3.0 ECOSYSTEM CHARACTERIZATION AND ECOSYSTEM-WIDE PROCESSES

This chapter describes the ecosystem-wide processes that influence and shape shoreline functions, in accordance with WAC 173-26-210(3)(d). Information is presented at a coarse scale and provides a basis for understanding shoreline management in the context of the broader landscape. Details on individual shoreline reaches are provided in Chapter 4. Maps depicting key shoreline attributes described in this chapter are provided in the map folio in Appendix C and listed in Table 3-1[1].

Table 3-1. Appendix C Map Folio Names and Numbers

Map #	Map Title/Theme
1a	Jefferson County Shorelines of the State
1b	Jefferson County Shorelines of the State
1C	Difference between current and proposed upstream jurisdiction limits
2	Hydrology – East Jefferson County
3	Hydrology – West Jefferson County
4	Water Quality – East Jefferson County
5	Water Quality – West Jefferson County
6	Sediment - East Jefferson County
7	Sediment - West Jefferson County
8	Aquatic Resources – Southeast Jefferson County
9	Aquatic Resources – Northeast Jefferson County
10	Aquatic Resources – West Jefferson County
11	Coastal Processes and Modifications – Southeast Jefferson County
12	Coastal Processes and Modifications – Northeast Jefferson County
13	Coastal Processes and Modifications – West Jefferson County
14	Critical Areas – Southeast Jefferson County
15	Critical Areas – Northeast Jefferson County
16	Critical Areas – West Jefferson County
17	Critical Shoreline Habitat – Southeast Jefferson County
18	Critical Shoreline Habitat – Northeast Jefferson County
19	Critical Shoreline Habitat – West Jefferson County
20	Aquatic Vegetation – East Jefferson County
21	Land and Shoreline Use Patterns – Southeast Jefferson County
22	Land and Shoreline Use Patterns – Northeast Jefferson County
23	Land and Shoreline Use Patterns – West Jefferson County
24	Shellfish Harvest Areas – Eastern Jefferson County
25	Forest Cover and Impervious Surface – Eastern Jefferson County
26	Geomorphic Classes – Southeast Jefferson County
27	Geomorphic Classes – Northeast Jefferson County

[1] Graphic displays that are incorporated into the report text are referred to as Figures (Figure 1, 2,…). References to Maps refer to the map folio in Appendix C. Readers are also encouraged to review the maps from the County 2005 shoreline inventory in Appendix B.

Map #	Map Title/Theme
28	Quinault River
29	Proposed SEDs – Southeast Jefferson County
30	Proposed SEDs – Northeast Jefferson County
31	Proposed SEDs – West Jefferson County

3.1 REGIONAL OVERVIEW

Jefferson County is located on the Olympic Peninsula in northwest Washington State. It stretches east from the Pacific Ocean through the high country of the Olympic Mountains to Puget Sound. To the north, it is bounded by Clallam County and the Strait of Juan de Fuca, to the southeast by Mason County, and to the southwest by Grays Harbor County. In 2005, the County population was estimated to be 28,666 people, with the majority living in the eastern part of the County. The County seat and only incorporated city is Port Townsend, with a population of about 8,500. Other population centers include Port Hadlock, Chimacum, and Irondale (the "Tri-Area"), Port Ludlow, Brinnon, and Quilcene. The federal lands within ONP and ONF encompass most of the Olympic Mountains in the center of the County. West of the Olympic Mountains, Jefferson County is sparsely populated along the Hoh River and in the Kalaloch, Clearwater and Queets village centers. The area is composed of mostly commercial and Washington Department of Natural Resources (WDNR)-owned timberlands.

Parts of five WRIAs occur within Jefferson County (Figure 3-1): WRIA 16 (Skokomish-Dosewallips), WRIA 17 (Quilcene-Snow), WRIA 18 (Elwha-Dungeness), WRIA 20 (Sol Duc-Hoh), and WRIA 21 (Queets-Quinault).

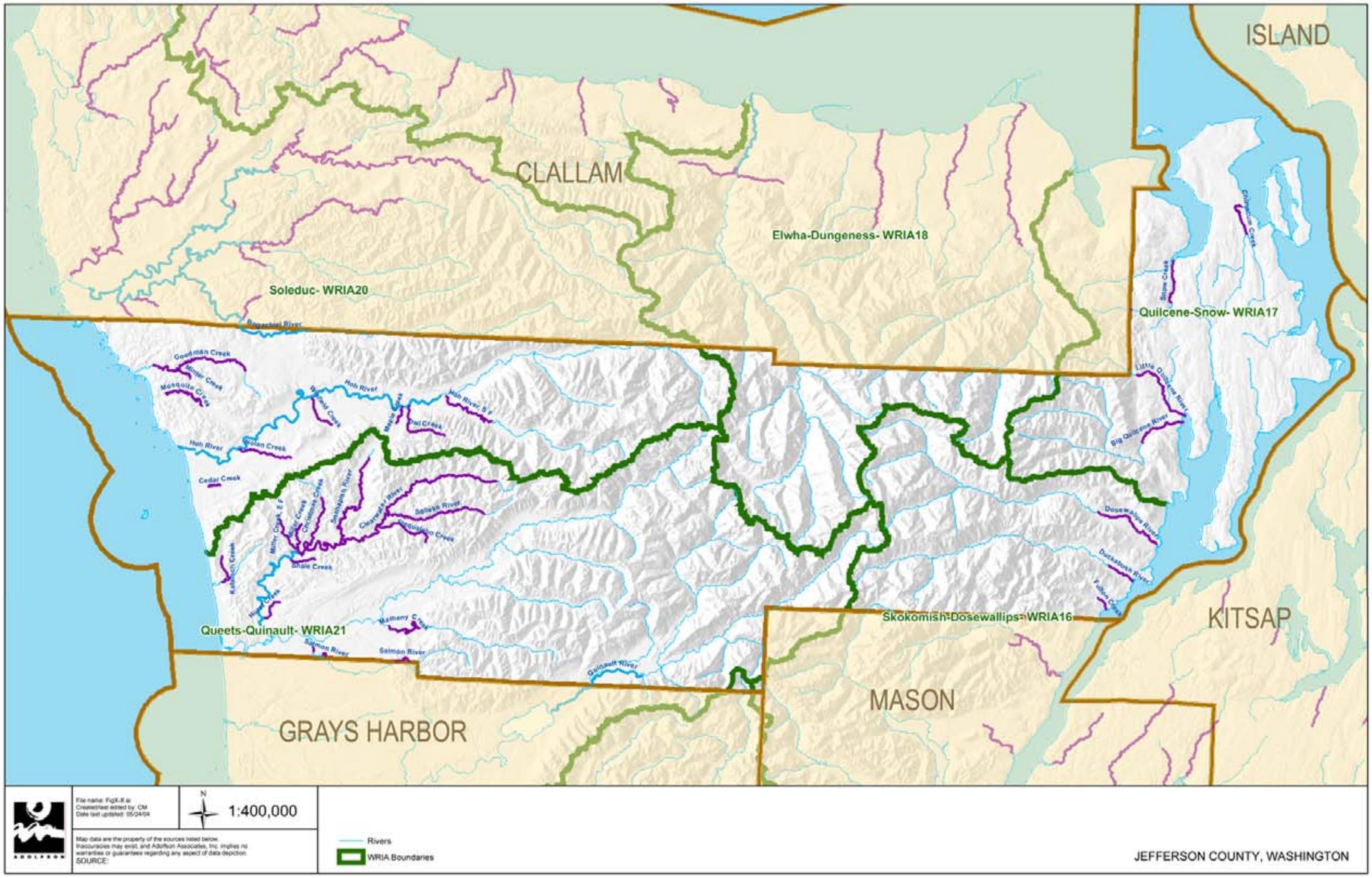
WRIA 16 extends from the Turner Creek watershed in southeast Jefferson County southward to, and including, the Skokomish watershed in northwest Mason County. The four principal watersheds within this WRIA—the Dosewallips, Duckabush, Hamma Hamma, and Skokomish—originate in the rugged terrain of the Olympic Mountains and terminate along the western shore of Hood Canal. The Dosewallips and Duckabush basins lie entirely within Jefferson County, while major portions the Hamma Hamma and Skokomish basins fall in Mason County. The upper portions of the major rivers are either not shorelines of the state (because mean annual flow is less than 20 cfs) or they lie within federal lands and therefore are not under Jefferson County shoreline jurisdiction. The ONP and ONF encompass more than 60 percent of WRIA 16.

WRIA 17 includes portions of Jefferson and Clallam Counties, extending from the Marple/Jackson watershed in southeast Jefferson County northward and westward to, and including, the Johnson Creek watershed along the west side of Sequim Bay. WRIA 17 is bordered to the north by the Strait of Juan de Fuca, to the east by Admiralty Inlet, northern Puget Sound and Hood Canal, and to the south and west by the Olympic Mountains and associated foothills and floodplains. Major basins within this watershed include the Big Quilcene River, Little Quilcene River, Hood Canal West, Admiralty Inlet, and Discovery Bay. Over 70 percent of the WRIA is privately owned (non-federal/tribal land).

WRIA 18 includes two large river systems (Dungeness and Elwha Rivers); one medium-sized river system (Morse Creek); and 14 smaller independent drainages, all of which drain to the

Strait of Juan de Fuca. The headwaters of the Upper Dungeness, Grey Wolf, and Elwha River Upper and Middle basins fall within Jefferson County. Thirty percent of the Dungeness River watershed and 83 percent of the Elwha River watershed are within the ONP. There are no designated shorelines of the state in WRIA 18 within Jefferson County.

Figure 3-1. Jefferson County, Washington, and WRIA Boundaries



WRIA 20 includes all streams that drain into the Pacific Ocean from Cape Flattery in Clallam County south to and excluding Kalaloch Creek in Jefferson County. The largest basin in WRIA 20 is the Quillayute. Other basins include the Waatch, Sooes, Ozette, and Hoh systems, as well as several small independent drainages. Basins within Jefferson County include the Upper, Middle, and Lower Hoh, Hoh River South Fork, Upper and Lower Bogachiel, Goodman Creek, and Sol Duc Lower.

WRIA 21 extends from Kalaloch Creek in Jefferson County in the north to Conner Creek in Grays Harbor County in the south. The largest basins within the WRIA are the Queets and Quinault. The Queets Upper, Middle, Lower, Matheny, and Salmon River basins, along with the Upper Quinault, Quinault North Fork, and Quinault Lake Frontal basins, lie within Jefferson County. Other basins in the WRIA include the Clearwater, Kalaloch, Raft, Moclips, and Copalis basins, of which the Clearwater Upper and Lower and Kalaloch basins fall within Jefferson County.

3.2 OVERVIEW OF KEY SPECIES AND HABITATS IN JEFFERSON COUNTY

This section describes some of the key shoreline-related resources of Jefferson County. This section is divided into the following main topics:

- Threatened and endangered species and critical habitats – Species listed under the federal Endangered Species Act (ESA) as threatened or endangered and their federally designated critical habitats,
- Nearshore habitats and species – Species and habitats primarily associated with saltwater environments,
- Freshwater habitats and species – Species and habitats primarily associated with freshwater environments, and
- Terrestrial habitats and species – Other species and habitats associated with upland areas.

In nature, species and habitats do not always have such clear distinctions: Some habitats are transitional between nearshore, freshwater, and terrestrial environments and many species use multiple habitat types or occupy different habitats at different times depending on the season, species life stage, and other factors.

This is not an exhaustive review of all habitats and species in the County, but a general overview of the resources that are most closely related to or affected by shoreline planning. The purpose of the overview is to assist the reader in understanding the elements of the biological environment that are created, maintained, altered, and/or potentially destroyed as a result of ecosystem processes and/or alterations of ecosystem processes described later in the chapter. Additional information on the locations of these specific resources in Jefferson County is provided in the reach inventory and analysis (Chapter 4) and in the map folio (Appendix C).

3.2.1 Threatened and Endangered Species and Critical Habitats

Jefferson County is home to several state and/or federally listed and proposed threatened and endangered species and critical habitats (Table 3-2). There are 91 bald eagle nesting territories in the County, along with three communal winter night roosts, and two wintering concentrations located along the Quinault River and Washington's Pacific Coast. Northern spotted owls and marbled murrelets also occur and nest in the County (USFWS, 2005). Large areas of critical habitat for marbled murrelets have been identified in western Jefferson County, while critical habitats for both marbled murrelets and spotted owls have been identified in eastern Jefferson County, particularly in old-growth areas of the ONP and along the Dosewallips River (Maps 17-19).

Table 3-2. Listed, Proposed, and Candidate Threatened and Endangered Species Occurring in Jefferson County

Common Name	Scientific Name	Federal Status [a]	State Status [b]
Birds			
Bald eagle	*Haliaeetus leucocephalus*	Threatened	Threatened
Brown pelican	*Pelecanus occidentalis*	Endangered	Endangered
Marbled murrelet	*Brachyramphus marmoratus*	Threatened	Threatened
Northern spotted owl	*Strix occidentalis caurina*	Threatened	Endangered
Short-tailed albatross	*Phoebastria albatrus*	Endangered	Candidate
Mammals			
West Coast DPS fisher	*Martes pennanti pacifica*	Candidate	Endangered
Southern resident killer whale	*Orcinus orca*	Endangered	Endangered
Humpback whale	*Megaptera novaeangliae*	Endangered	Endangered
Steller sea lion	*Eumetopias jubatus*	Threatened	Threatened
Blue whale	*Balaenoptera musculus*	Endangered	Endangered
Fin whale	*Balaenoptera physalus*	Endangered	Endangered
Sei whale	*Balaenoptera borealis*	Endangered	Endangered
Sperm whale	*Physeter macrocephalus*	Endangered	Endangered
Sea otter	*Enhydra lutris*	None	Endangered

Common Name	Scientific Name	Federal Status [a]	State Status [b]
Fish			
Puget Sound ESU Chinook salmon	*Oncorhynchus tshawytscha*	Threatened	Candidate
Eastern Strait of Juan de Fuca/Hood Canal ESU summer chum salmon	*Oncorhynchus keta*	Threatened	Candidate
Puget Sound DPS steelhead	*Oncorhynchus mykiss*	Proposed threatened	None
Coastal Puget Sound bull trout	*Salvelinus confluentus*	Threatened	Candidate
Olympic mudminnow	*Novumbra hubbsi*	None	Threatened
Reptiles			
Leatherback sea turtle	*Dermochelys coriacea*	Endangered	Endangered
Green sea turtle	*Chelonia mydas*	Endangered	Threatened
Loggerhead sea turtle	*Caretta caretta*	Threatened	Threatened
Olive ridley sea turtle	*Lepidochelys olivacea*	Endangered	None

DPS = distinct population segment
ESU = evolutionarily significant unit
[a] Federal status under the Endangered Species Act (ESA) of 1973 as amended.
[b] State Species of Concern List, February 2007.

While there have been occasional, unconfirmed sightings of fishers, there are no known populations in Washington. There is currently a proposal to reintroduce them to the ONP (ONP, 2006).

Listed marine mammals and sea turtles occur primarily off the Pacific coast, although Southern Resident killer whales, humpback whales, and Steller sea lions are known to occur in Puget Sound. NOAA Fisheries has proposed critical habitat for Southern Resident killer whales in marine waters of eastern Jefferson County, including areas deeper than 20 feet along Puget Sound (Area 2) and the Strait of Juan de Fuca (Area 3). Hood Canal was not proposed as part of killer whale critical habitat due to lack of confirmed sightings there, and a large area of Admiralty Inlet north of the Quimper Peninsula (Area 3) was excluded for national security reasons (Federal Register, 2006).

Species of special concern under the Washington Department of Fish and Wildlife (WDFW) endangered, threatened, sensitive, candidate, and monitor species programs potentially found in Jefferson County include great blue heron (*Ardea herodias*), pileated woodpecker (*Dryocopus pileatus*), purple martin (*Progne subis*), Vaux's swift (*Chaetura vauxi*), and western bluebird (*Sialia mexicana*). Candidate and threatened mammals may include western gray squirrel (*Sciurus griseus*) along with western pond turtle (*Clemmys marmorata*). Many of these remaining species can be found in close proximity to developed areas, although most need undisturbed vegetated areas large enough to maintain viable habitat (Jefferson County, 2002).

3.2.1.1 Salmonids

Salmonids (including both federally listed and non-listed species) use streams, rivers, and nearshore habitats throughout Jefferson County. In eastern Jefferson County, Chinook, coho, pink, and summer and fall chum salmon, resident and searun cutthroat trout, as well as summer and winter steelhead are documented in the larger rivers and streams (Correa, 2002, 2003). Western Jefferson County rivers and streams provide spawning and rearing habitat for summer and fall Chinook, coho, and chum salmon as well as for winter and summer steelhead trout.

In 1999, the summer chum salmon populations that naturally spawn in tributaries to Hood Canal and in Discovery Bay, Sequim Bay, and the Dungeness River on the Strait of Juan de Fuca were determined to be at risk of extinction and were listed as threatened (Brewer et al., 2005). Hood Canal streams that have been documented as supporting indigenous summer chum populations include the Big Quilcene River, Little Quilcene River, Dosewallips River, Duckabush River, Hamma Hamma River, Lilliwaup River, Union River, Tahuya River, Dewatto River, Anderson Creek, and Big Beef Creek. Summer chum are occasionally observed in other Hood Canal drainages, including the Skokomish River which once supported a large summer chum population (WDFW and PNPTC, 2000). Summer chum salmon populations in the eastern Strait of Juan de Fuca occur in Snow and Salmon Creeks in Discovery Bay, and in Chimacum Creek.

Chinook salmon spawning in streams of Hood Canal are part of the Puget Sound Chinook Evolutionarily Significant Unit (ESU), which is also listed as threatened under the ESA. This includes two independent populations: those that naturally reproduce in the Skokomish River watershed, and stocks that spawn in the Hamma Hamma, Duckabush, and Dosewallips watersheds. The Dosewallips River is the likely primary population or source for this grouped population (Brewer et al., 2005).

Critical habitat for Chinook and summer chum salmon in eastern Jefferson County includes the marine shorelines of Hood Canal and the Strait of Juan de Fuca, as well as Fulton Creek, Duckabush, Dosewallips, Big Quilcene, and Little Quilcene Rivers, and Chimacum, Snow, and Salmon Creeks (Federal Register, 2005a). Critical habitat for bull trout in Jefferson County includes the shorelines of the Pacific Ocean, Strait of Juan de Fuca, and Hood Canal, as well as all or a portion of the Hoh River, Clearwater River, Goodman Creek, Elwha River, Mosquito Creek, and Salmon River (Federal Register, 2005b).

The Hoh watershed, mainstem Salmon River, and upper Elwha and Dungeness River watersheds also provide habitat for bull trout, a threatened species (Haring, 1999; Smith, 2000; Smith and Culverwell, 2001). The Hoh River is one of six “core” areas for bull trout on the Olympic Peninsula, which include the Quinault, Queets, Hoh, Elwha, Dungeness, and Skokomish River basins. Core areas are defined by the U.S. Fish and Wildlife Service (USFWS) as areas supporting sustainable and reproducing populations of genetically distinct bull trout. The bull trout population in the Hoh watershed may be the largest population in Washington State (10,000 Years Institute, 2004). In general, Hoh River bull trout appear to be largely limited to the mainstem of the river, but anecdotal evidence suggests they have historically also used tributaries. Spawning has been documented only in the upper mainstem and South Fork Hoh River, and at floodplain interfaces at the mouths of two tributaries in ONP. Adults and juveniles use the entire river as a migration corridor to and from spawning, rearing, and foraging grounds (Brenkman 2004, pers. comm., as cited in 10,000 Years Institute, 2004).

3.2.2 Nearshore Habitats and Species

Key nearshore marine habitats in Jefferson County include eelgrass and kelp beds; shellfish beds; forage fish spawning areas; marine mammal habitats (seal and sea lion haulouts); seabird/waterfowl concentration areas; estuaries and other intertidal wetlands/marshes, and nearshore riparian habitats (Maps 14-20, 24, 26, and 27). These species and habitats occur so widely throughout the County on both the east and west shores that virtually all of the County's nearshore marine environment supports or has potential to support highly valuable and ecologically sensitive resources.

3.2.2.1 Eelgrass and Kelp

Eelgrass (*Zostera marina*) is a native marine seagrass that forms extensive meadows on gravel, fine sand, and mud substrates in the lower intertidal and shallow subtidal zones of protected or semi-protected shorelines (Bulthuis, 1994; Thom et al., 1998). Typical locations for eelgrass have medium to fine sands and contain relatively high levels of organic matter and nutrients (Simenstad, 2000). This generally includes shallow tideflats, along channels in tideflats or estuaries, and in the shallow subtidal fringe. The eelgrass zone is typically confined to areas between tidal elevations of +1 meter to -2 meters relative to mean lower low water (MLLW) (Thom et al., 2001; Simenstad, 2000).

Eelgrass can grow to a height of 2 meters, forming a relatively tall, dense canopy. In undisturbed environments, eelgrass corridors can be nearly contiguous within a drift cell but they also occur as patches between drift cells. Generally, the steeper the beach gradient and more turbid the waters, the narrower the eelgrass corridor (Simenstad, 2000). Eelgrass beds provide a source of organic matter to intertidal/shallow subtidal food webs. The plants produce organic carbon which enters the food web through the microbial decomposition and processing of both particulate and dissolved eelgrass materials (Williams and Thom, 2001). Numerous species of fish, including juvenile salmon, and other marine animals incorporate the decomposed organic matter into their diets. Salmon and other species also depend on eelgrass for habitat structure and refuge from predators. The leaves provide attachment sites for epiphytic algae and other organisms, and ameliorate wave and current energy. Herring use eelgrass for spawning and for protection while they mature (PSAT, 2001).

In eastern Jefferson County, fringing eelgrass beds are found along the shorelines of Discovery Bay, Port Townsend Bay, Marrowstone Island, Hood Canal, and between Tala and Kala Points (Map 20). Historically, eelgrass is believed to have occurred widely along the County's western shore including at the mouth of the Hoh River (Shaffer and Wray, 2004).

Kelp, or macrophytic brown algae, can form dense, highly productive undersea forests that support numerous species of fish and marine mammals. Dense kelp beds also dissipate wave energy and provide sheltered habitat for resting/rafting seabirds and other animals within the kelp bed or adjacent surface waters. Kelp forests are composed primarily of bull kelp (*Nereocystis luetkeana*) and other large brown algae. Kelp attach to the bottom with holdfasts and require rocky or coarse substrates. Distribution is limited to areas with appropriate substrates, light penetration to the bottom, and moderate wave/current energy.

In eastern Jefferson County, kelp beds are generally found along the Straits, with patchy distribution along the shores of western Discovery Bay, western Marrowstone Island, and Hood Head (Map 20). According to survey data from the WDNR Nearshore Habitat Program Research Project, the Protection Island kelp bed has seen significant decline over the past decade (http://www2.wadnr.gov/nearshore/research/projectpages.asp?pagename=kelp_page1&id=17). Understory kelp is still present in significant quantities on Dallas Bank, off the northwest shore of the island, but canopy-forming kelp is largely or entirely absent (Norris, personal communication, 2007). On the west coast of the County, kelp beds have been mapped near Tealwhit Head, Strawberry Point, Toleak Point, Hoh Head, and Diamond Rock, and near Destruction Island (Figure 3-2) (Shaffer and Wray, 2004; Silver, personal communication, 2006).

3.2.2.2 Shellfish Resources

Cobble to fine sand beaches and tidal sand and mudflats are important habitats for many shellfish species. Intertidal areas in Jefferson County support hardshell clams including butter clams (*Saxidomus gigantea*), native littleneck (*Protothaca staminea*), manila clams (*Venerupis philippinarum*), cockles (*Clinocardium nuttalli*), and horse clams (*Tresus* spp.). Geoducks (*Panopea abrupta*) typically burrow offshore in subtidal areas up to 2 to 3 feet into the mud or soft sand. Shrimp, crab, Olympia oysters (*Ostreola conchaphila*) and non-native Pacific oysters (*Crassostrea gigas*) also inhabit the shoreline areas. Dungeness crab (*Cancer magister*) frequent eelgrass beds, and red rock crab (*Cancer productus*) inhabit rocky terrain with less silt content (Jefferson County, 2002).

Figure 3-2. Coastal Watershed Institute, Tribal Marine Cultural Resource Survey for Portions of Western Jefferson County (Shaffer and Wray, 2004)

Shellfish beds perform a number of important ecological functions including cycling nutrients, stabilizing substrates, creating habitat structure (e.g., oyster reefs), enhancing water quality (filtering and retention), and providing food for a wide variety of marine invertebrates, birds, fish, and mammals. Extensive shellfish beds and commercial and recreational shellfish harvest beaches are found along the shorelines of Hood Canal, Discovery Bay, Oak Bay, Quilcene Bay, Port Townsend Bay, and Dabob Bay (Map 24). Tribal shellfish beaches and growing areas are also widely distributed throughout the east County (Figure 3-3). On the west shore, shellfish beds are found from the mouth of the Hoh River south past Kalaloch and near the northern edge of the County near Strawberry Bay, Strawberry Point, and Tealwhit Head (see Figure 3-2). There is an active razor clam (*Siliqua patula*) fishery on the County's west coast.

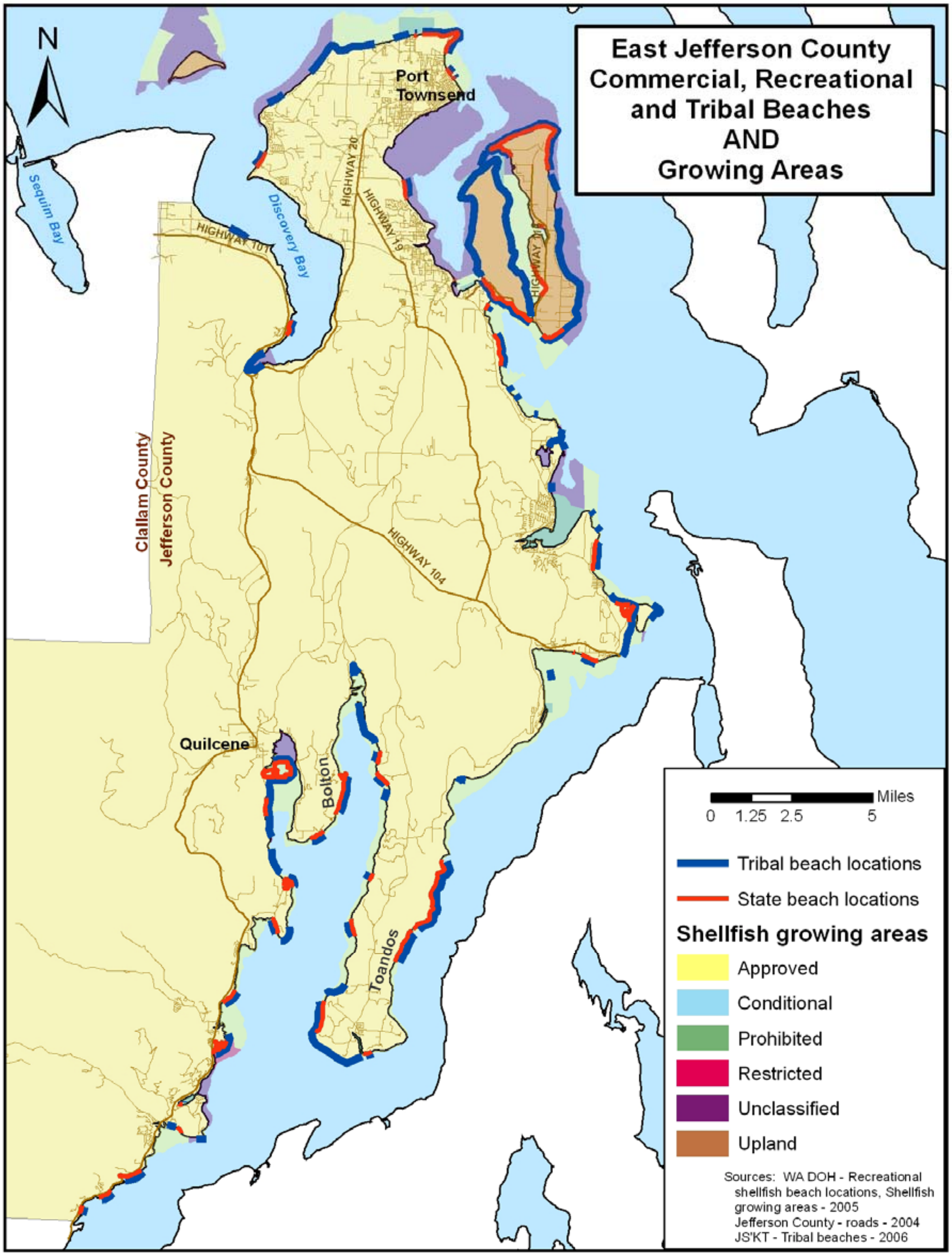
3.2.2.3 Forage Fish

Forage fish—a crucial prey base for salmonids including federally listed stocks—use a variety of shallow nearshore and estuarine habitats for spawning, feeding, and rearing (Long et al., 2005). Surf smelt (*Hypomesus pretiosus*) and Pacific sand lance (*Ammodytes hexapterus*) both spawn within a limited range of tidal elevations in the upper intertidal zones of beaches, and have specific habitat requirements including substrate size and type (Penttila, 1978; 1995). Pacific herring (*Clupea harengus*) spawn in intertidal and shallow subtidal areas, depositing eggs on marine vegetation at elevations between 0 and -10 feet MLLW (WDFW, 2000a). Suitable spawning habitat for these species is therefore limited within the region, and these species are particularly vulnerable to changes in beach sediment characteristics (sources, transport or deposition), nearshore riparian cover, or beach morphology (WDFW, 2000a).

The WDFW, North Olympic Salmon Commission (NOSC) and the Jefferson County Marine Resources Committee have mapped sand lance spawning beaches within Discovery Bay, Port Townsend Bay, Kilisut Harbor, Scow Bay, Oak Bay, Port Ludlow, Tala Point, Tarboo Bay, and other scattered sites along Hood Canal and Dabob Bay (Maps 17 and 18). Surf smelt spawning beaches are more limited in extent, with known spawning occurring in Discovery Bay, Port Townsend Bay, Kilisut Harbor and Scow Bay, Port Ludlow, Tala Point, and Dabob Bay, particularly along the western Toandos Peninsula, and Quilcene Bay. Herring pre-spawn holding areas include Discovery Bay and the entrance to Hood Canal; spawning sites have been documented within Discovery Bay, Port Townsend, Kilisut Harbor, and Dabob Bay (Long et al., 2005) (Maps 17 and 18).

The WDFW/NOSC surveys did not cover western Jefferson County, but Shaffer and Wray (2004) have identified several areas of the western coastal shore as supporting forage fish species as shown in Figure 3-2. These areas are mainly at the mouths of major rivers such as Mosquito Creek, the Hoh River, Cedar Creek, Kalaloch Creek, and Goodman Creek. In the Hoh River, surf smelt occur within the first river mile (10,000 Years Institute, 2004).

Figure 3-3. Commercial, Recreational, and Tribal Shellfish Growing Beaches and Harvest Areas in Eastern Jefferson County



3.2.2.4 Marine Mammals

Seals and sea lions known to occur in Jefferson County include harbor seals (*Phoca vitulina*), California sea lions (*Zalophus californianus*), Steller sea lions (*Eumetopias jubatus*), sea otters (*Enhydra lutris*), and northern elephant seals (*Mirounga angustirostris*). The harbor seal is the most common, widely distributed pinniped found in Washington waters. Harbor seals use hundreds of sites to rest or haul out along the coast and inland waters including intertidal sand bars and mudflats in estuaries, intertidal rocks and reefs, sandy, cobble, and rocky beaches, islands, logbooms, docks, and floats. California sea lions use haulout sites located on jetties, offshore rocks and islands, logbooms, marina docks, and navigation buoys. Steller sea lions use haulout sites primarily along the outer coast from the Columbia River to Cape Flattery. Solitary northern elephant seals are occasionally seen using beaches at Destruction, Protection, and Smith/Minor Islands as well as Dungeness Spit as haulout sites. In recent years, pups have been occasionally recorded at these sites as well. Seal and sea lion haulout sites have been identified near the mouths of Duckabush and Dosewallips Rivers, as well as Dabob Bay, Port Ludlow, Indian and Marrowstone Islands, Protection Island, and Discovery Bay (Jeffries et al., 2000) (Maps 17-19). Washington Department of Fish and Wildlife maintains a seal exclusion fence at the mouth of the Dosewallips River, to maintain water quality in recreational shellfish harvest areas (Christensen, 2004). Alexander Island, Toleak Point, and Hoh Head on the west coast have been identified as harbor seal/sea lion haulouts (see Figure 3-2) (Shaffer and Wray, 2004).

According to WDFW PHS data, sea otters (*Enhydra lutris*) also occur on the west coast at Destruction Island and several other offshore islands (Map 19). Sea otters are endangered in Washington State. Distribution is limited to the northwest coast from Destruction Island to Neah Bay (Lance et al., 2004).

Orcas or killer whales (*Orcinus orca*) and other whales may also use nearshore marine habitats, although they primarily occur in deeper waters and along the outer coast. These species are discussed in Section 3.2.1.

3.2.2.5 Seabirds and Waterfowl

Common seabirds and waterfowl along Jefferson County shorelines include rhinoceros auklets (*Cerorhinca monocerata*), mergansers (*Mergus* spp.), scoters (*Melanitta* spp.), guillemots (*Uria* and *Cepphus* spp.), loons (*Gavia* spp.), grebes (*Aechmophorus occidentalis*), cormorants (*Phalacrocorax* spp.), herons and egrets (Ardeidae), swans (*Cygnus* spp.), geese (*Branta canadensis*), brants (*Branta bernicla*), and a variety of ducks, sandpipers (Scolopacidae), gulls (Larinae), murrelets (*Brachyramphus marmoratus*), and puffins (*Fratercula* spp.). Migratory species including a number of shorebirds and seabirds may use shorelines of Jefferson County for periods of time during migration (Ecology, no date). Protection Island hosts a small, declining population of tufted puffins (*Fratercula* cirrhata), listed as a Candidate species in Washington State and a Species of Concern under the federal Endangered Species Act (McConnell, personal communication, 2007). State priority wildlife species that are associated with estuarine habitat include the bald eagle (*Haliaeetus leucocephalus*), great blue heron (*Ardea herodias*), and osprey (*Pandion haliaetus*). These species occur widely in nearshore habitats throughout Jefferson County (Maps 17 and 18).

Audubon Washington (2001) has identified Important Bird Areas (IBA) in Washington State, defined as places that are essential to maintaining healthy bird populations. In Jefferson County, IBAs include Protection Island – which hosts 70 percent of nesting seabirds in all of Puget Sound – and Indian-Marrowstone Island/Oak Bay, which provides important wintering habitat for thousands of waterfowl and several hundred brants.

3.2.2.6 Estuaries and Intertidal Wetlands/Marshes

Estuaries are embayments (bays) or semi-protected inland waters with freshwater inputs that serve as transition zones between freshwater and marine environments. They encompass the area at the mouth of a river or stream dominated by processes related to the discharge of fresh water (generally from the head of tidal influence seaward to the point where fluvial influences no longer dominate) .Within the large Puget Sound estuary, there are many larger river estuaries (e.g., Skagit, Nisqually) and numerous smaller estuaries. Estuarine habitat in Jefferson County is diverse, ranging from riverine estuaries to small alongshore salt marshes influenced mainly by marine processes. Estuaries provide critical ecological functions and biological resources including flood attenuation, nutrient retention and cycling, erosion/shoreline protection, food web support, and habitat structure/connectivity. Estuaries and deltas associated with watersheds where salmon spawn and rear provide salinity gradients that allow juveniles to gradually adjust to salt water. These areas also serve as nurseries for a wide variety of aquatic species that provide a forage base for salmon.

Juvenile salmonids and other species use estuaries and other shallow water habitats, including the shallow waters along gently sloping beaches, as a refuge from predation when migrating, especially in the absence of complex habitat features such as woody debris or submerged vegetation (Kahler et al., 2000). Juvenile Chinook salmon and summer chum are both highly dependent on estuarine environments (WDFW and PNPTC, 2000). For these and other reasons, preservation and/or restoration of estuaries is considered crucial to the success of ongoing efforts to recover threatened stocks in the Puget Sound and Hood Canal-Strait of Juan de Fuca (Brewer et al. 2005; Hood Canal Coordinating Council, 2005; Todd et al., 2006).

Salt marshes and brackish marshes are habitats that occur in areas with tidal inundation. Salt marshes typically occur at elevations at and above mean higher high water (MHHW) in areas where sediment supply and accumulation are relatively high. Therefore, salt marshes can occur in bays, along sand spits sheltered from waves and currents, and most commonly on river and stream deltas. Salt marsh vegetation, especially the root mats and dense stems, trap and stabilize sediments. Marshes tend to grow outward over time as sediments entering the delta from rivers are captured and retained by salt marsh vegetation. Marshes are fairly stable and respond to natural or human disturbances of watersheds and shorelines. Salt marshes provide complex, branching networks of tidal channels where juvenile salmonids feed and take refuge from predators. They also form migratory linkages to riverine and marine environments (Brewer et al., 2005).

Major estuaries in eastern Jefferson County include the Chimacum Creek, Shine, Mats Mats, Thorndyke Bay, Duckabush and Dosewallips River deltas, Quilcene Bay, Tarboo Creek delta, Port Ludlow, and Discovery Bay (Maps 26 and 27) (Todd et al., 2006). Salt marsh distribution in eastern Jefferson County is generally coincident with the major estuaries[2]. On the west coast of the County, there is a narrow but very productive estuary at the mouth of Goodman Creek (Silver, personal communications, 2006). The mouth of the Hoh River is confined by bedrock, so there is no classic estuary and the area lacks eelgrass beds or other aquatic vegetation (10,000 Years Institute, 2004).

In addition to the major "natal" estuaries listed above, there are tidal marsh systems that are not directly associated with natal watersheds but are believed to support the early marine life histories of juvenile salmon species (Hood Canal Coordinating Council, 2005). These so-called "pocket estuaries" occur where small streams or embayments with freshwater seeps occur. Linkages between major estuarine deltas (like the Dosewallips River and Dabob Bay) and other shallow nearshore habitats/corridors are critical for rearing and migrating salmonids (WDFW and PNPTC, 2000).

3.2.2.7 Nearshore Riparian Areas

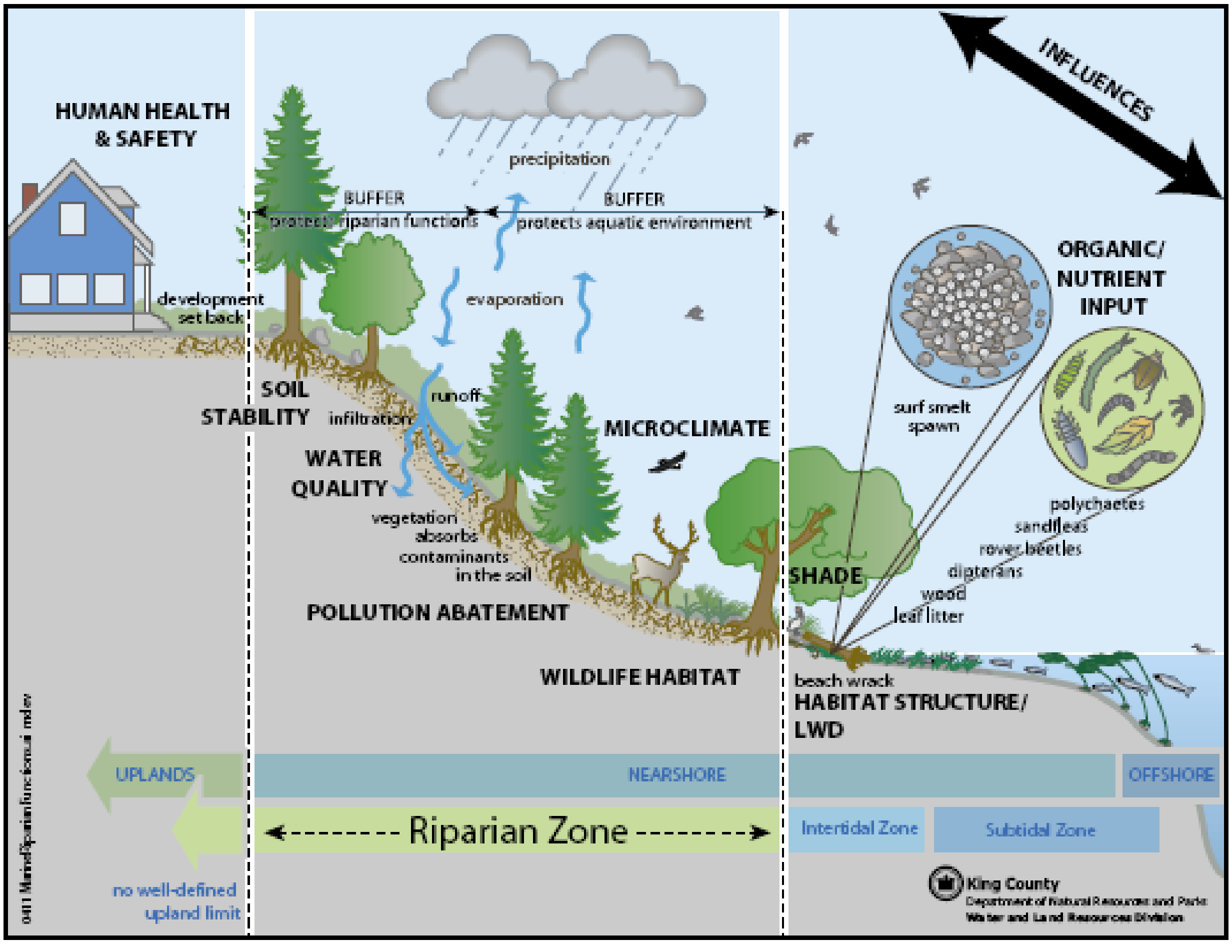
Riparian areas occur at the interface between upland and aquatic areas, both in the marine nearshore and freshwater environments. Brennan and Culverwell (2004) note that healthy nearshore riparian systems are defined by the following characteristics:

- Long linear shapes,
- High edge-to-area ratios,
- Microclimates distinct from those of adjacent uplands,
- Standing or flowing water present all or much of the year, or a capacity to convey or retain water,
- Periodic flooding, which results in greater natural diversity,
- Composition of native vegetation differing somewhat from upland (inland) systems (e.g., different species abundance, diversity, and structure), and
- Support systems for terrestrial and aquatic biota.

Intact riparian habitats provide a variety of essential ecological functions, including water quality protection, sediment control, wildlife habitat, nutrient microclimate control, insect food sources for juvenile fish, shaded cover, and woody debris to help build complex habitat and stabilize beach substrate (Brennan and Culverwell, 2004) (Figure 3-4). A healthy nearshore riparian vegetation zone is also essential for stabilizing slopes and protecting against landslides and other erosion hazards. Plant root masses provide mechanical stability and the vegetation promotes evapotranspiration. This can mitigate the effects of excessive soil moisture, which can lead to erosion and/or mass instability (Brennan and Culverwell, 2004).

[2] This report uses estimates of salt marsh and tidal wetland habitat as reported by Todd et al. (2006), which may vary from results reported by Collins and Sheik (2005) due to differences in habitat classification and analysis methods. Readers are encouraged to review the source materials for more information.

Figure 3-4. Conceptual Model of Marine Riparian Functions (as described in Brennan and Culverwell, 2004)



Because they perform critical functions for stream and freshwater wetland ecosystems, freshwater riparian habitats have been extensively studied. Marine riparian systems by comparison have received less scientific investigation. Nevertheless, recent work published in the Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2680 (Lemieux et al., 2004) shows that nearshore riparian vegetation provides similar functions as freshwater riparian habitats.

3.2.3 Freshwater Habitats and Species

3.2.3.1 Wetlands

The state of Washington (WAC 173-22-030) defines wetlands as "those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions." Wetlands generally include swamps, marshes, bogs, and similar areas. Wetlands are known to play a vital role in the landscape by performing:

- Biogeochemical functions related to trapping and transforming chemicals and improving water quality in the watershed;
- Hydrologic functions related to maintaining the water regime in a watershed and reducing flooding; and
- Food web and habitat functions (Granger et al., 2005).

The four principal wetland types identified within Jefferson County include:

- Wet meadows, which are characterized by having standing water from late fall to early spring and are often dominated by reed canarygrass (*Phalaris arundinacea*), spike rushes (*Eleocharis* spp.), bulrushes (*Scirpus* spp.), and sedges (*Carex* spp.);
- Scrub/shrub wetlands, with seasonal flooding and vegetation dominated by shrubs and small trees such as hardhack (*Spiraea douglasii*), willow (*Salix* spp.), red alder (*Alnus rubra*), or red osier dogwood (*Cornus stolonifera*);
- Forested wetlands, areas that are not usually flooded but have saturated soils, and where vegetation is dominated by large trees such as black cottonwood (*Populus trichocarpa*), red alder (*Alnus rubra*), Oregon ash (*Fraxinus latifolia*), and western red cedar (*Thuja plicata*) with an understory of vine maple (*Acer circinatum*), cascara (*Rhamnus purshiana*), salmonberry (*Rubus spectabilis*), and devil's club (*Oplopanax horridum*); and
- Shallow marsh, which includes freshwater marshes and open water wetlands (Jefferson County, 2002).

These areas are scattered throughout the County, particularly in areas dominated by certain "hydric" soil types (including organic soil deposits of peat and muck), areas of low slope/depressional areas, along streams, and on slopes/transitional areas where groundwater is expressed to the surface (Maps 2-7 and 14-16).

Wetlands associated with shorelands, shoreland areas, or shorelines of the state are managed under the SMA. In context of SMA, *associated wetlands* means wetlands that are in proximity to shorelines or that influence or are influenced by waters subject to the Act (WAC 173-22-030 (1)). These typically include wetlands that physically extend into the shoreline jurisdiction, and wetlands that are functionally related to the shoreline through a hydrologic connection or other factors.

3.2.3.2 Riparian Areas

Freshwater riparian areas function in many of the same ways as nearshore riparian areas. Riparian zones contribute to healthy streams by dissipating energy and inhibiting sediment input, suppressing the erosional processes that move sediment, and by mechanically filtering and/or storing upland sediments before they can enter stream channels (Knutson and Naef, 1997). Riparian areas also perform water quality functions related to pollutant removal. This occurs primarily through denitrification and trapping/storing phosphates and heavy metals that are adsorbed to fine sediments.

One of the most critical roles that riparian areas play in the ecosystem is creating habitat. Riparian zones are a major source of large woody debris (LWD) input to streams.

Approximately 70 percent of the structural complexity within streams 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. LWD creates complex hydraulic patterns that allow pools and side channels to form. It also creates waterfalls, enhances channel sinuosity, and instigates other physical and biochemical channel changes. The in-channel structural diversity created by LWD is essential to aquatic species in deep, low velocity areas for hiding, overwintering habitat, and juvenile rearing, in all sizes of streams and rivers (Knutson and Naef, 1997). Forest practices including clearcutting have damaged and degraded many of the riparian zones on state-owned and private forest lands in Jefferson County. In contrast, riparian habitat conditions in the federally owned lands in the upper watersheds of WRIAs 16, 17, 18, and 20 managed by the National Park Service (NPS) and the U.S. Forest Service (USFS) are among the best in the County. The lower Dosewallips River, lower Little Quilcene River, upper Chimacum Creek, and western Jefferson County rivers and streams outside of the National Park boundary typically have degraded riparian habitats and consequently poor LWD recruitment potential (Correa, 2002, 2003; Smith, 2000). Where data are available for WRIA 21, riparian conditions are mostly “fair” to “good” (Smith and Caldwell, 2001). Western Rivers Conservancy and Wild Salmon Center created the Hoh River Refugia Corridor, which is managed through the Hoh River Trust. Restoration of riparian function along the 30-mile-long, one-mile-wide corridor is underway (Hoh River Trust, 2006).

Wetlands and riparian zones in Jefferson County probably support muskrat (*Ondatra zibethicus*), mink (*Mustela vison*), river otter (*Lutra canadensis*), beaver (*Castor canadensis*), raccoon (*Procyon lotor*), weasel (*Mustela* spp.), and other species. Water bodies, wetlands, and adjacent agricultural fields also provide suitable nesting and feeding habitat for mallard duck (*Anas platyrhynchos*), American widgeon (*Anas americana*), green-wing teal (*Anas crecca*), common coot (*Fulica atra*), common merganser (*Mergus merganser*), blue-wing teal (*Anas discors*), great blue heron (*Ardea herodias*), and lesser and greater Canada goose (*Branta* spp.) (Jefferson County, 2002).

3.2.4 Terrestrial Wildlife Habitats

Other habitat resources within Jefferson County include terrestrial forests (including old growth), river-cut canyons, glacially eroded canyons, active glaciers, riparian areas, coastal dunes, wetlands, sphagnum bogs, grasslands, lakes, and rivers. A majority of the County falls within the Northwest Coast ecoregion, dominated by coniferous forests. Lowland forests are dominated by western hemlock (*Tsuga heterophylla*), Douglas-fir (*Pseudotsuga menziesii*), and western red cedar (*Thuja plicata*). Forests in the mountains are dominated by Pacific silver fir (*Abies amabilis*), and mountain (*Tsuga mertensiana*) or western hemlock. Within the coastal fog belt, Sitka spruce (*Picea sitchensis*) becomes abundant (WDNR, 2005). Bigleaf maple (*Acer macrophyllum*) is also a component of the rainforests. The old-growth conifers can reach up to 200 feet in height, and are characterized by somewhat open canopies and low densities (Smith, 2000). Low-elevation areas of eastern Jefferson County lie within the Puget Trough ecoregion; Douglas-fir forests with western hemlock and red cedar historically dominated vegetation in these areas.

Changes in forest cover and composition of forest stands outside the ONP have been extensive in Jefferson County. A study by Labbe et al. (2006) in Hood Canal showed dramatic changes in riparian forest composition and structure across different shoreline types, landforms, and landscape positions. Comparisons of historical and contemporary forest composition at 80 stream-riparian locations across Hood Canal showed significant vegetation change for particular vegetation types at lower elevation sites in/near bottomlands. Over the historical period, nearly 58 percent of cedar-spruce forest type sites transitioned to hardwood/mixed forest, as compared to other forest types, which showed change of 35 percent or less. Over two-thirds of sites that underwent vegetation change transitioned from conifer-dominance to hardwood/mixed forest (Labbe et al., 2006). Changes of this nature can adversely impact LWD recruitment to stream channels and cause loss of instream habitat complexity. Potential increases in nitrogen loading as a result of increased coverage of red alder are another concern, as alder has the capacity to fix nitrogen in soil.

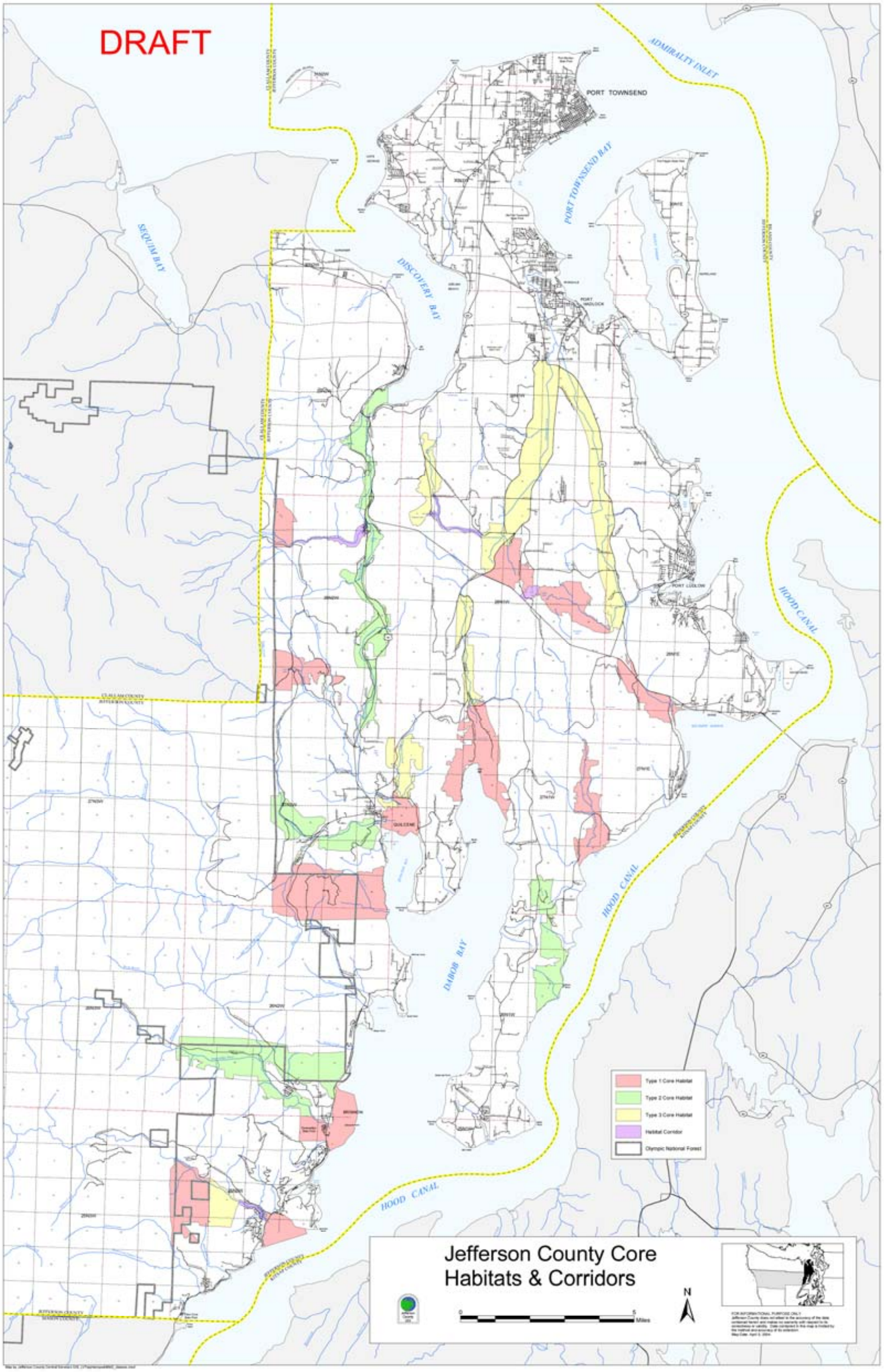
Grassland and oak habitats occur in the Puget Trough ecoregion as well. Many rare grassland species are declining with increased urbanization and the suppression of frequent fires that once sustained the grasslands, leading to more densely forested areas (WDNR, 2005). In Jefferson County, grassland and associated oak habitats are rare. Grassland habitat has been identified along the Big and Little Quilcene Rivers, while remaining oak habitats have only been documented along Discovery Bay.

The ONP, established in 1897 as a forest reserve, then nine years later as Mount Olympus National Monument, was intended to preserve elk, which were being hunted to the point of possible extermination for their teeth (popular as watch fobs). Congress designated the site as a national park in 1938. The park was expanded in 1956 to provide protection to an ocean corridor protecting the beaches and adjacent land along the northern coast of the Olympic Peninsula. ONP and ONF have been designated a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site (one of only 112 worldwide) and an International Biosphere Reserve (Jefferson County, 2002). The ONP, which covers a large portion of Jefferson County land area, protects and encompasses three distinct ecosystems, including some of the largest remaining tracts of Pacific Northwest old-growth forest and, on the west side of the park, temperate moist coniferous forest, as well as subalpine and alpine plant communities of the Olympic Mountains. The ONP also protects the largest population of Roosevelt elk in its natural environment in the world, and at least 16 animal and 8 plant species endemic to the Olympic Peninsula (Parametrix et al., 2005).

3.2.4.1 Priority Wildlife Habitats and Core Areas

WDFW-designated priority habitats for the County include elk herd habitat in the southeast portion of the County, and nest sites for several species of birds, including great blue herons, harlequin ducks, and purple martin. Nonbreeding concentrations of trumpeter swans, waterfowl, and seabirds have also been identified within the County (Tomassi, 2004).

Figure 3-5. Eastern Jefferson County Core Habitats and Corridors (Tomassi, 2004)



Jefferson County identified important wildlife habitat areas and corridors linking wildlife habitat in eastern Jefferson County (Tomassi, 2004) (Figure 3-5). Blocks of primary habitat used by wildlife species for breeding, rearing, foraging, wintering, roosting, and resting, and that are essential to the species' survival, as well as being key to the protection of biological diversity, were identified as "Core Areas". Core Areas contain features or habitat types of particular importance to wildlife, such as snag-rich stands, mature forest, or forested wetlands. Core Areas were identified along Snow Creek, Chimacum Creek, Thorndyke Creek, Tarboo Creek, Donovan Creek, Big Quilcene River, Dosewallips River, and Duckabush River, as well as the vicinity of Mt. Walker. As recommended by Tomassi (2004), Core Areas require special protection and management to ensure that land use practices related to clearing and grading, clearcutting, agriculture, snag removal, road construction, buffer reduction, residential development, and other activities do not fragment or destroy these areas.

3.3 ECOSYSTEM-WIDE PROCESSES

3.3.1 Hydrogeologic Setting

The movement of water, sediment, nutrients, pathogens, organic material, and heat/light through a watershed is governed to a large extent by the surrounding climate, topography, geology, and soils (Stanley et al., 2005). Collectively these governing factors are referred to as the hydrogeologic setting. The hydrogeologic setting plays a key role in determining most geochemical and biological processes within a watershed.

3.3.1.1 Climate

Jefferson County has a maritime climate dominated by moderate temperatures and abundant moisture. Maximum Fahrenheit (F°) temperatures average in the mid 40s in January in the lowlands; in the summer, average maximum temperatures range from 77°F in Quilcene in the east, to 69°F in Clearwater in the west. Temperatures in the lowlands rarely reach the 90s or fall into the teens in this region.

Some of the most extreme variations of annual precipitation in the United States occur on the Olympic Peninsula. In Jefferson County, annual precipitation varies from 126 inches at Spruce in the western foothills of the Olympic Mountains, to approximately 240 inches on Mt. Olympus at the crest of the mountains, to 50 inches in Quilcene along Hood Canal, to 18 inches in Port Townsend on the northeast tip of the Olympic Peninsula. Measurable precipitation falls on 176 days in Clearwater and 116 days in Port Townsend. This pattern of annual precipitation is caused by a dominant winter storm tract from the southwest creating a rain shadow over the northeastern Olympic Peninsula. Storms dump moisture as they rise over the mountains, and air dries and warms as it falls into the Puget Sound-Strait of Juan de Fuca trough. A storm that dumps heavy rain on the western slopes of the Olympic Mountains might only create a light mist along the Strait of Juan de Fuca. Most precipitation falls between October and April, as rain below 1,000 feet and snow above 2,500 feet elevation. Rain in the mid-summer is relatively rare, with high pressure aloft and moderate temperatures predominating.

Severe flooding and coastal bluff landslides often occur when there is a heavy snowfall followed by rain (called a rain-on-snow event). This creates a situation where the accumulated precipitation of several storms runs off the landscape over a very short time. Examples of this phenomenon are the storms of the winter of 1996-97, which triggered numerous, massive, coastal bluff landslides in the Puget Sound region, as well as numerous mass wasting events in west Jefferson County, causing significant tributary and river channel changes, sedimentation, and scour (Smith, 2000).

3.3.1.2 Topography and Bathymetry

Coniferous forest, high precipitation, and large rivers characterize Jefferson County west of the Olympic Mountains. Some of the largest trees in the world grow here in a temperate rainforest ecosystem. Larger rivers such as the Hoh, Queets, and Quinault are glacially fed at their headwaters. In their lower reaches these rivers meander over large floodplains. The landscape is generally hilly in the west but rises dramatically to the east in the Olympic Mountains. Although the Olympic Mountains are not particularly high (Mt. Olympus is the tallest peak at 7,969 feet above sea level), these mountains are rugged and composed of relatively recent metamorphic rock. The broad, hilly country between the Olympic Mountains and the Pacific Ocean has not been glaciated for at least the past 17,000 years (Abbe, 2000 as cited in Correa, 2002).

The landscape in eastern Jefferson County was shaped by repeated glaciations, the last retreating about 12,000 years ago. This left a landscape of layered glacial and outwash sediments (glacial till) with little exposed bedrock. The coastal shoreline of east Jefferson County is now characterized by bluffs carved out of these glacial sediments, often topped by Douglas-fir and hemlock forest. Several sizable rivers flow east out of the Olympic Mountains and into Hood Canal, providing salmon habitat and forming relatively large delta estuaries. Prairies occurred along Discovery Bay, on Protection Island, and in Port Townsend in the drier northeast section of the study area, but few remnants of this ecosystem exist today.

Similar to the glacially carved features that characterize the topography of eastern Jefferson County, the area's bathymetry was formed by glacial scouring and subglacial erosion. Glaciers and subglacial meltwater scoured channels and troughs (Booth, 1994). These interconnected, north-south trending basins dominate much of the marine environment of Puget Sound today. There are four major divisions in Puget Sound between these interconnected channels, which are marked by the presence of sills or submarine ridges that constrict water flow from one basin to the next.

The northern part of Jefferson County falls within the northernmost subbasin of the Main Basin in Puget Sound (Figure 3-6). The Main Basin originates at a shallow sill at the north end of Admiralty Inlet. The Main Basin is delimited to the north by a line between Point Wilson (near Port Townsend) and Partridge Point on Whidbey Island, to the south by Tacoma Narrows, and to the east by a line between Possession Point on Whidbey Island and Meadow Point (near Everett) (shown as Area 3 on Figure 3-6).

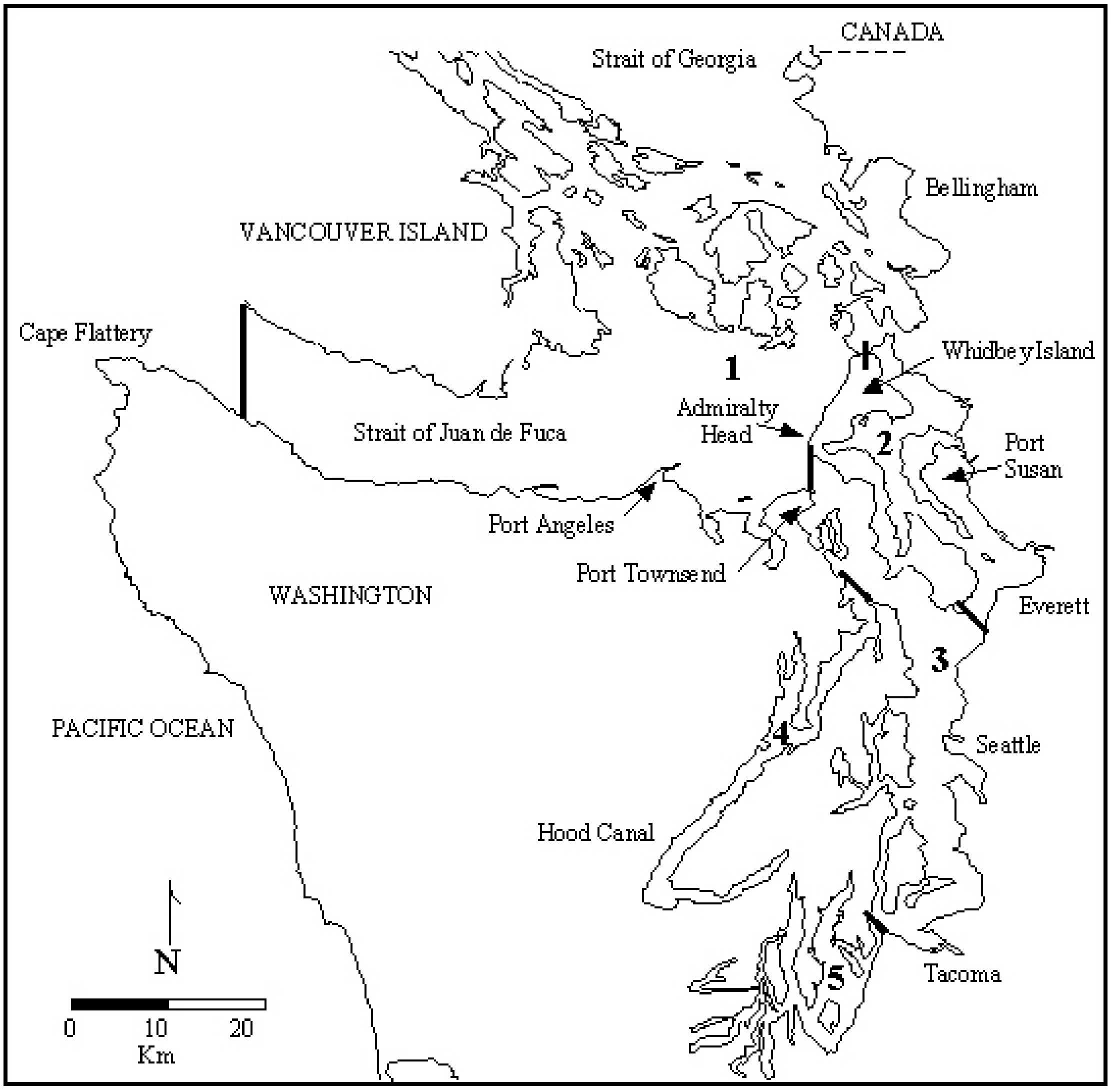
Deep, north-south trending basins (Admiralty Inlet, Hood Canal) and large bays (Port Townsend, Dabob, Quilcene and Discovery Bays) characterize the bathymetry of eastern Jefferson County. These basins and bays typically have deep water centrally and at the bay entrance, and shallower low-tide terraces close to shore, with river deltas near bay heads. Additionally, there are numerous smaller bays throughout the County that have more limited areas of deep water including Kilisut and Squamish Harbors, Oak and Thorndyke Bays, and Port Ludlow.

The predominant waterway of northern Jefferson County is the Strait of Juan de Fuca (shown as Area 1 on Figure 3-6). The deepest water in this portion of the study area is found between the entrance to Discovery Bay and Protection Island. Shallow Dallas Bank is located on the north side of Protection Island (12 to 54 feet deep). The shores on the Strait near Port Townsend possess broad sand flats and shallow water adjacent to shore, with considerably deeper water found farther offshore.

Admiralty Inlet marks the northern end of the Main Basin in Puget Sound, which extends approximately 62 miles from Point Wilson (near Port Townsend) to the Tacoma Narrows. The sill at the north end of Admiralty Inlet is 18.6 miles wide and is 213 feet deep at its shallowest point. Deep water is found immediately south of the sill (330 to 450 feet deep).

Hood Canal branches off Admiralty Inlet between Tala Point and Foulweather Bluff, and is the smallest of the Puget Sound area basins, being 56 miles long and 0.5 to 2.0 miles wide (shown as Area 4 on Figure 3-6). Like many of the other basins, it is partially isolated by a sill (164 feet deep), which is located between South Point and Lofall. The deepest water in the basin (over 617 feet deep) is found in central Dabob Bay. Generally, water depths in Hood Canal range from 138 to 348 feet.

Figure 3-6. Regional Water Masses and Subareas of Puget Sound: (1) Northern Puget Sound, (2) Whidbey Basin, (3) Main Basin, (4) Hood Canal, and (5) Southern Basin (Gustafson et al., 2000)



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3.3.1.3 Geology

Bedrock Geology

Bedrock at the coast of eastern Jefferson County was mapped as several different units that were originally deposited during the Cretaceous Period (66 to 146 million years ago). Exposed bedrock in the southern portion of the study area is part of the Crescent Formation, consisting primarily of Eocene basalt, deposited within the last 66 million years (Whetten et al., 1988; Ecology, 1978). Crescent Formation rocks are exposed along the northern, eastern, and southeastern flanks of the Olympic Mountains (Tabor and Cady, 1978). Basalt outcrops exist at the coast in southern Port Ludlow Bay and east of Mats Mats Bay, extending up to Olele Point. Basalt appears black or near black with reddish portions near the top of flows where oxidation has occurred. Basalt flows are characterized by closely spaced, random joints, and contain rare pillow lavas (Tabor and Cady, 1978). Basalt was deposited as massive flows and breccia (Whetten et al., 1988), and is also found in conglomerate along the east shore of Discovery Bay (Tabor and Cady, 1978). Basalt is a crystalline rock and is very resistant to erosion; erosion of the intertidal basalt has advanced generally less than 20 to 40 feet in approximately 4,500 to 5,000 years.

The Oak Bay and southernmost Port Townsend Bay shores contain outcrops of Quimper sandstone. This unit is gray to olive gray, fine to coarse grained, feldspathic sandstone that weathers yellowish brown (Whetten et al., 1988). Quimper sandstone contains minor siltstone beds and spherical to elliptical calcareous concretions as large as 1 foot in diameter. Quimper sandstone is quite resistant to marine erosion, but sea cliffs have eroded at a considerably higher rate than the more resistant basalt cliffs.

Unconsolidated Geologic Deposits

The Cordillera Ice Sheet advanced into and retreated from western Washington at least six times during the Pleistocene Epoch, within the last 24 million years (Easterbrook, 1986). Characteristics of the advance and retreat of the six known glaciations in the Puget Lowland show a very similar pattern (Easterbrook, 1992), especially during the three most recent glaciations that deposited stratigraphic sequences in eastern Jefferson County: the Double Bluff, Possession, and Fraser glaciations. Glacial advances typically began by the spreading of an apron of outwash in front of the advancing ice. Advance outwash deposits were deeply scoured by overriding ice, incorporating pebbles and cobbles that were already rounded into till that was deposited upon the truncated outwash sediment (Easterbrook, 1992).

The Double Bluff glaciation is the oldest known glacial deposit in the northern Puget Lowland. Evidence of glacial advance is present in exposures of Double Bluff Drift at its type locality at southwestern Whidbey Island and in bluffs in Hood Canal. Double Bluff Drift consists of glaciofluvial gravel, sand and silt, till, and glaciomarine drift (Easterbrook, 1969). The Double Bluff glaciomarine drift is dated at 150,000 to 200,000 years ago (Blunt et al., 1987; Easterbrook, 1992).

Non-glacial fluvial, peat, and lacustrine sediments of the Whidbey Formation are also exposed in bluffs between Port Townsend and Hood Canal. This formation was deposited during the Whidbey Interglaciation and overlies Double Bluff Drift. The Possession Drift of the Possession glaciation was deposited upon a surface of moderate relief, either on outwash sand and gravel or on the Whidbey Formation (Easterbrook, 1992). At its type locality on southeastern Whidbey Island, the Possession Drift consists of compact, sandy till, sand and gravel, and stony clay glaciomarine drift (Easterbrook, 1969). Possession Drift is exposed near Mats Mats Bay.

The most recent glacial advance into the Puget Lowland was the Vashon Stade of the Fraser glaciation. This followed the Olympia nonglacial interval during which floodplain and lacustrine silt, clay, and peat were deposited between 22,000 and 28,000 years ago in the central Puget Lowland (Hanson and Easterbrook, 1974). In the early stages of the Vashon Stade (16,000 to 18,000 years ago), meltwater streams delivered large quantities of outwash sand and gravel from the glacier terminus, creating a thick sequence of advance outwash sand and gravel deposits (Easterbrook, 1969). Advance outwash deposits are composed mostly of pebbly sand with cross bedding and scour-and-fill features. Advance outwash deposits are common in high bluffs underlying Vashon till, and provide abundant beach-forming sediment to the nearshore system.

The advance of the most recent continental ice sheet, in the Vashon Stade, deposited abundant till over advance outwash deposits. Glacial ice reached a maximum thickness of approximately 4,000 feet in the study area (Easterbrook, 1969). Vashon till, which is very common in the County, is a relatively high-strength deposit, having been compacted by the full thickness of the glacial ice sheet. Till can stand in very steep bluffs for extended periods of time, such as in the bluff at the Port Townsend ferry landing. Till appears as tan to light gray with pebbles among a fine grain matrix (diamicton). Late stage Vashon deposits in the study area include recessional-continental deposits that contain ice-contact deposits and outwash deposits (Pessl et al., 1989). Recessional-continental deposits contain sand, gravel, and silt in meltwater deposits that are generally very low strength and relatively thin beds. Deposits from the Vashon Stade are preserved in extensive unconsolidated deposits exposed in the upper parts of coastal bluffs throughout most of the study area. Bedrock outcrops are commonly overlain by a mantle of glacial deposits of varying thickness.

From the Strait of Juan de Fuca south to Quilcene Bay, the beaches generally have two similar sets of characteristics: either exposed high bluffs (composed primarily of glacial deposits) with mixed sediment beaches, or protected bays with moderate amounts of riparian and marsh vegetation. Both of these settings include expanses of undeveloped shores with clusters of residential and/or commercial development. The shores of southeastern Jefferson County are of differing geology, and are composed of a mix of glacial and non-glacially derived deposits. The relatively erosion-resistant basalt and marine sedimentary strata (notably along Hood Canal in the vicinity of Brinnon and the Olele Point area north of Port Ludlow) control the nearshore character and coastal processes, which will be discussed in more detail in the reach descriptions (Chapter 4).

3.3.2 Shoreline Processes, Process-intensive Areas, and Alterations

3.3.2.1 Nearshore Processes

Key processes at work in the marine nearshore environment are described below. These processes form the physical shape of the shoreline, influence nutrient dynamics, and create the other biogeochemical conditions that sustain the marine ecosystem. Emphasis is on processes affecting the shores of Puget Sound in eastern Jefferson County since the western coastal areas are outside of County shoreline jurisdiction. Much of the information described in text is depicted on maps 2 though 7 in Appendix C (Table 3-3). The reach-scale maps referenced in Chapter 4 and shown in Table 3-1 also depict some of the features discussed below.

Table 3-3. Map Locations for Ecosystem-scale Attributes, including Nearshore and Freshwater Process-intensive Areas and Alterations

Theme	Map Name/ No.
Permeability Channel Migration Zones (CMZ) Land Cover (early and late seral stage vegetation; human imprint)	Maps 2 and 3. Hydrology (Key areas and Alterations)
Septic Permits Tilled Fields Lost Wetlands Human Imprint	Maps 4 and 5. Water Quality (Key areas and Alterations)
Hydrology / Streams and Lakes WRIA Boundaries Watershed Boundary Road Density LSI Landslides Landslide Hazard Zonation Erodible Soils	Maps 6 and 7. Sediment (Key areas and Alterations)

This section discusses:

- Circulation processes, including tides and currents,
- Water quality processes for nitrogen, phosphorus, and pathogens,
- Beach processes including coastal erosion, net shore-drift, coastal bluff landslides, and fluvial influences, and
- Climate change including temperature, precipitation and runoff, and sea level rise.

Circulation

Eastern Jefferson County oceanographic processes are characteristic of the normal mean circulation pattern in a fjordal estuary, with seaward flow at the surface and landward flow at depth. Fresh water derived from local rivers typically flows seaward at the surface, since these water masses are of lower salinity and warmer (hence, less dense) than incoming ocean water. Colder, more saline water originating from the Pacific Ocean flows landward along the bottom (Nightingale, 2000). The combined forces of lunar influence, winds, and bathymetry determine the extent to which these layers are mixed. During neap tides (when the moon is in the first and last quarters) when the tidal range is smallest, seawater intrusions and the influx of saltier water to Puget Sound are greatest. However, during spring tides (that occur with the new and full moon), higher velocity tidal currents result in increased mixing of fresh and salt water (Nightingale, 2000).

A temperature, salinity, and density difference between freshwater runoff and nutrient upwelling from ocean water determines the extent of mixing. This is influenced strongly by the force exerted on the water surface by wind (Nightingale, 2000). Because the variables that drive circulation exhibit considerable spatial variability across the marine landscape, the degree of mixing can vary significantly across small distances. For example, strong winds, deep water, ocean intrusions, and currents coupled with riverine inputs result in the Strait of Juan de Fuca being well-mixed with cold and nutrient rich water year-round. The presence of a shallow sill at the entrance to Admiralty Inlet magnifies the extent of the mixing. This strong mixing zone produces well-mixed water in Port Townsend Bay, with higher levels of dissolved oxygen than inlets and bays outside of the influence of the Admiralty Inlet sill (Nightingale, 2000; Strickland, 1983).

In contrast, neighboring Discovery Bay is persistently stratified with colder, saltier, and denser water near the bottom and lower salinity and warmer water at the surface. The combined effect of bathymetry, low wind mixing, and low current exchange produces the seasonally stratified and poor flushing characteristics of Discovery Bay. This weak mixing and flushing produces low nutrient levels near the surface and low oxygen levels near the bottom (Newton et al., 1998; Strickland, 1983). A similar condition exists in Hood Canal where seawater density stratification, poor flushing and circulation, and high levels of organic production contribute to low-oxygen conditions (Fagergren et al., 2004; HCDOP, 2006).

Tides and Currents

A portion of the marine water originating from the Pacific Ocean enters through the Strait of Juan de Fuca then diverges south into the inlets and bays of eastern Jefferson County. Similar to the rest of Puget Sound, tides in eastern Jefferson County are semi-diurnal, exhibiting two unequal high and two unequal low tides per day.

Tidal currents are moderate throughout the larger straits, but become increasingly strong when water funnels through constrictions such as at Admiralty Inlet. The strongest tidal currents observed in the study area are found at Point Wilson (4.8 to 5.5 knots) and Admiralty Inlet (approximately 4 knots). Lesser tidal currents have been measured near Olele Point (1.6 knots) and Foulweather Bluff (1.3 knots).

The Strait of Juan de Fuca is a wind-dominated system, with currents changing dramatically within hours in response to both regional and larger scale oceanic winds. Strong seasonal storms contribute pulses of both fresh water and sediment to the Strait of Juan de Fuca. These pulses form large lenses of very low salinity and very high turbidity within the nearshore zone along the majority of the shoreline of the Strait of Juan de Fuca. These lenses appear to occur primarily during winter and spring months (Shaffer and Crain, 2004 as cited in PSAT, 2005).

Water Quality

Nutrients (Nitrogen and Phosphorus)

The nearshore and marine waters of Jefferson County receive inputs of nutrients and organic matter from adjacent uplands, streams, rivers, and groundwater seeps, as well as from nearshore bottom sediments and mixing with deeper ocean waters via upwelling and estuarine circulation. In general, inputs from natural sources of nitrogen and phosphorus are several orders of magnitude greater than anthropogenic sources in Puget Sound (Harrison et al., 1994). However, in some areas, including Hood Canal, anthropogenic inputs have been shown to far exceed what can be contributed naturally (Fagergren et al., 2004).

Nutrient loads from streams and rivers entering the nearshore are affected by the magnitude of river discharge, as well as watershed land uses. Major human sources of nutrients from upland areas include agricultural operations (animal manure, fertilizers), wastewater treatment plants, and stormwater runoff from residential landscapes (Embrey and Inkpen, 1998 as cited in Fagergren et al., 2004). Major anthropogenic sources of nutrients in Hood Canal include human sewage, stormwater runoff, chum salmon carcasses from hatchery returns, agricultural waste, and forestry (Fagergren et al., 2004).

In enclosed bays or inlets, or during periods of greater stratification and reduced circulation and mixing with oceanic waters, specific locations within Puget Sound can receive excess nutrients from anthropogenic sources. Nutrient levels in these protected waters (e.g., Hood Canal) can result in eutrophication and low levels of dissolved oxygen (hypoxia), which can be detrimental to marine organisms. Eutrophication can also lead to contamination of shellfish beds (including associated bacterial contamination) as well as negative impacts on riparian buffers and forage fish spawning; critical salmonid, shorebird and seabird nesting and foraging; and marine mammal foraging, migration, and haulout habitats. Nearshore areas of Jefferson County that are susceptible to eutrophication from increased nutrient inputs, or from stratification that can locally concentrate nutrients, include Hood Canal and enclosed bays such as Mats Mats Bay, Kilisut Harbor, and Discovery Bay.

The same processes that control nutrient inputs, dispersion, and areas of concentration also influence inputs and concentrations of pathogens, pollutants, and toxins in nearshore waters of Jefferson County. Water quality impairments are described in the reach analyses (Chapter 4).

Riparian buffers offer discernible water quality protection from nearshore nutrient sources. The effectiveness of riparian buffers for protecting water quality depends on a number of factors, including soil type, vegetation type, slope, annual rainfall, type and level of pollution, surrounding land uses, and sufficient buffer width and integrity. Soil stability and sediment control are directly related to the amount of impervious surface and vegetated cover. Soil quality is typically degraded in developed areas where riparian vegetation has been removed and soils have been compacted (May, 2003). Water that is not absorbed or intercepted by vegetation will increase the potential for landslides. Runoff over the surface can lead to erosion, siltation, burial of aquatic environs, and introduction of contaminants into water. Pollutants such as excess nutrients, metals, and organic chemicals are commonly found in stormwater and agricultural runoff, usually in particulate form. Sediment control therefore often removes a large percentage of the pollutant load as well (May, 2000).

Pathogens

This report focuses on fecal coliform as an indicator of pathogens because it is the most commonly occurring pathogen and because it is monitored in Ecology water quality studies. Fecal coliform bacteria signal the possible presence of feces and pathogenic organisms, yet there is growing concern that they do not reliably predict the occurrence and survival of enteric viruses and other pathogens in the marine environment (Glasoe and Christy, 2004). Human sources of fecal matter and associated pathogens include but are not limited to septic systems built on or near marine and estuarine shorelines, marina and boating activities, and pet waste.

Beach Processes and Coastal Erosion

Eastern Jefferson County beaches represent a commonly occurring beach character found in northern Puget Sound, with two distinct foreshore components: a high-tide beach and a low-tide terrace (Downing ,1983; Johannessen, 1993). The high-tide beach consists of a relatively steep beach face with coarse sediment and an abrupt break in slope at its waterward extent. Sand in a mixed sand and gravel beach is typically winnowed from the high-tide beach by waves (Chu, 1985) and deposited on the low-tide terrace. Extending seaward from the break in slope, the low-tide terrace typically consists of a gently sloping accumulation of poorly sorted, fine-grained sediment (Komar, 1976; Keuler, 1979). Lag deposits derived from bluff recession are also found in the low-tide terrace. These deposits are typically composed of larger clasts, ranging from cobbles to boulders.

Puget Sound area beach composition is dependent upon three main influences: wave energy, sediment sources, and relative position of the beach within a littoral cell. Wave energy is controlled by fetch, or the open water over which winds blow without any interference from land. Within the Jefferson County study area, the maximum fetch at some Strait of Juan de Fuca sites such as Fort Worden is essentially unlimited to the west (including the Strait of Juan de Fuca, west across the Pacific Ocean). Fetch from the north is greatest at Admiralty Inlet (to the Gulf Islands), and measures approximately 49 miles. Southerly fetch measures 28.5 miles from Hood Canal to Dabob Bay. Though southerly fetch measures the least at some of the County shores, winds and waves originating from the south are the strongest (predominant) and most frequent (prevailing) wind direction in Puget Sound. WDNR's ShoreZone Inventory classified most of the beaches in eastern Jefferson County as "semi-protected" (40.3 percent), "protected" (26.7 percent), and "very exposed" (19.2 percent). Fewer beaches were rated as "semi-exposed" (5.7 percent) and/or "very protected" (8.1 percent) (WDNR, 2001).

Wind-generated waves intermittently erode beaches and the toe of coastal bluffs, contributing to the initiation of bluff landslides. These coastal bluffs (referred to as feeder bluffs or contributing bluffs) are the primary source of sediment for most Puget Sound beaches, including the Jefferson County study area (Keuler, 1988; Downing, 1983). Bluff composition and wave energy influence the composition of beach sediment. Waves sort coarse and fine sediment, and large waves can transport cobbles that small waves cannot. Additionally, beaches supplied by the erosion of coarse gravel bluffs differ in composition from those fed by the erosion of sandy material. The exposed strata of the eroding bluffs in the study area are largely composed of sand, gravel, and silt (WDNR, 2001; Ecology, 1978). These same materials dominate sediment found on the beaches, with the exception of fine sand through clay, which are winnowed from the beach face and deposited in low-tide terraces and in deeper water.

In addition to the previously mentioned influences (wave energy and sediment sources), tidal range also affects beaches over time. Rosen (1977) demonstrated that, with other parameters equal, coastal erosion rates tend to increase with decreasing tidal range. This is due to the focusing of wave energy at a narrow vertical band with small tidal range, in comparison to the dissipation of wave energy over a large vertical band with a greater tidal range. The northeastern portion of the County, from the Strait of Juan de Fuca to Point Hannon (Hood Head), has a tidal range (MLLW to MHHW) on the order of 7.9 to 9.4 feet, which is considered to be *mesotidal* (2 to 4 meter range). The Hood Canal area of Jefferson County has a greater tidal range of 9.9 to 11.4 feet, which is in the upper range of *mesotidal*. This means that wave erosion, under the same wave conditions, would be greater in the Strait of Juan de Fuca, and progressively less into Hood Canal. This is because the wave energy is focused on the upper beach and bluff toe less of the time. When the greater wave energy at the Strait of Juan de Fuca is factored in, coastal erosion rates would be expected to be substantially greater in the Strait.

The majority of coastal erosion in the region occurs when high-wind events coincide with high tides and act directly on the backshore and bluffs (Downing, 1983). Most coastal landsliding occurs during and following prolonged high-precipitation periods in the winter (Tubbs, 1974; Gerstel et al., 1997; Shipman, 2004).

Net Shore-drift

Wind-generated waves typically approach the shore at an angle, creating beach drift and longshore currents and transporting sediment by a process called littoral drift. *Net shore-drift* refers to the long-term, net result of littoral drift. Net shore-drift cells represent a sediment transport sector from source area to deposition area along a reach of coast.

Each drift cell acts as a system consisting of three components: a sediment source (erosional feature) and origin of a drift cell; a transport zone where sediment is moved alongshore by wave action with minimal sediment input; and a deposition zone often creating spits or barrier beaches. The deposition area is the drift cell terminus. Deposition of sediment occurs where wave energy is no longer sufficient to transport the sediment in the drift cell.

This process of net shore-drift transporting sediment over time from a feeder bluff to a depositional shoreform creates unique drift cells—stretches of shoreline where sediment flow is essentially isolated from adjacent stretches of shoreline. Properly functioning drift cells are essential for creating and maintaining nearshore habitats for salmon, shellfish, and other species. Thus, drift cells are useful for planners to divide the shore into manageable, coherent reaches for characterization and management. Drift cells in the Puget Sound-Strait of Juan de Fuca region range in length from hundreds of feet to 5 miles or more.

Net shore-drift cells were mapped in eastern Jefferson County several times by different scientists. Mapping was performed by Ralph Keuler (1988) for the USGS in the early 1980s (Figure 3-7, see also Maps 11 and 12 in Appendix C). However, Keuler's mapping effort did not encompass the entire County; it extended only to northern Oak Bay. Johannessen (1992) completed a net shore-drift study of San Juan County and parts of Jefferson, Island, and Snohomish Counties for Ecology's Shorelands Division. This included southeast Jefferson County up to Oak Bay. This information was published as a compendium to the larger net shore-drift compilation by Schwartz et al. (1991).

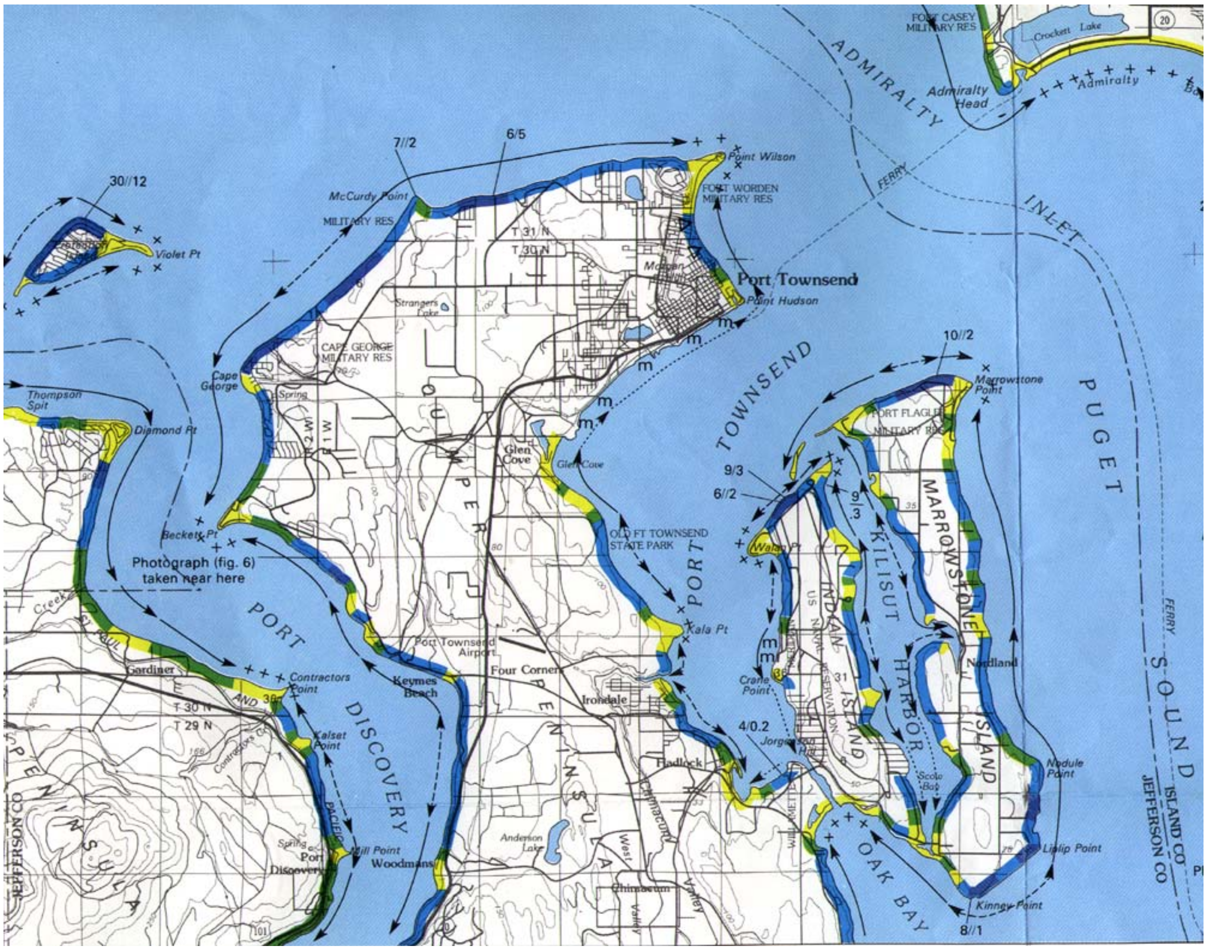
The Johannessen net shore-drift study was conducted through systematic field investigations of the entire coast to identify geomorphologic and sediment indicators that revealed net shore-drift cells and drift direction (Jacobsen and Schwartz, 1981). The net shore-drift mapping methods employed by Keuler and Johannessen used well-documented, isolated indicators of net shore-drift in a systematic fashion.

The first drift cell mapping effort was completed in the late 1970s as part of the Coastal Zone Atlas of Washington series (Ecology, 1978). The methods used in that study differed greatly from those applied by Johannessen and Keuler in that the Atlas relied exclusively on limited historic wind records. Recently, Ecology digitized the Johannessen and Keuler net shore-drift mapping, but the mapping was not technically reviewed and numerous errors and misinterpretations exist in the digital dataset. As a result, Coastal Geologic Services (CGS) reviewed and edited the eastern Jefferson County mapping, which is now as accurate as the original mapping allows without conducting new field or photographic investigations.

Eastern Jefferson County contains 52 net shore-drift cells and 7 regions of negligible net shore-drift (Maps 11 and 12). The general patterns of sediment transport through net shore-drift and sediment sources and depositional areas will be described in the individual reach descriptions (Chapter 4). In general, shores that are exposed to southerly wind and waves typically have northward net shore-drift. Shores that have substantial greater exposure to the northwest or north typically have eastward or southward drift. At the north-facing shores along the Strait of Juan de Fuca, easterly net shore-drift generally occurs due to substantial fetch from the west. Due to local variations in the north-south trending topography of the eastern Jefferson County marine landscape, there are some localized exceptions to these patterns such as at Olele Point and Whitney Point.

In eastern Jefferson County, there are areas where resistant basalt and sandstone (described above) are found at the coast, notably along Hood Canal south of Quilcene Bay and near the Olele Point area north of Port Ludlow, where there is little or no net shore-drift of sediment.

Figure 3-7. Net Shore-drift Mapping for Northeastern Jefferson County (from Keuler, 1988)



Coastal Bluff Landslides

The erosion of glacial and non-glacial sedimentary deposits has created high-elevation, often unstable bluffs along the shores of much of eastern Jefferson County. According to Ecology's recently digitized slope stability mapping (based on the 1970s Coastal Zone Atlas), 83 historic landslides were identified in the Jefferson County study area. Recent landslides were mapped at 327 locations. The greatest density of slides was found along the east and west shores of the Toandos Peninsula, east and west Marrowstone Island, north Indian Island, north of Point Ludlow, Point Wilson to Cape George, northeast Discovery Bay, and from Port Townsend to Kala Point. Landslides were also observed in higher density around the following headlands: Quatsap Point, Fisherman's Point, Termination Point, Point Hannon to Tala Point, Kinney Point, and South Point (Maps 26 and 27).

Coastal landslides contribute the majority of sediment input to the beach and net shore-drift system. Coastal landslides typically occur during periods of high precipitation, on bluffs where a combination of characteristics makes the bluff vulnerable to slope failure (Tubbs, 1974). These characteristics include the underlying geology of a bluff or bank, its level of exposure (fetch), the local hydrology (groundwater and surface water), and the extent of development impacts

(Hampton et al., 2004). Many Jefferson County bluffs are quite susceptible to coastal landslides as a result of wave exposure.

Undercutting of the toe of the bluff is usually the long-term “driver” of bluff recession (Keuler, 1988). Windstorms that create significant wave attack of the bluff toe can directly trigger bluff failures. Bluffs that are exposed to greater fetch are subject to higher wave energy during storms, resulting in greater toe erosion and bluff undercutting, and thus more frequent landslides (Shipman, 2004). More commonly, toe erosion precedes bluff landslides by a period of years, as bluff instability gradually progresses up the slopes. Bulkheads reduce wave attack to bluff toes and reduce or eliminate undercutting, but can accelerate erosion of the beach.

Storms that coincide with elevated water levels, such as a storm surge or extraordinary high-high tide, can produce dramatic toe erosion. An example of this was the February 4, 2006 windstorm, which brought near record high water levels coincident with 45 to 50 knot winds. Waves reached bluff toes during this storm where this had not occurred for many years and undermined reaches of bluff that may not fail (slide) until subsequent high-precipitation periods (Thorsen, 1987). Exposed bluffs composed of glacial drift south of Port Townsend typically experience long-term, mean erosion rates of 1.5 to 4 inches per year (Keuler, 1988), and bluffs farther west have little data for erosion rates. Coastal erosion rates are contingent on the position of a particular site within a net shore-drift cell, as described above.

Landslides are more likely to occur in areas where there is a history of landslides, or where the bluff strata are composed of an unconsolidated, permeable layer (sand), underlain by a relatively impermeable layer (such as dense silt or clay) (Gerstel et al., 1997). As water seeps through the permeable layer and collects above the impermeable layer, a zone of weakness or “slip-plane” is created. This stratigraphic pattern is a typical initiator of mass wasting (including landslides, but also including larger deep-seated failures). This bluff configuration is fairly common in eastern Jefferson County.

Abundant glacially derived sediment, delivered via landslides or eroded from bluffs, creates beaches primarily composed of sand and pea gravel overlying cobble. Sand lance and surf smelt (referred to as forage fish) prefer to spawn on beaches of mixed sand and pea gravel (Penttila, 2000). Eelgrass beds offshore depend on sediment high in sand and pea gravel and are not able to thrive in small sediment-deprived systems dominated by cobble (Hirschi, 1999). Salmon rely on forage fish for food, gently sloping beaches as safe havens from predators during migration, and eelgrass beds for cover and foraging habitat (Groot and Margolis, 1991).

Bluff-top trees are favorite spots for nesting and perching by bald eagles. Overhanging vegetation provides shade for surf smelt and sand lance eggs, serves as a source of terrestrial insects for consumption by marine fishes, and provides cover at high tide (Brennan and Culverwell, 2004).

A substantial quantity of seepage has been observed in some eastern Jefferson County bluffs including along Discovery Bay and Oak Bay. The highest volumes of groundwater observed seeping from the bluff face typically occur following prolonged heavy precipitation. Periods of high rainfall intensity and duration (especially during saturated soil conditions) are the most common trigger of coastal landslides (Tubbs, 1974), such as those observed during the New Year of 1996-97 (Gerstel et al., 1997; Shipman, 2001).

Fluvial Influences on the Nearshore

Fluvial sources (rivers and streams) contribute to nearshore character and can act as an agent of change on the marine landscape. Though most river sediment reaching the coast is initially deposited in deltas, much of the sediment is transported beyond beaches and deposited on delta fronts and in deeper water. This is the case because fluvial sediment is often too fine to remain in the nearshore due to prevailing wave regimes. Downing (1983) stated that 90 percent of river-borne sediment input to the Puget Lowland is too fine to remain in nearshore systems. The coarse grain portion of the sediment yield from rivers and streams is typically transported alongshore in net shore-drift cells, such as at the mouth of the Dosewallips and the Duckabush Rivers. However, some areas have net shore-drift cells converging on stream mouths, such as at the head of Dabob, Quilcene and Discovery Bays, and at Chimacum Creek (Maps 11-14). As stated previously, the majority of beach sediment is derived from recession of unconsolidated bluffs.

The quantity and quality of fluvial sediment delivered to the nearshore depends on the nature of the upland: its elevation, the types of rocks and soil found there, the density of vegetation, and the climate (Komar, 1976). The greater the volume of sediment, the greater the influence on nearshore processes. Some of the larger fluvial systems influencing nearshore processes include McDonald Creek, the Little and Big Quilcene Rivers, the Dosewallips River, the Duckabush River, and Snow and Salmon Creeks. When lower portions of river systems are diked or cut off from depositional floodplains, excessive fluvial sediment is often deposited at the river mouth, forming a prograded river delta and damaging valuable estuarine habitat.

Fluvial systems influence the nearshore by locally decreasing the salinity of the water, and by providing sediment to local beaches, which can aid in the formation of ecologically valuable habitats including marshes, distributary channels, shallow water deltaic habitats, and sand and mudflats. Fluvial influences also affect the abundance and density of aquatic flora (e.g., eelgrass) and fauna. Altered littoral drift patterns can be caused by the river or stream discharge into the nearshore. These altered conditions commonly lead to the deposition of alongshore bars or shoals and heightened shoreline complexity. Features such as these can be permanent or ephemeral, displaying seasonal dynamics concurrent with changes in discharge and wave conditions.

Global Climate Change

Over time, global climate change will undoubtedly impact Jefferson County’s shorelines. Effects are likely to be most pronounced on, but not limited to, nearshore areas. The United Nations Intergovernmental Panel on Climate Change (2007) concluded that, “Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level.”

Researchers at the University of Washington’s Climate Impacts Group and others have devoted significant effort to modeling potential effects of climate change on the Pacific Northwest in particular. They note that even if all carbon dioxide emissions were halted today, ambient atmospheric concentrations would continue to change climate conditions in the Puget Sound region for many decades, without taking projected emission increases into account (Snover et al., 2005 as cited in King County, 2006). A great deal of uncertainty exists as to the magnitude, precise timing, and extent of climate change impacts in the Puget Sound region. What is certain, however, is that impacts will occur. Developing plans and taking action now will serve to minimize harm to human communities and natural resources in the future.

The Intergovernmental Panel on Climate Change predicts that between 1990 and 2100, average global surface temperature could increase from 2.5 to 10.4^{o}F, and global sea level could rise between 4 and 35 inches, depending on both the rate of natural changes and the response of the climate system to greenhouse gas emissions now and in the future (IPCC, 2006 as cited in King County, 2006). Increasing temperatures and sea levels are likely to impact shorelines of Jefferson County in multiple ways, as described below.

Temperature

Casola et al. (2005a) note that Washington has already experienced climate change over the past century. Average surface air temperature has increased by approximately 1.5^{o}F. Snowpack has declined over the past 80 years, particularly at low elevations. The onset of snowmelt and peak stream flows in snow-fed rivers occurs earlier in the year, and many plants bloom earlier. Hydrologic models also indicate that spring soil moisture has been increasing, though no direct observations are available (Casola et al., 2005a).

Over time, Washington is likely to face an increase in temperature across all seasons (Casola et al., 2005a). Pacific Northwest average temperatures are likely to rise between 2.5 and 3.7^{o}F by the 2020s, and additional increases between 3.1 and 5.3^{o}F for the 2040s. Along with air temperatures, water temperatures are also expected to increase. These projected environmental changes may create inhospitable conditions for coldwater fish species (salmon, trout) in lakes, rivers, and salt water, potentially beyond those species' ability to adapt. Lake and ocean stratification may also increase along with temperatures, reducing available nutrients and increasing competition among fish species in those environments. Additionally, areas of Puget Sound that are already suffering from low dissolved oxygen levels (e.g., Hood Canal) may be further impaired with rising air and water temperatures (Casola et al., 2005a).

Snover et al. (2005, as cited in King County, 2006) note that some marine plant species, such as eelgrass and bull kelp, appear to have a narrow range of tolerance for water temperature and may suffer as a result of projected temperature increases. In turn, changes in those communities could alter habitat for other species that are not substantially affected by moderate water temperature increases, but that depend on bull kelp and eelgrass for food, shelter, or nesting sites.

Casola et al. (2005a) emphasize that the unusual life cycle of Pacific salmon species might make them particularly sensitive to air and water temperature changes. High summer stream temperatures could create thermal barriers to upstream migration of adult salmon, in addition to stressing juvenile salmon rearing in those streams. Reduced winter snowpack and runoff occurring earlier in the season may increase the frequency of redd-scouring events and prevent juvenile salmon from being flushed to salt water in runoff. In salt water, higher water temperatures or altered currents may affect the availability of food and change the distribution of predators, though impacts of climate change on these factors are not well understood (Casola et al., 2005a).

Marine and freshwater systems may also see changes in planktonic communities as water temperatures increase (King County, 2006). Prolonged periods of warm temperatures in shallow water favor several groups of organisms, including bluegreen cyanobacteria, some of which make substances that are toxic to people and animals; dinoflagellates, some of which make toxins that cause red tides; and chlorophyte algae, some of which form large filamentous masses that cover rocks and structures (King County, 2006).

Precipitation and Runoff

Models predicting precipitation levels in response to a changing climate are somewhat uncertain, as precipitation is influenced by many factors that are not well understood (Casola et al., 2005a). However, most models predict that climate change during the 21st century is likely to result in more precipitation throughout Washington, with most increases occurring from October through March. Warmer temperatures will cause more of this precipitation to fall as rain rather than snow, resulting in reduced snowpack and changes in the timing of spring runoff (Casola et al., 2005a).

Streamflow, stormwater runoff, and water temperature will all likely be affected by changes in air temperature and precipitation (Casola et al., 2005a). With regard to streamflow, Casola et al. (2005a) predict varying impacts depending on whether a stream is fed primarily by snowmelt or rainfall. Coastal rivers at low elevations (e.g., the Hoh River) exhibit flow volumes closely tied to seasonal precipitation patterns; winter flows in these systems are thus likely to increase along with precipitation during winter months. Rivers draining intermediate “transient snow zone” elevations (e.g., the Quinault River) are more sensitive to the percentage of winter precipitation falling as snow, and typically run at peak flows during November and December and again during spring runoff. These rivers are likely to see an increase in “wet season” flows as rainfall increases, reduced spring and summer flows, and an earlier occurrence of runoff. Projected average flows in the Quinault River after 2040, for example, are 4,000 to 5,000 cubic feet per second (cfs) higher in December than current average flows, while average flows in June after 2040 may be 3,000 to 4,000 cfs lower than current average flows. Moderate floods are also expected to increase in basins dominated by transient snow zones, though large floods are expected to occur at approximately the same frequency as they do today (Casola et al., 2005a).

Summer base flows in river systems that depend on snowmelt may become lower as temperatures warm and snowpack decreases toward mid-century (King County, 2006). Peak runoff will also likely occur earlier in the spring. This has the potential to greatly impact fish and other biota adapted to coldwater habitat during the warm, dry months of summer (King County, 2006).

In its Draft Shoreline Inventory Report, King County (2006) notes that, “while many predictions of the future have a degree of uncertainty, the temperature and precipitation predictions are based on much more rigorous and well understood scientific data and relationships for their conclusions than many predictions of the biological impacts.”

Sea Level Rise

The Intergovernmental Panel on Climate Change (IPCC) estimates that sea levels will rise between 4 and 35 inches by 2100 (IPCC, 2006 as cited in King County, 2006). In Olympia, land subsidence is already responsible for a sea level rise of approximately 1 foot per century. Coupled with climate change, this may cause port district inundation and central business district flooding in the future (Casola et al. 2005b).

Casola et al. (2005b) note a number of ways in which climate change might affect sea levels and coastlines of Washington State. Rising sea levels could increase coastal flooding and erosion, particularly at flat beaches and in areas of tectonic subsidence. Shoreline armoring in many areas may have to be enhanced to protect infrastructure, while development and housing in other areas may simply have to be abandoned or moved in response to flooding. The occurrence of landslides and freshwater flooding may also increase along with winter precipitation. Further development in coastal hazard areas could be discouraged in order to minimize additional risks to infrastructure in the future (Casola et al., 2005b).

Sea level rise also has the potential to considerably change shoreline jurisdiction geographic locations over time, as a sea level rise of up to 3 feet will cause a substantial movement of water inland (King County, 2006). This would have the potential to cause flooding of beachfront homes and associated property damage, in addition to significantly increasing erosion of feeder bluffs. Other ecological processes along coastlines are likely to be disrupted as well. Casola et al. (2005b) present a number of possible alternatives to address rising sea levels, including:

- Preserving ecological buffers to allow for inland beach migration;
- Enhancing shoreline protection while recognizing the negative consequences for shoreline habitat;
- Restoring wetlands for runoff and flood control;
- Monitoring for invasive species; and
- Creating a disaster relief plan for flooding and erosion events.

3.3.2.2 Nearshore Process-intensive Areas

Nearshore process-intensive areas are identified in this section. The process-intensive areas are discussed generally and then identified specifically for each WRIA. Process-intensive areas for water quality, coastal erosion, and beach processes in the Jefferson County study area often coincide (Table 3-4). In general, process-intensive areas include marine riparian areas, feeder bluffs, stream/river deltas, estuaries, accretionary landforms, and tidal inlets. These areas play a primary role in shaping and maintaining critical nearshore habitat including eelgrass meadows, kelp forests, mudflats, tidal marshes, sand spits, beaches and backshore, banks and bluffs, and marine riparian areas. These habitats in turn provide critical functions. For example, eelgrass meadows, kelp forests, flats, tidal marshes, sand spits, and riparian zones provide primary production. All habitat types support invertebrates and juvenile and adult fishes (including juvenile salmonids), and provide foraging and refuge opportunities for birds and other wildlife. The presence and maintenance of all of these habitats is completely dependent on continued bluff sediment input and the lack of disturbance to the net shore-drift system (Johannessen, 1999).

Several known factors cause these habitats stress, for example physical disturbances from shoreline armoring, marina construction, shading from overwater structures, contamination by chemicals, and competition from non-native species (King County DNR, 2001). Impacts of climate change were not analyzed as potential habitat stressors. (Alterations to nearshore processes are further discussed in the next section.)

Table 3-4. Processes and Process-intensive Areas in the Nearshore Zone

Process	Process-intensive Area	Description
Water quality, Coastal erosion	Marine riparian	Marine riparian areas play a role in nutrient cycling, sediment control, and heat/light inputs. Riparian scale processes affect wildlife habitat, microclimate, nutrient levels, fish prey production, shade, and habitat structure (Brennan and Culverwell, 2004). The effectiveness of riparian buffers for protecting water quality depends on soil type, vegetation type, slope, annual rainfall, type and level of pollution, surrounding land uses, and sufficient buffer width and integrity. Soil stability and sediment control are directly related to the amount of impervious surface and vegetated cover. Water that is not absorbed or intercepted by vegetation will increase potential for landslides, or run off the surface, which can lead to surficial erosion, siltation, burial of aquatic environs, and contamination of water. Pollutants such as excess nutrients, metals, and organic chemicals are commonly found in stormwater and agricultural runoff, usually in particulate form. Sediment control therefore often removes a large percentage of the pollutant load as well (May, 2000). For wildlife, the principal functions of riparian buffers are to provide habitat and travel corridors, microclimate regulation, organic input, and to ameliorate the impacts of human disturbance such as light and noise (Parametrix et al., 2005). Large woody debris from riparian sources provides potential nesting, roosting, refuge and foraging opportunities for wildlife; foraging, refuge, and spawning substrate for fishes; and foraging, refuge, spawning, and attachment substrate for aquatic invertebrates and algae.
Beach processes - Coastal erosion	Feeder bluffs	Drift cells are composed of feeder bluffs, transport zones, and accretionary zones. Feeder bluffs provide the beach sediment necessary to maintain critical habitats throughout the drift cell such as forage fish spawning areas and eelgrass beds, as well as the accretionary landforms at the end of a drift cell such as spits and pocket estuaries. Landslides, or run off the surface, can also contribute beach sediment to the nearshore which can lead to surficial erosion, siltation, burial of aquatic environs, and contamination of water. Spits and pocket estuaries often protect salt marsh habitat, which provides primary productivity, shelter and forage to a variety of species including juvenile salmonids. Tidal inlets (further discussed below) maintain circulation processes important for flushing spit/marsh complexes, maintaining water quality and nutrient dynamics for these critical habitats.

Process	Process-intensive Area	Description
Beach processes - Fluvial processes	Deltas	Deltas form at the mouth of streams and rivers where they enter the nearshore. As water enters the larger water body, streamflow velocity decreases and the stream loses capacity to carry most of the sediments and debris that were being transported in the stream. Deltas not only provide an additional source of sediment, organics, and LWD to the nearshore, but they generally provide habitat functions for salmonids including foraging, predator avoidance, physiological transition from fresh to salt water, and migratory corridors to marine feeding grounds (Simenstad et al., 1982). Other nearshore-dependent species also benefit from the habitat functions of deltas.
Beach processes - Circulation	Estuaries, tidal inlets, tidal marshes, lagoons, etc.	Estuaries are highly productive habitats that provide flood attenuation, nutrient retention and cycling, erosion/shoreline protection, food web support, and habitat structure/connectivity functions. Water circulation in an estuary has a fundamental influence on the functions of estuary habitat. Water movement from river flows, tides, and waves erodes and deposits sediments, conveys nutrients and organic material, and transports fish and prey items. Water movement also affects the physical shape and complexity of the estuary (e.g., slope, depth, connections to other habitats, size of the system, channel network, and landform) which affects habitat for shellfish, salmonids and other species. These same processes also create habitat features, such as pockets and bars within the estuary (Redman et al., 2005). Estuaries are important nurseries for outmigrating salmonid fry as they adjust to changing salinity levels. These areas also serve as nurseries for other aquatic species that provide a forage base for salmon. Juvenile salmonids and other species use shallow water habitats as a refuge from predators when migrating. Estuaries are also key areas for shellfish production and as such depend on healthy circulation patterns and good water quality. Pocket estuaries are non-natal lagoons with freshwater input and coastal stream mouths. Salt marshes, brackish marshes, and lagoons are habitats that occur in areas with tidal inundation and flushing. Salt marsh vegetation traps and stabilizes sediments. Salt marshes provide complex, branching networks of tidal channels where juvenile salmonids feed and take refuge from predators. They also form migratory linkages to riverine and marine environments (Brewer et al., 2005).

WRIAs 16 and 17

Eastern Jefferson County contains 52 net shore-drift cells and 7 regions of negligible net shore-drift, encompassing numerous feeder bluffs and accretionary shoreforms. Important feeder bluffs have been identified at Tala Point, just north of Mats Mats Bay, at Olele Point, just south of Kala Point, and just north of Hadlock (Johannessen, 1999). In addition, numerous areas along the Toandos Peninsula, the Bolton Peninsula, Marrowstone Island, and near McCurdy Point have been identified as unstable areas with recent or old landslides, suggesting they may be important for sediment generation (Maps 26 and 27).

Major estuaries and deltas include the Duckabush, Dosewallips, Quilcene, Tarboo Creek and Dabob Bay, Port Ludlow Bay, and Discovery Bay (Maps 26 and 27). A sill at the entrance to Hood Canal is considerably shallower than areas just north or south of the sill, limiting water exchange into and out of the Canal. Marine riparian and critical saltwater habitat areas are described in detail in the individual reach sections. Compared to the Hood Canal and Admiralty Inlet shorelines, the Strait of Juan de Fuca supports few spit features and other locations of wave-transported sediment deposition (Todd et al., 2006). Notable exceptions occur within Discovery Bay and very large spits such as Dungeness Spit (in Clallam County).

Collectively, the watersheds of WRIAs 16 and 17 are regionally important to the Puget Sound basin, and to the recovery of Puget Sound Chinook salmon and Eastern Strait of Juan de Fuca summer chum salmon (Redman et al., 2005). Nearshore areas in particular are identified as high priorities for protection and improvement if regional salmon recovery goals are to be achieved. Redman et al. (2005) identified the following actions as essential to the recovery of these species (this list includes actions specific to eastern Jefferson County, WRIA 16 and 17; see Chapter 6 of the *Regional Nearshore and Marine Aspects of Salmon Recovery in Puget Sound* for further information):

- Protect all feeder bluffs;
- Protect delivery of upland sediment sources to the nearshore from shoreline protection targets;
- Protect functioning drift cells that support eelgrass bands and depositional features along the shoreline of Discovery Bay to Fort Worden;
- Protect against catastrophic events (oil spills); and
- Protect pocket estuaries and shallow water/low velocity habitats from further degradation near the deltas (within 5 miles), but skew this protection area to the east to reflect oceanographic currents.

May and Peterson (2003) identified "Nearshore and Estuarine" (NSE) refugia as part of their comprehensive salmon refugia study for eastern Jefferson County. NSE refugia are based upon drift cells and include those estuaries, nearshore migration corridors, and shoreline areas that provide refuge habitat for migrating and rearing salmon. Refugia are classified as follows (from May and Peterson, 2003):

- Category A: Priority refugia with natural ecological integrity. While not necessarily pristine, these areas are nearly intact, relatively undisturbed, and generally exhibit properly functioning conditions. These areas are generally in excellent condition.
- Category B: Primary refugia with altered ecological conditions. These are refugia with somewhat disturbed conditions, but which still support natural assemblages of native salmon. These areas are generally in good condition.
- Category C: Secondary refugia with altered ecological integrity. These areas may belong in Category A or B if not for hatchery influences, migration barriers, and/or degraded habitat. These areas are generally in fair condition. The author also placed in this

category refugia that did not support a higher rating due to a lack of quantitative data. These areas could be called “possible refugia.”

- Category D: Potential refugia with altered ecological integrity. These areas are best described as “potential future refugia” due to significantly degraded habitat conditions. These areas were likely historically important for salmon, but today do not support natural levels of salmon productivity.

Category A refugia are limited to a few areas including the west shore of Dabob Bay, parts of Squamish Harbor/Shine Creek estuary, the west shore of Thorndyke Harbor (Thorndyke Creek estuary), and scattered parts of Port Townsend Bay near Chimacum Creek (Figure 3-8).

WRIAs 16 and 17 also provide some of the most important and productive shellfish harvesting areas in the Puget Sound basin. The major bays/estuaries including Discovery Bay, Tarboo Bay, Oak Bay, Quilcene Bay, and the beaches and inlets of Dabob Bay and Hood Canal are process-intensive areas for shellfish resources (Map 24).

WRIA 18

The portion of WRIA 18 within Jefferson County falls entirely within the ONP. The Elwha River dams and shoreline armoring are largely responsible for sediment starvation along the shoreline within the Elwha drift cell (located in Clallam County). An estimated 17.7 million cubic yards of clay, silt, sand, gravel, and cobbles have accumulated behind these dams (PSAT, 2005). Within the Jefferson County portion of WRIA 18, fluvial processes that may affect marine shorelines along the Strait of Juan de Fuca are generally protected within ONP.

WRIAs 20 and 21

A majority of process-intensive areas in WRIAs 20 and 21 lie in along the Pacific Coast and lower river reaches on federal and tribal land (not in Jefferson County jurisdiction). Land use along the middle reaches of rivers within Jefferson County jurisdiction is mainly private/commercial forestry, contributing organics, sediments, and tannins from wood waste (cedar spalts) to the nearshore. Overall, these river segments are contributing a small percentage of nearshore habitat processes relative to oceanic processes (temperature, currents, storms, etc.).

3.3.2.3 Nearshore Process Alterations

Alteration of the physical and biochemical processes that create and maintain the nearshore environment will typically have deleterious effects on shoreline functions and values. This section describes the primary alterations of concern for Jefferson County’s marine shores, including

- Shoreline armoring,
- Removal of nearshore riparian vegetation,
- Water quality degradation, and
- Hydrologic alterations and effects on slope stability

Figure 3-8. Nearshore Refugia in Eastern Jefferson County, WRIAs 16 and 17 (May and Peterson, 2003)

Executive Summary Salmonid Refugia Report

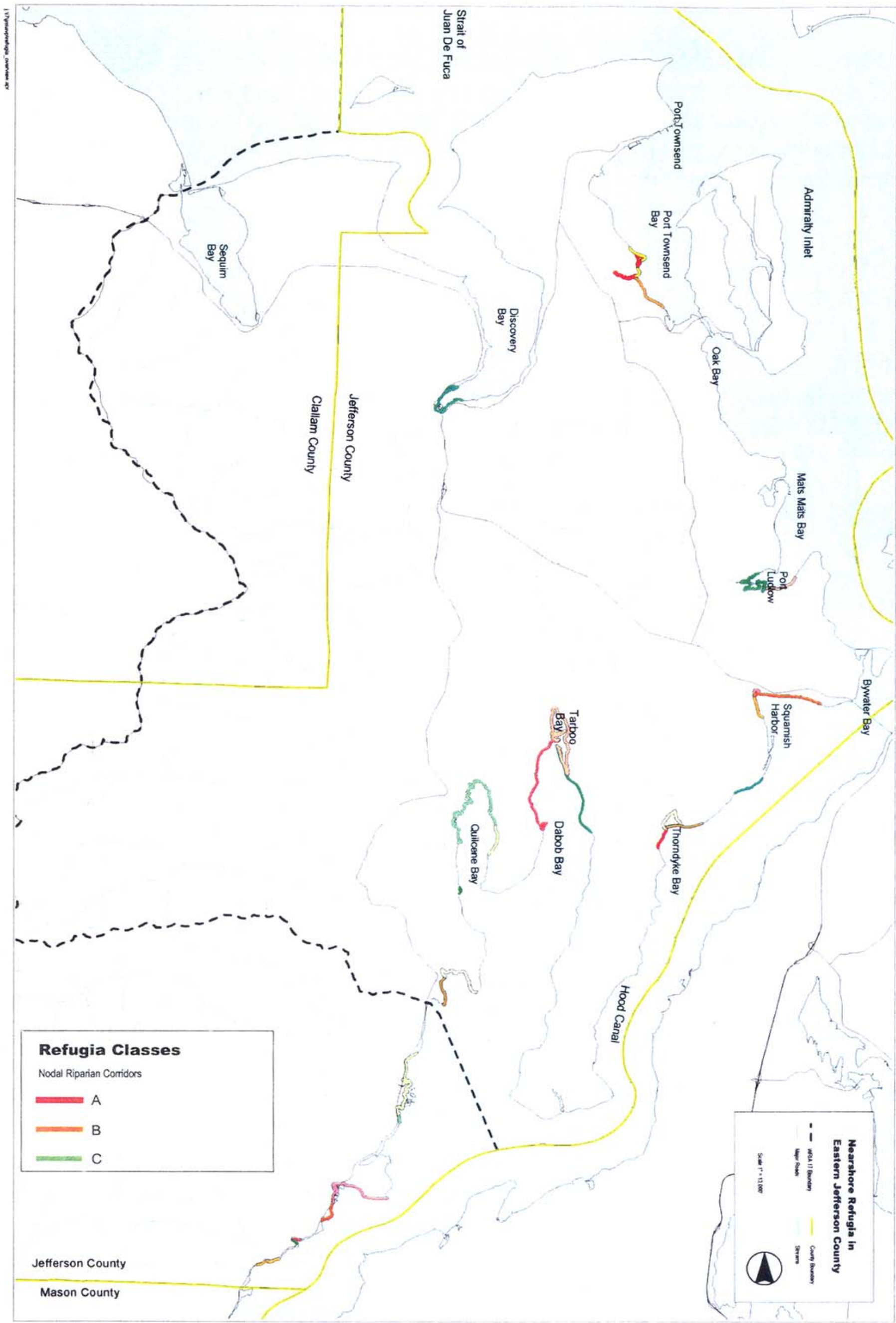


Figure ES-4. NSE Refugia in Jefferson County

Shoreline armoring can disrupt sediment generation and net shore-drift patterns, which can adversely affect shoreline morphology and habitat function (see Maps 12 –14). Bulkheads and other types of armoring along feeder bluffs inhibit or eliminate sources of beach sediment for drift cells. Beaches in front of armored shorelines can lose fine sediment through the increased wave reflection off of the armoring. Over time a heavily armored area (with bulkheads and/or groins) can lose its beach because the sediment that is necessary to sustain the beach is no longer reaching it or is not staying on the beach.

When "hard" structures intrude into the nearshore zone they can also increase the rate of beach erosion by intensifying the wave energy (Macdonald et al,. 1994). In a drift cell where bulkheads prevent bluff sediment from reaching the intertidal zone, the depositional beach at the terminus of the cell often experiences accelerated erosion even if it is miles "down drift" from the affected bluffs. These alterations can ultimately change the structure of the habitat from mixed-fine substrate communities (that often support eelgrass) to coarser substrate communities with less habitat value for migrating salmon fry. Other consequences are habitat fragmentation, loss of migratory corridors, and degradation of foraging habitat. Intertidal bulkheads, other types of fills, and docks can also force juvenile salmonids into deeper water, where the risk of predation may be significantly higher.

Bulkheads, groins, piers, ramps, docks, and other shoreline modifications affect forage fish spawning habitat directly and indirectly. Direct impacts include loss of shoreline/riparian vegetation, burying of habitat by structures, damage from equipment working in an area while eggs are incubating on the beach, and substrate coarsening and lowering of the beach profile in front of bulkheads (MacDonald et al., 1994). Indirect impacts occur primarily through disruption of sediment transport and/or sediment impoundment, and water quality degradation (Long et al., 2005). Because forage fish depend on suitable beach substrates, these species are particularly vulnerable to shoreline modifications and processes affecting sediment input, transport, or deposition (see Maps 17-19). Forage fish, particularly surf smelt and sand lance, require intact riparian vegetation, which provides shade and microclimate control for spawning areas (Rice, 2006). Pacific herring vary slightly in that their spawning is primarily in the lower intertidal and shallow subtidal zones, and therefore their habitat requirements are focused on vegetation such as eelgrass or algae.

Alteration of habitat forming processes (disruption of alongshore sediment generation and transport) can threaten important aquatic plant communities (Ruckelshaus and McClure, 2007;WDNR Nearshore Research Project, 2007 available at http://www2.wadnr.gov/nearshore/research/). Eelgrass and kelp beds are susceptible to altered sediment processes, reduced light penetration caused by overwater structures, and poor water quality (see Map 20). Since these aquatic communities provide essential feeding, rearing, and refuge areas for juvenile salmonids, alterations can be harmful to young fishes (Maps 17-19). Species of birds and fish that depend upon juvenile salmon as prey can also be impacted by habitat alterations affecting young fishes. Other threats to eelgrass and kelp include dredging, erosion/sedimentation from upland construction activities, construction of overwater structures (such as docks and piers) that impede light penetration, increased water temperature due to lack of shade and other causes, pollutant loading, excessive nutrient inputs, and competition from invasive exotic plants such as cordgrass and Sargassum (PSAT, 2001).

Removal of shoreline vegetation, which accompanies most types of shoreline modification or development, reduces shade and LWD recruitment potential, which impacts the supply of prey resources for juvenile and resident salmon. (WDFW and PNPTC, 2000). Failure to maintain or plant bluff vegetation along bluffs can result in low root strength (for example, with scattered ornamental plants and grass) and an increased likelihood of future landslides (Ziemer and Swanston, 1977; Bishop and Stevens, 1964). Bluffs with significant modifications to both the natural drainage regime and vegetation are particularly susceptible to landsliding. Reestablishment and maintenance of native vegetation cover or installation of a fibrous-rooted vegetation cover along with some type of drainage control can reduce the likelihood of bank failures (Gray and Sotir, 1996; Menashe, 1993; Menashe, 2001; Roering et al., 2003).

Alterations such as dredging, filling, and grading, and stormwater/wastewater disposal can negatively impact the quality of nearshore habitats. Improper application, excessive concentrations, and overuse of pesticides, herbicides, and fertilizers are common in urban shoreline areas where manicured landscapes are desired by landowners. Fertilizers and other urban and agricultural runoff degrade water quality by introducing high levels of organic nutrients, petroleum byproducts, and other contaminants into the aquatic system. The increase in nutrients (eutrophication) can cause plankton blooms, which may consume oxygen as the plankton die and are decomposed. Onsite septic systems are often implicated as one of the causes of excessive nutrients in runoff because these systems are generally ineffective at removing nitrates (WDOH, 2005) (Maps 4, 22, and 23). Flame retardants, pharmaceuticals, and estrogenic compounds are examples of other harmful substances that can impact water quality and accumulate within the tissues of marine species (EPA, 2006).

Bottom fish, various invertebrates, and other aquatic animals are susceptible to reduced dissolved oxygen levels that can occur as a result of nutrient and pathogen contamination. Water quality contamination, especially fecal coliform contamination, is potentially disastrous for shellfish communities and can shut down commercial and recreational harvesting (Map 24) (Glasoe and Christy, 2004). Fecal concentrations are influenced by such factors as rainfall and drainage area characteristics, including land uses, fecal pollution sources, and runoff patterns. In general, residential areas contribute the highest concentrations compared to commercial and industrial areas (Glasoe and Christy, 2004). Pollution sources that can potentially contribute to stormwater contamination include cross connections with sewage lines, failing onsite sewage systems, pet and other animal wastes, and bacterial growth within the drainage system itself. None of the potential sources is benign and the cumulative loadings can be immense.

Shellfish resources are highly susceptible to changes in water quality and habitat loss caused by urbanization and certain types of human development (Glasoe and Christy, 2004). Recreational harvest advisories or closures are in effect for much of the eastern Jefferson County marine shoreline. Closures due to marine biotoxins or pollution are in effect for portions of the Pacific Coast as well as areas around Discovery Bay, Port Ludlow, and Port Townsend Bay (WDH, 2006a, 2006b). Commercial shellfish harvesting is restricted or prohibited in some areas including Port Ludlow, South Point, and the north shore of Indian Island (Map 24).

Runoff volumes often increase and become more concentrated as a result of development due to loss of forest cover and increased impervious surfaces and roads (see Maps 6, 7, and 25). This is due to decreased infiltration and interception of water. Concentrated surface water can locally erode bluff crests while also saturating soils, which exacerbates natural slope stability problems along coastal bluffs and can trigger landslides (Shipman, 2004). Runoff flowing down a driveway and rapidly across a lawn (which can absorb little water when wet) as sheet flow to the bluff face is an example of this alteration. A broken tightline on a bluff face is another type of alteration that triggers slides. Failed tightlines (often constructed out of inexpensive and low-strength flexible, corrugated pipe) often contribute to initiating coastal landslides (Johannessen and Chase, 2003).

WRIA 16

Shoreline armoring, such as bulkheads, docks, stairs, and boat ramps, has contributed to beach erosion and disconnection of sediment sources throughout WRIA 16 (Correa, 2003). In addition, several intertidal areas have been filled for residential development. Stairways along the shoreline interrupt riparian corridors and may also lead to bluff instability. Highway 101 and various dikes truncate deltas of several streams and rivers, impairing the fluvial processes that sustain the nearshore. In general, the most altered areas in terms of shoreline structures (stairs, bulkheads, docks, etc) are just north of the Fulton Creek estuary and in the Brinnon area between Boston Point and Jackson Cove (Map 11).

Land use in WRIA 16 has altered the quality of nearshore waters. Paulson et al. (2006) found that 92 percent of total nitrogen in Hood Canal came from surface and groundwater from the surrounding subbasins. They found that point-source discharges and subsurface flow from shallow shoreline septic systems contributed less than 4 percent of the nitrogen load to the upper layer. Nitrogen leached from onsite sewage systems is potentially the largest anthropogenic source of nitrogen entering Hood Canal. Use of a well-maintained septic system can effectively reduce biochemical oxygen demand $(BOD)_4$, bacteria, and pathogens, but most are not designed to effectively reduce nitrogen. It has been estimated that nitrogen leached from onsite sewage systems contributes between 33 and 84 percent (39 and 241 tons) of all anthropogenic nitrogen entering Hood Canal. Past surveys along the shoreline of Lower Hood Canal found that as many as one-third of the onsite sewage treatment systems were failing, resulting in increased fecal coliform in this area, closure of shellfish harvesting areas, and declaration of a public health emergency (Fagergren et al., 2004). Other sources of nitrogen include stormwater runoff, agriculture/animal waste, wastes from boats/watercraft, and forestry.

Restoration projects could be targeted to actions that would trap nutrients now flowing directly to Hood Canal. Removing dikes, filling borrow pits, and restoring/preserving wetlands and side channels could improve conditions in altered areas (Fagergren et al., 2004).

WRIA 17

Shoreline armoring such as bulkheads, docks, jetties, and piers has contributed to beach erosion and disconnection of sediment sources throughout WRIA 17 (Map 12). Several intertidal areas have been filled for residential development, parking lots, and the footings for the Hood Canal Bridge. The most altered shores (in terms of structures and armoring) are at Port Ludlow, Port Hadlock, Mats Mats Bay, and Squamish Harbor. Scattered marinas and bulkheads, and an abandoned log storage yard near Ludlow Creek, may also contribute to disruption of net shore-drift processes in WRIA 17.

Diking and filling of deltas such as the Salmon/Snow Creek delta have reduced the complex web of distributary channels and sloughs that support post-emergent salmon fry. Further descriptions of drift process alterations can be found in the reach inventory and characterization sections in Chapter 4.

Potential pollutant sources in WRIA 17 include both point and non-point sources. According to 2006 Ecology National Pollutant Discharge Elimination System permit records, there are 28 regulated point-source discharges located in the County, most of which occur in WRIA 17. These point sources include wastewater and stormwater discharges to marine and freshwater receiving waters, as well as discharges to municipal wastewater systems by sand and gravel operators, hard rock quarries, boat yards, and other industrial facilities. The fish hatchery on the Big Quilcene River also contributes to the nutrient load within WRIA 17 (Fagergren et al., 2004).

WRIA 18

Headwaters of larger streams and rivers in WRIA 18 are found within Jefferson County, but these headwaters are protected within ONP. Process alterations in the WRIA downstream are located in Clallam County and include two dams on the Elwha River restricting fluvial sediments and LWD from entering the nearshore, as well as fish hatcheries and pulp mills contributing nutrients, metals, and toxics to the Strait of Juan de Fuca.

WRIA 20

Impacts to the estuarine environment in WRIA 20 include loss of habitat complexity due to filling, dikes, and channelization, and loss of tidal connectivity caused by tidegates (Smith, 2000). Nearshore impacts include bulkheads, overwater structures, filling, dredging, and alteration of sediment processes (Map 13). The nearshore area is influenced most by the Columbia River, which forms a low-salinity plume that extends along the Washington Coast, depositing sediments important for beach maintenance, particularly in those areas south of the Hoh River mouth. This sediment supply has decreased by 24 to 50 percent due to dams in the Snake and Columbia River basins.

The vast majority of land use in the WRIA is forestry (94 percent), and sedimentation has been identified as a major habitat problem in all of the subbasins. Sediment loads are transported downstream, and there is concern that increased sedimentation to the estuary and nearshore environment is reducing the eelgrass and kelp habitat by changing nearshore substrates and increasing turbidity. Water quality processes are generally thought to be good; however, some contaminants have been found offshore, the source of which is the aluminum smelters on the lower Columbia River (Smith, 2000).

WRIA 21

The sediment source for the beaches in WRIA 21 is mostly from nearby rivers and sea cliff erosion, with some sediment from the Columbia River. Forest practices in the middle and upper reaches of river basins within the WRIA that result in increased sedimentation and reduced LWD can have a negative effect on nearshore processes.

The overall condition of estuaries in the WRIA is "good" (Smith and Caldwell, 2001). However, the Queets and Quinault estuaries have reduced levels of LWD and the lowest reaches of the Quinault River have been impacted by a low level of bank hardening and shoreline development, mostly on the south bank. Various attempts to protect the village of Taholah from ocean wave action have resulted in the construction of a seawall. Large rock continues to be added to the north end of the seawall, affecting the mouth of the Quinault River and the lowest portion of the estuary (Smith and Caldwell, 2001).

3.3.2.4 Freshwater Processes

As with nearshore areas, the health and functioning of freshwater shoreline systems is influenced to a large degree by the movement or storage of materials such as water, sediment, nutrients, pathogens, and organic matter (e.g., LWD). This report focuses on the following key processes:

- Hydrology processes including surface water runoff, peak flows, surface water storage, groundwater flow/discharge,
- Water quality processes for nitrogen, phosphorus, pathogens, toxins/metals, and heat/light inputs,
- Sediment processes including mass wasting, surface erosion, and bank erosion, and
- Organic debris.

The process-intensive areas and alterations described in this section of the text are shown on the map folio in Appendix C and listed in Table 3-5.

Table 3-5. Map Locations for Key Freshwater Process-intensive Areas and Alteration Themes

Theme	Map Name/ No.
Hydrology / Streams and Lakes Permeability Wetlands / Potential Wetlands Topography Floodplains (100-year floodplain) Rain-on-Snow (ROS) and Snow-dominated Zones Channel Migration Zones (CMZ) Land Cover (early and late seral stage vegetation; human imprint)	Maps 2 and 3. Hydrology
Hydrology / Streams and Lakes WRIA Boundaries Watershed Boundary Permeability Wetlands Dairies Water Quality (not shown on map) Septic Permits Tilled Fields Lost Wetlands Human Imprint	Maps 4 and 5. Water Quality

Theme	Map Name/ No.
Land Use / Land Ownership (not shown on map) Zoning	Maps 21, 22, and 23. Land and Shoreline Use Patterns
Forest Cover Impervious Surface	Map 25. Forest Cover and Impervious Surface

Hydrology

Two important mechanisms by which hydrologic processes operate are infiltration and groundwater recharge. In the glaciated Puget Sound landscape, areas of high permeability include unconsolidated surficial geologic deposits of large grain size such as glacial outwash, especially recessional outwash (Dinicola, 1990 as cited in Vaccaro et al., 1998). These areas have a relatively high capacity for infiltrating precipitation and surface water, and they are identified as important infiltration/recharge areas (Winter, 1988). The main hydrogeologic units that produce groundwater for domestic residential or agricultural use in eastern Jefferson County are Vashon Advance Outwash (Qva), Older Glacial Deposits (Qgo), and to a much lesser extent, Vashon Recessional Outwash (Qvr). These hydrogeologic units make up most of the unconsolidated materials that overlie bedrock. The Vashon Lodgment Till (Qvt) is not an important water-bearing unit but it does control the rate of infiltration and therefore acts as a semi-confining layer (Simonds et al., 2003).

Impervious surfaces can impact infiltration in all areas of a watershed, but it is particularly detrimental in areas that naturally support high rates of infiltration and recharge (i.e., permeable deposits on low slopes). Land use is a predictor of effective impervious area. Vaccaro et al. (1998) showed that recharge in heavily developed areas (with 95 percent impervious surfaces) is reduced by 75 percent, while recharge in residential areas (with 50 percent impervious surfaces) is reduced by 50 percent (in Stanley et al., 2005). Numerous studies report that watersheds with greater than 10 percent impervious area experience increases in runoff resulting from decreased infiltration capacity (Glasoe and Christy, 2004; Paul and Meyer, 2001; Booth and Reinelt, 1993). Booth and Jackson (1997) describe numerous impacts to aquatic resources resulting from increased impervious area that are significant and measurable (see Map 25).

A related factor influencing hydrologic processes is the percent of forest cover in a watershed. Loss of hydrologically mature vegetation, especially in rain-on-snow and snow-dominated zones, can alter natural surface runoff patterns. Cleared portions of the rain-on-snow zone can produce 50 to 400 percent more outflow from snowpacks than forested areas during rain-on-snow events (Coffin and Harr, 1992 as cited in Stanley et al., 2005a). The primary causes of this increased outflow are the additional amount of snow on the ground, and the increased rate of snowmelt that occurs in the absence of sun-blocking vegetative cover (Brunengo et al., 1992; Coffin and Harr 1992). Rain-on-snow areas that are converted from forest cover to non-forest cover have a higher likelihood of generating peak runoff.

Surface Water Storage

Surface water storage is an important component of the hydrologic cycle. The loss of surface water storage potential can increase the volume and shift the timing of streamflow (Collins et al., 2003) or increase water level fluctuations in lentic systems (Euliss and Mushet, 1999). Land use can directly impact water storage through the filling of floodplains, wetlands, and/or hyporheic zones, or indirectly decrease storage by disconnecting a stream/river from its floodplain. Reduced connectivity occurs as a result of dikes or levees along stream channels; stream channelization and incision; and/or wetland ditching. Some of these alterations operate primarily at the watershed scale (e.g., increased sediment supply); others are more evident at the reach scale (i.e., channel modifications and incision).

Surface Runoff and Peak Flows

Much of the surface runoff in Jefferson County river systems is derived from rainfall and snowmelt for those rivers and streams with headwaters at high elevations in the Olympic Mountains. The spring snowmelt is driven by climate and does not change significantly based on land management. However, winter snowmelt is an important component of the rain-on-snow mechanism that causes most major peak flow events (WFPB, 1997). This analysis focuses on rain-on-snow zones as a key hydrologic mechanism influencing aquatic resource structure. In the Puget Sound region, rain-on-snow and snow-dominated zones are concentrated at elevations of 1,500 to 4,500 feet where weather patterns commonly cause temperature fluctuations from freezing to above freezing (WDNR, 1991). Mature forest, especially coniferous forest, in rain-on-snow forest zones influences winter snow accumulation and melt rates by changing the intensity of solar radiation and wind-assisted heat flux (WFPB, 1997).

Surface runoff and peak flows are closely linked to infiltration/recharge as described above. Runoff is inversely correlated to infiltration/recharge. Runoff is affected by development that increases drainage density, synchronizing runoff during peak events, and consequently increases the magnitude and frequency of peak flows. Road density is used in this analysis as an indicator of increased drainage density because roads are commonly associated with artificial conveyances such as ditches and storm sewers. Furthermore, roads in forested areas have been shown to cause physical disturbances that increase drainage density by extending the length of headwater channels, converting subsurface flow to overland flow. Forest practices and land clearing in rain-on-snow zones can also alter natural surface runoff patterns. Cleared portions of the rain-on-snow zone can produce 50 to 400 percent greater outflow from snowpacks than forested areas during rain-on-snow events (Coffin and Harr, 1992).

Groundwater Recharge/Discharge/Flow

Groundwater flow paths occur at regional, intermediate, and shallow scales corresponding to flow paths and residence time. Regional groundwater is maintained along deep flow paths in pre-Quaternary bedrock, which are defined by major topographic features such as the Strait of Juan de Fuca and the Olympic Mountains. Such groundwater is not readily influenced by the local land use patterns and is therefore not analyzed here.

Shallow groundwater occurs in upper Pleistocene and Holocene deposits and is governed largely by local topography and surficial deposits. Recharge of these shallow aquifers occurs mainly in glacial drift plains and is discharged as surface water via springs, seeps, lakes, and streambeds. Shallow groundwater boundaries typically follow surface watersheds.

Intermediate groundwater falls somewhere between regional and shallow groundwater in terms of flow path depth and the scale of movement. Intermediate groundwater often has the ability to move under major rivers and across drainage boundaries.

Precipitation is the primary source of groundwater recharge. However, alterations to flow paths and groundwater extraction/consumption influence the availability of groundwater for maintaining ecological functions during the summer low-flow period. Draining areas of shallow groundwater via ditching, pumping, or other practices shortens the groundwater flow paths and decreases retention time. Consequently, the availability of groundwater for discharge during low runoff periods decreases. Extraction also reduces the amount of groundwater available for discharge, and the placement of wells in the vicinity of surface water expressions can also limit discharge by altering groundwater flow paths (Freeze and Cherry, 1979; Morgan and Jones, 1999).

Shallow soils in the montane region limit shallow groundwater features. Infiltrated water either travels laterally as subsurface flow at the soil-bedrock contact, or percolates to deep groundwater through cracks and fissures in the bedrock. River valleys and outwash plains in the lowlands contain much deeper, porous soils on low relief that store large quantities of water in surficial aquifers. Data from Cox et al. (2005) also suggest that the presence of outwash and permeable alluvial fan deposits adjacent to river valleys/floodplains creates conditions for groundwater discharge. Therefore, the presence of these conditions increases the probability that groundwater discharge is occurring. Infiltration, recharge, and discharge processes are dependent on temporal and spatial factors. In general, recharge will take place during the later part of the season at lower flows in some portions of the river depending on the presence of adjacent permeable deposits.

Water Quality

Nutrients (Nitrogen and Phosphorus)

Changes to hydrology and sediment supply at the watershed scale can influence nutrient cycling in aquatic ecosystems. Alterations to these processes are discussed in other sections. This analysis focuses on alterations to nutrient inputs resulting from certain land uses. Fertilizer originating from commercial forest lands, agricultural, and residential areas can be a potential source of increased nitrogen inputs to both aquatic ecosystems and groundwater. In addition, fecal waste generated from septic tanks, commercial agriculture, and/or hobby farms can also contribute excess nitrogen and other nutrients.

Phosphorous is not strongly correlated to specific types of land use (Ebbert et al., 2000). However, areas in which fertilization and surface erosion are both prevalent (e.g., dairy farms, till agriculture, urban growth areas) can be potential sources of increased phosphorous input.

Other human impacts that alter aquatic resources can also influence nutrient retention and removal. Cox et al. (2005) found that denitrification occurs throughout riparian areas at high levels (4 to 16 milligrams per liter [mg/L]). Denitrification occurs when bacteria in the soil convert nitrogen to nitrates, making it easier for plants to absorb. When soil oxygen levels are low, another form of bacteria turns the nitrates into gases such as nitrogen, nitrous oxide, and nitrogen dioxide which return to the atmosphere. Consequently, floodplain disconnection and loss of riparian forest cover can limit hyporheic function and nitrogen fixation rates and preclude deposition of sediment and adsorbed phosphorous. Loss of wetlands decreases the amount and rate of denitrification in a watershed.

Pathogens

This report focuses on fecal coliform as an indicator of pathogens because it is the most commonly occurring pathogen and because it is monitored in Ecology water quality studies. For purposes of this report, process-intensive areas for water quality involving pathogens are areas where pathogens are stored or removed. Pathogen inputs are primarily associated with human disturbance, and natural concentrations in water are very low. Human sources of fecal matter and associated pathogens include onsite septic systems and animal operations such as dairies and hobby farms.

Because pathogens are derived primarily from anthropogenic sources, much of the research regarding their removal is based on water quality management facilities. However, some research results can be applied to natural systems. The U.S. Environmental Protection Agency (EPA) (2001) showed that standing water promotes pathogen removal through increased filtration and predation by other microbes. Additionally, recent USGS studies (Cox et al., 2005) found that fecal coliform was not discharged to surface water from groundwater. This indicates that surface transport is a major pathway for these pollutants. Therefore, areas that promote water and sediment retention and/or predation by microorganisms, such as floodplains, depressional wetlands, and permeable deposits draining into surface waters via subsurface flow or groundwater recharge, are process-intensive areas for pathogen removal (Tate, 1978; Hemond and Benoit, 1988). Destruction of these areas or land uses that lead to altered function can cause impairment of the landscape’s ability to process pathogens.

Toxins/Metals

Toxins and metals associated with certain land use practices can be harmful when released to aquatic ecosystems (Table 3-6). Many urban land uses can introduce contaminants such as organic compounds, polychlorinated aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and pesticides. For example, gas stations and industrial processing facilities may release PAHs from the combustion of petroleum, oil and coal (Van Metre et al., 2000; Schueler and Holland, 2000a). Heavy metals (e.g., cadmium, copper, and zinc) can be released from motor vehicles, building materials, and rooftops (Schueler and Holland, 2000b). Some lawn care products used by residential property owners and businesses contain potentially harmful insecticides, herbicides, and/or chemical fertilizers (Schueler and Holland, 2000c, 2000d). Rural land uses (i.e., agriculture and forestry) are also potential sources of pesticides (Allan, 2004).

Toxins and metals generally do not occur in naturally high concentrations, so the mechanisms by which these contaminants impact water quality are related to increased inputs (land uses) and storage or uptake in the environment. Depressional wetlands with organic soils and wetlands with clay soils that have a high cation exchange capacity retain metals/toxins through adsorption. Riparian areas also are likely to remove toxins through adsorption since there are organic soil layers present. Sediment deposited in floodplains can also temporarily store/adsorb toxins.

The primary mechanism of contaminant transport from urban and rural lands to the surrounding watershed is runoff. Impervious surfaces (i.e., roads, sidewalks, pavement, rooftops) are key in the transport of stormwater runoff and associated contaminants (Brabec et al., 2002; Booth, 2000).

Table 3-6. Sources of Toxins and Metals by Land Use

Land Use	Examples of Contaminant Sources	Potential Contaminants
Rural Agricultural	Irrigated crop farming, confined animal feeding operations	Insecticides, Herbicides
Rural Forestry	Logging, campgrounds	Metals
Urban Commercial	Automotive repair shops, dry cleaners, gas stations, food processing	Metals (Cu, Pb, Zn), Polychlorinated Hydrocarbons (PAHs), Polychlorinated Biphenyls (PCBs)
Urban Industrial	Chemical manufacturing, metal finishing fabricating, mining/milling, railroad yards	Metals (Cu, Pb, Zn), Polychlorinated Hydrocarbons (PAHs), Polychlorinated Biphenyls (PCBs)
Urban Municipal	Airports, landfills/dumps, septic systems, wastewater treatment plants, transportation corridors (motor vehicles), utility stations	Metals (Cu, Pb, Zn), Polychlorinated Hydrocarbons (PAHs), Polychlorinated Biphenyls (PCBs)
Urban Residential	Parks, septic systems, transportation corridors (motor vehicles)	Metals (Cu, Pb, Zn), Insecticides, Herbicides

Cu = copper, Pb = lead, Z = zinc

Heat and Light

Heat and light affect water temperature, which is an important component of water quality. A number of factors control heat and light inputs to aquatic resources. Most factors such as climate, groundwater inputs, and air temperature are difficult to manage in the context of the SMP. This analysis focuses on riparian areas as important for heat and light because these areas provide the best opportunity for management.

The relationship between riparian condition and its influence on heat/light inputs is discussed extensively in scientific literature (Welch et al., 2003). Thirty meters is the recommended minimum riparian width required to maintain natural function of heat/light inputs in Puget Sound (Castelle et al., 1994; May, 2000), but a wider buffer is necessary to maintain microclimate (Brosofske et al., 1997; May, 2000). Riparian zones as narrow as 11 meters may still provide a positive shading influence on streams (FEMAT, 1993; Knutson and Naef, 1997; May, 2000). The width of the riparian zone becomes less important in controlling thermal properties as streams become larger, because shading controls insolation to a lesser extent, and other factors such as channel geometry begin to have a more significant relative influence on temperature.

Organic Debris

Organic material including large woody debris (LWD) enters streams primarily via streambank erosion, mass wasting, and treethrow/windthrow from areas within roughly 200 feet of stream channels. Consistent sources such as treethrow (mortality, suppression, windthrow) and bank erosion/channel migration occur across all types and sizes of streams, while mass wasting is the primary source in low-order streams (Reeves et al., 2003; Benda et al., 2002). Fluvial transport and debris-laden floods are important mechanisms of LWD redistribution in large and small streams, respectively.

Riparian forest disturbances reduce woody debris in streams, which in turn leads to adverse changes in channel/habitat-forming processes (Bilby, 1984; Heifetz et al., 1986; McDade et al., 1990; Van Sickle and Gregory, 1990; Bilby and Ward, 1989). In headwater areas, roads may increase the incidence of landslides; however, associated loss of forest cover in these areas decreases LWD recruitment via landslides. Land use encroachment into riparian zones and channelization of streams reduce forest cover and decrease LWD recruitment potential via bank erosion or channel migration.

Sediment Delivery and Transport

Slopes with erodible soils and areas prone to mass wasting provide sediment input. Mechanisms for sediment input are closely aligned with geologic controls. Erosive soils are most commonly associated with alluvium and outwash. Sediment is often stored in depressional areas such as wetlands and lakes (Hruby et al., 2000) and on floodplains (Stanley et al., 2005), which by definition are composed of deposited alluvium. These areas trap sediment by reducing water velocity (or dissipating energy), allowing increased deposition of fine sediment. Process-intensive areas for sediment storage are the same as the water storage areas identified earlier.

Changes in sediment supply have wide-ranging impacts on aquatic ecosystems and can limit ecologic function by impairing habitat quality and water quality. Surface erosion and mass wasting are naturally occurring mechanisms of sediment supply, but each can increase sediment inputs to aquatic ecosystems when the landscape is altered by human use. Loss of forest cover and roads can increase inputs to aquatic systems by increasing rates of mass wasting and surface erosion. Altered hydrology may also increase hillslope inputs to aquatic resources as well as influencing rates of instream transport and storage. Sediment generated from construction sites is another potential source of sediment to aquatic habitats.

Mass Wasting

Mass wasting potential is a product of topography, soil and bedrock properties, hydrologic conditions, and vegetation. Roads (paved and unpaved) are often the most significant source of sediment inputs to aquatic ecosystems in Puget Sound (Swanson et al., 1987). Increased mass wasting rates are directly attributable to roads, which can influence slope failure directly by altering slope properties (Knutson and Naef, 1997) or indirectly by redistributing excess water to landslide-prone areas (Swanson et al., 1987). The loss of forest cover may also be an important factor that increases rates of mass wasting, but the literature demonstrates that roads are the dominant influence.

Surface Erosion

Surface erosion usually occurs as a result of particle entrainment by rainfall and overland flow. Historically, surface erosion was limited by forest cover (Swanson et al., 1987). However, loss of forest cover can lead to increased particle entrainment by rainfall and transport via overland flow, consequently increasing sediment inputs to aquatic systems. In general the denser the vegetative cover, the lower the rate of erosion (Dunne and Leopold, 1978). Roads are also a primary source of increased sediment inputs to aquatic systems via surface erosion. Beschta (1978) states that roads within approximately 200 feet of aquatic ecosystems dramatically increase sediment inputs from surface erosion. Areas of low erosion potential can also be significant sources of sediment, particularly for land uses that directly disturb soil. Till agriculture or bare fallow soil areas can increase surface erosion by 40 to 50 percent (Rapp et al., 1972). Erosion can be a water quality issue for infrequent higher intensity storms and in specific areas near water bodies or drainage ditches that drain to surface water features.

Bank Erosion

Streams, wetlands, and lakes can store sediment before it is transported farther downslope to estuaries and nearshore ecosystems. Channelization and floodplain disconnection cause loss of overbank sediment deposition in the floodplain during peak flows. Draining and filling depressional wetlands can also reduce sediment storage capacity on the landscape. Thus, alterations to surface water storage are also indicative of reduced sediment storage.

Changes in stream morphology brought on by altered sediment supply-transport processes in streams can include increased bank erosion and channel migration rates. Altered hydrology (increased flows) can cause channel enlargement and increased bank erosion. Loss of riparian vegetation also increases the susceptibility of streambanks to fluvial entrainment and mass failures. The alterations that indirectly influence bank erosion are discussed in other sections. Increases in bank erosion rates are noted where data are available.

3.3.2.5 Freshwater Process-intensive Areas

Process-intensive areas for hydrologic, water quality, organic matter, and sediment processes in Jefferson County often coincide (Table 3-7). These areas are depicted on Maps 2 through 7 in the accompanying map folio (Appendix C). The process-intensive areas are discussed generally and identified specifically for each WRIA in the following sections.

Table 3-7. Process-intensive Areas for Hydrologic, Water Quality, and Sediment Processes

Process	Process-intensive Area
Infiltration/recharge Groundwater flow/discharge Nutrient cycling Pathogen removal	Aquifer recharge areas
Surface runoff and peak flows Surface erosion	Bare ground/early seral stage vegetation cover
Surface runoff and peak flows Groundwater flow/discharge Surface erosion Sediment storage	Channel migration zones

Process	Process-intensive Area
Surface water storage Surface runoff and peak flows Groundwater flow/discharge Nutrient cycling Sediment storage	Floodplains
Surface water storage Sediment storage Nutrient retention/cycling	Lakes
Surface runoff and peak flows	Rain-on-snow and snow-dominated zones
Surface water storage Nutrient sink Sediment storage Pathogen removal Toxins/metals removal	Wetlands
Nutrient sink Toxins/metals removal Heat/light control	Riparian areas
Organic debris input Sediment delivery	Landslide-prone areas
Organic debris input Sediment delivery	Streambanks

Hydrologic Processes

Key areas for hydrologic processes (Maps 2 and 3) are influenced by soil permeability and precipitation, and include rain-on-snow zones, snow-dominated zones, channel migration zones, wetlands, lakes, and ponds. Areas with high levels of precipitation will increase the capacity of groundwater recharge through infiltration. Precipitation levels are higher west of the Olympic Mountains and foothills than in areas to the east. In Eastern Jefferson County, important areas for precipitation include the Fulton Creek, Spencer/Marple Creek, and Dosewallips/Rocky Brook basins (Ecology, 2007).

Areas with high infiltration and recharge capacity typically occur in glacial outwash and alluvial valleys such as the Hoh and Clearwater River valleys. These areas may contribute more infiltration and recharge per unit area compared to areas to the east because precipitation is higher. A study of the Nooksack River in Whatcom County showed that groundwater discharge occurs in areas containing permeable glacial outwash and alluvial fan deposits adjacent to the river valley (Cox et al., 2005). This suggests that the Chimacum Creek valley, Leland Creek valley, and similar areas may provide opportunities for groundwater discharge.

The Chimacum Creek valley has an extensive alluvial deposit on the valley floor, valley walls of exposed undifferentiated deposits, and highlands above consisting of lodgement till. The headwaters of this valley have large areas of recessional outwash, a relatively young deposit that has not been extensively eroded. Many marine bluff areas on the Toandos and Bolton Peninsulas have similar erosion patterns, with bluff faces composed of undifferentiated deposits, advanced outwash fringe toward the top, and lodgement till on upland areas. The landscape setting for these deposits, including how they have been shaped by wind, waves, and water erosion, determines the manner in which water moves across and through the land. For example, permeable outwash deposits on hillsides can be locations for groundwater discharge for wetlands and streams. On terraces, these deposits may act as recharge areas (Ecology, 2007).

Overall, the Lower and Middle Dosewallips River, the Toandos Peninsula West Shore, the Bolton Peninsula, and the Chimacum Creek East Fork were rated highest for groundwater processes (high precipitation, infiltration, percolation and recharge) by Ecology (Ecology, 2007).

The most widespread glacial deposit is lodgment till, which covers the majority of the upper portion of the lowland geographic units. In general this deposit is impermeable but does include some lenses of sand and gravel. Underlying this deposit is a relatively thick deposit of advance outwash, which has moderate to high permeability. Large quantities of water can be stored by this deposit, and it is both a principal source of potable water and a source of groundwater discharge for aquatic resources in the County. Advance outwash deposits are predominant in the northern portion of the study area but also present in surficial deposits in the Chimacum drift plain and the Toandos and Miller Peninsulas (Ecology, 2007).

An associated deposit is recessional outwash, which also has high permeability and water capacity and is of significant importance to water flow processes. Relatively large areas of this deposit are found on the west side of the Quimper Peninsula, in the Port Hadlock area, the Chimacum valley and West Chimacum Creek (upper portion), and above Squamish Harbor. Additionally, recessional outwash is found in the lower reaches of the rivers draining the Olympic Mountains area, with large deposits present near the mouth of the Big and Little Quilcene Rivers. In this landscape setting, recessional outwash would be critical to groundwater discharge to the Big Quilcene River.

Undifferentiated deposits consist of a variety of glacial and interglacial deposits including lacustrine and glaciolacustrine (very low permeability), outwash sands and other fluvial deposits (moderate to low permeability). These deposits vary greatly in their permeability and water holding capacity, but are generally considered to be of low permeability and to yield little to no water for potable water supplies (Ecology, 2007).

Overall, Ecology characterized the Lower Big Quilcene River, the Toandos Peninsula West Shore, the Bolton Peninsula, and the Chimacum Creek East Fork as the most important areas (highest scoring areas) for permeability (Ecology, 2007).

Most areas that are important for surface water storage are found in the lower watersheds of eastern Jefferson County, as well as the Hoh, Queets, and Quinault River floodplains. Wetlands are typically found along floodplains in areas of coarse outwash. In Jefferson County, small lakes occur in alpine and montane regions with larger lakes occurring in the lowlands.

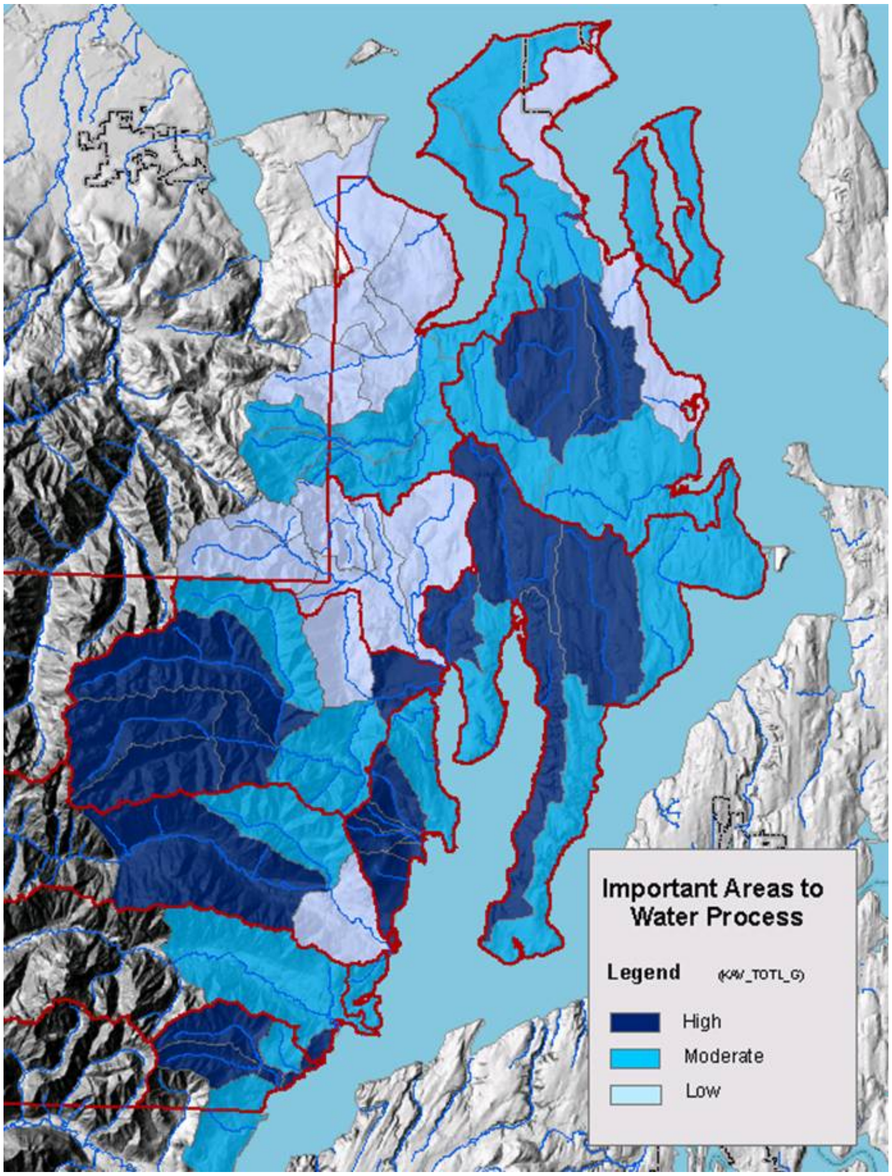
According to Ecology's (2007) watershed characterization, areas that scored highest overall for importance in surface water storage are in the following basins: Middle and East Fork Chimacum Creek, Tarboo Creek, Leland Creeks, the Lower Big Quilcene River, Spencer/Marple Creek, Turner/Walkers Creek, Fulton Creek, Middle Dosewallips, Rocky Brook, Big Quilcene Middle and Tunnel Creek.

Rain-on-snow and snow-dominated zones, which contribute to surface runoff and peak flow, are known to occur primarily in middle elevations above 1,400 feet in Jefferson County, principally on federal lands such as the ONP and ONF.

According to Ecology (2007) areas that received the highest relative score for combined water flow-related processes included the Olympic Mountains and the adjoining lowlands (Figure 3-9) (Ecology, 2007). This is due to the presence of higher precipitation (rain-on-snow, snow-dominated zones) and relatively large areas of permeable deposits in the lower portions of the watershed. The Little Quilcene River watershed was of lower overall importance due to a higher degree of impermeable deposits and lower relative rainfall.

The headwaters for the Chimacum drift plain and the upper watershed areas draining to Tarboo and Quilcene Bays also scored high relative to other areas for water flow processes. The high importance of the Chimacum area is primarily due to large areas of permeable deposits and moderate rainfall levels. The Tarboo and Quilcene Bay watersheds have less extensive permeable deposits but higher rainfall levels (Ecology, 2007). Other areas of lower importance were the small watersheds adjacent to the marine nearshore that are in areas of low rainfall and low permeability deposits.

Figure 3-9. Important Areas for Hydrologic Processes, Eastern Jefferson County (Ecology, 2007)



Water Quality Processes

Water quality processes such as nutrient cycling/uptake, pathogen and toxin removal, and heat and light control are influenced by wetlands, riparian areas, and surficial aquifers (Maps 4 and 5). Process intensive areas for removal and/or retention of fecal matter and associated pathogens are depressional wetlands and infiltrative soils. These areas are located primarily in lowland areas with outwash deposits as well as upland areas with marine sedimentary deposits.

Areas that provide nutrient retention and loss are concentrated in lowlands, while groundwater nutrient retention is associated with surficial aquifers. Valley bottoms provide functions such as nitrogen loss and some temporary storage of phosphorous. Upland areas or terraces are areas where nitrification (transformation) occurs. Headwater streams play a greater role in the temporary storage of nitrogen from biotic uptake and adsorption. Upland depressional wetlands provide storage (phosphorous, nitrogen), transformation (nitrogen) and loss (nitrogen). Areas with the full suite of loss/retention mechanisms occur primarily in the floodplains and to a lesser extent in the low-slope areas of WRIA 17.

Metals occur in trace concentrations in nature, but metals and other toxins are introduced by human actions as well. The process of metal/toxin inputs under natural conditions versus human input is not easily discernable. Storage of metals occurs through adsorption in wetlands with clay or organic soils. Information regarding wetland soil composition is not readily available. Therefore, it is assumed that wetlands throughout Jefferson County may provide increased rates of metal/toxin retention.

Sediment Processes

Process-intensive areas for sediment delivery and transport processes include landslide-prone areas and steep slopes with erodible soils (Maps 6 and 7). Areas of mass wasting are most common in the western Olympic Mountains and foothills, where relief is more extreme and precipitation is high. Surface erosion areas are mainly located in hilly areas along the Big and Little Quilcene Rivers, Dabob Bay, Hood Canal, and Tala Point. Streambanks and lakeshores are also important sediment sources.

In Jefferson County, much of the agricultural land is along the relatively flat areas of the Chimacum Creek valley and the Leland Creek valley where soils are typically quite permeable and precipitation usually falls at a low intensity. Nonetheless, the extent of agricultural land use and the level of associated soil disturbance make these areas a source of increased sediment supply. Bare areas can erode and redistribute sediment in the fields, but delivery to streams or wetlands is limited to areas near the water bodies because of the low runoff rates.

Organic Debris Inputs

Process intensive areas for organic debris inputs including LWD generally include riparian areas within 150 to 200 feet of aquatic resources or within the aquatic resource boundaries. Channel migration zones (CMZs) and areas of mass wasting also deliver LWD to streams. This includes designated CMZs on the Big and Little Quilcene Rivers, the Duckabush River, and the Dosewallips River in eastern Jefferson County (Klawon, 2004) as well as the CMZs identified on the Hoh River in western Jefferson County (USBOR, 2004; Perkins Geosciences and Terra Logic, 2004). Because the extent of the CMZs is not known for most streams and rivers in western Jefferson County, the Federal Emergency Management Agency (FEMA) 100-year floodplain was used to delineate the extent of potential LWD recruitment from channel migration and bank erosion.

WRIA 16

Process intensive areas important to infiltration and recharge are typically associated with surficial aquifers and alluvium in the lower Dosewallips and Duckabush River valleys. Surface water storage occurs in the lower river valleys as well, along with two small lakes identified near Black Point. The river corridors also support wetlands and CMZs, although the CMZs are disconnected in the lower watersheds where Highway 101 crosses the estuaries.

There are extensive areas of rain-on-snow and extensive snow-dominated areas within the ONP in this WRIA. Most of these areas are vegetated with late seral stage forest stands suggesting that runoff and peak flow patterns are relatively intact (Map 2) . Landslide-prone areas of the upper Dosewallips River watershed and steeper slope areas of the lower watersheds contribute to sediment transport processes, but road density on most subbasins is less than 1 mile per watershed square mile and most of the erodible and landslide-prone areas are covered with mature forest (Map 6).

WRIA 17

Process-intensive areas for hydrology include critical aquifer recharge areas associated with highly to moderately permeable soils and low slopes (Map 2). Surface water storage is found primarily along the floodplains of the lower Big Quilcene River, Snow Creek, Chimacum Creek, and Tarboo Creek. There are several lakes in this WRIA, mostly occurring in outwash plains and upland plateaus containing poorly drained till and fine-grained outwash. Rain-on-snow zones and snow-dominated are concentrated in the upper Big and Little Quilcene River watersheds within the ONP, and small areas of commercial forest and rural residential land in the Discovery Bay watershed (Map 6).

Wetlands are abundant along Chimacum Creek, as well as Snow and Tarboo Creeks, lower Little Quilcene River, Quilcene Bay, and inner Dabob Bay (Map 4).

CMZs on the Big Quilcene River, landslide-prone areas on steeper slopes in the mountains of Big Quilcene and Discovery Bay watersheds, and steep shorelines along Discovery Bay, Quilcene Bay, and Dabob Bay contribute to sediment processes in the WRIA. CMZs are disconnected in the lower Little Quilcene River due to Center Road crossing the estuary. Other floodplains/CMZs have also been impaired, such as Big Quilcene River and Salmon/Snow Creek (Todd, personal communication, 2006).

May and Petersen (2003) identified salmon nodal corridors as part of their comprehensive salmon refugia study. The report delineates freshwater refugia as one of two types: “Focal Sub-Watershed” or “Nodal-Riparian Corridor.” Generally, a “Focal Sub-Watershed” designation is more appropriate for headwater areas, while a “Nodal-Riparian Corridor” designation is more appropriate for lower reaches of a stream, or streams that are confined within steep-sloped valleys. One type is not necessarily "better" than the other; it is a matter of which type of refugia fits the specific situation in the field, and which type will be more effective for conserving salmon habitat (Figure 3-10)[3]

WRIA 18

The portion of this WRIA within Jefferson County falls entirely within the ONP. A large part of the watershed within the ONP is underlain by relatively impermeable bedrock. These generally mountainous areas receive large amounts of precipitation and, therefore, have the potential for large amounts of recharge. However, recharge in these areas is probably limited by the water-bearing and transmission properties of the bedrock rather than by precipitation amounts or soil-moisture characteristics (USGS, 2000). Process-intensive areas for infiltration and recharge, surface water storage, and groundwater flow generally occur outside of Jefferson County. Most of the recharge in the Elwha-Morse watershed is from precipitation (snow and rain), probably with some small local amounts by seepage from streams. The groundwater moves slowly from recharge areas to discharge areas such as lakes, springs, streams, wetlands, and the Strait of Juan de Fuca (USGS, 2000). Available information indicates that wetlands are associated with the Elwha River corridor, and rain-on-snow occurs in mid-elevations throughout the WRIA. No information was available on sediment transport and delivery or channel migration in the upper watersheds of WRIA 18.

WRIA 20

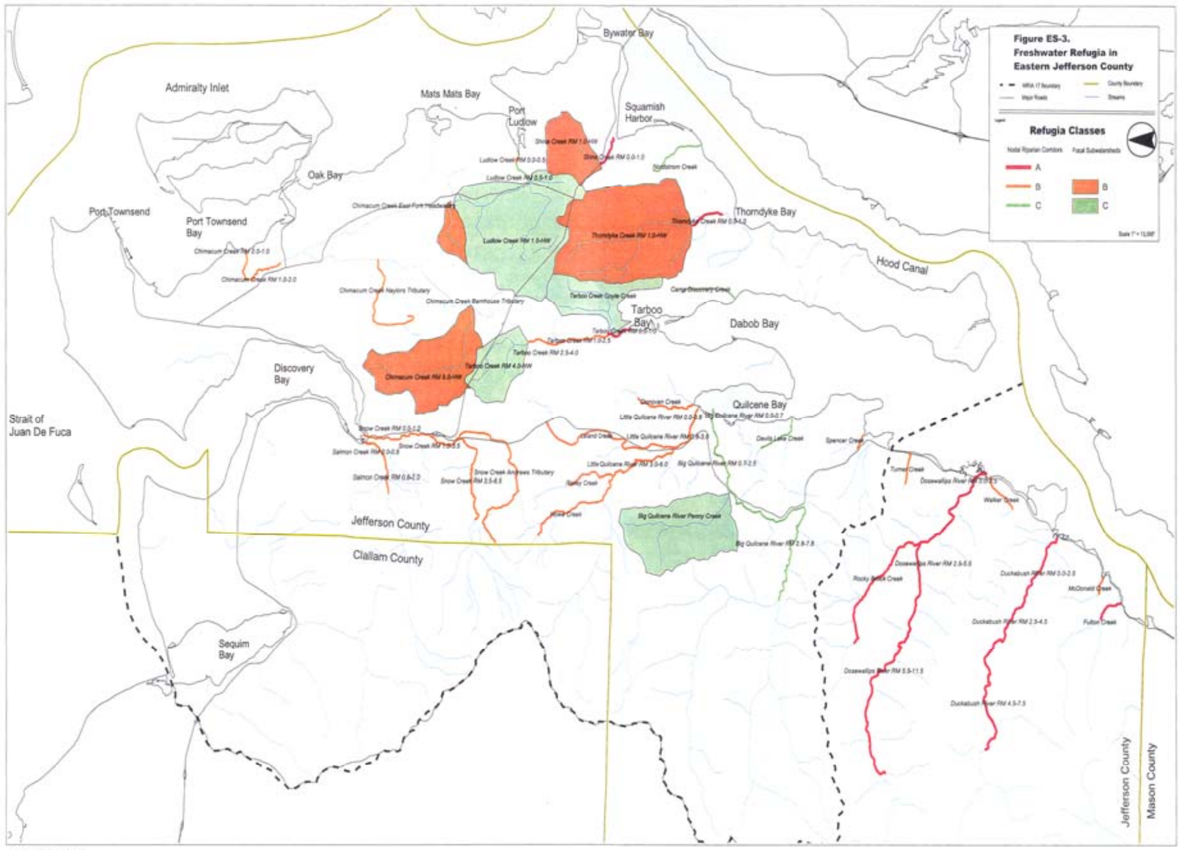
Approximately half of WRIA 20 within Jefferson County falls within the ONP, while the remainder is primarily commercial forest. Process-intensive areas for hydrology are primarily the floodplains of the Hoh and Bogachiel Rivers, Mosquito Creek, Goodman Creek, and Steamboat Creek. No lakes have been identified within this WRIA. Rain-on-snow zones have been identified in the middle to high elevations of the upper Bogachiel, upper and middle Hoh, and Hoh south fork watersheds.

Process-intensive areas for water quality include the wetlands along the Hoh River corridor, as well as around Goodman Creek, lower Bogachiel River, and middle Hoh watershed boundaries. Large coastal wetlands on the lower Hoh River also contribute to water quality processes.

Sediment transport and delivery processes are maintained by landslide-prone areas along the steep slopes of the Bogachiel River, middle Hoh River, and areas near Goodman Creek as well as along the coast. CMZ studies have not been conducted in WRIA 20; therefore, LWD recruitment and sediment storage, transport, and delivery processes remain uncharacterized.

[3] See section 3.3.2.2 for a description of the nodal corridor categories.

Figure 3-10. Salmon Nodal Riparian Corridor and Focal Sub-watershed for Eastern Jefferson County (May and Peterson, 2003)



WRIA 21

Approximately 70 percent of the Queets/Quinault WRIA 21 lies within the ONP/ONF. The remainder is primarily commercial and rural forest. Available information regarding process-intensive areas for hydrology indicates that infiltration and recharge may occur along highly permeable soils along the Queets River, Matheny Creek, and Clearwater River corridors. Surface water storage and water quality processes are likely to occur in wetland areas along the Queets and Quinault River, the lower reaches of the Clearwater River, and coastal wetland areas, as well as floodplains of the lower Queets and Clearwater Rivers. No large lakes have been mapped within this WRIA in Jefferson County, although smaller alpine lakes are likely to occur within the ONP. Rain-on-snow zones have been mapped in the middle to high elevations in the upper watershed of the Queets, Quinault, and Clearwater Rivers, primarily within the ONP.

Sediment transport and delivery processes are maintained by landslide-prone areas on the steep slopes of the upper Queets and Quinault Rivers and the Kalaloch Creek watershed, as well as areas of moderate soil permeability along the lower Queets River.

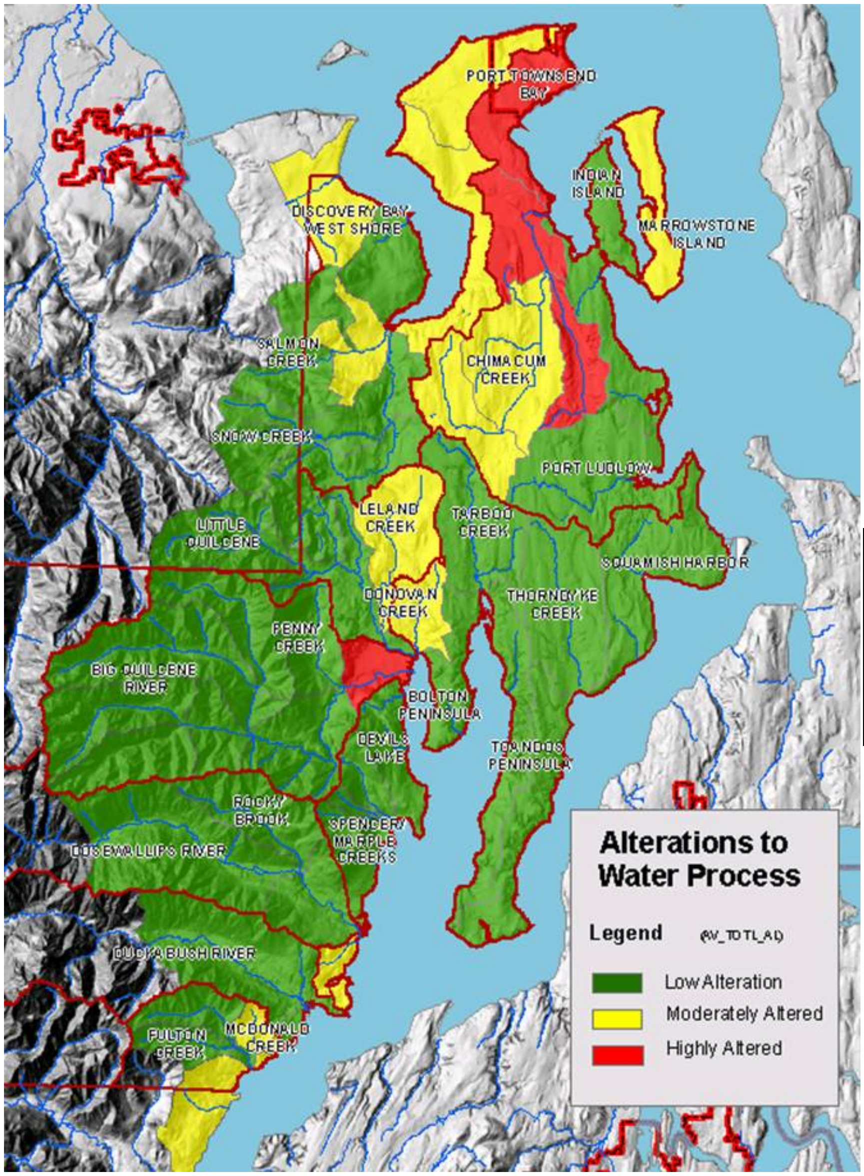
3.3.2.6 Freshwater Process Alterations

Land use and associated changes in land cover are the sources of altered processes that impair aquatic resources. The montane and foothill regions are subject primarily to forest practices, and forests are still the dominant land cover. The loss of hydrologically mature forest cover and the addition of roads are major causes of altered processes (Coffin and Harr, 1992 as cited in Stanley et al., 2005a). In addition, lost wetlands, particularly evident in the Chimacum Creek basin, and development on permeable deposits have altered processes in each WRIA (Maps 2 - 4). A number of urbanizing areas are located along the shorelines of east Jefferson County, including the City of Port Townsend and smaller pockets of urbanization such as Port Ludlow, Irondale, Hadlock, Quilcene, and Brinnon. Areas of high road density indicate potential for increased mass wasting. High road densities (more than 2 miles of road per square mile of watershed) can be found in half of the watersheds within the County. Surface erosion zones are indicated by areas where roads cross streams and by non-forested areas on erodible soils (Maps 6 and 7).

According to Ecology's watershed characterization, the Chimacum valley and Port Townsend area scored highest for relative degree of alteration of water processes compared to other areas of the east County (Figure 3-11) (Ecology, 2007). This is due primarily to forest clearing, wetland loss, and impervious surface from urban/suburban development. A significant portion of the lowland area scored "moderate" for alteration due primarily to forest clearing and wetland loss. The Olympic Mountains, Toandos and Bolton Peninsulas have large areas of low alteration, except for the mouths of the Little Quilcene and the Dosewallips Rivers due to impervious cover and forest clearing (Ecology, 2007).

The City of Port Townsend diverts water from the Big and Little Quilcene Rivers (2005 City of Port Townsend Annual Drinking Water Report available at http://www.cityofpt.us/NewsLetter/2005/05.pdf). The City and Crown-Zellerbach constructed the Big Quilcene diversion and 28.5 miles of transmission pipe between the Big Quilcene River and Port Townsend in 1927. The Little Quilcene River diversion was developed in 1956 as a supplemental supply to the Big Quilcene River. A diversion dam constructed on the Little Quilcene River conveys water via a pipeline to Lords Lake Reservoir.

Figure 3-11. Areas of High, Medium, and Low Alteration, Eastern Jefferson County (Ecology, 2007)



Hood Head is a protection area (color not shown)

WRIA 16

Process-intensive areas for infiltration/recharge are typically found in the lower watersheds of the large river valleys. Early seral stage vegetation and development (including impervious surface area) is seen in these areas, primarily north of the river mouths. The Duckabush and Dosewallips River floodplains are disconnected where Highway 101 crosses the estuaries. Rain-on-snow and snow-dominated zones are found primarily in the mountains and foothills. The peak runoff mechanism is altered where transitional areas occur in rain-on-snow zones. Generally, though, most rain-on-snow zones are within the ONP and at least partially forested.

Water quality alterations can occur from agricultural operations, failing septic systems, lost wetlands, and residential land use. Within WRIA 16, residential land use is concentrated near the marine shoreline, but septic systems are prevalent throughout the lower river valleys as well as along the marine shoreline. Large clearcuts, numerous roads, and often inadequate riparian vegetation buffer zones occur on state-owned and private forest lands. Mass wasting events in the lower Duckabush watershed have been directly linked to improper forest road construction, maintenance, and/or abandonment (Correa, 2003). Early seral stage vegetation is concentrated in the lower watersheds (Map 2);most of the watershed is characterized by late seral stage vegetation. Development on permeable deposits is apparent in the lower watersheds, particularly along the lower 2 miles of the north side of the Dosewallips River, several areas within a mile of the shore between the Dosewallips and Duckabush Rivers, and the vicinity of lower Fulton Creek.

Road density in WRIA 16 is generally low (less than 1 mile of road per watershed square mile) (Map 6). Road crossings of streams are abundant in the lower Dosewallips and Duckabush River watersheds, leading to alterations in sediment delivery processes in WRIA 16. Other factors are channel confinement of major streams, and localized loss of mature forest cover in erosion–prone areas (Map 6). Most of the WRIA is forested, and the areas outside of the ONP generally have low to moderate landslide potential (Map 4). Roads within 200 feet of streams are present throughout the WRIA, paralleling the mainstems of the major rivers in the upper watersheds and clustering near the coast. In addition, recent clearcut areas have been identified in the lower Duckabush River and Fulton Creek, adding to alterations of sediment and hydrological processes.

WRIA 17

Process-intensive areas of infiltration/recharge are found along the river corridors of the lower Big Quilcene River (Map 2). Early seral stage vegetation and human influence (including impervious surface area) is seen throughout the County, with high concentrations in the Little Quilcene and Snow Creek drainage basins. Other alterations within process-intensive areas include conversion of large areas of wetland in the upper Chimacum Creek drainage to agricultural use, and floodplain disconnection along the Little Quilcene River where Highway 101 crosses the estuary. Alterations to peak flow in the Snow Creek basin may result from early lack of forested areas within rain-on-snow zones. However, most rain-on-snow and snow-dominated zones are within the ONP and are mostly well forested.

Residential land use within WRIA 17 is concentrated in Port Townsend, Port Ludlow, and Quilcene. These areas generally do not coincide with process-intensive areas for hydrology. However, agriculture and septic systems are abundant outside of the urban areas, particularly along the Quimper Peninsula, Marrowstone Island, Chimacum Creek, and the shorelines of Hood Canal and Dabob and Quilcene Bays (Map 4). These are likely to alter water quality processes in wetlands and estuaries by introducing pathogens and nutrients. Large clearcuts and inadequate riparian zones occur on state-owned and private forest lands (Correa, 2002). Early seral stage vegetation occurs throughout the WRIA, but is primarily concentrated in the lower elevations. Development on permeable deposits is apparent in patches throughout the WRIA, but large areas of human disturbance are apparent along Snow Creek and the Discovery Bay shoreline, Port Townsend, Irondale and Chimacum Creek, and Port Ludlow.

Road density is relatively high (greater than 2 miles of road per watershed square mile) throughout WRIA 17. Consequently, roads within 200 feet of streams are abundant throughout the WRIA. As in WRIA 16, road crossings of streams, channel confinement, and localized removal of mature forest are key factors leading to alterations in sediment delivery processes in WRIA 17 (Map 4). Much of the WRIA remains forested, and most areas have little to low landslide potential. Mass wasting events in the Snow Creek and Chimacum Creek watersheds have been directly linked to improper forest road construction, maintenance, and/or abandonment (Correa, 2002).

WRIA 18

No alterations have been identified within WRIA 18 in Jefferson County. This area falls entirely within the ONP, and is either forested or glaciated. In Jefferson County, few roads within 200 feet of streams have been identified; a few were mapped along the Elwha and Dungeness River mainstems.

WRIA 20

Process-intensive areas of infiltration/recharge are typically found in the lower watersheds of the large river valleys. Overall, because much of WRIA 20 supports federal lands and forestry, alterations to infiltration/recharge are not likely to be as significant as other hydrology alterations. Early seral stage vegetation is seen primarily in logged areas within the Hoh River watershed. Human influence (including impervious surface area and septic systems) is limited to small settlements along the middle and lower Hoh River (Map 3) and Clearwater Village.

Floodplain connectivity in the Sol Duc basin is at risk. Impacts such as fill for road construction, and vegetation changes due to logging, agriculture, and development are reducing these already limited habitats (U.S. Forest Service, 1995 as cited in Smith, 2000).

Channel migration zones have been identified on various reaches of the Hoh River by Perkins Geosciences and TerraLogic GIS (2004), the U.S. Bureau of Reclamation (2004), and Herrera Environmental Consultants and Northwest Hydraulics (2002). These CMZs are important for sediment and hydrologic processes and for maintaining habitat. The studies were conducted in part to help identify management strategies for maintaining infrastructure, responding to flooding, and restoring habitat conditions for salmon and other species. Figures 3-12 and 3-13 depict a portion of the identified CMZ. Readers are encouraged to review the individual reports for additional information.

Channel incision within the North Fork Calawah and lower Bogachiel basins due to a combination of excessive sedimentation and a lack of LWD has resulted in ratings of “poor” for floodplain condition along the North Fork Calawah River and lower Bogachiel mainstem (Smith, 2000). Most rain-on-snow and snow-dominated zones are within ONP and at least partially forested (Map 3).

Figure 3-12. Lower Hoh River CMZ, Jefferson County (Perkins GeoSciences and TerraLogic 2004)

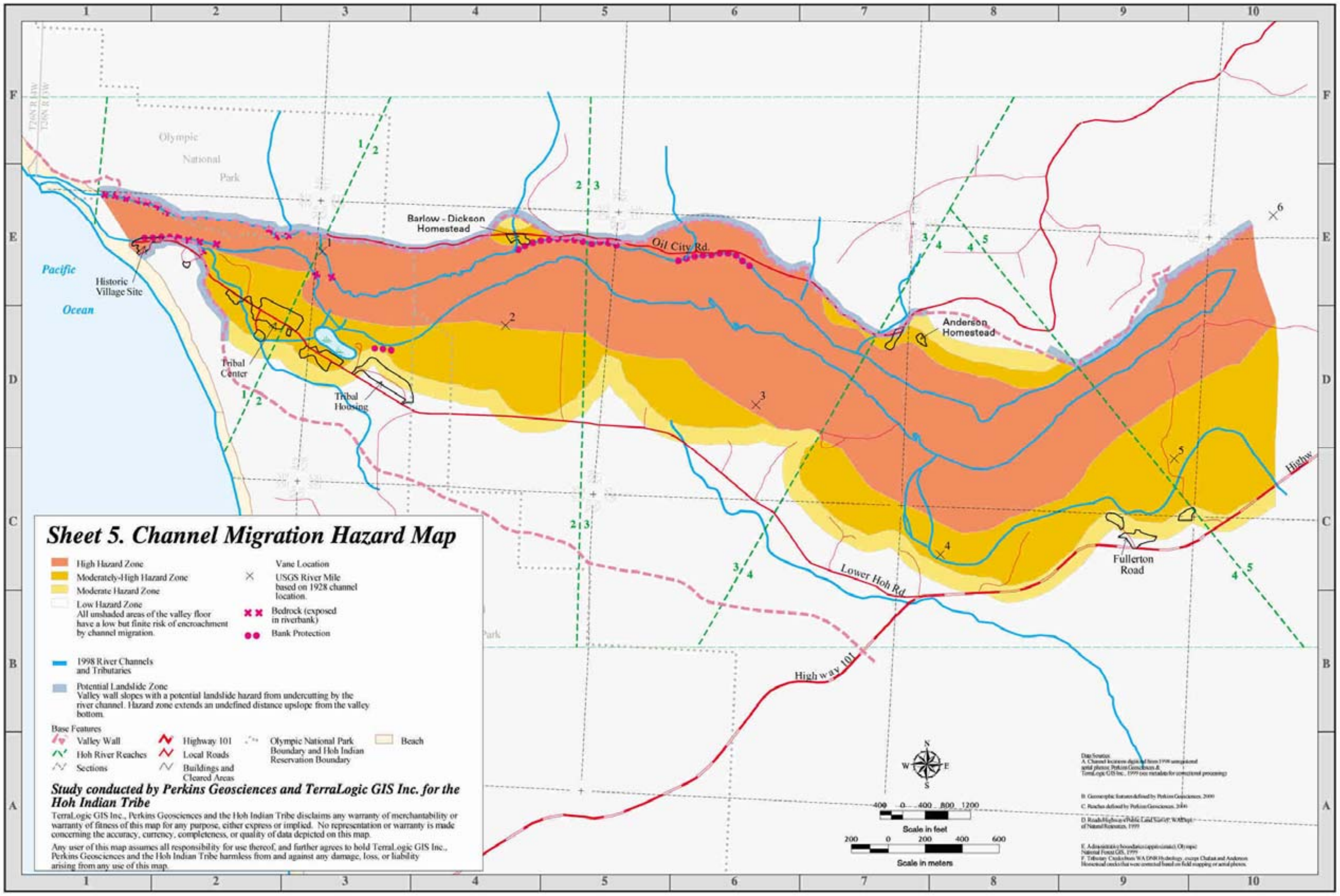
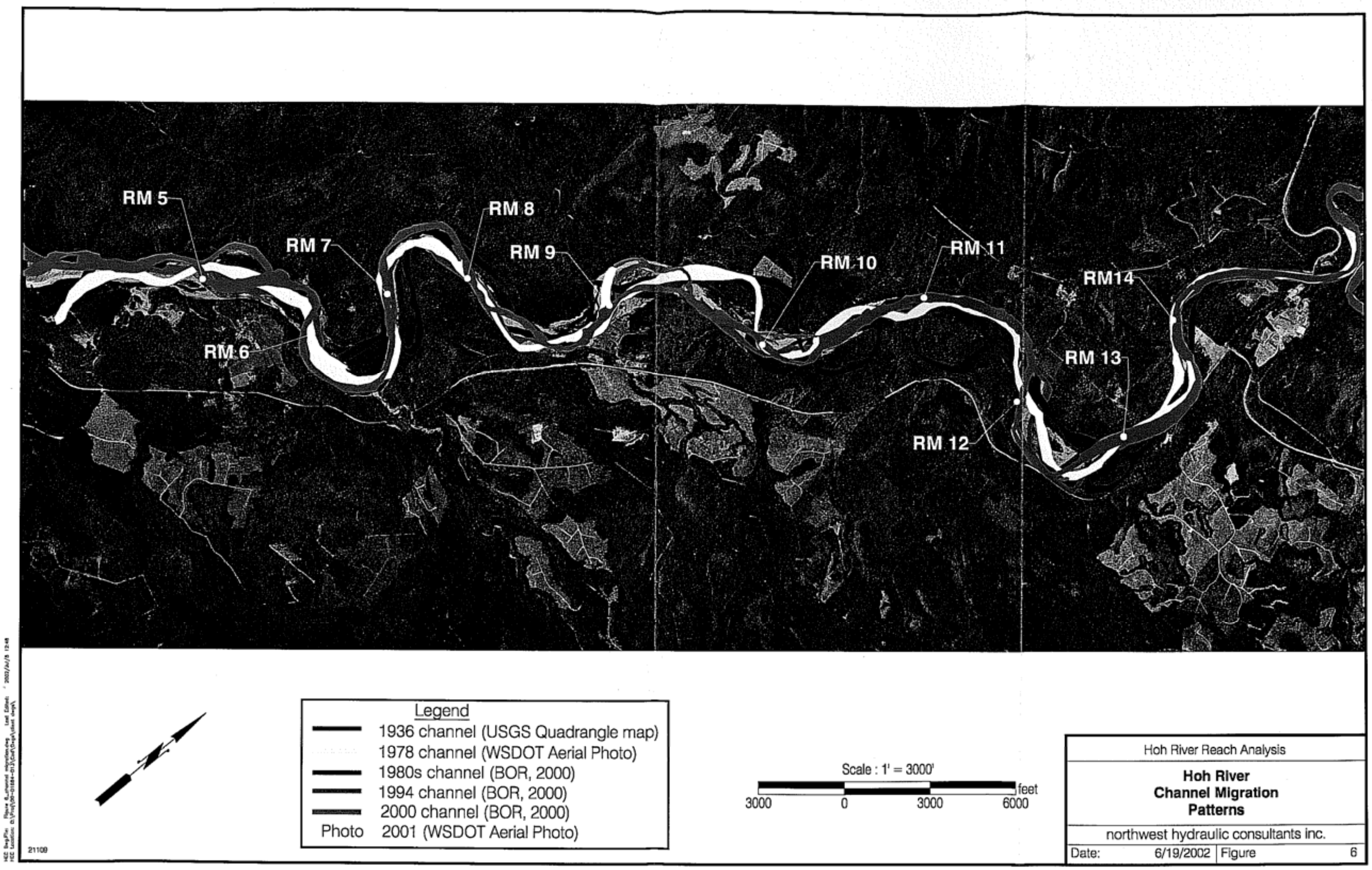


Figure 3-13. Hoh River CMZ, RM 5 to RM 14, Jefferson County (Herrera and Northwest Hydraulics 2004)



Road density is relatively high (greater than 2 miles of road per watershed square mile) in the lower elevation watersheds of WRIA 20 (Map 7). Consequently, road crossings of streams are a major factor leading to alterations in sediment delivery processes in WRIA 20. Roads within 200 feet of streams are extremely common, particularly along Goodman Creek and the lower Bogachiel River. Much of the WRIA falls within ONP and tribal land, and there are few potential landslide areas outside of this, with the exception of the Bogachiel River. Recent clearcut areas have been identified in the middle and lower Hoh River watersheds, further contributing to sediment delivery process alterations. LWD processes and riparian conditions have been classified as poor for most of the lower basins within this WRIA (Smith, 2000).

WRIA 21

Process-intensive areas of infiltration/recharge are typically found in the lower watersheds of the large river valleys. Overall, because much of WRIA 21 supports federal lands and forestry, alterations to infiltration/recharge are not likely to be as significant as other hydrology alterations. Early seral stage vegetation is seen primarily in logged areas within the lower Clearwater River and lower Queets River watersheds (Map 3). Human influence (including impervious surface area and septic systems) is limited to the town of Queets, as well as septic systems within the highly permeable floodplain area of the Clearwater River. Most rain-on-snow zones are within the ONP and are forested.

Road density is high (greater than 2 miles of road per watershed square mile) in the lower elevation watersheds of WRIA 21 (Map 7). Consequently, road crossings of streams are a major factor leading to alterations in sediment delivery processes. Roads within 200 feet of streams are densely distributed throughout the WRIA, but particularly in the Clearwater River, lower Queets River, and Matheny Creek basins.

A majority of the WRIA falls within federal and tribal land, and there are few potential landslide areas outside of this. The increased incidence of landslides and debris flows has affected tributary habitat in the Matheny Creek watershed (Smith and Caldwell, 2001). Soil erodibility has not been mapped for this WRIA.

Bank armoring is not a major concern within the Queets River basin, but road crossings in the lower watershed and Matheny Creek have disconnected floodplains and increased sedimentation in the river. No information is available on floodplain connectivity in the Clearwater River and Kalaloch Creek watersheds (Smith and Caldwell, 2001). Riparian conditions for the upper Quinault River have been classified as "good." Conditions are mostly "good" throughout the Queets basin, except in the lower Queets and lower Clearwater River and Kalaloch Creek basins, where conditions are mixed (Smith and Caldwell, 2001).