RESOURCES

NATURAL

Aquatic Resources Program
Endangered Species Act
Compliance Project

Covered Habitat Technical Paper

October 2005

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Doug Sutherland - Commissioner of Public Lands

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Contents

1. Introduction

This Washington Department of Natural Resources (Washington DNR) Endangered Species Act (ESA) Compliance Habitat Paper (Habitat Paper) is one of several documents developed to assist with ESA Compliance efforts. As steward of Washington's state-owned aquatic lands, Washington DNR manages over 2.4 million acres of tidelands, bedlands and shorelands in estuarine, saltwater and freshwater systems. State ownership for aquatic lands is determined on the basis of navigability which is defined in Section 332-30-106(40) as waters that are "…capable or susceptible of having been or being used for the transport of useful commerce…". The purpose of the ESA compliance documents is to organize information concerning species considered endangered, threatened, of concern or rare, associated habitat, and the interaction with Washington DNR authorized activities on state-owned aquatic lands. This information is for use within the framework of an ESA compliance process. Ultimately, the ESA compliance goal of Washington DNR is to:

Reduce the liability associated with authorization of activities for state-owned aquatic lands under the Endangered Species Act while enhancing efforts to conserve and recover endangered, threatened, and imperiled species.

Generally, the US Fish and Wildlife Service and NOAA Fisheries (the Services) require a standard information base for determining compliance with the ESA. Washington DNR has developed and initiated a process that accumulates, synthesizes, and presents this information in an efficient and compartmentalized manner for use in a final ESA compliance document. The basic information for direct application as components of an ESA compliance document include:

- Covered Species – Identifies species that would benefit from ESA compliance activities and their legal status (2007a).
- Proposed Covered Activities – Identifies Washington DNR management activities that may potentially cause take of covered species (Washington DNR 2005).
- Covered Habitat – Identifies the location being evaluated and describes baseline habitat conditions (this paper).
- Potential Effects and Expected Outcomes – Describes the direct and indirect effects of the potential covered activities, as well as benefits from applying selected conservation measures (Washington DNR 2007b).

The first phase of the process is to develop a science-based understanding of the relationship between species, habitats and the interaction with Washington DNR managed lands, including steps to conserve and recover species. Washington DNR is using an ecosystem-based approach to organize this information, which is a method compatible with both the agency's proprietary authorities and habitat-based management. The organization of information by ecosystem provides a habitat-based perspective for addressing the conservation needs of species and greatly assists in the analysis of take. By grouping species by habitat-type, existing spatial and temporal aspects of habitat use can more directly relate to activities authorized by Washington DNR.

Six ecosystems and several associated habitats were defined for organizing information (data) in a simple and logical manner. The ecosystem and habitat information was then organized in a database compatible with 1) data developed to describe temporal and spatial aspects of species/life-stage habitat use and 2) how the habitat relates to Washington DNR authorized activities. Therefore, the main purpose of the ecosystem and habitat definitions used in this process was to help organize data for screening and analysis of species, habitat and activities interactions. The ecosystem and habitat definitions were not used to explore detailed ecological or systematic questions. The combined data sets are used to assist in defining potential effects of Washington DNR actions on habitats and species and predicting the expected outcome from the implementation of various conservation measures. The six ecosystems, associated habitat types, and general descriptive characteristics are presented in Table 1.1. Table 1.2 presents a summary of authorized uses by ecosystem.

This Washington DNR ESA Compliance Habitat Paper provides definitions of ecosystems and associated habitats as used in the Washington DNR ESA compliance process. The ecosystem and habitat definitions provided in the Habitat Paper are founded on scientifically based and commonly-used classification systems (described in detail in later sections), but are simplified to some degree for this process. The simplification is in response to the practical realities of analyses that address a broad geographic scope, large number and variability of species and activities, and different resolution of available data. The Habitat Papers provide a perspective of how the simplified use of the terms "ecosystem" and "habitat" by Washington DNR in the ESA compliance process compares to current use in ecology and systematic biology.

Five basic criteria were employed in the selection of habitat types for the Ecosystems:

- The habitat types must have biological relevance to a broad array of species including amphibians, aquatic invertebrates, birds, fish, and reptiles,
- The habitat types must be based on physical processes,
- The habitat types must be based on a widely accepted classification system,
- It must be possible to create habitat types from existing data that were easily obtainable, and
- The spatial resolution of the habitat types must be consistent and compatible with other data sources used in the analysis (e.g., Washington DNR authorized activities), as well as adaptable to future refinements.

Ideally, the habitat types used for this classification system would incorporate all of the physical characteristics of an Ecosystem that might influence species assemblages. Because of the broad geographic extent of this project, synthesizing all of these variables was simply beyond the scope of the project. Furthermore, the spatial resolution of existing data on activities authorized by Washington DNR is very coarse. Washington DNR manages its business functions through the Revenue Timber and Assets (RTA) systems. The systems were originally developed to manage timber sales on state-owned lands, but have since been applied to other Washington DNR resources and functions. Although the RTA systems and associated databases have useful data and information that relate to activities and structures, it was not designed with either ecosystem or habitat management in mind. In particular the systems are limited by a) the locational assignment of use authorizations to 640 acre (259 hectare) sections without regard to the size or shape of the activity or structure within the section or adjacent sections; and b) the historical use of non-uniform protocols when describing and quantifying specific activity sub-groups and their components. Therefore, development of high resolution habitat types at this time is neither warranted nor appropriate. If the resolution of the use authorization data improves in the future, it may be possible to increase the resolution of the habitat data accordingly.

Table 1.1 - Characteristics of ecosystems and habitats used in the Washington DNR ESA Compliance process.

Ecosystem	Region/ Class	Habitat	Characteristics
Saltwater - Offshore			▪ Depth greater than 20 meters ▪ Benthic habitat below the photic zone ▪ Energy production derived from water column phytoplankton communities ▪ Dominated by unconsolidated sediments
	Coastal		▪ Unconsolidated habitats dominate, with consolidated habitats concentrated off the Olympic coast, west and southwest of Willapa Bay, and off Cape Flattery
	Inland		▪ Unconsolidated habitats dominate, with consolidated habitats concentrated off the San Juan Islands, the west coast of Whidbey Island and Admiralty Inlet, and the Tacoma Narrows
		Consolidated	▪ Substrate - rocks larger than cobble (265 millimeters in diameter), bedrock and consolidated clays ▪ Biota - high to moderate energy regimes: encrusting invertebrates and plants, urchins, rockfish, gobies, lingcod and sculpins; low energy - glass sponges, serpulid polychaetes, planktivorous invertebrates, cup coral, rockfish, longfin sculpin and gobies
		Unconsolidated	▪ Substrate - cobble, gravel, sand, mud and organic materials ▪ Biota ▪ High energy (cobble and mixed-coarse substrates) - mussels, barnacles, urchins, rock scallops, small bivalves, amphipods, and polychaetes ▪ Low energy (mud) - sea pens and whips, polychaetes, bivalves, amphipods, anemones, sea stars, urchins and sea cucumbers
		Water Column	▪ Greater than 10 meters above the bottom ▪ Biota - plankton (eggs, larvae, phytoplankton, zooplankton), fish (herring, salmonids, smelt, lamprey, spiny dogfish, cods, sandlance, rockfish), birds and marine mammals
		Deep	▪ Depth greater than 200 meters

Ecosystem	Region/ Class	Habitat	Characteristics
Saltwater - Nearshore			▪ Depth less than 20 meters ▪ Energy primarily derived from benthic vegetation and terrestrial sources ▪ Benthic habitats within the photic zone ▪ Vegetation has significant influence on species assemblages
	Coastal		▪ Unconsolidated habitat dominates, with consolidated substrates found in scattered along the northern coast and rocky headlands in estuaries
	Inland		▪ Unconsolidated habitat dominates, with consolidated habitat most common among the San Juan Islands, and on rocky headlands in Puget Sound
		Consolidated	▪ Intertidal and shallow subtidal areas dominated by bedrock or boulder ▪ Biota - Macroscopic red, green and brown algae; Kelp beds used by sea otters, and a variety of fish and invertebrate species for rearing, feeding and refuge; benthic diatoms
		Unconsolidated	▪ Eelgrass meadows (approximately +0.3 meters to –10 meters mllw) used by a variety of fish and invertebrates for rearing, feeding and refuge ▪ Flat areas of fine to coarse unconsolidated sediments near river and stream deltas and embayments not associated with freshwater systems; drift seaweeds; infauna (worms, small crustaceans and bivalves); shorebirds; abundant juvenile and adult fish; recreationally and commercially important stocks of clams ▪ Sub-estuaries characterized by variable salinity concentrations; riparian habitat, dune habitat, tidal marshes, seaweed assemblages, eelgrass meadows, and limited rocky shore habitat. ▪ Riparian Zone vegetated with overhanging shrubs and trees
		Water Column	▪ Greater than 10 meters above the bottom ▪ Biota - plankton (eggs, larvae, phytoplankton, zooplankton), fish (herring, salmonids, smelt, spiny dogfish, sandlance, rockfish), birds and marine mammals

Ecosystem	Region/ Class	Habitat	Characteristics
Tidal Wetlands			▪ Depth - mean high water to extreme higher high water ▪ Periodically inundated with tidal waters ▪ Emergent vegetation dominated by angiosperms ▪ Soft sediments, with anoxic subsurface conditions ▪ Protected from wave energies ▪ Significant localized freshwater input
Freshwater - Riverine			▪ Long linear interconnected networks, comprised of patterns and processes in that occur in longitudinal, lateral, and vertical dimensions ▪ Uni-directional flows terminating at the confluence with a larger stream or river, marine ecosystems or a lake ▪ Gradient typically decreases with longitudinal distance downstream ▪ Structure and variability of in channel habitat determined by topography ▪ Energy sources, community composition and behavioral adaptations vary with increasing distance downstream ▪ Includes riverine wetlands
		Low-gradient valley	▪ Slopes less than 0.1 percent with sand and gravel substrates ▪ Channels commonly have multiple threads ▪ Sediment supply generally greater than the river's transport capacity.
		Riffle-pool	▪ Alternating sequences of pools, bars, and riffles with gradients of 0.1 to 2 percent ▪ Sinuous with a high reach to valley length ratio ▪ Pools typically created by scour, with deposition occurring between pools in riffles or adjacent to pools on bars ▪ Particle sizes comprised of gravel and/or cobble

Ecosystem	Region/ Class	Habitat	Characteristics
		Plane bed	▪ Gradients between 2 and 4 percent ▪ Composed of intermediate substrate sizes (gravel to cobble)
		Step-pool	▪ Gradients between 4 and 8 percent ▪ Alternating sequences of relatively deep stream sections with flat, non-turbulent flow and shallow, steep sections with turbulent flow ▪ Pools formed by large boulders that restrict the flow of water, resulting in a backwater upstream of the restriction and a substantial drop in elevation downstream of the restriction
		Cascade	▪ Gradients greater than 8 percent ▪ Beds comprised of large boulders with channels typically confined by valley walls ▪ Movement of bed material is rare due to the large size of the dominant substrate and relatively shallow water depths
Freshwater - Lakes			▪ Standing body of water located in a topographic depression that is not directly connected to the sea ▪ Distinguished by relatively still waters, no ocean derived salts, and an absence of perennial emergent vegetation ▪ Includes lacustrine wetlands
	Oligotrophic		▪ Primary productivity rates low ▪ Trophic State Index less than 40
	Mesotrophic		▪ Moderate rates of primary productivity ▪ Trophic State Index 40 to 50
	Eutrophic		▪ High rate of primary production ▪ Trophic State Index greater than 50
		Littoral	▪ Ordinary high water waterward to a depth of 2 meters below low water or the extent of annual emergent vegetation

Ecosystem	**Region/ Class**	**Habitat**	**Characteristics**
		Limnetic	▪ Permanently wetted lands deeper than 2 meters, with little to no attached vegetation
		Profundal	▪ Deep water benthic habitat with no vegetation
Freshwater Wetlands (palustrine)			▪ Hydrophytic communities; undrained hydric soils; and non-soil substrates saturated with, or covered by, water at some point in the growing season ▪ Located in terrestrial areas adjacent to lakes and rivers (palustrine) ▪ Vegetation types may be forest, scrub-shrub, and emergent ▪ Emergent vegetation with ocean derived salinities of less than 0.5 practical salinity units (psu); **or** ▪ Lacking emergent vegetation and less than 8 hectares (20 acres), with no active wave formed or bedrock shorelines, and water depths of less than 2 meters

Table 1.2 - Compilation of current activity types and the number of authorizations from the RTA systems.

Activity		Authorizations				
Group	**Sub-group**	**Total**	**Saltwater**	**Rivers**	**Lakes**	**Unknown**
Aquaculture	Finfish	19	16	2	1	0
	Sand shrimp	13	13	0	0	0
	Shellfish	134	114	20	0	0
Flood, wave, erosion control	Non-specified	21	0	14	5	2
	Dike/dam	18	1	16	1	0
	Fill and bank armoring	78	40	25	10	3
	Breakwater	14	13	1	0	0
Miscellaneous nearshore	Log booming and storage	61	33	20	6	2
	Public access	113	67	24	18	4
	Sediment removal	77	38	32	3	4
Mitigation & enhancement	Artificial habitat	37	8	29	0	0
	Conservation	37	20	12	1	4
	Contamination & remediation	24	17	4	0	3
	Invasive species management	1	0	1	0	0
Outfall	Combined sewer outfall	3	1	2	0	0
	Desalinization	6	6	0	0	0
	Industrial, municipal	278	129	135	12	2
	Stormwater	60	19	22	17	2
Overwater structure	Boat ramp, launch, hoist	56	22	26	5	3
	Docks & wharves	309	200	53	52	4
	Rafts, floats	8	4	0	3	1
	Floating homes	68	0	37	30	1
	Marina	394	255	39	93	7
	Mooring buoy	274	228	8	10	28
	Nearshore building	98	72	19	7	0
	Shipyards & terminals	59	33	24	1	1
Transportation	Bridge	361	50	281	21	9
	Ferry	44	37	3	1	3
	Railroad	17	8	9	0	0
	Road	262	69	148	36	9
Unknown		89	33	24	12	20
Utility	Cables	695	170	448	62	15
	Oil/gas pipeline	124	19	102	2	1
	Sewer lines	47	12	26	8	1
	Water pipeline	108	28	72	5	3
	Water intake	48	10	28	9	1
Total		**4,055**	**1,785**	**1,706**	**431**	**133**

2. Saltwater Ecosystem Overview

Washington's saltwater environments extend 5.6 kilometers (3 nautical miles) off the Pacific Coast (Neah Bay to the Columbia River), covering more than 9,800 square kilometers (Lanzer 1999) with the total shoreline of the many islands, inlets and sub-estuaries along the Pacific Coast and in Puget Sound about 4,935 kilometers in length (Washington DNR 2002). Saltwater habitats in the state are commonly classified by using Cowardin et al. (1979) and Dethier (1990), with both schemes providing significant detail in terms of the numbers of habitat types. While the classification system presented here incorporates many of the elements in both Cowardin and Dethier, it has also been simplified to reflect the coarseness of the data available for Washington's state-owned aquatic lands.

Three saltwater ecosystems are defined here – offshore, nearshore and tidal wetlands (Table 2.1). The offshore ecosystem includes all saltwater areas where the water depth exceeds 20 meters mean lower low water, with the nearshore ecosystem ranging from 20 meters mean lower low water landward to sea level (extreme higher high water). Both ecosystems are further divided into coastal and inland regions (Figure 2-1.2), with the coastal region extending along the outer coast from the mouth of the Columbia River north to Cape Flattery. The inland region is comprised of the Strait of Juan de Fuca, the San Juan Islands north to the Canadian border, all of Puget Sound and the Columbia River from its mouth to the Bonneville Dam. Each region in these two ecosystems is characterized by three basic habitat types: consolidated (rock greater than 256 millimeters), unconsolidated (silt, mud, and rock less than 256 millimeters), and the water column (greater than 10 meters above the sea floor). The tidal wetland ecosystem encompasses emergent vegetation and wetland soils, and is periodically inundated with tidal waters. This ecosystem is found in estuaries where freshwater streams mix with marine waters and non-estuarine tidal marshes, and is not subdivided into classes or habitats.

Table 2.1 - Overview of saltwater classification scheme.

Ecosystem	**Offshore**		**Nearshore**		**Tidal Wetland**
Region	Coastal	Inland	Coastal	Inland	None distinguished
Habitats	Consolidated; Unconsolidated; Water Column	Consolidated; Unconsolidated; Water Column	Consolidated; Unconsolidated; Water Column	Consolidated; Unconsolidated; Water Column	None distinguished

2-1 Common properties and processes

2-1.1 Climate

Regional climate is damp and humid, with low evaporation rates and a relatively small annual temperature range. Forty percent of regional annual rainfall occurs during winter’s frequent storms (Burns 1985), with river runoff is at its maximum during spring snowmelt, and at the onset of the seasonal precipitation cycle during early winter.

2-1.2 Freshwater Input

The volume of freshwater flows entering Puget Sound is about 10 to 20 percent of that entering the Strait of Georgia, with most (about 60 percent) from the Skagit River (Thomsen 1994). The dominant contributor to freshwater discharge in the Strait of Juan de Fuca is the Fraser River. Discharge from the Columbia River plume accounts for 77 percent of the coastal drainage on the U.S. west coast, and is thought to have major ecological effects on offshore coastal waters of the Pacific northwest (Hickey and Banas 2003). The plume traditionally was thought to flow northward over the Washington shelf in the fall and winter, and southward and offshore in the spring and summer. However, recent studies by Hickey et al. (2005) showed that the plume may extend along the Washington coast as far as 150 kilometers from the river mouth from spring to fall. Additionally, the plume may include two branches that extend north and southwest of the river mouth. The plume resides on the Washington shelf for at least 50 percent of the summer. The Columbia River plume contributes water column iron and silica, which may affect phytoplankton growth. The plume edges are considered preferred feeding sites for zooplankton and perhaps, juvenile salmon (Salmonidae) (Emmett et al. 2003, Roegner et al. 2003) and may stop harmful algal blooms from reaching beaches during summer and fall (Hickey et al. 2005).

2-1.3 Tides

Tides in the Pacific Northwest are mixed semidiurnal (two high and two low tides each lunar day with unequal amplitude). For inland ecosystems, tidal range increases southward into Puget Sound, from less than 3 meters in the north to more than 5 meters near Olympia. On the coast, the maximum tidal range is about 4 meters, with an average range of approximately 2 meters (Komar 1997).

2-1.4 Circulation/Mixing

Locally, tidal currents and wind events also affect inland circulation patterns. In Puget Sound wind flow is predominantly from south-southwest during the winter, before gradually reversing direction in the spring (Williams et al. 2001). Highest net speeds are in the range of 6 to 9 meters per second. Wave conditions are generally mild, except during storms, and are locally generated, with height and period limited by fetch (Williams et al. 2001). Wind significantly influences the oceanography of interior waters by generating surface waves, mixing surface waters and forcing surface drift currents (Thomsen 1994).

In Puget Sound, stratification is greatest during the summer because of the combined effects of solar heating and river discharge, and lowest in the winter because of seasonal cooling and increased wind-induced mixing from storms (Thomsen 1994). Many of the deeper regions of Puget Sound exhibit persistent density stratification based on salinity and temperature (Williams et al. 2001). In comparison, seasonal stratification in the Strait of Juan de Fuca is relatively uncommon and the waters are well-mixed vertically.

2-1.5 Dissolved Oxygen

Dissolved oxygen (DO) is an important requirement for all aquatic and marine animals and plants for respiration. Sources of oxygen include the air overlying the water and photosynthesis by aquatic plants and algae. Incorporation of air into the water is facilitated by surface waves. Photosynthesis occurs during daylight periods, and its rate is at a maximum during periods of high light, such as in spring and summer. Both of these processes raise DO concentrations in the water, whereas respiratory demands by live animals, plants and microbes deplete DO. Because oxygen is vital to their metabolic processes, low DO concentrations may cause considerable stress to marine animals. A DO concentration of 5 milligrams per liter is often considered as the boundary between high and low conditions, with levels below this value often leading to biological stress (Newton et al. 2002). A dissolved oxygen concentration of 3 milligrams per liter may indicate near hypoxic conditions, which may be harmful to marine animals.

2-2 Offshore ecosystem

The offshore ecosystem covers about 5,870 square kilometers in Washington state and all but 0.3 square kilometers are owned by the state. This ecosystem includes marine areas where the water depth is greater than 20 meters. It was selected as one of the three primary saltwater ecosystems because it represents a biologically defined transition point for the benthic biota. Benthic vegetation influences animal species composition and ecological functions in shallower waters because of its inherent structural complexity, and also serves as a source of primary production to the food web. However, the benthic habitats that occur in the offshore ecosystems lie below the euphotic zone, the region where enough light energy reaches the bottom to sustain photosynthesis by benthic vegetation. Therefore, offshore ecosystems are primarily driven by energy derived from water column phytoplankton communities, whereas nearshore ecosystems (discussed in Section 2-3) are fueled primarily by energy from benthic vegetation and terrestrial sources (Valiela 1984). Thus, the shallow-water boundary of the offshore ecosystem approximates the transitional zone between the contrasting energy sources characteristic of the nearshore and offshore zones.

Within the offshore ecosystem, the coastal region includes those areas along the outer coast of Washington from the mouth of the Columbia River to Cape Flattery, and the inland region is comprised of the Strait of Juan de Fuca, the San Juan Islands north to the Canadian border, all of Puget Sound and the Columbia River from its mouth to the Bonneville Dam (Figure 2-2.1).

2-2.1 Distinguishing Characteristics

The predominant benthic habitat of coastal offshore areas is unconsolidated soft bottom, with consolidated habitats, found primarily in scattered pockets off the Olympic coast, in larger aggregations west and southwest of Willapa Bay, and off Cape Flattery.

Unconsolidated habitats also prevail in inland offshore areas, and comprise most of the area within the Strait of Juan de Fuca and Puget Sound. Consolidated habitats occur primarily among the San Juan Islands, off the west coast of Whidbey Island and Admiralty Inlet, and in the Tacoma Narrows channel.

2-2.2 Properties and Processes

PHYSICAL PROPERTIES

Thomsen’s (1994) review of the physical oceanography of the Strait of Georgia-Strait of Juan de Fuca system provides an excellent summary of the processes affecting the offshore saltwater ecosystems within the inland region, especially with regard to water properties and basin characteristics. In addition, Hickey and Banas’ (2003) synthesis of the oceanography of the US Pacific Northwest serves as the basis for our understanding of large-scale current patterns and water patterns in the coastal region. Both documents provide the basis for the descriptions of the physical properties presented in the following sections.

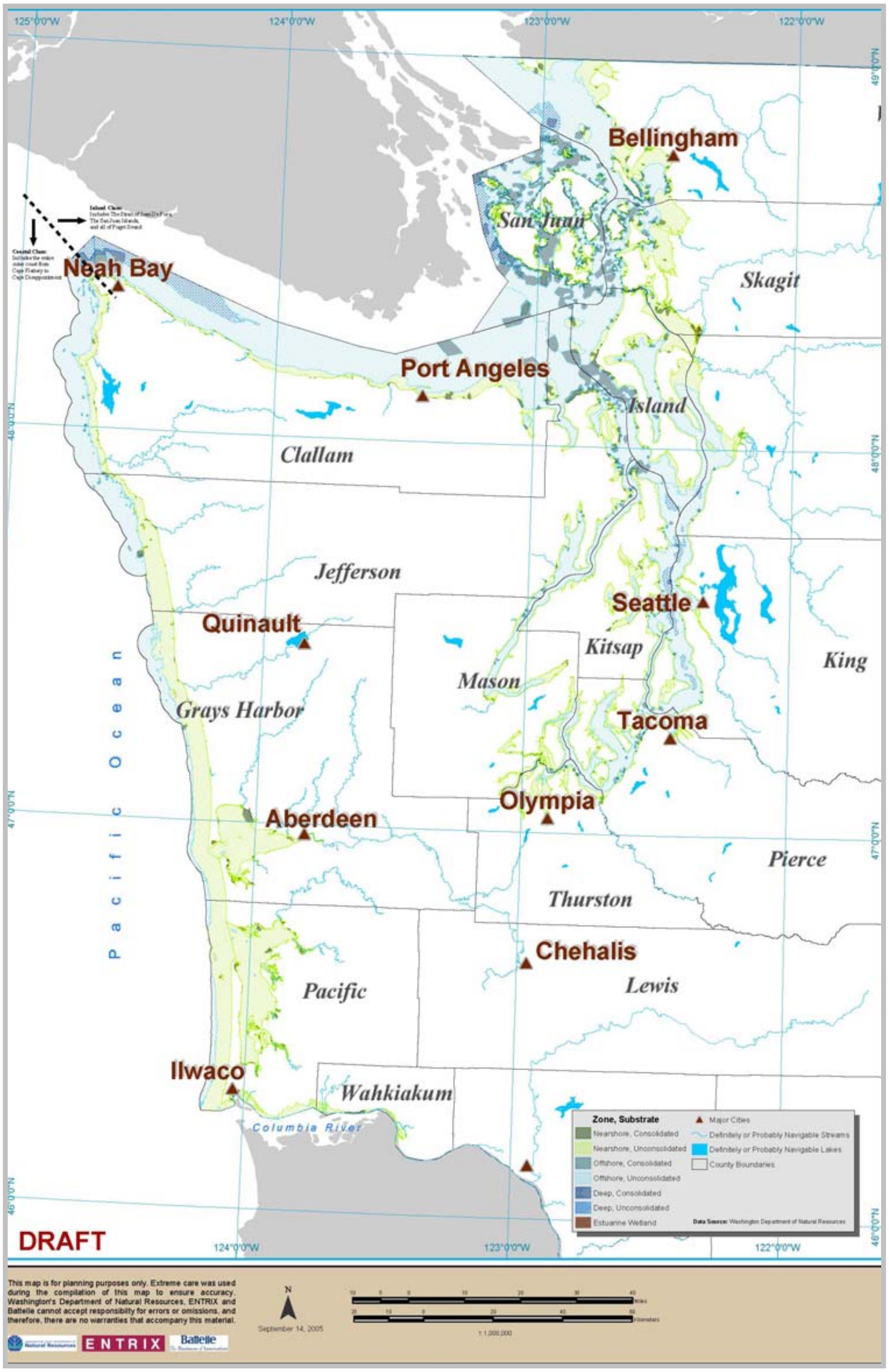
Bathymetry

Bathymetry, the shape of submarine landforms, strongly influences water circulation and water chemistry of offshore ecosystems, especially for inland fjord-like estuaries such as Puget Sound. Bathymetric features, such as sills, define the geometry of the interconnected basins, affecting lateral water exchange and oceanographic conditions in each region (Burns 1985; Thomsen 1994). For the purposes of this work, we consider the inland regions to contain two major, distinct basins – Puget Sound and the Strait of Juan de Fuca. Puget Sound is defined at its northern end by a 65 meter sill at Admiralty Inlet, which accounts for 98 percent of the tidal prism flow, and is comprised of all of the marine waters south to Olympia, including Hood Canal.

The Strait of Juan de Fuca is classified as a positive estuary (i.e., one in which freshwater inputs exceed losses from evaporation) with strong tidal currents. The western end of the Strait is influenced by oceanic processes, whereas the eastern end is modified by intense tidal processes near the entrance to various tidal passages (Thomsen 1994).

The continental shelf is wide and gently sloping off the coast of Washington, which may result in slower circulation times and greater particle residence times (Hickey and Banas 2003). Bathymetric features, such as submarine canyons, river plumes, and banks also modulate the local upwelling response in coastal offshore systems.

Figure 2-2.1 - Saltwater ecosystem and associated habitat types



This map is for planning purposes only. Extreme care was used during the compilation of this map to ensure accuracy. Washington's Department of Natural Resources, ENTRIX and Battelle cannot accept responsibility for errors or omissions, and therefore, there are no warranties that accompany this material.

Circulation/Mixing

The circulation of inland offshore habitats is governed primarily by winter rainfall and summer snowmelt, which results in a net seaward outflow in the upper portion of the water column and landward inflow in the lower water column (Thomsen 1994).

Oceanic conditions in coastal offshore areas are strongly influenced by large scale, seasonal upwelling-downwelling fluctuations (Hickey and Banas 2003). From late spring to early fall, coastal winds are predominantly from the north to northwest, which produces an offshore transport of water in the upper 100 meters of the water column, with compensating onshore transport at depth (Thomsen 1994). This upwelling process results in relatively cold, high salinity, nutrient rich water over the continental shelf in the summer. From late fall to early spring, wind direction is primarily from the southeast, which causes a reversal of these conditions associated with downwelling. Offshore coastal ecosystems are affected by abrupt fluctuations in these currents, water properties and sea level that are driven by wind forcing at relatively short day-time scales (Hickey and Banas 2003). Hickey and Banas (2003) further postulate that mesoscale features associated with bathymetry, the Columbia River plume and Juan de Fuca eddy further enhance primary production and chlorophyll associated with upwelling off the Washington Coast.

Sediment

In inland systems, flowing water is generally the most important process governing particle transport, with streams and rivers representing the primary means for moving unconsolidated sediments (Burns 1985). Sediment particles introduced into Puget Sound are derived equally between rivers and non-point shoreline sources (e.g., beach or cliff erosion) (Burns 1985). The bulk of the offshore inland ecosystem is a low energy, depositional environment.

For coastal systems, winter storms generate large waves and stronger ocean currents than observed during the summer (Komar 1997). Beaches erode during the winter, then rebuild during the following summer, which can lead to changes sediment composition in the deeper offshore regions.

WATER PROPERTIES

Temperature

Surface water temperature to a depth of about 60 meters varies from about 8 to 15 degrees Celsius between winter and summer in the main basin of Puget Sound (Washington Department of Ecology 2002). Stratification within 10 meters of the surface can develop where water temperatures are colder below the stratified layer and warmer on the surface. River flow, when highest, can also affect surface water temperatures.

Salinity

Surface water salinity varies with season also, with summer typically exhibiting greater salinities on the order of 29 to 30 practical salinity units[1] (Washington Department of Energy 2002). Salinity varies more in winter depending on river input, and can get as low as 27 practical salinity units. Salinity at 10 meters depth is often greater than at the surface during periods of heavy river input and can help create water stratification.

Water Clarity

Water clarity is affected by plankton concentration and suspended sediments. Secchi depth, a measure of water clarity, varies from 4 to more than 11meters, with the clearest waters often occurring during calm periods in winter, and after the massive phytoplankton blooms in spring and summer have died off (Washington Department of Energy 2002). Plumes of turbid water from larger rivers, like the Skagit River, can create widespread reduction in water clarity, as can phytoplankton blooms and strong storm activity that resuspends fine sediments.

Nutrients

Nitrogen and phosphorus in coastal waters come from three primary sources – upwelling of nutrient rich water, input from land sources and recycling of nutrients with surface waters and sediments (Harris 1986). As previously noted, the upwelling of nutrient rich water from the Pacific Ocean is the major source of macronutrients to coastal offshore ecosystems. Rich oceanic waters are the primary source of nutrients for inland offshore ecosystems, with anthropogenic sources considered negligible in well-flushed regions (Williams et al. 2001).

Water column primary productivity rates in Puget Sound are generally considered to be very high relative to those in other temperate estuaries, with rates primarily affected by sunlight, stratification and water residence time (Williams et al. 2001). Because all of these factors are highly variable in time and space, primary productivity and abundance occurs in extremes, characterized by phytoplankton blooms. Intense blooms mostly occur in the spring and fall, with smaller blooms in summer and sparse growth in the winter. Major types of phytoplankton present in Puget Sound include diatoms (Bacillariophyceae), dinoflagellates (Dinoflagellata), and microflagellates (Protozoa) (Strickland 1983).

Dissolved Oxygen

Many offshore habitats in Puget Sound have DO concentrations between 5 and 3 milligrams per liter, which reflects the influence of dense, high salinity, naturally low-

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[1] With the advent of devices that electronically measure continuous records of conductivity (e.g., CTD or conductivity–temperature–depth profiler), a new “practical salinity scale” has been determined. It is defined in terms of its electrical conductivity relative to a prescribed standard and is a ratio without units. These values are often given the units psu, for “practical salinity units.” For most purposes one can assume that the new unit, psu, and the older unit, part per thousand are synonymous. http://amsglossary.allenpress.com/glossary/search?id=salinity1

oxygenated waters from the Pacific Ocean that persist in some of the deeper basins (Newton et al. 2002).

2-2.3 Habitat Types Overview

Habitats in this ecosystem include the water column and consolidated and unconsolidated benthic areas. The water column is that portion of either the coastal or inland regions that is more than 10 meters (33 feet) above the bottom. Consolidated benthic habitats are typically rocks larger than cobble (approximately 265 millimeters in diameter), but also may include bedrock and consolidated clays (hardpan) (Dethier 1990). Hardpan supports epibenthic organisms and certain boring animals (e.g., *Adula californiensis*), but is too hard to be inhabited by typical infaunal animals (Dethier 1990). Unconsolidated habitats include cobble (less than 265 millimeter-diameter particles) and gravel in addition to the primary soft-bottom constituents, sand and mud. Dethier (1990) also includes organic materials, such as wood chips and leaf litter, as unconsolidated habitat. The following habitats are found within the coastal and inland regions of the offshore ecosystem and are discussed in detail below:

- Consolidated habitats - Moderate- to high-energy regimes; Low-energy regimes.
- Unconsolidated habitats - Moderate- to high-energy regimes; Low-energy regimes.
- Water column habitats.

HABITAT TYPES DESCRIPTION

The nature of the communities inhabiting each of the benthic habitat types is at least partially correlated with the particular physical energy regime in which it occurs. Dethier (1990) defines three basic energy regimes; high, in which the habitat is exposed to oceanic swells or very strong currents; moderate, in which the habitat is exposed to wind waves or to moderate tidal currents; and low, in which habitats encounter little wave action or, at the most, very weak currents.

Consolidated Habitats

Consolidated hard-bottom habitats in moderate- to high-energy regimes, primarily among the San Juan Islands, are often predominantly characterized by encrusting invertebrate species, particularly filter-feeding taxa, such as the anemones (*Metridium senile* and *Urticina* spp.), the rock scallop (*Hinnites giganteus*), and large barnacles (*Balanus nubilus*) (Dethier 1990). Common algae inhabiting the shallower reaches of this habitat include coralline algae (Corallinales) and foliose red algae (Rhodophyta). In the deeper portions, only encrusting algae occur and brachiopods are common. Motile invertebrates include sea urchins (*Strongylocentrotus* spp.). Rockfish (*Sebastes* spp.), gobies (*Coryphopterus nicholsi*), lingcod (*Ophiodon elongatus*) and sculpins (*Artiedius* spp.) are the more common fishes.

Low-energy consolidated habitats are characterized by glass sponges (Hyalospongia), serpulid polychaetes, and the squat lobster (*Munida quadrispina*). A variety of planktivorous invertebrates, including anemones (*Urticina* spp.), the cup coral

(*Balanophyllia elegans*) and the zoanthid *Epizoanthus scotinus*, are common inhabitants. Quillback (*S. maliger*), copper (*S. caurinus*) and widow (*S. entomelas*) rockfish, three species discussed in the Covered Species Paper (Washington DNR 2007a), are common residents, as are the longfin sculpin (*Jordania zonope*) and gobies. Additional information regarding the habitat types used by species under consideration in this ESA compliance process is presented in Appendix A.

Unconsolidated Habitats

The communities characteristic of unconsolidated habitats in high-energy offshore regions depend on the specific habitat component. Unconsolidated cobble and mixed-coarse (gravel, shell hash, sand) substrates are inhabited by horse mussels (*Modiolus modiolus*) and barnacles (*Balanus* spp.). Cobbles are also inhabited by sea urchins and rock scallops. Mixed-coarse substrates in coastal areas house a variety of infauna including the small bivalves, *Nuculana minuta* and *Nemocardium centifilosum*, and ampeliscid and other amphipods. Sandy unconsolidated habitats in high-energy areas are relatively stable communities comprised of the small bivalves *Tellina modesta* and *Macoma expansa*, fossorial amphipods, such as *Rhepoxynius abronius*, *Eohaustorius washingtonianus* and *Foxiphalus obtusidens*, and the polychaetes *Maldane glebifex* and *Chaetozone setosa* (Dethier 1990).

In low-energy regimes, shallower unconsolidated sands may be inhabited by sea pens and sea whips (*Ptilosarcus gurneyi* and *Virgularia* spp., respectively), chaetopterid polychaetes, many bivalve species, and motile crustaceans such as *Cancer magister* and *Pugettia* spp. Deeper (greater than 50 meters) unconsolidated sand and silt substrates in the Strait of Juan de Fuca, and along the outer coast, are inhabited by polychaetes, several small bivalve species and fossorial amphipods. Unconsolidated substrates in low-energy environments are comprised of mud, which are characterized in shallower waters (20 to 30 meters) by the bivalves *Pecten caurinus* and *Saxidomus giganteus*, many smaller bivalves, sea whips (*Virgularia* spp.), anemones (*Pachycerianthus fimbriatus*) and several polychaete species. Larger motile fauna include the seastars *Pycnopodia helianthoides* and *Luidia foliolata*. Deeper low-energy unconsolidated muds house the tusk shell (*Dentalium rectius*), heart urchins (*Brisaster latifrons*), sea cucumbers (*Molpadia intermedia*) and an assortment of small bivalves and polychaete worms (Dethier 1990).

Water Column Habitats

Some of the predominant and most visible species in the offshore community are not directly associated with the bottom community, but rather, function primarily at the surface and in the upper and middle layers of the water column (Long 1982). Plankton and fish, along with the birds and marine mammals that prey on them, comprise this community. At least 21 marine mammal species have been reported in the interior offshore ecosystem of the Strait of Juan de Fuca and Northern Puget Sound, which they primarily use for feeding and migration (Long 1982). Some of the more common species include: gray whale (*Eschrichtius robustus*), minke whale (*Balaenoptera acutorostrata*), killer whale (*Orcinus orca*), harbor porpoise (*Phocoena phocoena*), Dall's porpoise (*Phocoenoides dalli)*, and harbor seal (*Phoca vitulina*). Bird populations in offshore areas are composed of large numbers of a relatively few species, including loons (*Gavia* spp.), grebes (Podicipedidae), murres (Alcidae), cormorants (*Phalacrocorax* spp.), and gulls (Laridae) (Long 1982). Most species are obligate piscivores, with murres forming one of the major components of the offshore system in interior waters.

Surface waters in offshore areas are known to have large quantities of pelagic fish eggs and larvae dominated by flatfish (Pleuronectidae and Bothidae), cod (Gadidae), greenling (*Hexagrammos* spp.), smelt (Osmeridae), and sculpin (Cottidae) species during the winter and spring months (Long 1982). In addition, unpublished work from NOAA Fisheries indicates that juvenile and adult herring (*Clupea pallasi*), and at times juvenile salmon, congregate in surface waters, along with surf smelt (*Hypomesus pretiosus*) and lamprey (*Lampetra tridentatus*). Standardized surveys of offshore mid-water column fish communities are generally lacking, although commercial and recreational catches provide some insight into typical species found in these habitats. These include spiny dogfish (*Squalus acanthias*), Pacific herring, salmon (all seven species), several cods (pollock *Theragra chalcogramma*, tomcod *Microgadus proximus*, Pacific cod *Gadus macrocephalus* and hake *Merluccius productus*), Pacific sandlance (*Ammodytes hexapterus*), surf smelt and several species of pelagic *Sebastes* rockfish (Long 1982).

2-2.4 Baseline Conditions and Impact of Covered Activities in Relation to Current Condition

The offshore ecosystem includes the benthos and water column. The plankton in the water column is largely responsible for primary production, nutrient cycling and food production for higher trophic levels. The benthos benefits from food produced in the water column. Nutrient cycling also occurs in the benthos. Benthic invertebrates are utilized as food by epibenthic predators including bottom dwelling flat fish, shrimp and crab (both Decapoda). Pelagic predators, such as fish and marine mammals, are also known to forage on benthic fauna and provide linkages back to the water column.

Inorganic and organic materials discharged into the water are eventually buried through sedimentation. Some larger wastewater treatment outfalls discharge at or near the offshore ecosystem. The ultimate effect of discharge, depending upon the level of treatment, is deposition of organic matter and any associated contaminants. This can alter the community structure of the benthos, and serve as a vector for the transfer of contaminants to higher trophic levels (Long 1982). Disposal of dredged material can bury benthic communities, and thereby at least temporarily disrupt ecological processes associated with the benthos. Dredging removes benthic communities and may alter sediment structure such as grain size and organic matter content at a site.

Any activity that increases the turbidity of the water column, such as dredged material disposal, outfall discharges or runoff from land (e.g., stormwater), can affect primary productivity in the water column. Alteration of this process will theoretically affect secondary and higher order productivity. Studies demonstrating this effect in the Washington have not been carried out, however. Log booms, although infrequently moored over deep water, would shade the water column and potentially reduce primary productivity. In addition, loss of bark from the logs may impact organic matter composition and sediment redox potential, and thus affect benthic community structure.

2-2.5 Potential Alterations Related to Activities Authorized by Washington DNR

Table 1.2 provides a summary of the types of activities authorized by Washington DNR in the saltwater ecosystems and is based on information derived from Washington DNR's Revenue Timber and Assets (RTA) systems. Information in the RTA is not sufficiently detailed to differentiate between agreements that occur in the offshore, nearshore, or tidal wetland ecosystem. More information regarding the RTA systems and the activities authorized by Washington DNR is presented in the Covered Activities Paper (Washington DNR 2005), with a detailed examination of the effects associated with these activities presented in a Potential Effects and Expected Outcomes Technical paper (Washington DNR 2007b). Additional information illustrating the occurrence of various activity sub-groups by habitat type is presented in Appendix B.

2-3 Nearshore ecosystem

The nearshore ecosystem is comprised of those waters ranging from 20 meters mean lower low water landward to sea level (extreme higher high water). This ecosystem represents a biologically defined transition zone for the benthic and possibly water column biota, and is fueled primarily by energy from benthic vegetation and terrestrial sources (Valiela 1984). Benthic vegetation not only influences animal species composition and ecological functions because of its inherent structural complexity, but also serves as a source of primary production to the food web (Simenstad and Wissmar 1985). Additionally, Long (1982) found that bird populations differed in the offshore and nearshore ecosystems, with the boundary marking the change falling roughly at the 20 meter depth contour. While benthic habitats in the nearshore ecosystem generally lie within the euphotic zone, the lower depth of light penetration is highly dependent on water clarity.

Within the nearshore ecosystem, the coastal class includes those areas along the Washington outer coast from the mouth of the Columbia River to Cape Flattery, and the inland class is comprised of the Strait of Juan de Fuca, the San Juan Islands, all of Puget Sound and the Columbia River from its mouth to the Bonneville Dam (Figure 2-1.1).

This ecosystem covers about 3,380 square kilometers in Washington State, with unconsolidated habitats accounting for approximately 3,120 square kilometers or 92 percent of the total nearshore habitat. Approximately 2,700 square kilometers (approximately 80 percent) are owned by the state of which 2,460 square kilometers are classified as unconsolidated. Ownership for the remaining areas in nearshore ecosystem is divided among private landowners, municipalities, counties, ports, the federal government and other interests. Coastal and inland nearshore unconsolidated habitats account for most of the total area owned by entities other than the state of Washington (approximately 660 square kilometers).

2-3.1 Distinguishing Characteristics

The predominant benthic habitat of coastal nearshore areas is unconsolidated soft bottom. Consolidated habitats, which comprise only a small proportion of the system, are in scattered pockets found primarily along the northern coast and on rocky headlands in the estuaries. Unconsolidated habitats also prevail in inland nearshore areas, and comprise most of the area within the Strait of Juan de Fuca and Puget Sound. Consolidated habitats are most common among the San Juan Islands, and on rocky headlands in Puget Sound.

2-3.2 Properties and Processes

PHYSICAL PROPERTIES

Hickey and Banas' (2003) synthesis of the oceanography of the US Pacific Northwest includes an evaluation of oceanic processes on the nearshore and estuaries of the coast of Washington. The reconnaissance assessment of the eastern shore of Central Puget Sound nearshore ecosystems (Williams et al. 2001) provides a good synopsis of physical processes affecting the nearshore in Puget Sound. Both documents provide the basis for the descriptions of the physical properties presented in the following sections.

Bathymetry

The bathymetry of the nearshore ecosystem varies depending on the geomorphology of the surrounding landscape. In Puget Sound much of the nearshore ecosystem is a narrow fringe along the edge of the steep-sided fjord estuary; the exception is in shallow inlets and back-bay areas of the convoluted shoreline. In northern Puget Sound there are shallow estuaries at river mouths (Bellingham Bay, Skagit Bay, Port Susan Bay) or the historical location of river mouths (Padilla Bay). The nearshore habitat in southern Puget Sound is most prominent in several shallow inlet areas, including Henderson, Budd, Eld, Totten, and Hammersley Inlets, and the northern parts of Case and Carr Inlets (Burns 1985). Nearshore habitats in Hood Canal are found primarily in the shallow waters in Quilcene Bay, at the mouth of the Skokomish River, and in Lynch Cove (Burns 1985). The predominant portion of the nearshore ecosystem occurs in the coastal region because of the gently sloping bathymetry associated with the continental shelf and two large shallow estuaries along the southern part of the shoreline (Grays Harbor and Willapa Bay).

Freshwater Input

Freshwater inputs to the nearshore ecosystem result in variable salinity concentrations and nutrient supplies. Because of this, many of the plant and animal species in the nearshore ecosystem are adapted to withstand large salinity fluctuations.

Tides

Nearshore habitats are directly affected by wetting and drying as the tide moves up and down the beach, and accordingly, most intertidal plant and animal species are adapted to some degree of desiccation. In addition, intertidal plants are adapted for highly variable light conditions as the water column depth changes with the tide.

Circulation/Mixing

During periods of water column stratification, the nearshore ecosystem is most affected by the upper water column stratum. In summer, this layer can be warmer and more nutrient poor as compared to deeper waters. In winter, the upper layer is less saline because of freshwater flows from streams and rivers.

Upwelling can directly affect the nearshore ecosystem and result in enhanced production because of the abundance of nutrients supplied from depth. The movement of these nutrient-rich waters into the euphotic zone in the nearshore ecosystem stimulates rapid phytoplankton growth, which in turn provides support for larger zooplankton populations. Tidal exchange then transports these highly productive waters into estuaries, which are especially important for outmigrating juvenile salmon in the spring and summer (Emmett et al. 2000). In the fall and winter, wind direction is primarily from the southeast, which causes a reversal of these conditions associated with downwelling and onshore surface currents. This process can move phytoplankton (Roegner et al. 2002) and planktonic larvae, like Dungeness crab larvae, from offshore into the estuaries (Emmett et al. 2000).

Sediment

The nearshore in coastal ecosystems is shaped by sediment transport caused by waves and wave currents, with approach patterns determining the type of currents and resulting sediment movement. When waves approach the beach parallel to the shoreline a series of rip currents develop causing erosion in pockets along the beach, while waves approaching at an angle form a longshore current or littoral drift. These currents can move sediment along the shore for hundreds of miles (Komar 1997) and the direction of the sediment transport is determined by wind direction. The net littoral drift is the difference between the seasonal sand movements (Komar 1997) and sand accumulation along jetties or spits is an indication of the direction of the drift. Along the Pacific Coast of Washington the net direction is northward as indicated by the Long Beach Peninsula, which was formed by transport of sand from the Columbia River.

While glaciation shaped the general geomorphology of the aquatic basins in Washington (Burns 1985), present-day sediment processes are responsible for forming and maintaining unconsolidated nearshore features such as dunes, marsh plains, unvegetated beaches (e.g. flats). Disruption or alteration of sedimentary processes necessarily impacts these features.

WATER PROPERTIES

Temperature

Water temperature varies dramatically seasonally and spatially. Solar energy heats the water and the intertidal substrata at low tides, which results in dramatic seasonal variation in water temperature. For example, water temperature can range from 6 to 9 degrees Celsius during winter and from 16 to 19 degrees Celsius in summer (Thom and Albright 1990). Summer temperatures in shallow embayments with restricted circulation can reach 20 to 25 degrees Celsius during warm sunny days. Infrequent long cold periods can drive temperatures to as low as 2 degrees Celsius, especially in shallow systems. Infrequently, very shallow water can even freeze. Rivers and stream flows can affect temperature in the nearshore. Typically, warming of freshwater during summer will increase water temperature in the nearshore where flows impact the beach. In winter, freshwater flows can cool nearshore water temperatures. Winds that blow offshore cause vertical mixing of the water column and can create upwelling which brings colder deeper water from offshore into the nearshore environment. Stratification of the water column in the nearshore typically results in a warm surface layer during summer and a cold surface layer in winter. The most protected water and shallowest sites show the greatest extremes in temperature (e.g., Budd Inlet in southern Puget Sound), whereas sites most exposed, deep and open to circulation (e.g., outer coast) show the least extremes. The greatest range in water temperatures between winter and summer can occur during strong El Niño periods.

Salinity

Salinity varies seasonally and spatially in the nearshore. Salinity is determined by the relative amounts of freshwater inputs from rivers and streams flows and saline ocean water. Winds and currents cause vertical and horizontal mixing of fresh and salt water. Nearshore areas along the outer coast that are not affected by freshwater typically have ocean salinities (about 35 practical salinity units), whereas nearshore areas dominated by rivers can have periods of very low salinity. In central Puget Sound, salinity observations can vary between about 15 practical salinity units in winter-spring to about 31 practical salinity units in late summer and early autumn. In the Columbia River estuary, extreme freshets induced by high levels of precipitation and runoff can completely flush any salinity from the estuary.

Nutrients

Inorganic nutrients typically include nitrate, nitrite, ammonia and phosphate, which are typically called macronutrients. These macronutrients are important to the support of phytoplankton, seaweed, seagrass and marsh plant growth in nearshore areas and can limit productivity if found in low concentrations. An overabundance of one or more of these nutrients can result in abnormal abundances of phytoplankton or seaweed, which upon decay can create areas of low dissolved oxygen (hypoxia). Nutrients are supplied to the nearshore zone by ocean inputs and freshwater runoff. Upwelling will result in increased nutrient concentrations in the nearshore. Large rivers and small streams can bring significant amounts of nutrients into the nearshore zone also. Plant use and uptake also affects the seasonal concentrations of nutrients. For example, in the nearshore zone in central Puget Sound, nitrate concentration varies from a high of about 35 micromoles per liter in winter to a low of less than 5 micromoles per liter in early summer (Thom and Albright 1990). Phytoplankton and benthic algae production in spring and early summer are responsible for utilizing the nitrate. Besides upwelling and freshwater sources, remineralization of nutrients from dead organic matter in the nearshore can contribute to nutrients in the nearshore. In shallow embayments with restricted circulation and no freshwater input, nutrients can become extremely low in summer. Nutrients are typically in greater concentrations in open nearshore areas where upwelling and wave energies are dynamic.

Dissolved Oxygen

Dissolved oxygen (DO) concentration is highly variable in space and time in the nearshore zone. Because the water column is shallow and often overlies very productive habitats, periods of high photosynthesis can result in oxygen levels greater than 100 percent of the theoretical maximum oxygen concentration possible in water (supersaturation). In central Puget Sound, nearshore DO concentrations are typically greatest and most variable in spring (e.g., 11 to 16 milligrams per liter) and summer and least in autumn and winter (e.g., 7 to 9 milligrams per liter) (Thom and Albright 1990). Oxygen demand by sediment-associated microbes and chemical processes can be great in embayments with low circulation, where sediments are high in organic matter concentration or with very high densities of large infauna such as clams.

2-3.3 Habitat Types Overview

The nearshore consists of many diverse habitats that provide critical functions for marine algae, seagrasses, invertebrates, adult and juvenile fish, marine mammals and birds. The following habitats are found in the inland and coastal regions of the nearshore ecosystem and are discussed in detail below:

- Consolidated habitats - Rocky shore assemblages; Some seaweed assemblages.
- Unconsolidated habitats - Some seaweed assemblages; Eelgrass meadows; Flats; River and stream deltas (sub-estuaries); Saltwater riparian zones.
- Water column habitats.

HABITAT TYPES DESCRIPTION

Consolidated Habitats

Rocky Shore Assemblages

Rocky shores include those areas of the intertidal and shallow subtidal zone that are dominated by bedrock or boulder substrata. A characteristic group of aquatic plants and animals colonizes these substrata. Habitats are generally defined by relatively large-sized or numerically abundant taxa. These assemblages can be dominated by kelp beds and other seaweed or benthic invertebrates.

Seaweed Assemblages

Seaweeds are macroscopic algae that occur in the sea. The group is divided into three taxonomic subgroups distinguished by their dominant photosynthetic pigmentation (i.e., red, green and brown algae). Seaweeds occur throughout the nearshore zone where the water is somewhat saline and light levels are great enough to support their growth. They reach greatest abundance in areas where salinity is routinely above about 15 practical salinity units, and the general trend is for the greatest numbers of species to occur at salinities in the range of 31 to 35 practical salinity units (Thom 1980). Although most seaweed species grow attached to consolidated substrata (i.e., rocks and larger), some species such as ulvoids, a group of flat green seaweeds, can live unattached to the bottom. Gabrielson et al. (2000) list 633 species of seaweed from the Pacific Northwest (southeast Alaska through Oregon). The vast expanses of rocky shores along the Strait of Juan de Fuca and rocky outcrops on the outer coast of Washington support many of these species. In central Puget Sound, seaweed diversity on the order of 160 species of seaweed has been documented. Fewer species are reported from southern Puget Sound (Thom et al. 1976).

Seaweed species, along with associated animals, are distributed along the vertical depth gradient (zonation). Their distribution is controlled by a variety of factors including species-specific requirements and tolerances for light, desiccation and thermal stress, physical stress (e.g., log bashing, wave action and currents), herbivore grazing, competitive interactions, and life-history strategies (e.g., *r*-selected, *k*-selected species). The morphology of the species often reflects its tolerance. For example, small, desiccation-resistant turf-like species occur in the upper intertidal zone where desiccation stress is strong. Red algae often are found at the deepest depth because of the ability of their pigment systems to utilize the wavelengths and energy levels of light that are found at these depths. Interspecific competition can often be very strong in deeper areas that are subjected to low desiccation stress. In these areas, larger species with an ability to hold space often dominate. Seaweed assemblage zonation is most evident in the Straits, and other rocky shores. Zonation in the intertidal zone is much less evident in south Puget Sound.

Specific zonation can often be described for localities. Along many rocky shores in Washington, the upper intertidal band consists of low growing turf and crust-forming species. Below this is a band of the fucoid brown seaweed (*Fucus* spp), usually followed by a diverse mix of red, green and brown seaweed. In the shallow subtidal zone, larger brown algae can dominate and form an assemblage comprised of an understory of smaller species which may occur associated with the large dominant species. Eventually the brown algae will give way to the more shade tolerant red algae and invertebrates as the end of the euphotic zone is reached.

One group of brown algae includes all of the order Laminariales and is commonly referred to as kelp. While all kelp are attached to the substrate by root-like holdfasts, kelp is divided into floating and non-floating kelp. Bull kelp (*Nereocystis luetkeana*) and giant kelp (*Macrocystis integrifolia*) are floating kelp that can form extensive canopies at or near the surface of the ocean. These beds are most common in rocky, high-energy marine environments. In Washington State, floating kelp beds are found on approximately 11 percent of the shoreline, primarily on the north coast of the Olympic Peninsula (Washington DNR 2002). Washington DNR's Nearshore Habitat Program has been monitoring the aerial extent of kelp habitat along the Strait of Juan de Fuca and the Olympic Peninsula coast annually since 1989 to evaluate natural variation and changes related to human impacts (Washington DNR 2005). Annual variability is high, with the overall extent of kelp fluctuating between a high of 4,788 hectares (11,832 acres) in 2000 and a low of 1,911 hectares (4,722 acres) in 1989.

Kelp beds are used by sea otters, and a variety of fish and invertebrate species for rearing, feeding and predator avoidance. In some areas, herring may lay eggs on kelp fronds.

Although not seaweeds, benthic diatoms can be important components of the algal communities on rocky shores and in unconsolidated substrata, and as epiphytes on seaweeds and eelgrass (*Zostera* spp.). Certain diatom species form colonies in gelatinous tubes or filaments, while others form a golden-brown surface layer on sand and mud. Macroscopically, these colonies appear to be small brown seaweed and are generally most abundant in the nearshore in spring and early summer. Primary production from benthic diatoms can be as high as that in eelgrass beds (Thom 1989)

Seaweed abundance varies by season in response to seasonal changes in light, temperature, salinity and nutrients. Other factor such as grazing pressure, reproduction timing and occurrence of storm events can also influence seasonal variations in abundance. Species with an annual life history die out completely each year, whereas perennial species will persist throughout the year, but may have a much-reduced size in winter. In central Puget Sound, the succession of species generally goes from a period of lowest abundance and species richness in winter to an early spring bloom of benthic diatoms (Thom 1980). This is followed by an increase in the size and abundance of brown algae. In mid-late summer, green algal species are at their most abundant. Finally, in autumn red algal species are most prevalent.

Unconsolidated Habitats

Eelgrass Meadows

Unlike seaweeds, seagrasses are rooted flowering plants found in submerged marine aquatic habitats; five species of seagrass occur in Washington State. Eelgrasses (*Zostera marina* and the exotic *Z. japonica*) are the most widespread seagrass and are documented to occur along approximately 1,135 kilometers of shoreline (Washington Department of Natural Resources 2002). Species within the genus *Phyllospadix* (commonly called surf grass) are much less abundant and are restricted to the lower intertidal and shallow subtidal zone in high-energy (exposed) rocky marine shorelines. Eelgrass forms essentially monotypic stands, referred to as meadows, in unconsolidated sediments throughout much of Puget Sound, in areas along the Straits and in coastal estuaries. Eelgrass does occur in small areas in the outermost portion of the Columbia River estuary. Eelgrass grows from approximately +0.3 meters to –10 meters relative to mean lower low water (Thom et al. 1998). The lower extent is controlled by light penetration through the water column, and the upper extent is controlled by desiccation (Thom et al. 2003).

Eelgrass meadows are major sources of carbon to the nearshore ecosystem in many areas of the State. The meadows harbor one of the richest assemblages of animals among all aquatic habitats in the State (Phillips 1984). Juvenile salmon are often found in high abundance in eelgrass meadows during spring and summer (Thom et al. 1989). Juvenile salmon prey are produced in high densities in eelgrass meadows, and the young salmon utilize the meadow for feeding and refuge during their outmigration to the ocean. Herring lay their eggs preferentially on eelgrass in many areas (Phillips 1984). Crab, including Dungeness, utilize the meadows for feeding and refuge (McMillan et al. 1995, Holsman et al. 2003).

Flats

Flats consist of gently sloping shores that contain fine to coarse unconsolidated sediments, although patches of cobble may also occur on flats. Flats occur associated with river and stream deltas (see below), and in embayments not associated with freshwater systems. Flats in these latter areas are largely formed by deposition of material eroded from bluffs. Benthic diatoms associated with the sediments can be the major source of primary production in these areas. Drift seaweeds, such as ulvoids, may also accumulate on flats. Benthic infauna including worms, small crustaceans and bivalves inhabit flats. Many of the infaunal species can be important prey for shorebirds. Juvenile salmon prey can be abundant in these areas also. Juvenile and adult flat fish are common on flats. Where cobble patches form, densities and numbers of species of infaunal animals can be very high. Recreationally and commercially important stocks of clams (Bivalvia) can develop in cobble/gravel habitats on flats. Geoducks (*Panopea abrupta*) occur in the lower intertidal and shallow subtidal elevations on flats.

River and Stream Deltas (sub-estuaries)

Rivers and streams that enter into larger estuarine and tidal systems such as Puget Sound, the Columbia River, and Willapa Bay can form distinct sets of habitats. As noted, flats form at the mouths of rivers and streams. In addition, deltaic areas include channels through the flats that can contain water even at the lowest tides. Sub-estuaries are characterized by having a variable salinity concentration depending on riverflow. Flats associated with sub-estuaries contain many of the same species as are found on flats. Sub-estuaries can also contain riparian habitat, dune habitat, tidal marshes, seaweed assemblages, eelgrass meadows and limited rocky shore habitat. These systems represent the transition between fresh and salt water for migratory salmonids. Recent studies indicate that salmonids spend considerable time in sub-estuaries that are along their migratory route to the ocean (Beamer et al. 2005). The overall ecological importance of these sub-estuaries is not well documented.

Saltwater Riparian Zone

This zone of habitat is immediately landward of the intertidal zone and is often naturally vegetated with shrubs and trees that sometimes overhang the intertidal zone (Williams et al. 2001). Like the river riparian zone, it is believed that nearshore overhanging vegetation habitat provides shade, organic matter, and water and noise buffering functions. Organic matter debris deposited in the intertidal zone can form floating mats that move offshore. Recent research has shown that insects produced in this zone can enter the nearshore food web (Sobocinski 2003). In urbanized regions such as central Puget Sound, this zone is often heavily impacted by coastal development.

Water Column Habitats

The nearshore water column habitat is home to many species of planktonic invertebrates, fish species and is used by several species of mammals and birds. Yet, probably the most valuable component of this habitat is the phytoplankton community that is responsible for much of the primary production in nearshore waters. The phytoplankton (microscopic plants) community in this habitat is comprised of three main groups–dinoflagellates, diatoms and microflagellates (Strickland 1983). Diatoms are typically the most abundant group, particularly during spring blooms, periods of dramatic population increases in response to changes in the light regime and nutrient availability in the water column. *Skeletonema costatum* is often the predominant diatom in these blooms. Dinoflagellates typically are more common in relatively quiescent waters than they are elsewhere and may be predominant in some parts of the central Puget Sound area (Strickland 1983). Zooplankton (microscopic animals) are the main consumers of phytoplankton and, thus, serve to link primary production to higher trophic levels, such as fish and other vertebrates. Zooplankton communities are comprised of permanent residents, such as copepods, and temporary inhabitants, such as the larvae of many invertebrate species. Additionally, some mobile invertebrates, such as amphipods and other small crustaceans, that typically inhabit sediments by day become part of the plankton community at night. Zooplankton are capable of limited movement within the water column and often migrate horizontally to follow phytoplankton blooms (Williams et al. 2001).

Zooplankton are important prey for many species of fishes that inhabit nearshore water column waters, particularly juvenile salmon. Williams et al. (2001) described the most efficient trophic pathway within the water column habitat as one that progresses from diatoms to large copepods to fish, such as juvenile salmon. Other species that feed primarily on zooplankton include juvenile and adult herring (*Clupea pallasi*), smelt, stickleback and sand lance (*Ammodytes hexapterus*), and juvenile salmon, cod (*Gadus macrocephala*), hake (*Merluccius productus*), pollock (*Theragra chalcogramma*), lingcod (*Ophiodon elongatus*), sablefish (*Anoploploma fimbria*), and dogfish (*Squalus acanthias*) (Williams et al. 2001). Several mammal species are important, if typically only occasional, residents of nearshore water column habitats. Harbor seals (*Phoca vitulina*) frequent these waters attracting their primary predator, killer whales (*Orcinus orca*). Grey whales (*Eschrichtius robustus*) may frequent this habitat during feeding forays on soft-bottom habitats. River otters (*Lutra canadensis*)may be found in this habitat, especially near inland bays (such as Sequim Bay). Sea otters are common water column inhabitants in coastal nearshore waters, particularly along the northwest coast of Washington. Birds that may occur in this habitat include loons (*Gavia* spp.), grebes (Podicipedidae), cormorants (*Phalacrocorax* spp.), gulls (Laridae), and several species of ducks (Long 1982).

2-3.4 Baseline Conditions and Impact of Covered Activities in Relation to Current Condition

Shoreline modifications can greatly change the functional capacity of the nearshore ecosystem. Although some modifications may perform multiple functions, there are three primary functional categories: wave energy dissipation, shoreline stabilization, and other human needs (Williams and Thom 2001). Breakwaters and jetties project into subtidal areas and are designed to dissipate wave energy, protect backshore areas, and direct tidal flow. Shoreline armoring or stabilization structures include bulkheads, revetments, seawalls, groins, ramps, beach nourishment and biotechnical approaches. There are approximately 1,476 kilometers of shoreline armoring in the nearshore of Washington State, excluding the Columbia River (Washington DNR 2002). Finally, shoreline or nearshore structures such as tide gates, sewer outfalls and artificial reefs provide for other human needs (e.g., farmland creation, runoff and waste conveyance, fishing and diving opportunities) and directly affect nearshore hydrology in other ways.

OVERWATER STRUCTURES

Overwater structures can alter the nearshore ecosystem by changing key controlling factors such as light, wave energy and sediment transport (Nightengale and Simenstad 2001). Excluding the Columbia River, there are approximately 3,578 piers and docks, 29,809 small slips and 717 large slips in the nearshore ecosystem of Washington State (Washington DNR 2002). In general, overwater structures create shade which can affect the ability of plants to grow and also can cause behavioral changes in fish migrating along the shoreline. Overwater structures can also change the wave energy, currents, and transport mechanisms which can affect habitat forming processes.

FILLING, DREDGING, DIKING

Filling has occurred historically in the urbanized areas of Puget Sound and the Strait of Juan de Fuca as these areas were developed to meet the needs of port facilities and other economic activities on the waterfront. Dredging occurs primarily in the Columbia River navigation channel and in some urban areas where large port facilities are located. There have been several large (greater than 100,000 cubic yards) dredging projects within Puget Sound within the last two years (2004 to 2005), including two in Seattle and two in Tacoma (US Army Corps of Engineers 2005). The largest of these is the Blair Inner Reach Cutback and Turning Basin Expansion, which removed 2.6 million cubic yards of material (US Army Corps of Engineers 2005). Diking has occurred in areas along the nearshore for flood protection and agriculture, with many of the diked areas are located in former tidal wetlands (Section 2-3).

AQUACULTURE

The major aquaculture activities in the nearshore ecosystem of Washington State are focused on growing oysters and fish. Oysters (largely *Crassostrea gigas*) are typically grown near the sediment surface in either ground or line culture. Fish (e.g., Atlantic salmon, *Salmo salar*) are raised primarily in pens suspended above the bottom. Concerns related to aquaculture activities include the effect of oyster culture on eelgrass and the effect of fish pens on the water and sediment quality in the area.

2-3.5 Potential Alterations Related to Activities Authorized by Washington DNR

Table 1.2 provides a summary of the types of activities authorized by Washington DNR in the saltwater ecosystem. The information presented in this table was derived from the Revenue, Timber and Assets (RTA) systems. Information in the RTA is not sufficiently detailed to differentiate between agreements that occur in the offshore, nearshore, or tidal wetland ecosystem. More information regarding the RTA systems and the activities authorized by Washington DNR is presented in the Covered Activities Paper (Washington DNR 2005a), with a detailed examination of the effects associated with these activities presented in a Potential Effects Analysis paper (Washington DNR 2007b).

2-4 Tidal wetland ecosystem

As defined in this paper, the tidal wetland ecosystem (Figure 2-1.1), includes all areas within the intertidal zone with emergent vegetation (i.e., vegetation not including seagrasses or macroalgae) and wetland soils that are periodically inundated with tidal waters. This ecosystem includes estuaries where streams and rivers mix with marine waters. The tidal wetland ecosystem was selected as one of the three primary saltwater ecosystems because it is a biologically distinct ecosystem from other nearshore habitats, with recognized issues for sensitive, wetland dependent species. Because of their recognized ecological importance, tidal wetlands have received specific protection under the Federal Clean Water Act and other federal, state and local laws and regulations. While no separate habitats are distinguished in this ecosystem, tidal wetland habitats commonly include submerged aquatic macrophytes, intertidal emergent marshes, tidal swamps, and tidal riparian fringe habitats. The various habitat types composing this ecosystem type are commonly studied and reported in the literature (e.g., Mitsch and Gosselink 1993).

The total area of the tidal wetland ecosystem within the state of Washington is approximately 66 square kilometers. Washington state tidal wetland ecosystems are predominantly represented in the following locations: Columbia River Estuary, Willapa Bay, Grays Harbor, Skagit Bay, Nooksack River delta, Nisqually River delta, and several river deltas in Hood Canal. Although these areas are predominantly owned by entities other than the state of Washington, about 14 square kilometers are state-owned aquatic lands.

2-4.1 Distinguishing Characteristics

Tidal wetlands differ from nearshore tidal marshes in that tidal wetlands are generally more protected from wave energies. Tidal wetlands are situated in quiet bays that are significantly affected by local sources of freshwater runoff. As compared to sandier nearshore systems, tidal wetlands often contain very soft sediments, with anoxic conditions persisting below the surface. Ecologically, the tidal wetlands serve as habitat, refuge, and feeding areas for resident and migratory estuarine animal species (Thom 1987). This ecosystem forms a physiological transition zone for young salmon migrating from their spawning habitat through nearshore ecosystems and finally into the open ocean.

For the purposes of this analysis, the tidal wetland ecosystem is defined as that area of the estuary dominated by angiosperm vegetation that is routinely submerged. Tidal wetlands occur in tidally influenced systems with significant dilution of the salt water by freshwater discharged from land. We also include tidal wetlands that are located inland from any influence of salt from the ocean. Tidal wetlands occur from about mean high water to extreme higher high water (Frenkel et al. 1984), although the actual elevation of these wetlands is poorly documented regionally. Terrestrial habitats (e.g., spruce, cedar) fringing these intertidal habitats are often included in tidal wetlands. The tidal wetland ecosystem covers approximately 66 square kilometers in Washington State. The predominant substrate found in tidal wetland areas is unconsolidated fine sand to silt and clay.

2-4.2 Properties and Processes

PHYSICAL PROPERTIES

The papers by Hickey and Banas (2003) and Williams et al. (2001) provide a good summary of physical processes affecting the tidal wetland habitats in Puget Sound, and outer coast estuaries. For the Columbia River estuary, a series of papers in Small (1990) provides a major portion of the present understanding of the dynamics of physical processes in that system. The recent work by Kukulka and Jay (2002, 2003) has added significantly to this understanding. The following sections were crafted primarily from information contained in these papers.

Bathymetry

The bathymetry of the tidal wetland ecosystem varies depending on the geomorphology of the surrounding landscape. In general, tidal wetlands develop most extensively in moderately to very protected areas with a gently sloping bathymetry (less than 1:10 slope). Tidal wetlands frequently contain incised channels that are often unvegetated. These channels generally connect directly or indirectly to open water of the main body of the estuary.

Freshwater Input

Freshwater inflow through tidal wetlands has a large influence on the distribution of plant species both vertically and horizontally through the system. Typically, the tidal wetlands receive highest flows during spring freshets, and lowest flows during winter and in late summer-early fall. However, the flows of many of Washington’s rivers are highly regulated by dams, and as a result flood events and seasonal variation in flow regimes have been dramatically altered.

Tides

As previously mentioned, tides in the Pacific Northwest are mixed semidiurnal. However, as one moves up an estuary, tidal level variation becomes more complex and tidal amplitude decreases. For example, in Puget Sound the mean tidal range near Admiralty Inlet is similar to 1.6 meters, whereas near Olympia, the mean range is approximately 3.2 meters.

Circulation/Mixing

Circulation in tidal wetlands is driven primarily by freshwater flowing outward and seawater moving inward as a function of the tides, with wind-forced circulation also exerting an influence (Hickey and Banas 2003). Mixing of the freshwater and salt water occurs in the estuary, where salt water coming in at depth interacts with freshwater moving seaward at the surface. This mixing zone can vary in location relative to river flow and tides. Because tidal wetlands may be located in relatively high elevations compared to the mean water level, the net effect of circulation and mixing is periodic inundation with freshwater or diluted seawater. The affects of groundwater on tidal wetlands is poorly studied, but it is known that water level in the ground will vary relative to the surface.

Sediment

Tidal wetlands depend on a supply of sediment to build vertically (accrete) and horizontally (prograde). Accretion is a natural process that includes the deposition of sediment and organic matter in the soils. Because of the quiescent nature of the tidal wetlands, sediments are comprised of fine-grained material. The organic matter that is trapped in the sediment will decompose at a rate dependent upon sediment oxygen levels. This breakdown increases inorganic nutrient concentrations that are required for plant growth. Progradation happens in concert with accretion. This process results in the natural lateral expansion of wetlands as elevation is built through the accretion process.

Wetland soils are highly organically enriched (Mitsch and Gosselink 1993). In the Northwest, tidal wetland soils contain on the order of 20 to 40 percent organic matter by dry weight (Thom 1992, Thom et al. 2001). The soil is frequently saturated to the surface elevating soil moisture levels. Where soil moisture is high for extended periods, the soil profile can become anoxic because of microbial metabolism.

WATER PROPERTIES

Although similar to the nearshore ecosystem properties, some distinctive characteristics of tidal wetland water properties are described below.

Temperature

It is relatively difficult to find data sets on temperature in tidal wetlands. Most often, temperature is measured in the water in channels within the wetland (Simenstad 1983), with temperature varying widely (Simenstad 1983) as a result of solar heating during summer low flows and winter and spring floods. Temperature variation within a day is generally correlated with the tidal flooding of the system.

Salinity

While data describing salinity conditions in tidal wetlands are difficult to find, soil salinities are affected by tidal regime and the salinity of the flooding water (Ewing 1986; Thom et al. 2000) and some tidal wetland soils may become hypersaline due to evapotranspiration. The distribution of wetland plant species correlates with salinity in the soils, and is related to the salt tolerance of the species (Hutchinson 1989; Dethier 1990; Thom et al. 2000).

Water Clarity

Although there are no studies evaluating the ability of tidal wetlands in the Pacific Northwest to trap sediments, they are generally assumed to reduce suspended sediment loads (Mitsch and Gosselink 1993). Tannins from decaying woody vegetation are often observed in the water emanating from estuarine forested wetlands. This material coupled with dissolved and fine particulate organic matter that floats at the surface, can result in a very turbid surface water layer in channels adjacent to tidal wetlands (Simenstad 1983).

Nutrients

Soils in wetlands are organically enriched, and contain large quantities of inorganic nutrients such as nitrate, phosphate and ammonia. While plant uptake accounts for a large portion of nutrients usage (Mitsch and Gosselink 1993), nutrients are also exported from wetlands to the surrounding aquatic system (Naiman and Sibert 1979). Preliminary studies on a constructed and natural wetlands show that these habitats can be a sink of nitrate and a source of ammonia (Mitsch and Gosselink 1993).

Dissolved Oxygen

Unpublished data from monitoring water properties in wetlands in the Columbia River indicated that dissolved oxygen concentrations can be highly variable in tidal wetland channels, with the variation tied to periods of high demand when temperatures were relatively high. In addition, soil oxygen levels can be variable spatially, and are often very low in fine, organically-enriched soils.

2-4.3 Habitat Types Overview

The tidal wetland ecosystem consists of many habitat types providing critical functions for invertebrates, adult and juvenile fish and birds. Tidal marshes and tidal swamps are the major types of tidal wetland habitats.

GENERIC WETLAND DESIGNATIONS

Tidal Marshes

Tidal marshes are dominated by emergent grasses and herbaceous marsh vegetation ranging in height from about 0.2 to 2.0 meters. Tidal marshes include vegetation existing in almost full salinity (salt marshes), through those existing in brackish conditions, to those existing under constant freshwater conditions (tidal freshwater marshes). Species that dominate salt marshes include seashore saltgrass (*Distichlis spicata*), orache (*Atriplex patula*), saltwort (*Salicornia virginica*), and sea arrow-grass (*Triglochin maritimum*). Brackish marshes are dominated by Lyngby's sedge (*Carex lyngbyei*), slough sedge (*Carex obnupta*), fleshy jaumea (*Jaumea carnosa*), sea plantain (*Plantago martitima*) and American bulrush (*Scirpus americanus*) (Frenkel et al. 1978; Dethier 1990; Cooke 1997). Tidal freshwater marshes often contain water plantain (*Alisima plantago-aquatica*), nodding beggarticks (*Bidens cernua*), spike-rush (*Eleocharis* spp.), reed canary grass (*Phalaris arundinacea*), cattails (*Typha* spp.) and several grass species (Frenkel et al. 1978; Cooke 1997; MacDonald 1984).

Tidal Swamps

These consist of woody shrubs and trees tolerant of regular inundation by the tides. Swamps can also have an understory of herbaceous emergent species. Riparian wetlands are included in this classification, and are found adjacent to tidally-influenced streams and sloughs. Tidal swamps are forested wetlands and scrub/shrub wetlands according to the classification by Cowardin et al. (1979). Forested wetlands normally do not develop where salinity consistently occurs. Tree species common to forested tidal wetlands include Sitka spruce (*Picea sitchensis*), Oregon ash (*Fraxinus latifolia*), willow (*Salix* spp.) and red alder (*Alnus rubra*). Scrub and shrub species include Douglas spirea

(*Spiraea douglasii*), blackberry (*Rubus* spp.), and salmonberry (*Rubus spectabilis*). Skunk cabbage (*Lysichiton americanum*) is also often found in swamps (Cooke 1997; MacDonald 1984).

Saltwater Riparian Zone

Overhanging vegetation is a common feature of the tidal freshwater wetlands in the Pacific Northwest. Overhanging trees such as Sitka spruce, willow and ash can form a dense canopy above the edges of stream channels and slough. Overhanging shoreline vegetation in these ecosystems offers considerable shade and a source of organic matter.

2-4.4 Baseline Conditions and Impact of Covered Activities in Relation to Current Condition

Tidal wetlands are potentially impacted by the same set of activities as described for the nearshore ecosystem. Wetlands functions can be categorized as: organic matter production, food web support, nutrient cycling, sediment trapping, flood attenuation, refugia and feeding habitat for fish and wildlife. Any activity that affects the wetlands plant and plant-soil processes (primary production, nutrient cycling) will affect capacity of the system to support these functions. Dredging, diking, filling and forest clearing are generally regarded as having had the most widespread and significant impacts contributing to loss and degradation of tidal wetlands (Thom and Hallum 1990, Thomas 1983, Emmett et al. 2000). Loss of these habitats has general impacts to the ecosystem including loss of organic matter production and food web support. Since wetlands are known to process nutrients, loss or degradation of these systems reduces their capacity to trap inorganic nutrients such as nitrate, thereby affecting water properties in the region. Loss of wetlands also affects their ability to naturally trap suspended sediments, and thus reduce turbidity and clarify water. Diking of natural wetlands in tidal floodplains is well known to exacerbate flooding during intense storms in the Northwest. Overwater structures such as bridges, docks, walkways, piers, etc., will cast shade on the bottom thereby reducing light reaching the vegetation. Similar to filling and dredging, shading will result in a reduction in primary productivity. Because wetlands, particularly the tidal channels associated with these systems, are utilized by small fish such as juvenile salmon for feeding and refuge, loss of these areas will directly and indirectly affect salmon, other fishes and motile invertebrates.

Development has caused the loss of about 70 percent of the tidal wetlands that existed in Puget Sound in the mid-1800’s (Thom and Hallum 1990), with similar losses in the Columbia estuary (Thomas 1983). While losses in the Straits and along the outer coast have probably been lower, the alteration of almost all deltaic systems in Washington has resulted in important losses of tidal wetlands (Emmett et al. 2000).

2-4.5 Potential Alterations Related to Activities Authorized by Washington DNR

Table 1.2 provides a summary of the types of activities authorized by Washington DNR in the saltwater ecosystem. The information presented in this table was derived from the Revenue, Timber and Assets (RTA) systems. Information in the RTA is not sufficiently detailed to differentiate between agreements that occur in the tidal wetland ecosystem from those that occur in the nearshore, or offshore ecosystems. More information regarding the RTA systems and the activities authorized by Washington DNR is presented in the Covered Activities Paper (Washington DNR 2005a), with a detailed examination of the effects associated with these activities presented in a Potential Effects Analysis paper (Washington DNR 2007b).

3. Freshwater Ecosystem Overview

There are three ecosystem types within the general freshwater ecosystem: 1) riverine, 2) lakes, and 3) freshwater wetlands (Table 3.1). The classifications presented here are based on the classification system presented in Cowardin et al. (1979) and utilize shared hydrologic, geomorphic, chemical, or biological factors.

The riverine ecosystem includes areas with flowing water and is defined as "...wetland and deepwater habitats within a channel...", with channel defined as "...an open conduit either naturally or artificially created which periodically or continuously contains moving water..." (Cowardin et al. 1979). Habitat types within the riverine ecosystem are based on a reach classification system presented by Montgomery and Buffington (1998) and are described as cascade, step-pool, plane-bed, riffle-pool, and low-valley gradient.

Lakes are generally defined as non-flowing inland waters that are impounded by either natural or anthropogenic processes. The Lakes ecosystem presented here defines lakes as "...wetlands and deepwater habitats with all of the following characteristics: 1) situated in a topographic depression or a dammed river channel; 2) lacking trees, shrubs, persistent emergents, emergent mosses or lichens with greater than 30 percent areal coverage; and 3) total area exceeds 8 hectares (20 acres)..." (Cowardin et al. 1979). Wetlands and deepwater habitats with surface areas of less than 8 hectares have also been included if water depth exceeds 2 meters (6.6 feet), as have water bodies where the shoreline is either wave formed or bedrock, and ocean derived salinity is less than 0.5 percent. This classification system also divides the Lakes Ecosystem into three distinct classes based on their relative rates of primary production (Carlson 1977): eutrophic (productive), mesotrophic (moderately productive), and oligotrophic (unproductive); with three habitat types: littoral, limnetic, and profundal.

The freshwater wetlands ecosystem is defined in this work as "...nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 percent" (Cowardin et al. 1979) and includes wetlands lacking such vegetation if all of the following conditions are met: "...1) area less than 8 hectares (20 acres); 2) no active wave-formed or bedrock shoreline features; 3) water depth in the deepest part of the basin less than 2 meters at low water; and 4) salinity due to ocean-derived salts less than 0.5 percent..." (Cowardin et al. 1979). This ecosystem includes wetlands that occur adjacent to riverine and lacustrine wetlands in the riparian zone as well as wetlands that are isolated from riverine and lacustrine wetlands.

Table 3.1 - Overview of freshwater classification scheme.

Ecosystem	Riverine	Lakes			Freshwater Wetlands
Class	None distinguished	Oligotrophic	Mesotrophic	Eutrophic	None distinguished
Habitats	Low-gradient valley Riffle-pool Plane bed Step-pool Cascade	Littoral Limnetic Profundal	Littoral Limnetic Profundal	Littoral Limnetic Profundal	None distinguished

3-1 Riverine ecosystem

3-1.1 Distinguishing Characteristics

Riverine ecosystems are distinguished from other freshwater ecosystems by the uni-directional flow of water from higher to lower elevations that typically terminates at the confluence with a larger stream or river, marine ecosystems or a lake. Essentially long linear interconnected networks, riverine systems are comprised of patterns and processes in that occur in three dimensions: 1) longitudinal, 2) lateral, and 3) vertical (Stanford and Ward 1993; Townsend 1996).

The longitudinal dimension refers to structural and functional changes that occur between headwater channels and the downstream reaches. The amount of water carried within the channel (discharge) typically increases with increasing drainage area. Other properties of rivers such as width, depth, and velocity also vary as a function of discharge and thus drainage area (Leopold and Maddock 1953). Rivers typically decrease in gradient with longitudinal distance downstream.

In addition to the predictable changes in linear physical characteristics, some biological characteristics are also predictable in the longitudinal dimension (Vannote et al. 1980). Changes in the type and quantity of biologically available energy sources increases with distance downstream, resulting in distinct behavioral and morphological adaptations in the species present. For example, small streams derive most of their energy from terrestrial sources with primary production a small proportion of the total energy budget. As flow increases, litter from terrestrial vegetation comprises a smaller proportion of the energy budget and fine particulate organic matter becomes an increasingly important component of the food web, resulting in a change in the composition of species and functional feeding groups. While a high proportion of the total biomass in small streams is comprised of organisms adapted to directly consume leaf litter and its associated microbes, organisms in large rivers are adapted to utilize smaller particles of decomposed material.

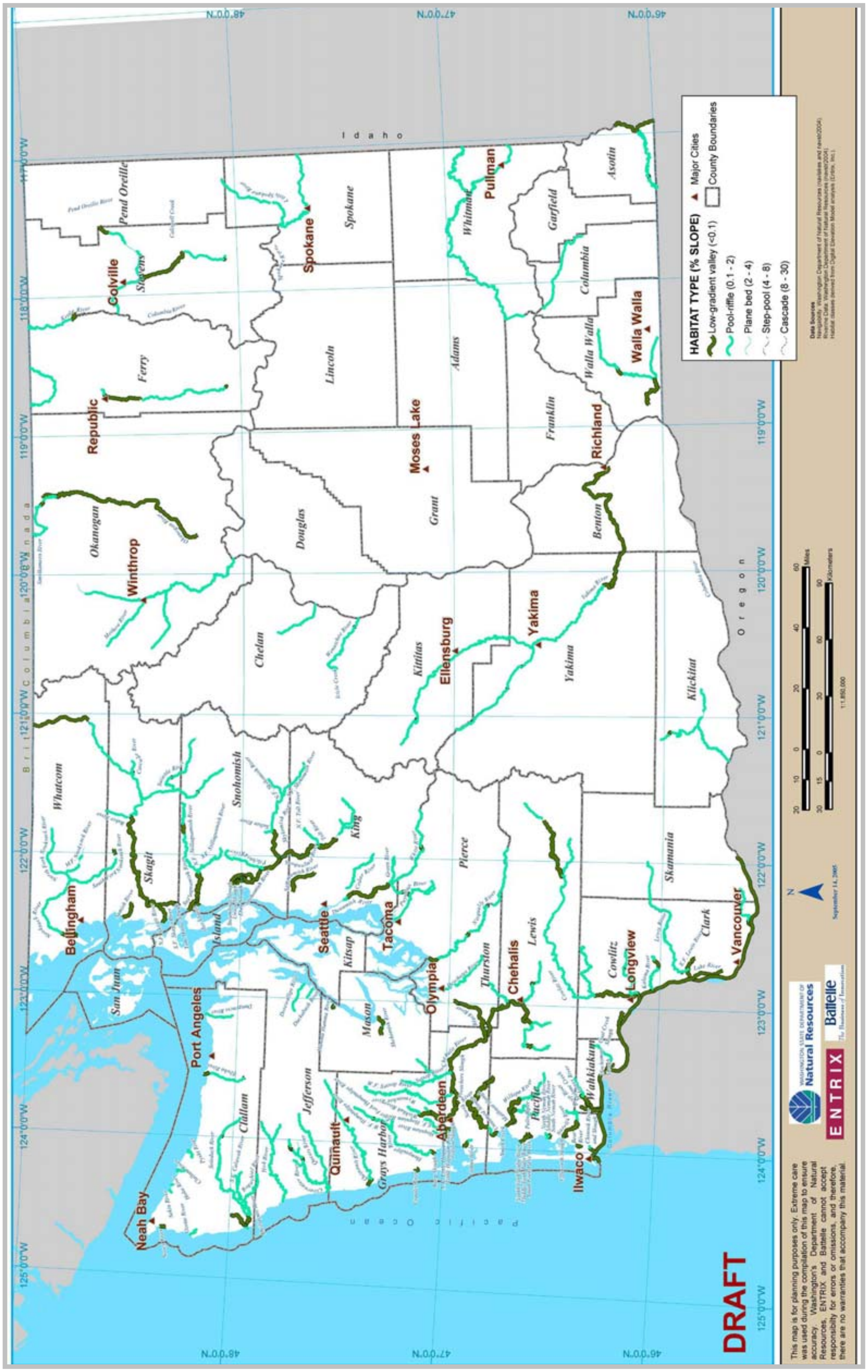
The lateral dimension of riverine ecosystems typically refers to patterns and processes that occur perpendicular to the direction of flow, and as defined above includes only riverine wetlands. Although seasonal changes in discharge influence the width of the river, the likelihood that the margins of this zone will be inundated decreases as elevation and the distance from the low flow channel increase. Similar to changes in species composition along the length of the river, the organisms present along the lateral dimension reflect the magnitude, intensity, and duration of flood disturbances (Gregory et al. 1991).

In the forests of the Pacific Northwest vegetation within the active channel may consist only of flood tolerant grasses and herbs, while the vegetation adjacent to the active channel generally consists of deciduous shrubs and younger stands of trees. With increasing distance from the channel, forest stands may increase in age and the proportion of flood tolerant species decreases. Junk et al. (1989) and Bayley (1995) suggest that seasonal flood pulses that inundate the floodplains of large rivers facilitate the exchange of key nutrients, enhance productivity, and maintain biological diversity. Because of the high number of species that use riparian zones for all or a portion of their life history, researchers have identified these areas as key to the conservation of biodiversity (Gregory et al. 1991; Naiman et al. 1993).

The vertical dimension refers to the connection between ground and surface water and is commonly referred to as the hyporheic zone. Stanford and Ward (1993) suggest that the hyporheic zone is inhabited by aquatic invertebrate species uniquely adapted to utilize dissolved materials, as well as organic and inorganic matter in the spaces between sediment particles. The vertical dimension has been shown to be of critical importance for a number of species, with upwelling playing a role in redd site selection for both chinook (Geist and Dauble 1998) and chum salmon (Reub 1987). Groundwater seeps or springs may also provide important thermal refugia for salmonids in streams that would otherwise be too warm for prolonged exposure (Torgenson et al. 2001).

The riverine ecosystem within the State of Washington (Figure 3-1.1) is approximately 319,000 kilometers in length. Navigable rivers owned by the state of Washington's ownership total approximately 7,000 km in length and encompass approximately 400 square kilometers or approximately 2 percent of the total Ecosystem. The vast majority of riverine habitat in state ownership may be classified as either pool-riffle (200 square kilometers) or low-gradient valley (193 square kilometers), with plane-bed (0.44 square kilometers), step-pool (0.03 square kilometers), and cascade (0.01 square kilometers) habitat types making up less than 0.12 percent of the total area of navigable waterways.

Figure 3-1.1 - Riverine ecosystem and associated habitat types.



3-1.2 Properties and Processes

PHYSICAL PROPERTIES

Geology

Tectonic processes (e.g., uplift, subduction), the characteristics of local rock formations, and climate history combine to control geomorphic processes and stream channel response through the distribution of bedrock types, surface deposits, and topography (Montgomery and Buffington 1998; Montgomery 1999). Regional geology also determines sediment supply as well as the gradient and sediment transport capacity of the stream, and may also influence the composition of vegetative communities and stream chemistry. In addition, hillslope processes such as landslides; slumps and earthflows; and debris avalanches and torrents are also important mechanisms for the delivery of sediment and large woody debris to stream channels (Swanston 1991) and in the creation of new land forms.

The structure of riverine networks is influenced by a number of factors related to topography including basin size and shape; drainage density; the number of connecting streams; and the geometry of the connections (Benda et al. 2004). Ultimately the structure and variability of in-channel habitat is a function of channel slope, which is largely determined by topography (Montgomery 1999). The type, frequency, and intensity of disturbance regimes depend on channel size and location within the watershed which in turn vary with topography (Reeves et al. 1995). Disturbances in the adjacent floodplain are characterized by seasonal inundation with bed mobility and shifts in channel location also influenced by topography and the type, frequency, and intensity of the inundation. The dynamic interactions between geology, climate, land use, and basin shape with their associated physical processes result in "...a shifting mosaic of abiotic and biotic conditions..." (Resh et al. 1988).

Climate

While climatic regimes influence riverine habitat types on a number of scales, within Washington climatic influences are generally related to the most recent glacial period and seasonal variability in precipitation. Glacial deposits are generally responsible for the variety of river channel patterns observed in the Puget Lowlands, with some rivers (e.g., the Nisqually) cutting multiple braided channels with islands in Pleistocene glacial deposits. Rivers created by sub-glacial runoff (e.g., the Snoqualmie River) are more contained and have single thread channels that may be higher in elevation than the surrounding valley floor (Collins et al. 2001). In eastern Washington, the advance of the continental ice sheet caused the formation of a large inland lake known as Glacial Lake Missoula. The ice dam that formed this lake breached episodically throughout the last ice age (US Geological Survey. 2005) causing massive floods with flows that are thought to have been more than 10 times the combined flow of all the other rivers in the world. These massive floods were responsible for the formation of canyons and scablands within the interior Columbia Basin.

The annual variability in the quantity and timing of streamflow patterns in Washington is driven by the interaction between moist air from the Pacific and the region's mountain ranges. As moisture-laden air cools and passes over topographic barriers such as mountains, a phenomenon known as orographic lifting causes condensation and precipitation. Orographic lifting is most prevalent on the western side of mountain ranges within Washington, with the eastern side of the mountains experiencing a reversal of the process as the air mass loses elevation and becomes warmer resulting in a rain shadow effect. Within the rain shadow, snow is the dominant form of precipitation and is most prevalent at the higher elevations. Consequently, much of the mean annual discharge for streams and rivers within the rain shadow comes from snowmelt. Peak flows in these basins occur during the spring and summer months and do not necessarily coincide with precipitation events. Hydrographs for streams and rivers on the western side of the mountains (especially those at lower elevations) are driven by rainfall events, with peak precipitation occurring from fall through spring.

Precipitation patterns also influence vegetation patterns, with western Washington generally forested at all elevations and the eastern side of the state forested in higher and moister mountain elevations. As a result, both the quantity and type of organic matter delivered to channel also varies west to east.

Research indicates that aquatic communities are structured by the magnitude, timing, frequency, duration, and rate of change of instream flows (Richter et al. 1996), with Junk et al. (1989) suggesting that aquatic and terrestrial organisms have anatomical, morphological, behavioral, and physiological adaptations that capitalize on the relatively predictable timing and duration of flood pulses. In addition, Poff and Allen (1995) found that hydrological variability could be used to predict the functional organization of species assemblages in streams of many different sizes throughout Wisconsin and Minnesota.

WATER PROPERTIES

Temperature

River temperatures are strongly correlated with air temperatures (Wetzel 2001) and vary with both season and time of day. They are also strongly influenced by the presence or absence of vegetative shading, solar radiation, and other hydrologic inputs such as groundwater input, tributary inflow and overland flow (Welch et. al 1998). In the Pacific Northwest, a number of rivers are fed by glaciers and as a result tend to be cooler year round. While rivers rarely experience temperature stratification, benthic regions are generally cooler due to groundwater inputs and depth.

Water Clarity

Similar to temperature, the clarity or transparency of rivers varies spatially and temporally. Clarity is also strongly influenced by the amount of suspended sediment present, as well as the ability of both suspended and dissolved matter to absorb light. Rivers originating from glaciers and those either flowing through fine grained materials or watersheds with significant erosion have high sediment loads, and are less transparent than those with lower sediment loads and/or flowing through bedrock.

Nutrients

Washington's rivers generally have low concentrations of macronutrients such as phosphorous and nitrogen, and as a result have low rates of primary productivity (Welch et. al 1998). Naturally occurring inputs are the result of decomposition of organic material and support the growth of attached algae, as well as submerged, emergent and riparian plants. However unlike lakes, riverine nutrients are concentrated in detritus rather than in plant or algal material, with dissolved material continually being washed downstream (Welch et. al 1998).

Dissolved Oxygen

Similar to other aquatic ecosystems, dissolved oxygen is a critical factor in determining the types of organisms present in rivers. In addition to being influenced by site specific conditions such as stream velocity, algal and plant respiration, and water chemistry, dissolved oxygen is also factored by daily and seasonal variation in water temperature. Levels are highest in fast, cool waters and forested reaches, with slower and warmer reaches having lower levels.

3-1.3 Habitat Types Overview

Creating a classification system utilizing all the variables influencing species assemblages in riverine networks was beyond the scope of this project (see Chapter 1). As a result, a single variable that is a component of many of riverine physical characteristics was selected – slope. A slope based classification system has biological relevance, is based on physical processes, is widely used in classifying channel types, and is relatively easy to implement. The habitat types used for this project are based on the stream reach classification system presented in Montgomery and Buffington (1998), with individual habitat types (Table 3-1.1) identified using channel gradient (or slope). As discussed in previous sections, riverine ecosystems have many predictable physical and biological characteristics, which relate to slope in the following ways:

- Rivers typically decrease in gradient with longitudinal distance downstream.
- The structure and variability of in channel habitat is a function of channel slope, which is largely determined by topography (Montgomery 1999).
- Changes in the type and quantity of available energy sources with increasing distance downstream result in distinct behavioral and morphological adaptations in the species present (Vannote et al. 1980, Junk et al. 1989).
- Some riverine species, salmonids in particular, may select stream channels that fall within certain slope classes for critical parts of their life history (Montgomery et al. 1999).

Two features of riverine ecosystems that were readily available across the state of Washington were geographic location and elevation. Habitat types were classified using the Washington DNR navigable streams data set (1:100,000) and a US Geological Survey statewide 10 meter Digital Elevation Model to calculate gradients for individual stream segments.

Table 3-1.1 - Riverine habitat types and corresponding channel gradients

Habitat type	Channel slope (percent)
Low-gradient valley	Less than 0.1
Pool-riffle	0.1 to 2
Plane bed	2 to 4
Step-pool	4 to 8
Cascade	8 to 30

Low-gradient Valley

Low-gradient valley rivers typically have slopes less than 0.1 percent. In watersheds where sand supply is abundant, the stream bed may consist of a series of mobile sand dunes whose length and height depend on the velocity of the river. In watersheds where sand supply is absent, the dominant bed material may be small gravel. Low-gradient valley channels commonly have multiple threads and the supply of sediment is typically greater than the river's sediment transport capacity.

Pool-riffle

Pool-riffle reaches are comprised of alternating sequences of pools, bars, and riffles and typically have low gradients (0.1 to 2 percent). These reaches are not generally confined by steep valley walls and are typically sinuous with a high reach to valley length ratio. Pools in these reaches typically form on alternating banks of the channel and are created by scour that results from the convergence of flow. Sediment deposition occurs either between pools in riffles or adjacent to pools on bars. Particle sizes in pool-riffle reaches are typically smaller than those observed in higher gradient reaches and comprised of gravel and/or cobble.

Plane-bed

Plane-bed reaches are defined as those reaches with gradients between 2 and 4 percent. This reach type is intermediate between higher gradient streams where sediment transport is limited by supply and lower gradient streams where transport is limited by current velocity. Plane-bed reaches are typically composed of intermediate substrate sizes (gravel to cobble) and lack the characteristic steps that are common in step-pool and cascade reaches.

Step-pool

Step-pool morphology is characterized by alternating sequences of relatively deep stream sections with flat, non-turbulent flow and shallow, steep sections with turbulent flow. Pools in these reaches are typically formed by a cluster of large boulders that restrict the flow of water, resulting in a backwater upstream of the restriction and a substantial drop in elevation downstream of the restriction. Step-pools gradients range between 4 and 8 percent.

Cascade

For this classification system cascade reaches are defined as those with gradients greater than 8 percent. These reaches are characterized by beds comprised of large boulders and channels typically confined by valley walls (Montgomery and Buffington 1998). Movement of bed material is rare in cascades due to the large size of the dominant substrate and relatively shallow water depths.

The correspondence between the slope classes and the habitat types presented here is not absolute - a study of streams in Oregon, Washington, and Alaska by Montgomery and Buffington (1998) found more than 20 percent of cascades had gradients between 4 and 8 percent, while more than 5 percent of step-pool reaches had gradients greater than 8 percent. In addition, the system does not allow for identification of stream reach types which may occur across slope classes (e.g., bedrock) and as a result such reaches are not included as distinct habitat types in this work.

IMPORTANT HABITAT UNITS

Montgomery and Buffington (1998) define channel units as "...morphologically distinct areas that extend up to several channel widths in length and are spatially embedded within a channel reach..." and state that they are the "...morphologic building blocks of reaches...". Habitat units may be divided into two general classes: fast water and slow water, with fast water further divided into turbulent and non-turbulent habitats. Turbulent habitats are characterized by emergent substrate and may include cascades, riffles, and pocket waters, while non-turbulent fast water habitats are characterized by sheet flow over broad flat areas. Slow water habitats may be divided into classes that are related to their formative mechanism and include dammed pools that result from hydraulic controls such as a row of boulders, and scour pools formed by erosive processes associated with woody debris or boulders.

In large river systems, habitat features on the lateral margins of the channel can be especially important for juvenile salmonids (Beechie et al. 2005). These edge unit types include the stream banks, the lateral margins of exposed bars, and backwater side channels. Areas such as backwater side channels, deltas at tributary confluences, and pools on slow-moving streams often support the development of aquatic vegetation which provides refugia and foraging opportunities for a wide variety of aquatic species (Cowardin et al. 1979).

3-1.4 Baseline Conditions and Impact of Covered Activities in Relation to Current Condition

Riverine ecosystems within the state of Washington have been extensively modified. While the following paragraphs are not a comprehensive review of alterations, they do provide an overview of some of the more prominent and widely documented alterations and impacts.

Dams

There are 1,067 surface water impoundments within the state of Washington (Johnson 2004). A comprehensive review of the effects of anthropogenically altered flow regimes are presented in Poff et al (1997) and summarized here. Among the effects of dams are migration barriers, wash-out or stranding of species, altered thermal regimes, disruption of cues (e.g., spawning, egg hatching, etc.), encroachment of terrestrial vegetation into channels, and sediment trapping. A significant proportion of riverine ecosystems have been converted to lake-like systems rendering them unsuitable for organisms that require flowing water and/or lengthy migration corridors.

Land-use Practices

Land use practices such as levees, bank armoring, channel simplification, dredging, and removal of woody debris have simplified and degraded Washington’s riverine ecosystems in a variety of ways. Floodplain and secondary channels have been disconnected from the stream channel by flood control structures such as levees, reducing or eliminating wetland and shallower water refuge habitat for amphibians, fish and birds. River channels have been straightened to increase flood conveyance resulting in reduced habitat complexity and elimination of high flow refugia. Bank armoring, to prevent channel migration and bank erosion, has altered the dynamic equilibrium of riverine ecosystems and altered riparian succession. In addition, virtually all of the navigable waterways in the state of Washington were historically subjected to systematic removal of large woody debris, further reducing refuge habitat and altering flow dynamics throughout the state.

Agriculture and Livestock Grazing

Agriculture and livestock grazing have been, and continue to be, significant factors in the degradation of riverine ecosystems. Increased nutrient inputs from fertilizers and livestock waste stimulate algal and plant growth, resulting in and increase in biological oxygen demand. Irrigation diversions increase summertime water temperatures, and may reduce the quantity and quality of instream habitat for aquatic organisms. Livestock grazing and/or trampling often eliminates riparian vegetation, resulting in increased erosion and sedimentation. The absence of streamside vegetation and increased sediment load negatively impacts water temperature, reduces wood recruitment potential, and decreases the quality of salmonid spawning habitat (Wissmar et al. 1994).

Urbanization

Similar to agricultural areas, riverine ecosystems within urbanized areas have been intensively altered. Impacts of urbanization include altered hydrograph and increased likelihood of channel instability (Booth 1997), as well as degraded water quality, loss of associated wetlands, loss of riparian forests, and loss of instream habitat and habitat connectivity (Gregory and Bisson 1997).

3-1.5 Potential Alterations Related to Activities Authorized by Washington DNR

Activities authorized by Washington DNR in the riverine ecosystem are presented in Table 1.2. It was not possible to use the RTA System to identify use authorizations that occur in freshwater wetlands. It is possible that use authorizations classified as riverine also occur in freshwater wetlands. Although it was possible to use the RTA System to assign individual use authorizations to the riverine ecosystem it was not possible to assign every authorization to an ecosystem, therefore some riverine use authorization may remain unclassified. More information regarding the RTA and the activities authorized by Washington DNR is presented in the Covered Activities Paper (Washington DNR 2005a). A detailed examination of the effects associated with these activities is presented in a Potential Effects Analysis paper (Washington DNR 2007b).

3-2 Lakes ecosystem

3-2.1 Distinguishing Characteristics

A lake is defined as a standing body of water located in a topographic depression that is not directly connected to the sea (Johnson *et. al*. 1985). Thus, lakes are distinguished from rivers by the presence of relatively still waters (Horne and Goldman 1994), from marine ecosystems by the absence of ocean derived salt (Cowardin et al. 1979), and from freshwater wetlands by both size (greater than 20 hectares) and the absence of perennial emergent vegetation (Cowardin et al. 1979). Washington has more than 7,800 lakes, ponds, and reservoirs (Sumioka and Dion 1985) of which 70 are currently considered to be state-owned aquatic land.

The Lake Ecosystem within the State of Washington (Figures 3-2.1 and 3-2.2) encompasses approximately 664.5 square kilometers. Navigable lakes in state of Washington’s ownership encompass approximately 597.4 square kilometers or approximately 90 percent of the total ecosystem, with roughly 80 percent of the state’s lake habitat classified as either Oligotrophic-limnetic (242.8 square kilometers) or Unspecified-limnetic (236.5 square kilometers). The mesotrophic-limnetic (43.6 square kilometers), eutrophic-limnetic (42.2 square kilometers), and oligotrophic-littoral (7.0 square kilometers) habitat types comprise approximately 15.5 percent of the total surface area of navigable lakes.

Figure 3-2.1 - Lake ecosystems and associated habitat types – western Washington.

Data Sources:
Wetland Ecosystem data: National Wetlands Inventory
*Note: Limnetic and Littoral zones were not symbolized as they would be difficult to distinguish at this scale

Figure 3-2.2 - Lake ecosystems and associated habitat types – eastern Washington.

3-2.2 Properties and Processes

PHYSICAL PROPERTIES

Geology

The geology of naturally occurring lakes is largely a product of tectonic, volcanic and/or glacial processes. Lakes formed by tectonic processes generally result from convergent fault blocks uplifting or slipping and creating a depression that fills with water. Volcanic lakes are typically formed through catastrophic events (caldera lakes) or through lava dams. Glacial lakes are typically formed by one of two processes - the scouring action of advancing glaciers or by deposition of material forming dams across valleys and topographic depressions. While lakes formed by other processes are less numerous than those discussed previously, they occur as a result of landslides, river migration (oxbow lakes), migration of coastal sand dunes, or animal activities (beaver dams) (Johnson et al. 1985). Lakes may also be formed as a result of humans impounding rivers for power generation, water supply, flood control, irrigation, or recreation (Horne and Goldman 1994).

Circulation/Mixing

As mentioned previously, wave action is an important physical process in maintaining the diversity of lake habitat types. Similar to saltwater systems, wave height and velocity are determined by depth of water, the distance of open water over which the wind blows (fetch), and both the speed and duration of the wind. The appropriate combination of these conditions can generate substantial wave energy and the direction of littoral currents determines whether wave energy will result in erosion or sediment deposition for a particular section of shoreline (Herdendorf et al. 1992).

In addition to the generation of waves, wind is the physical force responsible for currents, upwelling, and most lake oscillations (seiches). These processes may influence aquatic organisms in a variety ways by facilitating mixing in the water column and nutrient exchange, which in turn influences primary production. These physical processes may also provide important behavioral cues for fish species, with a study of a large lake in British Columbia suggesting that juvenile sockeye salmon altered their position in the water column in response to temperature changes resulting from an internal seiche (Levy et al. 1990). The influence of changes in water temperature on spawning behavior of fish is a widely documented phenomena (Herdendorf et al. 1992). For very large lakes, changes in water levels resulting from seiches may influence the distribution of aquatic vegetation in the littoral zone and along the shoreline.

Sediments

Lake substrates can be divided into two general classes: nearshore (littoral) and the zone below light penetration (profundal). The variety of substrate size classes is generally greatest in the littoral zone and ranges from clays and silts to boulders and consolidated bedrock, and particle sizes typically becoming smaller with increasing distance from shore. In the littoral zone, particle size heterogeneity is related to formative processes (e.g., glacial deposits, landslides) and hydraulic regimes (e.g., wave energy, currents)

(Herdendorf et al. 1992), with the absence of high energy disturbances in the profundal zone leading to the deposition of finer grained sediment.

The array of species found in the littoral zone can be more diverse than in either the open water (limnetic) or profundal zones and is generally attributed to the variety of substrates and vegetation comprising the habitats present (Herdendorf et al. 1992; Horne and Goldman 1994). The absence of disturbances in the physically and chemically homogeneous profundal zone enables species adapted to these conditions to competitively exclude those that are not. Consequently, the species present in the profundal zone typically belong to one of four major groups: oligachaete worms, amphipods, insect larvae, and spaerid and unionid clams (Horne and Goldman 1994).

WATER PROPERTIES

Temperature

While the surface temperature of a lake can be influenced by changes in ambient air temperatures, seasonal changes in solar radiation and physical properties such as water clarity and density have a much greater affect on lakes thermal regime. Lakes are generally thermally stratified and comprised of three layers - an upper layer called the epilimnion, a lower layer called the hypolimnion, and a transitional middle layer known as the metalimnion. Thermal stratification occurs as a function of the density of water at different temperatures, with colder and denser water in the hypolimnion and warmer less dense water in the epilimnion. As surface water temperatures equilibrate with ambient air temperatures, stratification may become less pronounced and may result in mixing or turnover of the lake’s waters. Thermally stratified lakes may also be chemically stratified, and stratification and the frequency of mixing events influence nutrient cycling and dissolved oxygen levels.

Thermal stratification also influences the distribution of species within the water column. For example, cutthroat trout in Lake Washington were found in or below the metalimnion during the summer months when surface water temperatures were high but were concentrated in shallow littoral habitats within the epilimnion when the lake was mixed and surface water temperatures were low (Nowak and Quinn 2002). It is important to note that many windswept shallow lakes may never become thermally stratified.

Water Clarity

Similar to saltwater systems, the clarity of lakes varies spatially and temporally. Clarity is also affected by materials suspended or dissolved by wind and wave action, as well as inputs of material from rivers, streams and the surrounding land mass. Water clarity is lowest during warmer months when phytoplankton and zooplankton production is highest, and when stream runoff and overland flow is high.

Nutrients

The productivity of a lake is related to land use practices (Birch et al. 1980); hydraulic residence time (Dillon 1975); atmospheric deposition (Horne and Goldman 1994); and soil characteristics (Birch et al. 1980), and is generally limited by the availability of nitrogen and phosphorous in the lake. Nitrogen is principally derived from the atmosphere whereas phosphorous has no atmospheric cycle and is derived from the soils or anthropogenic sources. For example, Birch et al. (1980) report that timber harvest in the basins surrounding Lake Washington, Lake Sammamish, and Chester Morse Lake increased phosphorous loading and caused an increase in primary production (Birch et al. 1980).

Biological productivity in lakes is referred to as the lakes trophic status and is measured as the amount of organic material produced by algae and plants. Trophic status is a continuum from unproductive (oligotrophic), to moderately productive (mesotrophic), very productive (eutrophic) and is determined by the interaction of factors such as latitude; soil characteristics; watershed inputs; climate; human action; lake depth and surface area; and water circulation patterns. Researchers have demonstrated relationships between plankton biomass and mean depth, lake surface area and fish productivity, and surface area and fish community structure (Herdendorf et al. 1992; Leach and Herron 1992). Generally, small shallow lakes tend to have higher rates of productivity than large deep lakes because they have a greater proportion of their surface area in the photic zone (Herdendorf et al. 1992), however increases in nutrients from human activities may also lead to increases in production in oligotrophic and mesotrophic lakes (cultural eutrophication).

Dissolved Oxygen

Dissolved oxygen concentrations in the water column are controlled by gas exchange with the atmosphere through diffusion and wave action or seiches; production of oxygen by plants (photosynthesis); and consumption as a result of decomposition and respiration. Oxygen depletion and stratification is common in highly productive lakes where the demand from decaying phytoplankton may consume virtually all of the oxygen in the hypolimnion (Horne and Goldman 1994).

3-2.3 Habitat Types Overview

The habitat types presented in this section (Table 3-2.1) are largely based on the classification of wetland and deepwater habitats presented in Cowardin et al. (1979) and the Trophic State Index (TSI) presented by Carlson (1977). The TSI was used to place lakes in one of three distinct classes, eutrophic, mesotrophic, or oligotrophic (Table 3-2.2). Trophic status was included as a variable in the habitat types to incorporate species affinities for different trophic statuses. For example, pygmy whitefish (Wydoski and Whitney 2003), water lobelia (Risgaard-Petersen and Jensen 1997), and the common loon (McIntyre and Barr 1997) occur primarily in oligotrophic lakes. Information on trophic status was obtained from the Washington Department of Ecology and the US Geological Survey. No trophic status was available for a number of state-owned lakes and their status is listed as “unknown”.

The trophic classification for each lake was further divided into one of two categories (littoral or limnetic) to derive habitat types. Both habitats were defined similar to Cowardin et al. (1979) with littoral habitats being “...all wetland habitats from the shoreward boundary to a depth of 2 meters (6.6 feet) below low water or to the maximum extent of nonpersistent emergents...” and limnetic as those permanently flooded lands deeper than 2m. In this classification scheme littoral and limnetic habitats were separated on the basis of differences in soil development, dominant plant assemblages, and duration of inundation. For the purposes of this paper we wanted to recognize the potential biological significance of profundal habitats. However, it was not possibly to explicitly include this habitat type in the analysis because it is spatially coincident with limnetic habitat.

Table 3-2.1 - Lake ecosystem habitat types.

Ecosystem	**Lakes**		
Class	Oligotrophic	Mesotrophic	Eutrophic
Habitats	Littoral Limnetic Profundal	Littoral Limnetic Profundal	Littoral Limnetic Profundal

Table 3-2.2 - Range of trophic state index values corresponding to a trophic classification.

Trophic Status	Trophic State Index
Oligotrophic	Less than 40
Mesotrophic	40 to 50
Eutrophic	greater than 50

IMPORTANT HABITAT UNITS

Rock Bottom

Rock bottom habitat units may occur in either littoral and limnetic habitat types. These habitats units are characterized by substrates comprised primarily of stones, boulders, or bedrock and typically lack vegetative cover due to wind and wave energy. Rock bottom habitat units are typically inhabited by organisms who employ attachment strategies such as hooks or suction devices in response to the high-energy environment (Cowardin et al. 1979)

Unconsolidated Bottom

Unconsolidated bottom habitat units may occur in both littoral and limnetic habitat types, and are characterized by mud, sand, or gravel substrates. These habitat units are also common in the profundal zone of eutrophic lakes, where light penetration is insufficient for plant growth and dissolved oxygen levels are low.

Aquatic Bed

Aquatic bed habitat units may occur in either littoral or limnetic habitat types and are differentiated from other habitat units by the presence of aquatic vegetation that is attached to the substrate or floating at the surface. The surface area of the substrate in these habitat units is primarily comprised of algal beds, rooted vascular, and floating vascular plants.

Rocky Shore

Similar to rocky bottom habitats, these habitats typically occur in high energy areas and are characterized by the dominance of exposed bedrock and rubble substrates resulting from exposure to wind and wave erosion. However, this habitat unit only includes the littoral zone.

Unconsolidated Shore

Unconsolidated shore habitats also only occur in the littoral zone and are comprised of small particles (less than 75 percent of the surface area larger than cobbles), little vegetative cover (less than 30 percent of the surface area), and varying degrees of periodic inundation.

3-2.4 Baseline Conditions and Impact of Covered Activities in Relation to Current Condition

Cultural Eutrophication

Cultural eutrophication is a phenomenon by which human activities increase the productivity of a lake. Activities such as wastewater treatment discharges, failing septic tanks, timber harvest, agricultural practices, and residential development may increase the loading of nutrients to a lake. This increased supply of nutrients often causes an increase in productivity and a shift in trophic status.

Shoreline Modifications

The concentration of shoreline modifications including shoreline armoring, overwater structures, and road and bridge construction may all alter the structure and function of lake ecosystems. The effects are particularly severe in urbanized areas, with littoral habitats impacted most heavily. In general, these modifications have altered substrate composition, natural water movement processes (e.g., wave energy), and water chemistry (e.g., increased nutrient supply).

Exotic Species

While not all exotic species become an ecological threat, in some cases they have significantly altered the structure and function lake ecosystems. For example, the introduction of predatory centrarchid fishes in lakes in Washington has caused the reduction in population sizes for many native fish species. Aquatic noxious weeds such as the Eurasian water milfoil, Brazilian elodea, parrot-feather, hydrilla, and fanwort have also become established in lakes and are outcompeting native plant species (Washington Fish and Wildlife 1997).

3-2.5 Potential Alterations Related to Activities Authorized by Washington DNR

The number and type of use authorizations that occur in the lakes ecosystem are presented in Table 1.2. Although it was possible to use the RTA System to assign individual use authorizations to the lakes ecosystem it was not possible to assign every authorization to an ecosystem. Further, while the RTA does differentiate authorizations associated with rivers and lakes this information is not sufficiently detailed to discern agreements that may occur in or affect the freshwater wetland ecosystem. More information regarding the RTA and the activities authorized by Washington DNR is presented in the Covered Activities Paper (Washington DNR 2005a). A detailed examination of the effects associated with these activities is presented in a Potential Effects Analysis paper (Washington DNR 2007b).

3-3 Freshwater wetland ecosystem

3-3.1 Distinguishing Characteristics

This paper relies on Cowardin, et al. (1979) to define wetlands as "... lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water..." and having three primary attributes: periodically supporting hydrophytic communities; undrained hydric soils; and non-soil substrates saturated with, or covered by, water at some point in the growing season.

Freshwater wetlands fall into three general categories - those that occur within a river channel (riverine); wetlands that are located in a topographic depression (e.g., lake) or a dammed river channel and/or are part of an active wave formed or bedrock shoreline (lacustrine); and those wetlands in transition areas between uplands and lakes and rivers (palustrine) (Mitsch and Gosselink 1993). As discussed previously, riverine and lacustrine wetlands are included in the riverine and lakes ecosystems defined in this work, with the freshwater wetland ecosystem defined here encompassing only palustrine wetlands.

In addition to its location, the freshwater wetland ecosystem described here is distinguished by the presence of emergent vegetation and ocean derived salinities of less than 0.5 practical salinity units (psu). Freshwater wetlands that lack emergent vegetation may also be included in this ecosystem if they include all of the following charecteristics: are less than 8 hectares (20 acres), lack active wave formed or bedrock shorelines, and have water depths of less than 2 meters (Cowardin, et al. 1979; Mitsch and Gosselink 1993). Examples of the wetlands included in this ecosystem include marshes, swamps, bogs and fens.

While wetlands in this ecosystem may either develop in the riparian zone or as isolated basins unconnected to other aquatic habitat, they are all subject to seasonal ponding or saturation of the root zone during the growing season (Mitsch and Gosselink 2000). Because wetland types are classified by the general category of vegetation present (e.g., trees, persistent emergent vegetation) they are not geographically restricted and may be found wherever hydrologic conditions permit their development (Mitsch and Gosselink 2000).

The Freshwater Wetland Ecosystem within the State of Washington (Figure 3-3.1 and 3-3.2) is approximately 3,800 kilometers^2 in extent (Lane and Taylor 1997). The total extent of freshwater wetlands considered in this paper is approximately 600 kilometers^2 or approximately 15 percent of the total ecosystem.

Figure 3-3.1 - Freshwater wetland ecosystem – Western Washington.

This map is for planning purposes only. Extreme care was used during the compilation of this map to ensure accuracy. Washington's Department of Natural Resources, ENTRIX and Battelle cannot accept responsibility for errors or omissions, and therefore, there are no warranties that accompany this material.

Data Sources:
Wetland Ecosystem data: National Wetlands Inventory

Figure 3-3.2 - Freshwater wetland ecosystem – Eastern Washington.

This map is for planning purposes only. Extreme care was used during the compilation of this map to ensure accuracy. Washington's Department of Natural Resources, ENTRIX and Battelle cannot accept responsibility for errors or omissions, and therefore, there are no warranties that accompany this material.

Data Sources:
Wetland Ecosystem data: National Wetlands Inventory

3-3.2 Properties and Processes

Although wetlands have traditionally been identified by the presence of plants adapted to water (hydrophytic), the primary factor in this habitat is the presence of water. While the biological, chemical and physical characteristics of the wetland are influenced by the hydrologic conditions, biotic elements such as evapotranspiration or the presence of beaver dams are also factors in wetland hydrology (Committee on Characterization of Wetlands 1995).

PHYSICAL PROPERTIES

Geology

Tectonic processes, the physical character of rock formations, and glaciation are all factors in the distribution of wetlands. Similarly to lakes, tectonic shifts leave depressions that may either fill with groundwater or receive flows from adjacent rivers and lakes, with the character of the underlying substrate and topography factors in drainage and groundwater recharge (Schoeneberger et al. 2002). While the development of extensive wetlands is generally dependent on the presence of broad minor relief areas such as floodplains, glaciation can be a primary factor in the development of pothole and other isolated wetlands such as those in western Washington (Mitsch and Gosselink 2000; Lane and Taylor 1997). Although wetlands in northeastern Washington and the east slope of the Cascade Range are associated with either surface waterbodies or glacial depressions, most wetlands in the Columbia Basin are anthropogenic and the result of shallow water tables created by large hydroelectric and irrigation projects (Lane and Taylor 1997).

Climate

Regions where precipitation exceeds losses from surface runoff and evapotranspiration support the most extensive wetlands (Mitsch and Gosselink 2000). However, extensive freshwater marshes can develop in drier areas where the necessary water is provided by seasonal flooding of adjacent rivers and lakes, with wetlands adjacent to rivers generally receiving river overflows every two out of three years, regardless of their geographical location (Mitsch and Gosselink 2000). In the wetter areas of Washington, 60 to 80 percent of precipitation becomes surface runoff (Mitsch and Gosselink 2000), flowing downslope into lakes, rivers and/or wetlands (Mitsch and Gosselink 2000). While some of the wetlands described here are sustained entirely by groundwater flow, others depend solely on precipitation (Committee on Characterization of Wetlands 1995).

Sediments

Wetlands are defined by the presence of soils that are "...saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions in the upper part..." (US Soil Conservation Service 1987). Prolonged inundation reduces the rate at which oxygen can diffuse through the soil, and in combination with other factors (e.g., temperature, microbial respiration, etc.) may lead to the near or complete absence of available oxygen in the soil. The absence of oxygen (anaerobic conditions) has implications for physical, chemical, and biological processes that facilitate the transport and transformation of chemicals in wetlands. For example, the absence of oxygen may affect vascular plants by limiting the availability of nutrients, increasing the concentration of certain elements and organic compounds to toxic levels, and interfering with aerobic root respiration (Mitsch and Gosselink 2000). Consequently, wetland plants have developed structural (e.g., the development of air spaces in the roots and stems to allow for oxygen diffusion), biochemical (e.g., adaptations that allow the plant to maintain sufficient metabolic activity to absorb nutrients), and life history (e.g., the timing of seed production) adaptations that allow them to overcome stresses associated with prolonged water inundation, periodic drying, and the biogeochemical transformations that occur in the soil.

3-3.3 Habitat Types Overview

The habitat data used for this ecosystem was derived from the National Wetland Inventory (NWI) which was based on the classification system presented by (Cowardin et al. 1979). Through the NWI program, the US Fish and Wildlife Service has developed wetland maps based for much of the country, including Washington. These types are used not only in the NWI, but also by local inventories that are intended to be consistent with the NWI. Palustrine wetlands, as discussed previously, are those temporarily flooded wetlands that are often associated with rivers and lakes but may also occur in upland topographic depressions (Cowardin et al. 1979). As with the Tidal Wetlands ecosystem, we did not identify explicit habitat types for this ecosystem. While the Cowardin classification is hierarchical and allows high-resolution distinctions to be made, the broad geographic extent of this project made doing so impractical. In addition, the spatial resolution of existing data on species and Washington DNR activities is too coarse to support the development of high resolution wetland habitat types.

Palustrine Habitat

Palustrine wetland habitats are found in areas smaller than lakes (Lane and Taylor 1997) that are inundated for at least part of the growing season. This category covers the range from permanent ponds to small, isolated, seasonally-inundated wetlands. Palustrine wetland types include emergent wetland vegetation (as described above), scrub-shrub wetland vegetation, and forested wetlands. Scrub-shrub wetlands are dominated by woody vegetation that is less than six meters tall and in addition to species that are always shrubby, this vegetation may include both young trees and taller species stunted by the effects of inundation. Forested wetlands are dominated by woody vegetation that is greater than six meters tall (Cowardin, et al. 1979).

Only those wetlands that are associated with navigable waterways were included within the scope of this analysis. The uppermost limit of state-owned aquatic land commonly extends to the “ordinary high water line”, with areas higher in elevation generally privately owned. However, Cowardin et al. (1979) indicate that palustrine wetlands may occur both above and below the “high water line”, and the uncertainties regarding the spatial extent of state freshwater wetland ownership led to the inclusion of palustrine wetlands within a 200 meter buffer around a navigable water body in the analysis. This approach likely overestimates the total size of freshwater wetland ecosystem within the state of Washington.

IMPORTANT HABITAT UNITS

Forested Wetland

Forested wetlands, as presented in Cowardin et al. (1979) are also commonly described as riparian forest wetlands (Mitsch and Gosselink 2000). In eastern Washington these wetlands are typically narrow linear features surrounding either rivers or lakes and stand out in stark contrast to the unforested uplands. In the forests of western Washington and some higher elevation areas in eastern Washington, the transition between riparian wetlands and uplands is not so easily discerned. Forested wetlands provide much of the energy (in the form of leaf litter) for small headwater streams (Vannote et al. 1980).

Scrub-shrub Wetland

Scrub-shrub wetlands are comprised of woody vegetation that is less than 6m tall (Mitsch and Gosselink 2000). These wetlands may be comprised of a relatively stable assemblage of species or they may be the early successional stages of a forested wetland.

Emergent Wetland

These wetlands typically consist of rooted herbaceous species. Emergent wetlands are classified as persistent (vegetation present year round) or non-persistent (obvious signs of vegetation only in the growing season). There are numerous types of wetlands included within this classification including marshes, wet meadows, potholes, and sloughs.

3-3.4 Baseline Conditions and Impact of Covered Activities in Relation to Current Condition

Freshwater wetland ecosystems within the state of Washington have been extensively modified. The text in the following paragraphs is not a comprehensive review of alterations but, instead, an overview of some of the more prominent and widely documented alterations and impacts.

Land-use Practices

Land use practices in the state of Washington have modified freshwater wetland ecosystems in a variety of ways. Current and historic causes of wetland degradation and loss include conversion to agriculture and grazing lands; filling for urban, port and industrial development (Lane and Taylor 1997); and logging.

Prior to the 1980s, drainage of wetlands for agriculture was conducted by many private landholders, and was also promoted by the federal projects (Committee on Characterization of Wetlands 1995). In the co-terminous United States, about one-half of the historical wetland area is estimated to have been converted to terrestrial habitat, although the percentages vary considerably between states (Committee on Characterization of Wetlands 1995). Several estimates of pre-settlement wetland acreage in Washington have been developed, with the estimates ranging from 1.17 to 1.53 million acres (Lane and Taylor 1997).

In addition, shoreline armoring and flood control structures may also degrade or destroy palustrine wetlands.

Exotic Species

The introduction of exotic species also may result in the degradation of wetlands. (Lane and Taylor 1997). For example, while purple loosestrife (*Lythrum salicaria*) was originally introduced for horticultural use, it has since invaded riparian and wetland systems across much of the United States and Canada. While this species can displace native wetland vegetation and reduce habitat for native wildlife (Bury 1979; Rawinski and Malecki 1984), recent studies indicate that its presence in wetlands may not be as detrimental as had previously been supposed (Hager and McCoy 1998; Morrison 2002; Treberg and Husband 1999). Regardless, purple loosestrife is considered a noxious weed in Washington (Washington State Noxious Weed Control Board 2005) and many states and provinces (US Department of Agriculture 2005).

Other exotic species that may adversely affect Washington's freshwater wetlands include: water primrose (*Ludwigia hexapetala*) and yellow floating heart (*Nymphoides peltata*), (WAC 16-752-505).

3-3.5 Potential Alterations Related to Activities Authorized by Washington DNR

Table 1.2 provides a summary of the types of activities authorized by Washington DNR in the saltwater, riverine, and lakes ecosystems. As discussed in previous sections, limitations in the RTA System make it difficult to assign each use authorization to a specific ecosystem. The RTA does identify riverine and lake use authorizations in some cases, as illustrated in Table 1.2. This information is not sufficiently detailed to discern agreements that may occur in or affect the freshwater wetland ecosystem. More information regarding the RTA and the activities authorized by Washington DNR is presented in the Covered Activities Paper (Washington DNR 2005a). A detailed examination of the effects associated with these activities is presented in a Potential Effects Analysis paper (Washington DNR 2007b).

4. Glossary

Abiotic	The non-living factors of a given area, such as temperature, wind, substrate, etc.
Accretion	May be either natural or artificial. Natural accretion is the buildup of land, solely by the action of the forces of nature, on a beach by deposition of water- or airborne material. Artificial accretion is a similar buildup of land by reason of an act of man, such as the accretion formed by a groin, breakwater, or beach fill deposited by mechanical means.
Anaerobic	A situation in which molecular oxygen is virtually absent from the environment.
Anthropogenic	Caused by humans
Armoring	Physical modifications to the shoreline implemented by man.
Artificial Reef	A man-made structure designed to simulate a natural reef.
Assemblage	The group of species generally associated with a given habitat type.
Backshore	Zone of beach lying between foreshore and coastline acted upon by waves only during severe storms.
Bathymetry	The measurement of depths of water in oceans, seas, and lakes. Also, information derived from such measurements.
Benthos	Organisms growing on or associated principally with the water bottom. (Benthic).
Biota	The animal and plant life of a region.
Biotechnical	Method of shoreline stabilization that utilizes vegetation to enhance slope stability and resist erosion.
Breakwater	Structure protecting shore area, harbor, anchorage, or basin from waves. See Jetties.
Bulkhead	Structure or partition built to prevent sliding of the land behind it. It is normally vertical or consists of a series of vertical sections stepped back from the water. A bulkhead is ordinarily built parallel or nearly parallel to the shoreline.
Cascade	High gradient habitat units consisting of alternating waterfalls and shallow pools. Substrate typically comprised of bedrock or boulders.
Channel	A natural or artificial waterway of perceptible extent which either periodically or continuously contains moving water, or which forms a connecting link between two bodies of water.
Community	Any naturally occurring group of species inhabiting a common environment, interacting with each other especially through

	food relationships and relatively independent of other groups.
Current	A flow of water.
Deposition	The deposit of sediment in an area through natural means such as wave action or currents; may also be done by man through mechanical means.
Dessication	Critical loss of fluids; drying out.
Dike	Wall or mound built around low-lying area to control flooding.
Disphotic Zone	The region of water below the euphotic zone, that receives low levels of light, but not enough for photosynthesis
Disturbance	Any natural or man-caused impact to an ecosystem.
Dredge	To deepen by removing substrate material. Also, mechanical or hydraulic equipment used for excavation.
Ecosystem	The organization of all biotic and abiotic factors in an area, usually delineated by natural geographic barriers.
Encrusting (Invertebrate, Plant)	Animal or plant life that attaches itself to a given substrate or object, such as a barnacle or mussel.
Epilimnion	The warmer less dense upper layer of a thermally stratified lake.
Erosion	The wearing away of land by natural forces. On a beach, the carrying away of beach material by wave action, tidal currents, littoral currents, or by deflation.
Estuary	Region near river mouth where fresh water mixes with salt water of sea. (Estuarine)
Euphotic Zone	The surface waters of the oceans that receive sufficient light for photosynthesis to occur.
Eutrophic	A very productive lake.
Evapo-transpiration	The combined processes by which water is transferred from the earth's surface to the atmosphere: evaporation of liquid or solid water plus transpiration from plants
Fetch	The distance over unobstructed open water on which waves are generated by a wind having a constant direction and speed.
Floodplain	Any flat, or nearly flat lowland that boarders a stream and is covered by its waters at flood stage.
Fossorial	Adapted for, or used in, burrowing or digging.
Geomorphology	The shape or form of a natural surface or object. Also, the study of the forms of the land surface and the processes producing them.
Glide	Wide uniform channel without flow obstructions and lacking a thalweg. Little or no surface turbulence, and moderate velocities.
Groin	A rigid structure built at an angle (usually perpendicular) from the shore to protect it from erosion or to trap sand. A groin may be further defined as permeable or impermeable depending on whether or not it is designed to pass sand through it.

Groundwater	Underground water supplies, also called aquifers. Water soaks into the ground until it reaches a point where the ground is not permeable. Ground water usually then flows laterally toward a river or lake, or the ocean.
Habitat	The location where a particular taxon of plant or animal lives and its surroundings, both living and non-living; the term includes the presence of a group of particular environmental conditions surrounding an organism including air, water, soil, mineral elements, moisture, temperature and topography.
Hydric soil	Soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions in the upper part.
Hydrology	he dynamics of water movement through an area.
Hydroperiod	The annual variability in the quantity and timing of streamflow Patterns.
Hydrophyte	A plant adapted to grow in water.
Hydrophytic vegetation	Plant life growing in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content.
Hypolimnion	The cooler denser lower layer of a thermally stratified lake.
Impact	An action producing a significant causal effect or the whole or part of a given phenomenon.
Infauna	Organisms that live within the sediment.
Interspecific Competition	Competition for resources between different species.
Intertidal	The area between high and low tides, which is uncovered periodically.
Invertebrates	Animals that lack a bony or cartilaginous skeletal structure.
Jetties	Structure extending into body of water designed to prevent shoaling of channel by littoral materials and to direct or confine stream or tidal flow.
***k*-selected**	Species that have low reproduction rates and have relatively long life spans
Littoral	Of or pertaining to the shore
Lahar	A mudflow composed of volcanic debris and water.
Laminar flow	The type of flow in a stream of water in which each particle moves in a direction parallel to every particle.
Lithology	The characteristics of a rock formation.
Marine	Water that contains high salt content, as opposed to freshwater.
Marsh	An area of soft, wet, or periodically inundated land, generally treeless and usually characterized by grasses and other low growth.
Mesotrophic	A moderately productive lake.
Migration	The seasonal travel of an animal between habitats.

Morphometry	The shape of a lake's underwater basin.
Nearshore	In beach terminology an indefinite zone extending seaward from the shoreline well beyond the breaker zone.
Nourishment	Process of replenishing a beach; naturally by longshore transport or artificially by deposition of dredged material. (Beach Nourishment)
Oligotrophic	An unproductive lake.
Outfall	Structure extending into a body of water for the purpose of discharging an effluent (sewage, storm runoff, cooling water).
Outmigration	Refers to the act of anadromous salmonids when leaving freshwater and migrating to the sea for part of their life.
Overwater Structures	Man-made structures that extend over all or part of the surface of a body of water, such as a pier.
Photic Zone	The surface waters of the ocean that receive light. Includes the euphotic and disphotic zones.
Plankton	Suspended microorganisms with relatively little power of locomotion that drift in water and are subject to action of waves or currents.
Profundal	The deep zone within a lake below the extent of light penetration also known as the aphotic zone.
Pocket Water	A section of the stream channel containing numerous boulders or other large obstructions which create eddies or scour pockets. May contain multiple water surface elevations, eddies, and shear zones.
Pool	Topographic depression within stream channel characterized by smooth laminar flow and low velocities.
Primary Production	The biomass produced by plants via photosynthesis.
Ramp	A uniformly sloping platform, walkway, or driveway. The ramp commonly seen in the coastal environment is the launching ramp, which is a sloping platform for launching small craft.
Redox Potential	A measurement of the tendency of sediment to exchange electrons with a reference electrode that is used to indicate whether or not the sediment is aerobic or anaerobic.
Refuge	Habitat area that provides protection from predators or disturbance.
Relief	The elevational features of a surface.
Revetment	A sloped facing built to protect existing land or newly created embankments against erosion by wave action, currents, or weather. Revetments are usually placed parallel to the natural shoreline.
Riffle	Shallow areas characterized by surface water turbulence, high water column velocity, and exposed substrate.
Rip Current	A strong surface current flowing seaward from the shore.
***r*-selected**	Species that have high reproduction rates and have relatively short life spans
Run	Habitat unit with little or no surface turbulence, relatively

	shallow depths, and a uniform channel profile. Water column velocities high when compared to pools.
Salinity	A measure of the concentration of dissolved salts in water, traditionally expressed as parts per thousand (ppt.), but more recently given as Practical Salinity Units (psu).
Saturated	A condition in which all voids (pores) between soil particles are filled with water.
Scour	The removal of underwater material by waves and currents, especially at base or toe of a structure.
Seawall	Structure separating land and water areas, primarily designed to protect land from wave action.
Seiche	A phenomena that occurs when prolonged wind from one direction drives water away from one shore causing it to "pile up" on the opposite shore. With the cessation of the wind the water is driven back under the influence of gravity producing a series of standing waves
Shoreline	The intersection of a specified plane of water with the shore or beach.
Spawning	Production and deposition of eggs, with reference to aquatic animals.
Species Richness	A metric used to compare the diversity of species among ecosystems, indicative of variety.
Step Run	A sequence of runs separated by short riffle steps. Substrate usually cobble and boulder dominated.
Substrate	Solid material upon which an organism lives or to which it is attached.
Subtidal	The marine environment below low tide.
Surf Zone	The area between the outermost breaker and the limit of wave uprush.
Surface Water	Water that travels across the surface of the ground, rather than infiltrating.
Terrestrial	Growing or living on or peculiar to the land, as opposed to the aquatic environment.
Thermocline	The region of greatest inflection on the temperature curve for a stratified lake.
Tide Gate	An opening through which water may flow freely when the tide or water level is low or high, but which will be closed to prevent water from flowing in the other direction when the water level changes.
Transport	The movement of sediment along a current pathway.
Trophic	Of or involving the feeding habits or food relationship of different organisms in a food chain. *Alternatively*: a classification system used to describe the productivity status and nutrient richness in lakes.
Turbidity	A measure of the clarity of water, indicating quantities of suspended material. Higher turbidity results in lower levels of light penetration throughout the water column.

Turbulence	The motion of water where local velocities fluctuate and the direction of flow changes abruptly and frequently at any particular location, resulting in disruption of laminar flow. It causes surface disturbance and uneven surface level, and often masks subsurface areas because air bubbles are entrained in the water.
Water Column	The water in a lake, estuary, or ocean that extends from the bottom substrate to the water surface.
Wave Energy	Force exhibited by waves, which culminates in impact to an object or surface.
Wetlands	Lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water.

5. References

Bayley, P.B. 1995. Understanding Large River-Floodplain Ecosystems. BioScience, 45(3): 153-128.

Beamer, E., A. McBride, C. Greene, R. Henderson, G. Hood, K. Wolf, K. Larsen, and K. Fresh. 2005. Delta and Nearshore Restoration for the Recovery of Wild Skagit River Chinook Salmon: Linking Estuary Restoration to Wild Chinook Salmon Populations. Supplement to the Skagit Chinook Recovery Plan, Skagit River System Cooperative. LaConner, WA.

Beechie, T.J., M. Liermann, E.M. Beamer, and R. Henderson. 2005. A Classification of Habitat Types in Large Rivers and their Use by Juvenile Salmonids. Transactions of the American Fisheries Society, 134: 717-729.

Benda, L., N.L. Poff, D. Miller, T. Dunne, G. Reeves, G. Pess, and M. Pollock. 2004. The Network Dynamics Hypothesis: How Channel Networks Structure Riverine Habitats. BioScience, 54(5):413-427.

Birch, P.B., R.S. Barnes, and D.E. Spyridakis. 1980. Recent Sedimentation and its Relationship with Primary Productivity in Four Western Washington Lakes. Limnology and Oceanography, 25(2): 240-247.

Booth, D.B. and C.R. Jackson. 1997. Urbanization of Aquatic Systems-degradation Thresholds, Stormwater Detention, and Limits of Mitigation. Journal of American Water Resources Association, 33(5): 1077-1090.

Burns, R.E. 1985. The Shape and Form of Puget Sound. University of Washington Press, Seattle, WA.

Bury, R.B. 1979. Review of the Ecology and Conservation of the Bog Turtle, *Clemmys muhlenbergii.* U.S. Fish and Wildlife Service, Special Science Report, Wildlife No. 219.

Carlson, R.E. 1977. A Trophic State Index for Lakes. Limnology and Oceanography, 22(2): 361-369.

Collins, B.D., D.R. Montgomery, and A.J. Sheikh. 2003. Reconstructing the Historical Riverine Landscape of the Puget Lowland. In: Restoration of Puget Sound Rivers. D. R. Montgomery, S. M. Bolton, D. B. Booth, and L. Wall (eds). University of Washington Press, Seattle, WA..

Committee on Characterization of Wetlands, Water Science and Technology Board, Board on Environmental Studies and Toxicology, Commission on Geosciences, Environment, and Resources, National Research Council (Committee on Characterization of Wetlands). 1995. Wetlands: Characteristics and Boundaries. National Academy Press, Washington, D.C.

Cooke, S.S. (editor). 1997. A Field Guide to the Common Wetland Plants of Western Washington and Northwestern Oregon. Seattle Audubon Society, Seattle, WA.
Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. FWS/OBS-79/31. US Fish and Wildlife Service. Washington, DC

Dethier, M.N. 1990. A Marine and Estuarine Habitat Classification System for Washington State. Washington Natural Heritage Program, Department of Natural Resources, Olympia, WA..

Dillon, P.J. 1975. The Phosphorous Budget of Cameron Lake, Ontario: The Importance of Flushing Rate to the Degree of Eutrophy of Lakes. Limnology and Oceanography, 20(1): 28-39.

Emmett, R., R. Llanso, J. Newton, R. Thom, M. Hornberger, C. Morgan, C. Levings, A. Copping, and P. Fishman. 2000. Geographic Signatures of North American West Coast Estuaries. Estuaries, 23: 765-792.

Emmett, R.L., R.D. Brodeur, and P.M. Orton. 2004. The Vertical Distribution of Juvenile Salmon (*Oncorhynchus* Spp.) and Associated Fishes in the Columbia River Plume. Fisheries Oceanography, 13: 392-402.

Ewing, K. 1986. Plant Growth and Productivity Along Complex Gradients in a Pacific Northwest Brackish Intertidal Marsh. Estuaries, 9: 49-62.

Frenkel, R.E., T. Boss, and S.R. Schuller. 1978. Transition Zone Vegetation Between Intertidal Marsh and Upland in Oregon and Washington. Report to U.S. Environmental protection Agency. Oregon State University, Department of Geography. Corvallis, OR.

Gabrielson, P.W., T.B. Widdowson, S.C. Lindstrom, M.W. Hawkes, and R.F. Scagel. 2000. Keys to the Benthic Marine Algae and Seagrasses of British Columbia, Southeast Alaska, Washington and Oregon. Phycological Contribution number 5. University of British Columbia, Botany Department. Vancouver, BC.

Geist, D.R. and D.D. Dauble. 1998. Redd Site Selection and Spawning Habitat Use by Fall Chinook Salmon: The Importance of Geomorphic Features Of Large Rivers. Environmental Management, 22(5): 655-669.

Gregory, S.V. and P.B. Bisson. 1997. Degradation and Loss of Anadromous Salmonid Habitat in the Pacific Northwest. In: Pacific Salmon and their Ecosystems: Status and Future Options. D.J. Stouder, P.B. Bisson, and R.J. Naiman (eds), Chapman and Hall, New York, NY.

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An Ecosystem Perspective on Riparian Zones. BioScience, 41(8): 540-5551.

Hager, H.A. and K.D. McCoy. 1998. The Implications of Accepting Untested Hypotheses: A Review of the Effects of Purple Loosestrife (*Lythrum salicaria*) in North America. Biodiversity and Conservation, 7(8): 1069-1079.

Harris, G.P. 1986. Phytoplankton Ecology, Structure, Function, and Fluctuation. Chapman and Hall, London.

Herdendorf, C.E., L. Hakanson, D.J. Jude, and P.G. Sly. 1992. A Review of the Physical and Chemical Components of the Great Lakes: A Basis for Classification and Inventory of Aquatic Habitats. In: The Development of an Aquatic Habitat Classification System for Lakes. W.-Dieter N. Busch and Peter G. Sly (eds). CRC Press, Ann Arbor, MI.

Hickey, B.M. and N.S. Banas. 2003. Oceanography of the U. S. Pacific Northwest Coastal Ocean and Estuaries with Application to Coastal Ecology. Estuaries, 26: 1010-1031.

Holsman, K.K., D.A. Armstrong, D.A. Beauchamp, and J.L. Ruesink. 2003. The Necessity for Intertidal Foraging by Estuarine Populations of Subadult Dungeness Crab, *Cancer magister*: Evidence from a Bioenergetics Model. Estuaries, 26: 1155-1173.

Hutchinson, I. 1989. Salinity Tolerance of Plants of Tidal wetlands and Associated Uplands. Report to Washington State Department of Ecology, Shoreline and Coastal Zone Management Program, Wetlands Section. Olympia, WA.

Johnson, D. 2004. Report to the Legislature. Status of High and Significant Hazard Dams in Washington with Safety Deficiencies. Publication No. 04-11-024. Washington State Department of Ecology. Olympia, WA.

Junk, W.J., P.B. Bayley, and R.E. Sparks. 1989. The Flood Pulse Concept in River-Floodplain Systems. In: Proceedings of the International Large River Symposium. D.P. Dodge (ed). Canadian Special Publication of Fisheries and Aquatic Sciences, 106: 110-127.

Komar, P.D. 1998. The Pacific Northwest Coast: Living with the Shores of Oregon and Washington. Duke University Press, Durham, SC.

Kukulka, T. and D.A. Jay. 2003a. Impacts of Columbia River Discharge on Salmonid Habitat: 1. A Nonstationary Fluvial Tide Model. Journal of Geophysical Research, 108(9): 3293.

Kulkulka, T. and D.A. Jay. 2003b. Impacts of Columbia River Discharge on Salmonid Habitat: 2. Changes in Shallow Water Habitat. Journal of Geophysical Research 108(9): 3294.

Lane, R.C. and W.A. Taylor. 1997. Washington's Wetland Resources. In: National Water Summary on Wetland Resources Fretwell, J.D., J.S. Williams, and P.J. Redman (compilers),. U.S. Geological Survey, Water-Supply Paper 2425: 393-397.

Lanzer, E. L. 1999. Aquatic Land Area Estimation. Public Land Report to the Legislature. Washington State Department of Natural Resources, Aquatic Resources Division. Olympia, WA.

Leach, J.H. and R.C. Herron. 1992. A Review of Lake Habitat Classification. In: The Development of an Aquatic Habitat Classification System for Lakes. W.-Dieter N. Busch and Peter G. Sly (eds). CRC Press, Ann Arbor, MI.

Leopold, L.B. and T. Maddock. 1953. The Hydraulic Geometry of Stream Channels and Some Physiographic Implications. U.S. Geological Survey Professional Paper 252.

Levy, D.A. R.L. Johnson. 1990. Shift in Vertical Distribution in Response to an Internal Seiche in a Stratified Lake. Limnology and Oceanography, 36(1): 187-192.

Long, E.R. (ed). 1982. A Synthesis of Biological Data from The Strait Of Juan De Fuca and Northern Puget Sound. Interagency Energy/Environment R&D Program Report. EPA-600/7-82-004. Department of Commerce, National Oceanic and Atmospheric Administration and Environmental Protection Agency. Washington, DC.

MacDonald, K. 1984. Tidal Marsh Plant Production in the Columbia River Estuary. Final Report on the Emergent Plant Primary Production Work Unit of the Columbia River Estuary Development Program.

McIntyre, J.W. and J.F. Barr. 1997. Common Loon. In: The Birds of North America, No. 313. Poole, A. and F. Gill (eds). The Birds of North America, Inc., Philadelphia, PA

McMillan, R.O., D.A. Armstrong, and P.A. Dinnell. 1995. Comparison of Intertidal Habitat Use and Growth Rates of Two Northern Puget Sound Cohorts of 0+ Age Dungeness Crab, *Cancer magister*. Estuaries, 18: 390-398.

Mitsch, W.J. and J.G. Gosselink. 1993. Wetlands, 2nd Edition. Van Nostrand Reinhold New York, NY.

Mitsch, W.J. and J.G. Gosselink. 2000. Wetlands, 3rd Edition. John Wiley, New York, NY.

Montgomery, D.R. 1999. Process Domains and the River Continuum. Journal of American Water Resources Association, 35: 397-410.

Montgomery, D.R. and J.M. Buffington. 1998. Channel Processes, Classification, and Response Potential. In: River Ecology and Management. R.J. Naiman and R.E. Bilby (eds), Springer-Verlag Inc., New York, NY.

Montgomery, D.R., G. Pess, E.M. Beamer, and T.P. Quinn. 1999. Channel Type and Salmonid Spawning Distributions and Abundance. Canadian Journal of Fisheries and Aquatic Sciences, 56: 377-387.

Morrison, J.A. 2002. Wetland Vegetation Before and After Experimental Purple Loosestrife Removal. Wetlands, 22(1): 159-169.

Naimann, R.J., H. DeCamps, and M. Pollock. 1993. The Role of Riparian Corridors in Maintaining Regional Biodiversity. Ecological Applications, 3(2): 209-212.

Naiman, R.J. and J.R. Sibert. 1979. Detritus and juvenile salmon production in the Nanaimo Estuary: III. Importance of detrital carbon to the estuarine ecosystem. Journal of the Fisheries Research Board of Canada 36:504-520.

Newton, J.A., S.L. Albertson, K. Van Voorhis, C. Maloy, and E. Siegel. Washington State Marine Water Quality, 1998 through 2000. Publication No. 02-03-056. Washington Department of Ecology, Environmental Assessment Program. Olympia, WA.

Nightengale, B. and C. Simenstad. 2001. Overwater Structures: Washington State Department of Fish and Wildlife, Aquatic Habitat Guidelines. Olympia, WA

Nowak, G.M. and T.P. Quinn. 2002. Diel and Seasonal Patterns of Horizontal and Vertical Movements of Telemetered Cutthroat Trout in Lake Washington, Washington. Transactions of the American Fisheries Society, 131: 452-462.

Phillips, R.C. 1984. Ecology of Eelgrass Meadows in the Pacific Northwest: A Community Profile. FWS/OBS-84/24. U.S. Fish and Wildlife Service, Washington, D.C.

Poff, N.L. and J.D. Allan. 1995. Functional Organization of Stream Fish Assemblages in Relation to Hydrological Variability. Ecology, 76(2): 606-627.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The Natural Flow Regime. A Paradigm for River Conservation and Restoration. BioScience , 47(11): 769-784.

Rawinski, T.J. and R.A. Malecki. 1984. Ecological Relationships Among Purple Loosestrife, Cattail, and Wildlife at the Montezuma National Wildlife Refuge. New York Fish and Game Journal, 31(1): 81-87.

Reeves, G.H., L.E. Benda, K.M. Burnett, P.B. Bisson, and J.R. Sedell. 1995. A Disturbance-based Ecosystem Approach to Maintaining and Restoring Freshwater Habitats of Evolutionarily Significant Units of Anadromous Salmonids in the Pacific Northwest. American Fisheries Society Symposium, 17: 334-349.

Resh, V.H., A.V. Brown, A.P. Covidi, M.E. Gurtz, H.W. Li, G.W. Minshall, S.R. Reice, A.L. Sheldon, J.B. Wallace, and R.C. Wissmar. 1988. The Role of Disturbance in Stream Ecology. In: Community, Structure, and Function in Temperate and Tropical Streams. Proceedings of a Symposium, 24-28 April 1987, Flathead Lake Biological Station, Univ. Montana. J.A. Stanford and A.F. Covidi (eds), Journal of the Northe American Benthological Society, 7(4): 433-455.

Reub, G.S. 1990. The Influence of Groundwater Upwelling in the Selection of Spawning Locations by Chum Salmon (*Oncorhynchus keta*) in the Susitna River, Alaska. Masters Thesis. San Francisco State University. San Francisco, CA.

Richter, B.D., J.V. Baumgartner, J. Powell, and D.P. Braun. 1996. A Method for Assessing Hydrologic Alteration within Ecosystems. Conservation Biology, 10(4): 1163-1174.

Risgaard-Petersen, N. and K. Jensen. 1997. Nitrification and Denitrification in the Rhizosphere of the Aquatic Macrophyte *Lobelia dortmanna* L. Limnology and Oceanography, 42: 529-537.

Roegner, G.C., B.M. Hickey, J.A. Newton, A.L. Shanks, and D.A. Armstrong. 2002. Wind-induced Plume and Bloom Intrusions into Willapa Bay, Washington. Limnology and Oceanography, 47: 1033-1042.

Roegner, G.C., D.A. Armstrong, B.M. Hickey, and A.L. Shanks. 2003. Ocean Distribution of Dungeness Crab Megalopae and Recruitment Patterns to Estuaries in Southern Washington State. Estuaries, 26: 1058-1070.

Schoeneberger, P.J., Wysocki, D.A., Benham, E.C., and Broderson, W.D. (eds). 2002. Field Book for Describing and Sampling Soils, Version 2.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Sherwood, C.R. and J.S. Creager. 1990. Sedimentary Geology of the Columbia River Estuary. In: L.F. Small, (ed), Columbia River: Estuarine System. Progress in Oceanography 25(1-4): 15-79.

Simenstad, C.A. 1983. The Ecology of Estuarine Channels of the Pacific Northwest Coast: A Community Profile. FWS/OBS-83/05. U.S. Fish and Wildlife Service. Washington, DC.

Simenstad, C.A. and R.C. Wissmar. 1985. d^{13}C Evidence of the Origins and Fates of Organic Carbon in Estuarine and Nearshore Food Webs. Marine Ecology Progress Series, 22: 141-152.

Small, L.F. (ed). 1990. Columbia River: Estuarine System. Progress in Oceanography, 25, 1-4: 1-358.

Sobocinski, K.L. 2003. The Impact of Shoreline Armoring on Supratidal Beach Fauna of Central Puget Sound. Masters Thesis. University of Washington, School of Aquatic and Fishery Sciences . Seattle, WA.

Stanford, J.A. and J.V. Ward. 1993. An Ecosystem Perspective of Alluvial Rivers: Connectivity and the Hyporheic Corridor. Journal of the North American Benthological Society, 12(1): 48-60.

Strickland, R.M. 1983. The Fertile Fjord. University of Washington Press, Seattle, WA.

Swanston, D.N. 1991. Natural Processes. American Fisheries Society Special Publication, 19: 139-179.

Thom, R.M. 1980. Seasonality in Low Intertidal Benthic Marine Algal Communities in Central Puget Sound, Washington, USA. Botanica Marina, 23: 7-11.

Thom, R.M. and L. Hallum. 1990. Long-term Changes in the Areal Extent on Tidal Marshes, Eelgrass Meadows, and Kelp Forests of Puget Sound. FRI-UW-9008. University of Washington, Fisheries Research Institute, School of Fisheries. Seattle, WA.

Thom, R.M. 1987. The Biological Importance of Pacific Northwest Estuaries. Northwest Environmental Journal, 3: 21-42.

Thom, R.M. 1989. Plant Standing Stock and Productivity on Tidal Flats and Gravel in Padilla Bay, Washington: A Temperate North Pacific Estuarine Embayment. FRI-UW-8909. University of Washington, Fisheries Research Institute. Seattle, WA.

Thom, R.M. 1992. Accretion Rates of Low Intertidal Salt Marshes in the Pacific Northwest. Wetlands, 12: 147-156.

Thom, R.M., J.W. Armstrong, C.P. Staude, K.K. Chew, and R.E. Norris. 1976. A Survey of the Attached Marine Flora at Five Beaches in the Seattle, Washington Area. Syesis, 9: 267-275.

Thom, R.M., C.A. Simenstad, J.R. Cordell, and E.O. Salo. 1989. Fish and their Epibenthic Prey in a Marina and Adjacent Mudflats and Eelgrass Meadow in a Small Estuarine Bay. FRI-UW-8901. University of Washington, Fisheries Research Institute. Seattle, WA.

Thom, R.M. and R.G. Albright. 1990. Dynamics of Benthic Vegetation Standing Stock, Irradiance, and Water Properties in Central Puget Sound. Marine Biology, 104: 129-141.

Thom, R.M., L.D. Antrim, A.B. Borde, W.W. Gardiner, D.K. Shreffler, and P.G. Farley. 1998. Puget Sound's Eelgrass Meadows: Factors Contributing to Depth Distribution and Spatial Patchiness. Proceedings, Puget Sound Research '98. Puget Sound Water Quality Action Team, Olympia, WA.

Thom, R.M., A.B. Borde, and D.L. Woodruff. 2000. Tidal Wetland Plants Distribution and Primary Control Factors in Commencement Bay. Prepared for NOAA Damage Assessment and Restoration Center NW. Seattle, WA.

Thom, R.M., A.B. Borde, S. Rumrill, D.L. Woodruff, G.D. Williams, J.A. Southard, and S.L. Sargeant. 2003. Factors Influencing Spatial and Annual Variability in Eelgrass (*Zostera marina* L.) Meadows in Willapa Bay, Washington, and Coos Bay, Oregon, Estuaries. Estuaries, 26: 1117-1129.

Thom, R.M., S.L. Blanton, D.L. Woodruff, G.D. Williams, and A.B. Borde. 2001. Carbon Sinks in Nearshore Marine Vegetated Ecosystems. Proceedings of First National Conference on Carbon Sequestration. DOE/NETL-2001/1144. U.S. Department of Energy. Washington, DC.

Thomas, D.W. 1983. Changes in the Columbia River estuary Habitat Types Over the Past Century. Columbia River Estuary Data Development Program, Columbia River Estuary Task Force. Astoria, OR.

Thomsen, R.E. 1994. Physical Oceanography of the Strait of Georgia-Puget Sound-Juan de Fuca Strait System. In: Review of the Marine Environment and Biota of Strait of Georgia-Puget Sound-Juan de Fuca Strait. Proceedings of the BC/Washington Symposium on the Marine Environment, R.C.H. Wilson, R.J. Beamish, F. Aitkens, and J. Bell, (eds). Canadian Technical Report of Fisheries and Aquatic Sciences 1948.

Torgenson, C.E., R.N. Faux, B.A. McIntosh, N.J. Poage, and D.J. Norton. 2001. Airborne Thermal Remote Sensing for Water Temperature Assessment in Rivers and Streams. Remote Sensing of Environment, 76: 386-398.

Townsend, C.R. 1996. Concepts in River Ecology: Pattern and Process in the Catchment Hierarchy. Archiv fuer Hydrobiologie. Supplementband, 113.

Treberg, M.A. and B.C. Husband. 1999. Relationship Between the Abundance *of Lythrum salicaria* (Purple Loosestrife) and Plant Species Richness Along the Bar River, Canada. Wetlands, 19(1): 118-125.

US Army Corps of Engineers. 2005. Sediment Management Annual Review Meeting May 5, 2005 Meeting Minutes. Prepared by: Science Applications International Corporation.

US Department of Agriculture, Natural Resource Conservation Service. 2002. The PLANTS Database, Version 3.5. National Plant Data Center, Baton Rouge, LA. Accessed April 30, 2004. http://plants.usda.gov/cgi_bin/topics.cgi.

US Geological Survey. 2005. Glacial Lake Missoula and the Missoula Floods. Accessed on 3/15/2005. http://vulcan.wr.usgs.gov/Glossary/Glaciers/IceSheets/description_lake_missoula.html

US Soil Conservation Service. 1987. Hydric Soils of the United States. In cooperation with the National Technical Committee for Hydric Soils, Washington D.C.

Valiela, I. 1984. Marine Ecological Processes. Springer-Verlag, New York, NY.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The River Continuum Concept. Canadian Journal of Fisheries and Aquatic Sciences, 37: 130-137.

Washington State Department of Ecology. 2002. Washington State Marine Water Quality (1998-2000). Publication 02-03-056. Washington Department of Ecology, Olympia, WA.

Washington State Department of Fish and Wildlife. 1997. Aquatic Plants and Fish. Publication # APF-11-97. Washington State Department of Fish and Wildlife. Olympia, WA.

Washington State Department of Natural Resources. April 20, 2002. ShoreZone Inventory Database. http://www2.wadnr.gov/nearshore/research/index.asp?sp=y&id=9

Washington State Department of Natural Resources. 2007a. Aquatic Resources Program Endangered Species Act Compliance Project, Covered Species Technical Paper. Aquatic Resources, Washington Department of Natural Resources. Olympia, WA.

Washington State Department of Natural Resources. 2005a. Aquatic Resources Program Endangered Species Act Compliance Project, Potential Covered Activities Technical Paper. Aquatic Resources, Washington Department of Natural Resources. Olympia, WA.

Washington State Department of Natural Resources. 2007b. Aquatic Resources Program Endangered Species Act Compliance Project, Potential Effects and Expected Outcomes Technical Paper. Aquatic Resources, Washington Department of Natural Resources. Olympia, WA.

Washington State Noxious Weed Control Board. 2005. Purple Loosestrife (Lythrum salicaria L.). Revised 3/12/2005. Accessed September 25, 2005. http://www.nwcb.wa.gov/weed_info/Written_findings/Lythrum_salicaria.html.

Welch, E, B., J. M. Jacoby and C. W. May. 1998. Stream Quality. In: River Ecology and Management. R. J. Naiman and R. E. Bilby, editors. Springer Verlag. New York, NY.

Wetzel, R. G. 2001. Limnology - Lake and River Ecosystems. 3rd Edition. Academic Press. San Diego, CA.

Williams, G.D., R.M. Thom, J. E. Starkes, J.S. Brennan, J.P. Houghton, D. Woodruff, P.L. Striplin, M. Miller, M. Pedersen, A. Skillman, R. Kropp, A. Borde, C. Freeland, K. McArthur, V. Fagerness, S. Blanton, and L. Blackmore. 2001. Reconnaissance Assessment of the State of the Nearshore Ecosystem: Eastern Shore of Central Puget Sound, Including Vashon and Maury Islands (WRIAs 8 and 9). J.S. Brennan, (ed). Available at: http://dnr.metrokc.gov/wlr/watersheds/puget/nearshore/sonr.htm.

Wissmar, R.J., J.E. Smith, B.A. McIntosh, H.W. Li, G.H. Reeves, and J.R. Sedell. 1994. A History of Resource Use and Disturbance in Riverine Basins of Eastern Oregon and Washington (Early 1800s-1990s). Northwest Science, 68.

Wydoski, R.S. and R.L. Whitney. 2003. Inland Fishes of Washington. 2nd Edition. University of Washington Press, Seattle, WA.

Appendix A - Species and lifestage associations by habitat types.

Species	Life Stage	Saltwater									Freshwater													
		Offshore				Nearshore				Tidal Wetland	Riverine					Lacustrine								Freshwater Wetlands
		Coastal		Inland		Coastal		Inland								Oligotrophic		Mesotrophic		Eutrophic		Unspecified		
		Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated		Low-Gradient Valley	Pool-Riffle	Plane Bed	Step-Pool	Cascade	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	
American White Pelican *(Pelecanus erythrorhynchos)*	Nesting										x	x	x	x	x			x		x				
	Resident non-breeding / Wintering					x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Ashyy Pebblesnail (*Fuminicola columbiana)*	Juvenile / Adult										x	x	x	x										
	Nesting					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Bald Eagle (*Haliaeetus leucicephalus)*	Adult / Juvenile / Wintering					x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	x	
	Adult / Parturition		x		x		x		x															
Black Rockfish (*Sebastes melanops)*	Pelagic Larvae				x																			
	Benthic Juvenile						x																	
Black Tern (*Childonias niger)*	Nesting										x					x		x		x		x		x
	Migration										x					x		x		x		x		x
Blue Whale *(Balaenoptera musculus)*	All																							

Species	Life Stage	Saltwater									Freshwater													
		Offshore				Nearshore				Tidal Wetland	Riverine					Lacustrine								Freshwater Wetlands
		Coastal		Inland		Coastal		Inland								Oligotrophic		Mesotrophic		Eutrophic		Unspecified		
		Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated		Low-Gradient Valley	Pool-Riffle	Plane Bed	Step-Pool	Cascade	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	
Bocaccio (*Sebastes paucispinis)*	Adult / Parturition	x	x	x	x																			
	Pelagic Larvae																							
	Benthic Juvenile		x		x																			
Bowhead Whale *(Balaena mysticetus)*	All																							
Brandt's Cormorant *(Phalacrocorax penicillatus)*	Nesting					x	x	x	x	x														
	Resident non-breeding / Migration / Wintering					x	x	x	x	x														
Brown Rockfish (*Sebastes auriculatus)*	Adult / Parturition			x	x			x	x															
	Pelagic Larvae							x	x															
	Benthic Juvenile							x	x															
Bull Trout (*Salvelinus confluentus)*	Adult Migration / Spawning / Marine Rearing					x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x
	Incubation / Emergence											x	x	x										
	Freshwater Rearing / Outmigration					x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x

Species	Life Stage	Saltwater									Freshwater													
		Offshore				Nearshore				Tidal Wetland	Riverine					Lacustrine								Freshwater Wetlands
		Coastal		Inland		Coastal		Inland								Oligotrophic		Mesotrophic		Eutrophic		Unspecified		
		Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated		Low-Gradient Valley	Pool-Riffle	Plane Bed	Step-Pool	Cascade	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	
California Brown Pelican (*Pelecanus occidentalis califormicus)*	Resident non-breeding / Migration	x	x	x	x	x	x	x	x	x														
California Floater (*Anodonta californiensis)*	Juvenile / Adult										x	x				x						x		
	Free Floating Larvae										x	x				x						x		
	Glochidia										x	x				x						x		
Canary Rockfish (*Sebastes Pinniger)*	Adult / Parturition		x		x																			
	Pelagic Larvae																							
	Benthic Juvenile		x		x		x		x															
Cascades Frog *(Rana cascadae)*	Egg											x		x		x		x		x		x		x
	Tadpole											x		x		x		x		x		x		x
	Adult / Migration / Spawning / Overwintering										x	x	x	x		x		x		x		x		x
Cassin's Auklet *(Pychoramphys aleuticus)*	Nesting						x																	
	Resident non-breeding						x																	

		Saltwater									Freshwater													
		Offshore				Nearshore					Riverine					Lacustrine								
		Coastal		Inland		Coastal		Inland								Oligotrophic		Mesotrophic		Eutrophic		Unspecified		
Species	**Life Stage**	**Unconsolidated**	**Consolidated**	**Unconsolidated**	**Consolidated**	**Unconsolidated**	**Consolidated**	**Unconsolidated**	**Consolidated**	**Tidal Wetland**	**Low-Gradient Valley**	**Pool-Riffle**	**Plane Bed**	**Step-Pool**	**Cascade**	**Littoral**	**Limnetic**	**Littoral**	**Limnetic**	**Littoral**	**Limnetic**	**Littoral**	**Limnetic**	**Freshwater Wetlands**
Chinook Salmon (*Oncorhynchus tshawytscha)*	Adult Migration / Spawning / Marine Rearing	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Incubation / Emergence										x	x	x	x	x									
	Freshwater rearing / Outmigration	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Chum Salmon *(Oncorhynchus keta)*	Adult Migration / Spawning / Marine Rearing	x	x	x	x	x	x	x	x	x	x	x	x	x										x
	Incubation / Emergence											x	x											
	Freshwater Rearing / Outmigration					x	x	x	x	x	x	x	x											x
Clark's Grebe (*Aechmorphus clarkii)*	Nesting										x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Migration										x	x	x	x	x	x	x	x	x	x	x	x	x	x
Coast Tailed Frog (*Ascaphus truei)*	Egg											x	x	x										
	Tadpole											x	x	x	x									
	Adult / Migration / Spawning / Overwintering											x	x	x										

		Saltwater									Freshwater													
		Offshore				Nearshore					Riverine					Lacustrine								
		Coastal		Inland		Coastal		Inland								Oligotrophic		Mesotrophic		Eutrophic		Unspecified		
Species	**Life Stage**	**Unconsolidated**	**Consolidated**	**Unconsolidated**	**Consolidated**	**Unconsolidated**	**Consolidated**	**Unconsolidated**	**Consolidated**	**Tidal Wetland**	**Low-Gradient Valley**	**Pool-Riffle**	**Plane Bed**	**Step-Pool**	**Cascade**	**Littoral**	**Limnetic**	**Littoral**	**Limnetic**	**Littoral**	**Limnetic**	**Littoral**	**Limnetic**	**Freshwater Wetlands**
Coastal Cutthrout Trout *(Oncorhynchus clarki clarki)*	Adult Migration / Spawning / Marine Rearing	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x
	Incubation / Emergence										x	x	x	x										
	Freshwater Rearing / Outmigration					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Coho Salmon *(Oncorhynchus kisutch)*	Adult Migration / Spawning / Marine Rearing	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Incubation / Emergence											x	x	x										
	Freshwater rearing / Outmigration	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Columbia Spotted Frog *(Rana luteiventris)*	Egg										x	x	x	x		x		x		x		x		x
	Tadpole										x	x	x	x		x		x		x		x		x
	Adult / Migration / Spawning / Overwintering										x	x	x	x		x		x		x		x		x
Common Loon *(Gavia*	Nesting															x	x					x	x	x

		Saltwater									Freshwater													
		Offshore				Nearshore					Riverine					Lacustrine								
		Coastal		Inland		Coastal		Inland								Oligotrophic		Mesotrophic		Eutrophic		Unspecified		
Species	**Life Stage**	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Tidal Wetland	Low-Gradient Valley	Pool-Riffle	Plane Bed	Step-Pool	Cascade	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	Freshwater Wetlands
immer)	Migration / Resident non-breeding / Wintering	x	x	x	x	x	x	x	x		x					x	x					x	x	x
Common Murre (*Uria aalge)*	Wintering	x	x	x	x	x	x	x	x															
	Nesting	x	x	x	x	x	x	x	x															
Copper Rockfish *(Sebastes caurinus)*	Adult / Parturition		x		x		x		x															
	Pelagic Larvae				x	x	x	x	x															
	Benthic Juvenile					x	x	x	x															
Demersal Rockfish (*Sebastes group*)	Adult / Parturition		x		x		x		x															
	Pelagic Larvae					x	x	x	x															
	Benthic Juvenile					x	x	x	x															
Eared Grebe (*Podiceps nigricollis)*	Nesting																							x
	Wintering					x	x	x	x	x										x	x	x	x	
Eulachon (*Thaleichthys pacificus)*	Adult Migration / Spawning / Marine Rearing	x	x	x	x	x	x	x	x		x													
	Incubation / Emergence										x													
	Freshwater Rearing / Outmigration	x	x	x	x	x	x	x	x															

		Saltwater									Freshwater													
		Offshore				Nearshore					Riverine					Lacustrine								
		Coastal		Inland		Coastal		Inland								Oligotrophic		Mesotrophic		Eutrophic		Unspecified		
Species	**Life Stage**	**Unconsolidated**	**Consolidated**	**Unconsolidated**	**Consolidated**	**Unconsolidated**	**Consolidated**	**Unconsolidated**	**Consolidated**	**Tidal Wetland**	**Low-Gradient Valley**	**Pool-Riffle**	**Plane Bed**	**Step-Pool**	**Cascade**	**Littoral**	**Limnetic**	**Littoral**	**Limnetic**	**Littoral**	**Limnetic**	**Littoral**	**Limnetic**	**Freshwater Wetlands**
Gray Whale *(Eschrichtius robustus)*	Migration																							
	Resident	x		x		x		x																
Green Sturgeon (*Acipenser medirostris)*	Adult	x	x	x	x	x	x	x	x	x	x													
	Egg / Larvae																							
	Juvenile																							
Harlequin Duck (*Histrionicus histrionicus)*	Nesting									x		x	x	x		x	x	x	x	x	x	x	x	x
	Resident non-breeding / Migration / Wintering					x	x	x	x	x	x													
Humpback Whale (*Megaptera novaeamgliae)*	All																							
Idaho Springsnail (*Pyrgulopsis idahoensis)*	Juvenile / Adult										x	x	x	x										
Kalm's Lobelia (*Lobelia kalmii)*	All																							x
Killer Whale *(Orcinus orca)*	Offshore - All																							
	Resident - All	x	x	x	x	x	x	x	x															

Species	Life Stage	Saltwater									Freshwater													
		Offshore				Nearshore				Tidal Wetland	Riverine					Lacustrine								Freshwater Wetlands
		Coastal		Inland		Coastal		Inland								Oligotrophic		Mesotrophic		Eutrophic		Unspecified		
		Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated		Low-Gradient Valley	Pool-Riffle	Plane Bed	Step-Pool	Cascade	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	
	Transient	x	x	x	x	x	x	x	x															
Kokanee (*Oncorhynchus nerka)*	All										x	x	x	x		x	x	x	x	x	x	x	x	x
Leopard Dace (*Rhinichtys falcatus)*	Adult											x												
	Juvenile											x												
Marbled Murrelet (*Branchyramphus marmoratus)*	Nesting	x	x	x	x	x	x	x	x	x						x	x					x	x	
	Resident non-breeding / Wintering	x	x	x	x	x	x	x	x	x						x	x					x	x	
Margined Sculpin (*Cottus marginatus)*	Adult											x												
	Adult											x												
Masked Duskysnail (*Lyogyrus* sp 2)	Juvenile / Adult															x						x		
Nerite Rams-Horn (*Vorticiflex neritoides)*	Juvenile / Adult										x	x												
Newcomb's Littorine Snail (*Littorine subrotundata)*	Adult									x														
	Egg									x														
	Juvenile									x														
Northern Leopard Frog	Egg																							x

Species	Life Stage	Saltwater									Freshwater													
		Offshore				Nearshore				Tidal Wetland	Riverine					Lacustrine								Freshwater Wetlands
		Coastal		Inland		Coastal		Inland								Oligotrophic		Mesotrophic		Eutrophic		Unspecified		
		Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated		Low-Gradient Valley	Pool-Riffle	Plane Bed	Step-Pool	Cascade	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	
(*Rana pipiens)*	Tadpole																							x
	Adult / Migration / Spawning / Overwintering										x	x	x	x		x		x		x		x		x
Northern Red-Legged Frog (*Rana aurora aurora)*	Egg										x	x	x	x		x		x		x		x		x
	Tadpole										x	x	x	x		x		x		x		x		x
	Adult / Migration / Spawning / Overwintering										x	x	x	x		x		x		x		x		x
Northern Sea Otter (*Enhydra lutris kenyoni)*	All					x	x	x	x															
Olympia Oyster (*Ostrea conchaphila)*	Adult / Spawning					x	x	x	x															
	Larvae / Juvenile					x	x	x	x															
Olympic Mudminnow (*Novumbra hubbsi)*	All										x	x				x		x		x		x		x
Olympia Pebblesnail *(Fluminicola virens)*	Juvenile / Adult										x	x	x	x										
Oregon Spotted Frog	Egg																							x

Species	Life Stage	Saltwater									Freshwater													
		Offshore				Nearshore					Riverine					Lacustrine								
		Coastal		Inland		Coastal		Inland								Oligotrophic		Mesotrophic		Eutrophic		Unspecified		
		Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Tidal Wetland	Low-Gradient Valley	Pool-Riffle	Plane Bed	Step-Pool	Cascade	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	Freshwater Wetlands
(*Rana pretiosa)*	Tadpole																							x
	Adult / Migration / Spawning / Overwintering																							x
Pacific Cod *(Gadus macrocephalus)*	Adult / Spawning	x		x		x																		
	Egg	x		x		x																		
	Pelagic Larvae					x	x	x	x															
	Benthic Juvenile					x		x																
Pacific Hake *(Merluccius productus)*	Adult / Spawning	x	x	x	x																			
	Pelagic Larvae	x	x	x	x	x	x	x	x															
	Benthic Juvenile					x		x																
Pacific Herring *(Clupea pallasi)*	Adult	x	x	x	x	x	x	x	x															
	Egg / Larvae					x	x	x	x															
	Juvenile	x	x	x	x	x	x	x	x															
Pacific Herring (Cherry Point) *(Clupea pallasi)*	Adult			x	x			x	x															
	Egg / Larvae							x	x															
	Juvenile							x	x															
Pacific Lamprey	Adult										x	x	x	x	x									

		Saltwater									Freshwater													
		Offshore				Nearshore					Riverine					Lacustrine								
		Coastal		Inland		Coastal		Inland								Oligotrophic		Mesotrophic		Eutrophic		Unspecified		
Species	**Life Stage**	**Unconsolidated**	**Consolidated**	**Unconsolidated**	**Consolidated**	**Unconsolidated**	**Consolidated**	**Unconsolidated**	**Consolidated**	**Tidal Wetland**	**Low-Gradient Valley**	**Pool-Riffle**	**Plane Bed**	**Step-Pool**	**Cascade**	**Littoral**	**Limnetic**	**Littoral**	**Limnetic**	**Littoral**	**Limnetic**	**Littoral**	**Limnetic**	**Freshwater Wetlands**
(Lampetra tridentata)	Spawning											x												
	Egg / Ammocoete Larvae										x	x	x											
Persistentsepal Yellowcress *(Rorippa columbiae)*	All										x	x	x	x	x									
Pink Salmon *(Oncorhynchus gorbuscha)*	Adult Migration / Spawning / Marine Rearing	x	x	x	x	x	x	x	x	x	x	x	x	x										
	Incubation / Emergence										x	x	x	x										
	Freshwater rearing / Outmigration	x	x	x	x	x	x	x	x	x	x	x	x	x										
Pinto Abalone *(Haliotis kamschatkana)*	Adult								x															
	Egg							x	x															
	Juvenile								x															
Purple martin *(Progne subis)*	Breeding							x	x	x	x	x	x	x	x			x	x	x	x	x	x	x
	Migration							x	x	x	x	x	x	x	x			x	x	x	x	x	x	x
	Wintering																							

		Saltwater									Freshwater													
		Offshore				Nearshore				Tidal Wetland	Riverine					Lacustrine								Freshwater Wetlands
		Coastal		Inland		Coastal		Inland								Oligotrophic		Mesotrophic		Eutrophic		Unspecified		
Species	**Life Stage**	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated		Low-Gradient Valley	Pool-Riffle	Plane Bed	Step-Pool	Cascade	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	
Pygmy Water Lily *(Nymphaea teragona)*	All										x					x		x		x		x		
Pygmy Whitefish *(Prosopium coulteri)*	Adult / Spawning															x	x	x	x			x	x	
	Egg / Incubation											x				x		x				x		
	Juvenile															x	x	x	x			x	x	
Quillback Rockfish *(Sebastes maliger)*	Adult / Parturition			x	x			x	x															
	Pelagic Larvae							x	x															
	Benthic Juvenile							x	x															
Right Whale *(Eubalaena japonica)*	All																							
River Lamprey *(Lampetra ayresi)*	Adult										x	x	x	x										
	Spawning											x												
	Egg / Ammocoete Larvae										x	x												
Rocky Mountain Tailed-Frog *(Ascaphus*	Egg											x	x	x										
	Tadpole											x	x	x	x									

Species	Life Stage	Saltwater									Freshwater													
		Offshore				Nearshore				Tidal Wetland	Riverine					Lacustrine								Freshwater Wetlands
		Coastal		Inland		Coastal		Inland								Oligotrophic		Mesotrophic		Eutrophic		Unspecified		
		Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated		Low-Gradient Valley	Pool-Riffle	Plane Bed	Step-Pool	Cascade	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	
montanus)	Adult / Migration / Spawning / Overwintering											x	x	x										
Shortface Lanx *(Fisherola nuttalli)*	Juvenile / Adult										x	x	x	x										
Sockeye Salmon *(Oncorhynchus nerka)*	Adult Migration / Spawning / Marine Rearing	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x
	Incubation / Emergence												x			x	x	x	x	x	x	x	x	
	Freshwater rearing / Outmigration	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x
Steelhead Trout *(Oncorhynchus mykiss)*	Adult Migration / Spawning / Marine Rearing	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Incubation / Emergence										x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Freshwater rearing / Outmigration	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Steller Sea Lion *(Eumetopias jubatus)*	Adult nonbreeding	x	x	x	x	x	x	x	x	x														

Species	Life Stage	Saltwater									Freshwater													
		Offshore				Nearshore					Riverine					Lacustrine								
		Coastal		Inland		Coastal		Inland								Oligotrophic		Mesotrophic		Eutrophic		Unspecified		
		Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Tidal Wetland	Low-Gradient Valley	Pool-Riffle	Plane Bed	Step-Pool	Cascade	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	Freshwater Wetlands
Tufted Puffin (*Fratercula cirrhata*)	Nesting	x	x	x	x																			
	Wintering (>3mi offshore)	x	x																					
Umatilla Dace *(Rhinichthys umatilla)*	Adult											x												
	Juvenile											x												
Walleye Pollock *(Theragra chalcogramma)*	Adult / Spawning			x	x			x	x															
	Pelagic Larvae							x	x															
	Benthic Juvenile			x				x																
Washington Duskysnail (*Amnicola* sp 2)	Juvenile / Adult															x						x		
Water Howellia (*Howellia aquatilis)*	All																							x
Water Lobelia (*Lobelia dortmanna)*	All															x						x		
Western Pond Turtle (*Clemmys marmorata)*	Nesting (terrestrial)																							
	Foraging										x	x	x	x		x		x		x		x		x
	OverWintering															x		x		x		x		x
Western Ridgemussel	Juvenile / Adult										x	x	x	x		x						x		

Species	Life Stage	Saltwater									Freshwater													
		Offshore				Nearshore				Tidal Wetland	Riverine					Lacustrine								Freshwater Wetlands
		Coastal		Inland		Coastal		Inland								Oligotrophic		Mesotrophic		Eutrophic		Unspecified		
		Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated		Low-Gradient Valley	Pool-Riffle	Plane Bed	Step-Pool	Cascade	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	
(Gonidea angulata)	Free Floating Larvae										x	x	x	x		x						x		
	Glochidia										x	x	x	x		x						x		
Western Snowy Plover *(Charadrius alexandrinus nivosus)*	Breeding					x		x		x														
	Wintering					x	x			x														x
Western Toad *(Bufo boreas)*	Egg										x	x	x	x		x		x		x		x		x
	Tadpole										x	x	x	x		x		x		x		x		x
	Adult / Migration / Spawning / Overwintering										x	x	x	x		x		x		x		x		x
Westslope Cutthroat *(Oncorhynchus clarki lewisi)*	All										x	x	x	x	x	x	x	x	x	x	x	x	x	x
White Sturgeon *(Acipenser transmontanus)*	Adult / Spawning	x	x	x	x	x	x	x	x	x	x	x	x	x				x	x			x	x	
	Egg / Larvae										x	x	x	x										
	Juvenile					x					x	x	x					x	x			x	x	
Widow Rockfish *(Sebastes entomelas)*	Adult / Parturition		x		x																			
	Pelagic Larvae					x	x	x	x															

Species	Life Stage	Saltwater									Freshwater													
		Offshore				Nearshore					Riverine					Lacustrine								Freshwater Wetlands
		Coastal		Inland		Coastal		Inland								Oligotrophic		Mesotrophic		Eutrophic		Unspecified		
		Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Tidal Wetland	Low-Gradient Valley	Pool-Riffle	Plane Bed	Step-Pool	Cascade	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	
	Benthic Juvenile		x		x		x		x															
Yelloweye Rockfish (*Sebastes ruberrimus)*	Adult / Parturition		x		x																			
	Pelagic Larvae					x	x	x	x															
	Benthic Juvenile		x		x		x		x															
Yellowtail Rockfish (*Sebastes flavidus*)	Adult / Parturition		x		x																			
	Pelagic Larvae																							
	Benthic Juvenile		x		x		x		x															

Appendix B - Distribution of authorize activities by habitat class and/or type as described in the Covered Habitat paper.

	Saltwater									Freshwater												
	Offshore				Nearshore					Riverine				Lacustrine								
	Coastal		Inland		Coastal		Inland							Oligotrophic		Mesotrophic		Eutrophic		Unspecified		
Activity	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Unconsolidated	Consolidated	Tidal Wetland	Low-gradient valley	Plane bed	Pool-riffle	Step-pool	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	Littoral	Limnetic	Freshwater Wetland
Artificial Habitat			X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
Boat Ramp/Launch/Hoist					X	X	X	X		X		X		X		X		X		X		X
Breakwater					X		X	X												X	X	
Bridges			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cables			X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
Combined Sewer Overflow			X	X			X	X		X		X				X	X			X	X	X
Conservation			X	X	X	X	X	X	X	X	X	X				X	X	X	X	X	X	X
Contamination and Remediation			X	X			X	X	X	X		X						X		X		X
Desalinization			X	X			X	X														
Dike/Dam					X		X		X	X		X				X	X	X	X	X	X	X
Docks and Wharves					X	X	X	X		X		X		X	X	X	X	X	X	X	X	X
Ferries			X	X			X	X	X					X	X	X	X			X	X	X
Fill and Bank Armoring					X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
Fisheries							X	X		X		X		X	X							
Floating Homes					X		X			X								X	X	X	X	
Floats and Rafts			X	X	X	X	X	X		X								X	X	X	X	

	Saltwater									Freshwater												
	Offshore				Nearshore					Riverine				Lacustrine								
	Coastal		Inland		Coastal		Inland							Oligotrophic		Mesotrophic		Eutrophic		Unspecified		
Activity	**Unconsolidated**	**Consolidated**	**Unconsolidated**	**Consolidated**	**Unconsolidated**	**Consolidated**	**Unconsolidated**	**Consolidated**	**Tidal Wetland**	**Low-gradient valley**	**Plane bed**	**Pool-riffle**	**Step-pool**	**Littoral**	**Limnetic**	**Littoral**	**Limnetic**	**Littoral**	**Limnetic**	**Littoral**	**Limnetic**	**Freshwater Wetland**
Industrial and Municipal	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Log Booming and Storage			X	X	X		X	X		X				X	X	X	X	X	X	X	X	
Marina					X	X	X	X		X		X		X	X	X	X	X	X	X	X	
Mooring Buoys			X	X			X	X		X				X	X	X	X	X	X	X	X	
Mussels, Clams, and Oysters					X	X	X	X														
Nearshore Buildings					X	X	X	X	X	X		X		X		X		X		X		X
Oil/Gas Pipelines			X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Public Access			X	X	X	X	X	X	X	X	X	X		X		X		X		X		X
Railroads			X	X	X		X	X	X	X		X				X	X			X	X	X
Roads			X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X
Sand Shrimp					X		X	X														
Sediment Removal	X				X		X		X	X		X				X	X	X	X	X	X	X
Sewage Pipelines							X	X	X	X		X				X	X	X	X	X	X	X
Stormwater			X	X	X		X	X	X	X		X				X	X			X	X	X
Terminal					X		X	X		X						X	X	X	X	X	X	
Water Intakes							X	X	X	X		X		X	X	X	X			X	X	X
Water Pipeline							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Note: Data is derived from intersection of the activities table in the RTA Database & GIS habitat dataset at the Township Range level