential for successful long-term reclamation.

11.3 Sediment Capping

There are numerous ways in which to conduct a sediment capping project, and each technique will be associated with different impacts. Some projects, like the Boston Harbor Capping Project (see Lyons et al. 2006), may require the construction of a confined aquatic disposal (CAD) cell to contain dredged material and a sediment cap. Construction of a CAD cell will be associated with numerous impacts such as noise caused by pile driving, and contaminants leaching from treated wood products. Other projects may only require the deposition of a small in-situ cap. The impacts associated with these projects will be relatively small. However, independent of project size, practitioners should follow a number of common best management practices:

1. Practitioners should use clean capping material preferably dredged from areas where dredging was going to occur independent of the need for capping sediment. For instance, the sediment for the Eagle Harbor Sediment Cap was obtained from the Snohomish River Navigation Project (Palermo et al. 1998).

2. To ensure sufficient cap thickness, practitioners should account for bioturbation depth, erosion potential (USACE 1991c), and leaching potential. A minimum depth of 3 to 4 feet is recommended (USACE 1991a).

3. To avoid displacement of contaminated sediment, capping material should be of an equal or lesser density than the contaminated sediment that is to be covered (USACE 1991a).

4. Although such systems are expensive, practitioners should use an active barrier system (ABS), such as activated carbon (Murphy et al. 2006), zeolite (Jacobs and Forstner 1999), calcium carbonate (Hart et al. 2003), coke (McDonough et al. 2007), or a low hydraulic conductivity layer (Hull et al. 1999).

These recommendations can apply to any cap placement method; however, some methods have a greater impact than others. To reduce suspended solids concentrations and contaminated sediment displacement during construction, pump-down capping techniques should be used over point-dump techniques (USACE 1991b) (see Section 4.1 [*Channel Modification Activities and*

Areas of Alteration] for a description of these techniques). Although more expensive, pump-down techniques allow for more control of where capping material is deposited while simultaneously reducing ambient suspended solids and contaminated material entrainment.

Capping is frequently associated with dredging, either to obtain the cap material (e.g., Eagle Harbor, Washington) or in projects where dredging spoils are capped (e.g., Boston Harbor, Massachusetts). The best management practices concerning dredging are addressed above in Section 11.1 (*Dredging*).

11.4 Channel Creation and Alignment

The adverse ecological impacts and effects on HCP species caused by channel creation and alignment activities can be diminished using techniques that are based on an understanding of site-specific geomorphic and ecological processes. For example, the engineered placement of wood, planting of riparian vegetation, avoidance of erosion-prone areas, and levee setback all illustrate techniques that can be incorporated into bank stabilization projects to promote desirable ecological outcomes. WDFW has published a series of guidelines through the department's Aquatic Habitat Guidelines Program. These guidelines are available from WDFW and include the Integrated Streambank Protection Guidelines document (WDFW 2003), which provides guidance for assessing and selecting bank protection techniques, and the Stream Habitat Restoration Guidelines document (Saldi-Caromile 2004), which has an entire chapter devoted to of channel modification techniques.

The structural failure of wood placed in aquatic environments as mitigation for channel creation and alignment activities can impose construction impacts on HCP species. The adverse ecological impacts on HCP species caused by the structural instability and failure of instream woody debris can be minimized or avoided by ensuring that wood placed in rivers is properly engineered according to accepted engineering guidelines. Such guidelines are currently under development by the Washington chapter of the American Council of Engineering Companies (ACEC). Project success depends on a thorough understanding of the site-specific geomorphic constraints, quantifiable habitat goals, and the development of performance-based criteria that account for the anticipated hydrodynamic forces and the desired factor of safety for stability (Miller and Skidmore 2003; Slate et al. 2007).

Construction-phase recommendations have been thoroughly addressed in a recent U.S. Environmental Protection Agency (USEPA) publication (USEPA 2007). The report summarizes best management practices that should be applied to hydromodification projects to reduce non-point source pollution. The recommendations relevant to construction-phase activities include:

- Stockpile fertile topsoil for later use for plants

- Use hand equipment rather than heavy equipment

- If using heavy equipment, use wide-tracks or rubberized tires

- Avoid instream work except as authorized by your local fishery and wildlife authority

- Stay 100 ft away from water when refueling or adding oil

- Avoid using wood treated with creosote or copper compounds

- Protect areas exposed during construction.

Other non-construction-related recommendations put forth by the USEPA (USEPA 2007) include:

- Incorporating monitoring and maintenance of structures
- Using adaptive management
- Conducting a watershed assessment to determine project fate and effects
- Focusing on prevention rather than mitigation
- Emphasizing simple, low-tech, and low cost methods
- Distributing small-scale practices throughout the landscape.

For activities that require dewatering, impacts can be minimized by performing work during low-flow or dry conditions and by pumping sediment-laden water from the work area to an infiltration treatment site. Disturbed areas within the channel should be stabilized with a layer of sediment corresponding to the ambient bed to prevent an influx of fine sediment once water is reintroduced to the site. Science-based protocols for fish removal and exclusion activities should be adopted to track and report the number and species of fish captured, injured, or killed. Projects should also require slow dewatering and passive fish removal from the dewatered area before initiating active fish-removal protocols. During passive fish removal, seining is recommended before using electrofishing, which carries a greater risk of mortality (NMFS 2006).

The primary purpose of channel creation and alignment activities is to modify the channel hydraulics and morphology to minimize the risks of flooding, erosion, and encroachment on adjacent property. These changes in the channel geometry can modify the relationship between channel topography and sediment transport and result in conditions that are out of equilibrium with natural channel processes. The hydraulic and geomorphic modifications induced by channel creation and alignment activities can result in lost opportunity impacts. Mitigation for lost opportunity requires mitigation for channel processes affected by a project. In some situations, off-site mitigation may be the only option (WDFW 2003). According to WDFW (2003), the concept of mitigation for lost opportunity should only be applied when consistent, acceptable, assessment methods or specific site information are available. More detailed information on mitigation for lost opportunity is provided in WDFW (2003).

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