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Strategic Needs Assessment: Analysis of Nearshore Ecosystem Process Degradation in Puget Sound

Prepared in support of the
Puget Sound Nearshore Ecosystem Restoration Project

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PUGET SOUND
NEARSHORE
ECOSYSTEM RESTORATION PROJECT

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LIST OF ACRONYMS AND ABBREVIATIONS

ACZA	ammoniacal copper zinc arsenate
CCA	chromated copper arsenate
Corps	U.S. Army Corps of Engineers
DPU	delta process unit
EFG&S	ecosystem functions, goods, and services
GSU	geographic scale unit
km	kilometer
km^2	square kilometer
LWD	large woody debris
m	meter
m^2	square meter
MHHW	mean higher high water
MLLW	mean lower low water
NST	Nearshore Science Team
NWI	National Wetland Inventory
OHWM	ordinary high water mark
PAH	polycyclic aromatic hydrocarbon
PSNERP	Puget Sound Nearshore Ecosystem Restoration Project
SPU	shoreline process unit
VEC	valued ecosystem component
WDFW	Washington Department of Fish and Wildlife
WDNR	Washington Department of Natural Resources
WDOE	Washington State Department of Ecology
WSDOT	Washington State Department of Transportation

LEGENDS

DPU Abbreviation Legend

DPU Code	River	Sub-basin
NKS	Nooksack	San Juan Islands – Strait of Georgia
SAM	Samish	San Juan Islands – Strait of Georgia
SKG	Skagit	Whidbey
STL	Stillaguamish	Whidbey
SNH	Snohomish	Whidbey
DUW	Duwamish/Green/White/Cedar/ Black/Lake Washington/Sammamish Rivers	South Central Puget Sound
PUY	Puyallup	South Central Puget Sound
NSQ	Nisqually	South Puget Sound
DES	Deschutes	South Puget Sound
ELW	Elwha	Strait of Juan de Fuca
DUN	Dungeness	Strait of Juan de Fuca
QUL	Big Quilcene	Hood Canal
DOS	Dosewallips	Hood Canal
DUC	Duckabush	Hood Canal
HAM	Hamma Hamma	Hood Canal
SKO	Skokomish	Hood Canal

Sub-basin Abbreviation Legend

Sub-basin Abbreviation	Sub-basin Name
JF	Strait of Juan de Fuca
SJ	San Juan Islands – Strait of Georgia
HC	Hood Canal
NC	North Central Puget Sound
WH	Whidbey
SC	South Central Puget Sound
SP	South Puget Sound

Shipman (2008) Geomorphic Shoreforms Abbreviation Legend

Shoreform Abbreviation	Shoreform
BAB	Barrier Beach
BLB	Bluff-backed Beach
BE	Barrier Estuary
BL	Barrier Lagoon
CLM	Closed Lagoon/Marsh
OCI	Open Coastal Inlet
PB	Pocket Beach
PL	Plunging Rocky Shoreline
RP	Rocky Platform
D	Delta

GLOSSARY

accretion	The gradual addition of sediment to a beach or to marsh surface as a result of deposition by flowing water or air. Accretion leads to increases in the elevation of a marsh surface, the seaward building of the coastline, or an increase in the elevation of a beach profile (the opposite of erosion) (Shipman 2008).
anthropogenic	Caused or produced by humans.
backshore	The upper zone of a beach beyond the reach of normal waves and tides, landward of the beach face. The backshore is subject to periodic flooding by storms and extreme tides, and is often the site of dunes and back-barrier wetlands (Clancy et al. 2009).
barrier beach	A linear ridge of sand or gravel extending above high tide, built by wave action and sediment deposition seaward of the original coastline. Includes variety of depositional coastal landforms, including spits, tombolos, cuspate forelands, and barrier islands (Shipman 2008).
beach	The gently-sloping zone of unconsolidated sediment along the shoreline that is moved by waves, wind and tidal currents (Shipman 2008).
bluff	A steep bank or slope rising from the shoreline, generally formed by erosion of poorly consolidated material such as glacial or fluvial sediments (Shipman 2008).
conceptual model	A model, either numerical or diagrammatic, that summarizes and describes the relationships and interactions between specified model components.
delta	A deposit of sediment formed at a stream or river mouth, or other location where the slowing of water flow results in sediment deposition (Clancy et al. 2009).
detritus import and export	(This is one of the eleven broad physiographic nearshore processes investigated in the Strategic Needs Assessment; these are discussed in

	Section 2.3 of this report). Import and deposition of particulate (dead) organic matter. Soil formation. Recruitment, disturbance, and export of large wood.
distributary channel migration	(This is one of the eleven broad physiographic nearshore processes investigated in the Strategic Needs Assessment; these are discussed in Section 2.3 of this report). Change of distributary channel form and location caused by combined freshwater and tidal flow. Distributary channel migration affects the distribution of alluvial material across a river delta.
drift cell (or littoral cell)	A littoral [drift] cell is a coastal compartment that contains a complete cycle of sedimentation including sources, transport paths, and sinks. The cell boundaries delineate the geographical area within which the budget of sediment is balanced, providing the framework for the quantitative analysis of coastal erosion and accretion (Inman 2005). See Johannessen and MacLennan (2007) for further description of drift cells.
ecosystem	A dynamic complex of plant, animal, and micro-organism communities and their non-living environment interacting as a functional unit. An ecosystem can be of any size—a log, pond, field, forest, or the earth's biosphere—depending upon the organisms that are the frame of reference, but it always functions as a whole unit. Ecosystems are commonly described according to the major type of vegetation, for example, forest ecosystem, old-growth ecosystem, or range ecosystem.
ecosystem function	The specific mechanisms through which we benefit from Puget Sound, such as production of forage fish, or wave attenuation. Functions are roughly synonymous with goods and services. Ecosystem functions are delivered through the interaction of processes and structures (Simenstad et al. 2006).

ecosystem processes	Any interaction among physiochemical and biological elements of an ecosystem that involve changes in character or “state” (NRC 1992). Processes like primary production or tidal flux alter structures that in turn provide ecosystem functions goods and services.
ecosystem structure	The position and character of the physical components of an ecosystem; the character or “state” of the system. Structures are created through the effects of ecosystem processes, and in turn provide ecosystem function goods and services.
embayment	An indentation of the shoreline larger in size than a cove but smaller than a gulf.
erosion	The wearing away of land by the action of natural forces. On a beach, the carrying away of beach material by wave action, tidal currents, littoral currents, or by deflation (wind action; opposite of accretion) (Shipman 2008).
erosion and accretion of sediments	(This is one of the eleven broad physiographic nearshore processes investigated in the Strategic Needs Assessment; these are discussed in Section 2.3 of this report). Deposition (dune formation, delta building) of non-suspended (e.g., bedload) sediments and mineral particulate material by water, wind, and other forces. Settling (accretion) of suspended sediments and organic matter on marsh and other intertidal wetland surfaces. These processes are responsible for creation and maintenance of barrier beaches (e.g., spits) and tidal wetlands.
estuary	A semi-enclosed coastal body of water that has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage (Pritchard 1967). Sometimes defined more broadly to include other coastal inlets that connect coastal lagoons and swamps to the sea.

exchange of aquatic organisms	(This is one of the eleven broad physiographic nearshore processes investigated in the Strategic Needs Assessment; these are discussed in Section 2.3 of this report). Organism transport and movement driven predominantly by water (tidal, fluvial) movement.
freshwater inputs	(This is one of the eleven broad physiographic nearshore processes investigated in the Strategic Needs Assessment; these are discussed in Section 2.3 of this report). Freshwater inflow from surface (streamflow) or groundwater (seepage) in terms of seasonal and event hydrography. Freshwater input affects the pattern of salinity and sediment and soil moisture content across the nearshore.
geomorphic system	As used here, four broad categories of coastline (rocky coasts, beaches, embayments, and river deltas) that reflect the relative influences of wind, tidal, and fluvial processes in controlling the transport and distribution of sediments and the resulting evolution of landforms (Shipman 2008). See Shipman (2008) for a full explanation of typology.
habitat	The physical, biological, and chemical characteristics of a specific unit of the environment occupied by a specific plant or animal. Habitat is unique to specific organisms and provides all the physiochemical and biological requirements of that organism within a specific location (Fresh et al. 2004).
longshore transport	Transport of sediment parallel to the shoreline by waves and currents (Shipman 2008).
morphology	The shape or form of the land surface or of the seabed and the study of its change over time (Clancy et al. 2009).

nearshore	As defined by PSNERP, includes the area from the deepest part of the photic zone (approximately 10 meters below Mean Lower Low Water [MLLW]) landward to the top of shoreline bluffs, or in estuaries upstream to the head of tidal influence (Clancy et al. 2009).
physical disturbance	(This is one of the eleven broad physiographic nearshore processes investigated in the Strategic Needs Assessment; these are discussed in Section 2.3 of this report). Change of shoreline shape or character caused by exposure to local wind and wave energy input. Localized and chronic disturbance of biotic assemblages caused by large wood movement, scour, and overwash.
pocket estuary	Term used in the Puget Sound region to describe small estuaries and lagoons (and are a type of embayment), partially isolated by their configuration from the main body of Puget Sound (Shipman 2008).
primary production	The in situ fixation of atmospheric carbon and energy into organic compounds that form the basis for all food chains. Nearshore primary production is supplemented by detritus import and export to determine the energetic budget for nearshore biota.
process-based restoration	Restoration and other management measures that target the recovery of natural nearshore ecosystem processes, for the purpose of maximizing the effectiveness and durability or restoration action effects within dynamic systems.
Puget Sound	Defined here to include all inland marine waters of Washington State inside of the entrance to the Strait of Juan de Fuca and including Georgia Strait south of the Canadian border (Shipman 2008).
Puget Sound Basin	Term used to mean the entire Puget Sound Nearshore General Investigation study area and all seven of its sub-basins. Used in tables and figures to describe Puget Sound-wide conditions, rather than sub-basin conditions.

sediment input	(This is one of the eleven broad physiographic nearshore processes investigated in the Strategic Needs Assessment; these are discussed in Section 2.3 of this report). Delivery of sediment from bluff, stream, and marine sources into the nearshore; depending on landscape setting, inputs can vary in scale from acute, low-frequency episodes (hillslope mass wasting from bluffs) to chronic, high-frequency events (some streams and rivers). Sediment input interacts with sediment transport to control the structure of beaches.
sediment transport	(This is one of the eleven broad physiographic nearshore processes investigated in the Strategic Needs Assessment; these are discussed in Section 2.3 of this report). Bedload and suspended transport of sediments and other matter by water and wind along (longshore) and across (cross-shore) the shoreline. The continuity of sediment transport strongly influences the longshore structure of beaches.
shoreform	A term often used in Puget Sound to describe a coastal landform. The term is generally used to describe landscape features on the scale of hundreds to thousands of meters in scale, such as coastal bluffs, estuaries, barrier beaches, or river deltas.
solar incidence	(This is one of the eleven broad physiographic nearshore processes investigated in the Strategic Needs Assessment; these are discussed in Section 2.3 of this report). Exposure, absorption, and reflectance of solar radiation (e.g., radiant light and heat) and resulting effects. Solar incidence controls photosynthesis rates and temperature patterns in the nearshore.

tidal channel formation and maintenance	(This is one of the eleven broad physiographic nearshore processes investigated in the Strategic Needs Assessment; these are discussed in Section 2.3 of this report). Geomorphic processes, primarily tidally driven, that form and maintain tidal channel geometry. Natural levee formation.
tidal delta	Accumulations of sand and gravel deposited inside or outside of tidal inlets when tidal currents slow. Flood tide and ebb tidal deltas can be distinguished and are commonly associated with barrier lagoons and estuaries (Shipman 2008).
tidal flow	(This is one of the eleven broad physiographic nearshore processes investigated in the Strategic Needs Assessment; these are discussed in Section 2.3 of this report). Localized tidal effects on water elevation and currents, differing significantly from regional tidal regime mostly in tidal freshwater and estuarine ecosystems.
tidal prism	The change in the volume of water that flows into a tidal area between a low tide and the subsequent high tide.
Valued Ecosystem Component (VEC)	Elements (i.e. flora, fauna, landscapes) of Puget Sound that are considered the most important and easy to understand examples of ecosystem goods and services valued by society. Improved conditions for VECs exemplify the benefits that restoration aims to achieve (Leschine and Petersen 2007). See http://www.pugetsoundnearshore.org/technical_reports.htm

EXECUTIVE SUMMARY

This report describes the approach, analytical framework, and findings of the Strategic Needs Assessment conducted by the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP). PSNERP is a General Investigation Study co-led by the Seattle District U.S. Army Corps of Engineers (Corps) and the Washington Department of Fish and Wildlife (WDFW). The PSNERP General Investigation is a large-scale, comprehensive initiative to protect and restore the natural processes and functions in the nearshore environments of Puget Sound. The study area extends along nearly 4,000 kilometers of shoreline and the associated 36,000 square kilometers of drainage area in Puget Sound, the Strait of Juan de Fuca, and southern portions of the Strait of Georgia. PSNERP defines the nearshore as the area that extends from the top of shoreline bluffs or upstream in estuaries to the head of tidal influence waterward to the deepest extent of the photic zone.

The primary goals of this report are to characterize the impacts of shoreline and watershed alterations on nearshore ecosystem processes, identify the major problems contributing to the observed ecosystem degradation, and assess which of the causes most need to be addressed through restoration and protection actions. This report will inform the PSNERP Feasibility Study, which will describe solutions to identified nearshore problems.

This Strategic Needs Assessment evaluates the implications of extensive anthropogenic alterations on the nearshore ecosystem processes that create and sustain the nearshore ecosystems of Puget Sound by documenting the linkages between nearshore ecosystem processes and the anthropogenic alterations (stressors) acting upon them. A spatially explicit evaluation framework (Framework) was created and applied to characterize the extent to which the observed distribution of stressors has degraded each of the 11 nearshore ecosystem processes evaluated. The outputs of the Framework and additional information on the distribution of intact shoreforms were interpreted to investigate broader landscape-scale conditions throughout the study area. This information on degradation of ecosystem processes, as well as the distributions of stressors presented in this report and in the Change Analysis (Simenstad et al. 2011), was used to identify major problems in Puget Sound and identify recommended restoration and protection priorities.

The assessment documents the pervasiveness of human alterations throughout the PSNERP General Investigation study area and the widespread degradation of the nearshore processes that create and sustain the Puget Sound ecosystem. The findings were distilled to identify the six major changes to the physical characteristics of the nearshore ecosystems of Puget Sound. These changes were grouped into two broad categories: 1) major physical changes to the nearshore ecosystems of Puget Sound; and 2) major types of cumulative impacts.

Four of the six major findings are grouped in the category of major physical changes to nearshore ecosystems:

1. Large river deltas have been widely impacted by multiple alterations that significantly limit the size of the river estuaries and degrade the nearshore ecosystem processes they support.
2. Many coastal embayments, including open coastal inlets, barrier estuaries, barrier lagoons, and closed lagoons/marshes, have been eliminated or disconnected from Puget Sound by the placement of fill, tidal barriers, and other stressors.
3. Impacts to beaches and bluffs have disconnected sediment inputs and altered sediment transport and accretion for long sections of the Puget Sound shoreline.
4. Estuarine wetlands have been extensively lost throughout Puget Sound.

Two of the six major findings are categorized as major types of cumulative impacts:

5. The shoreline of Puget Sound has become much shorter and simpler, as well as more artificial.
6. Large portions of Puget Sound have been altered by multiple types of changes that may cumulatively combine to severely degrade nearshore ecosystem processes.

These major findings are discussed in more detail in Fresh et al. (2011). The findings of the Strategic Needs Assessment and Change Analysis, including the problem statement already described, can be used to further advance the strategies for process-based restoration. For the purposes of this report, the term “restoration” is used in a broad sense that encompasses the restoration, rehabilitation, and substitution actions that bring about process restoration to various degrees as described in Fresh et al. (2004). The following four restoration priorities are recommended (in no particular order):

- Restore the connectivity and size of large river deltas. The 16 large river deltas distributed throughout Puget Sound are vital contributors to the overall health of Puget Sound ecosystems. Many of these large river deltas have been altered by multiple stressors that greatly impact nearshore ecosystem processes. Restoration actions to reconnect the historic delta areas that have been converted to upland, re-establish tidal wetlands, and remove tidal barriers, roads, and railroads would be particularly beneficial in large river deltas.
- Restore sediment input, sediment transport, and sediment accretion processes. The nearshore ecosystem processes of sediment input, transport, and accretion provide vital support for many of the unique and important characteristics of Puget Sound. There is a widespread need for the restoration of this type of sediment movement throughout Puget Sound. The benefits of restoring these processes extend far beyond the site of restoration (Johannessen and MacLennan 2007), and the shoreline improvements will also benefit several other processes.
- Restore embayments to increase distribution, shoreline complexity, and length. Embayments are significant landscape features contributing to the complexity and heterogeneity of the Puget Sound shoreline. Embayments also contribute significantly to nearshore ecosystem processes and provide important shallow water and tidal wetland habitats. Restoration of embayments is needed to restore embayments at sites where they have been eliminated by fill and other stressors. Restoration of embayments is also needed to recover the historic footprint (size and shape) and associated functions of embayments.
- Enhance landscape heterogeneity and ecological connectivity. Restoration of habitat diversity and ecological connectivity along shorelines can improve multiple nearshore ecosystem processes and address landscape principles that, when applied, contribute to more successful ecosystem restoration. In this recommendation, ecological connectivity refers to the natural, uninterrupted shoreform sequences along the shoreline, including the sequence of bluff-backed beaches to barrier beaches and then embayment shoreforms.

A natural starting point for protection strategies is to conserve those processes and shoreforms identified in the restoration priorities that are relatively intact (i.e., conserve healthy deltas, shorelines with intact sediment movement processes, and embayments).

Successful ecosystem restoration will require stopping the loss of relatively intact areas through protection actions; three protection priorities that merit highlighting include:

- Conserve relatively intact large river delta areas. An important aspect of ecosystem restoration will be to prevent degradation of those large river deltas or portions of large river deltas that are relatively intact.
- Conserve intact or minimally degraded sediment input, sediment transport, and sediment accretion processes. With the extensive placement of armoring and other stressors affecting how well bluffs feed sediment to beaches, protection of intact or minimally degraded bluff-backed beaches is critical. These shoreforms, particularly those positioned in divergence zones or near the updrift end of drift cells, provide the sediment inputs that drive the sediment transport and sediment accretion processes over extended stretches of shoreline far beyond the sediment input areas.
- Conserve relatively intact embayment shoreforms. Embayment shoreforms range in size from river deltas slightly smaller than the 16 delineated delta process units to small barrier lagoons, closed lagoons/marshes, and all intermediate sizes of inlets and coves, which are classified as some combination of barrier estuaries and open coastal inlets. These shoreforms support nearshore ecosystem processes, unique habitat conditions such as pocket estuaries, and a wide diversity of biological resources, including numerous Valued Ecosystem Components (VECs).

1 INTRODUCTION

The U.S. Army Corps of Engineers (Corps), operating as the federal lead, and Washington Department of Fish and Wildlife (WDFW) and Puget Sound Partnership, operating jointly as the local lead, co-lead an ecosystem study of Puget Sound called the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP). PSNERP was initiated by the Corps as a General Investigation Study for the purpose of establishing a partnership between the federal government and local sponsors to investigate water resource problems and opportunities in Puget Sound. The PSNERP General Investigation is a large-scale, comprehensive initiative to protect and restore the natural processes and functions in the nearshore environment. The product of the General Investigation is a Feasibility Study report that formulates, evaluates, and screens potential solutions to identified problems; analyzes what the future might be like without the project; and recommends a series of solutions (protection and restoration actions) to the identified problems. The Feasibility Study report will be presented to Congress in order to obtain ecosystem restoration authority with significant federal funding to support the needed actions identified in the report.

This Strategic Needs Assessment represents one of the key building blocks of the Feasibility Study report (Figure 1-1). This report builds on the preceding steps and work products of the PSNERP program, particularly the *Historical Change and Impairment of Puget Sound Shorelines* (Simenstad et al. 2011), herein referred to as the Change Analysis, the *Principles for Strategic Protection and Restoration* (Greiner 2010), and the Valued Ecosystem Component (VEC) technical papers. These contributing work products are described in more detail in later sections of this report.

The primary goals of this Strategic Needs Assessment are to characterize the impacts of alterations to shorelines and watersheds on nearshore ecosystem processes, identify the major problems contributing to the observed degradation of ecosystems, and assess which of the causes most need to be addressed through restoration and protection actions that will be proposed in the Feasibility Study report. This effort is unique in that it is a focused assessment of the ecosystem processes and the physical problems that underlie ecosystem degradation, rather than an assessment of the symptoms of ecosystem degradation such as species-specific population declines or lost habitat.

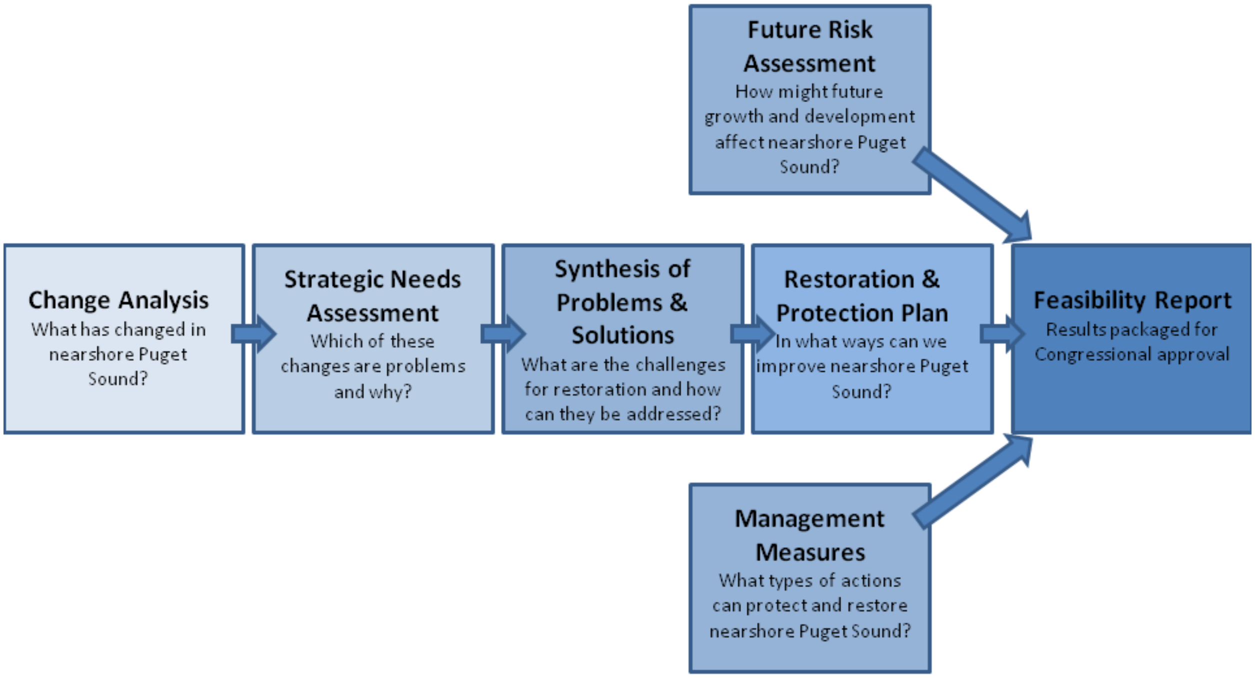

Figure 1-1

Relationship of Strategic Needs Assessment to Other Components of PSNERP Process to Plan Restoration and Protection Strategies for Puget Sound Nearshore Ecosystems

The specific objectives of this Strategic Needs Assessment are to:

- Explain the impacts of physical stressors (human alterations) on the nearshore processes that create and sustain ecosystems along shorelines and in watersheds. Also explain the resulting effects of the impacted nearshore processes on nearshore habitat structure and functions.
- Present a spatial analysis that applies a set of rules or principles for assessing degradation of nearshore ecosystem processes resulting from physical stressors along the shoreline and throughout the watershed. This tool is to be used in subsequent steps leading up to the Feasibility Study report.
- Using the spatial analysis outputs, identify and characterize the locations and magnitudes of degradation of nearshore ecosystem processes at multiple scales: for process units, for sub-basins, and Sound-wide.
- Present a discussion of the major physical changes and problems affecting the overall functioning of Puget Sound nearshore ecosystems.
- Identify restoration and protection needs and recommended priority locations for potential protection actions.

This Strategic Needs Assessment identifies how the changes to the Puget Sound nearshore have impacted nearshore processes and the main problems caused by the changes. The findings and recommendations presented in this Strategic Needs Assessment will be used in the next steps of the PSNERP program to support the identification and evaluation of comprehensive restoration and protection alternatives to be included in the Feasibility Study. In addition, the findings and recommendations will be used by PSNERP to identify specific projects contributing to the comprehensive alternatives. It is further anticipated that this Strategic Needs Assessment will be used as a tool by restoration planners and practitioners working in the watersheds around Puget Sound.

2 BUILDING BLOCKS FROM PRECEDING PSNERP PRODUCTS

2.1 Geographic Scope

The PSNERP General Investigation study area includes the entirety of Puget Sound, the Strait of Juan de Fuca, and southern portions of the Strait of Georgia that occur within the borders of the United States. This study area was divided into seven sub-basins for analysis and reporting (Figure 2-1). As shown on the figure, there are small areas of overlap among some of the sub-basins due to process unit mapping rules explained in Section 2.4. The shoreline length and drainage area contained in each sub-basin is presented in Table 2-1.

Within the study area, PSNERP confined its focus of restoration and protection to nearshore ecosystems, defined to occur within estuarine delta or marine shoreline areas; beaches and areas of shallow water from the top of the coastal bank or bluffs; and tidal waters from the head of tide to a depth of approximately 10 meters (m) relative to mean lower low water (MLLW) (Figure 2-2). By definition, this includes the entire marine and estuarine shoreline within the study area as a contiguous band of diverse ecosystems shaped by coastal geomorphology and local environmental conditions, such as wave energy and salinity. While the focus of restoration and protection is in the nearshore ecosystems, many of the processes creating and sustaining these areas are influenced by conditions throughout the watershed. Therefore, the scope of the analysis extends to the headwaters of the watersheds comprising the PSNERP General Investigation study area.

Figure 2-1

PSNERP General Investigation Study Area with Delineated Sub-Basins

Table 2-1

Shoreline Length and Drainage Areas in the Puget Sound Basin and its Sub-basins

Basin/Sub-basin	Total Length (km)	Total Watershed Area (km^2)
Strait of Juan de Fuca	329	3,231
San Juan Islands - Strait of Georgia	1,187	4,176
Hood Canal	395	2,790
Whidbey	634	14,687
North Central Puget Sound	249	502
South Central Puget Sound	648	6,459
South Puget Sound	725	4,610
Puget Sound Basin	3,969	36,080

Note: The organization of spatial data in the PSNERP database intentionally includes areas of overlap; therefore, the sum of shoreline lengths and watershed areas among sub-basins does not equal the number calculated for the entire Puget Sound Basin The rationale for overlap is described in Section 2.4.

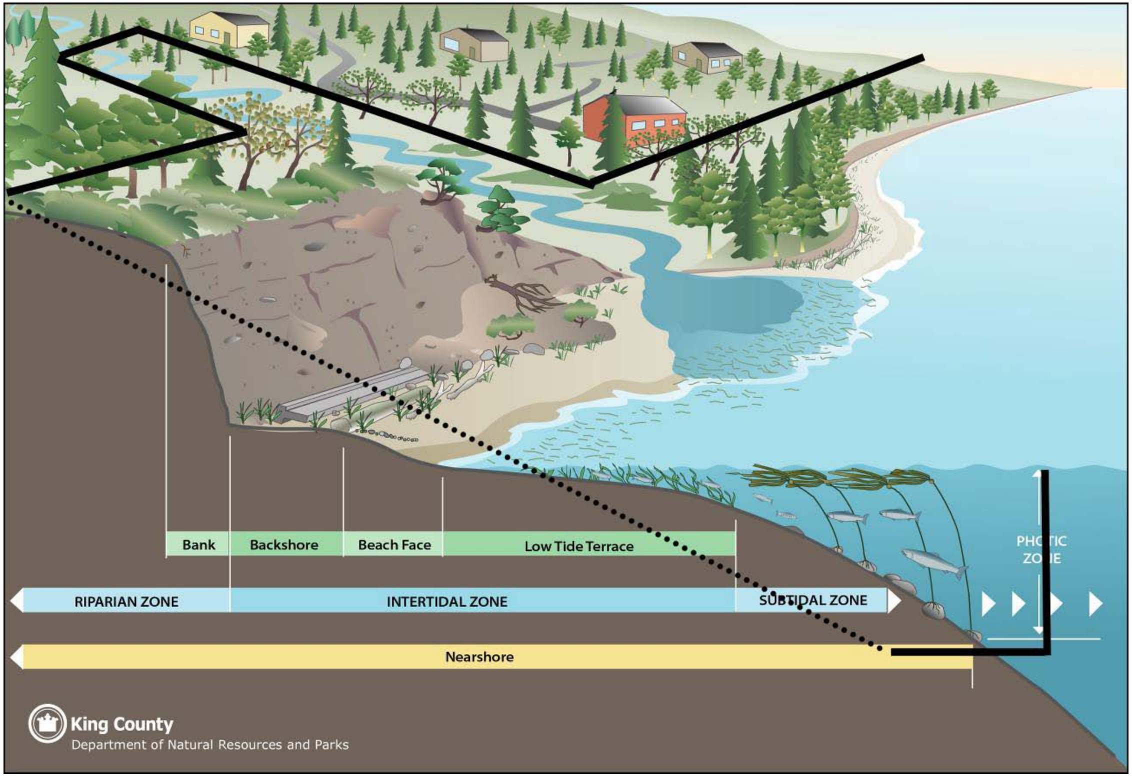

Figure 2-2

Boundaries of Nearshore Ecosystems between Riparian and Subtidal Zones

(Source: King County Department of Natural Resources and Parks)

2.2 PSNERP Analysis Approach and Strategy

Under the guidance of the project's Nearshore Science Team (NST), PSNERP has focused its approach to:

- Concentrate on shallow-water, marine, and estuarine nearshore ecosystems
- Emphasize the (predominantly physical) ecological processes that create and sustain natural ecosystems
- Include both restoration and protection strategies

The emphasis on protecting and restoring the underlying ecological processes that form nearshore ecosystems, rather than attempting to modify habitat structure to benefit a few target species, provides the essential foundation for protecting and restoring sustainable ecosystems. The scientific and technical basis for this approach is documented in PSNERP guidance documents (e.g., Fresh et al. 2004; Goetz et al. 2004; Finlayson 2006; Simenstad et al. 2006) and reflects much of the emerging scientific discussion about the need to integrate understanding of ecosystem process into protection and restoration planning (Noss 1996; Leslie 2005). For all PSNERP guidance documentation, see www.pugetsoundnearshore.org. The program chose not to assess water or sediment quality problems (e.g., effects of toxins) because these are the specific focus of other programs.

2.3 Nearshore Ecosystem Processes

The analysis of restoration and protection needs rests on linking changes in nearshore ecosystem processes (nearshore processes) to physical, structural changes of the shore and the resulting impairment of ecosystem function. Ecosystem processes are interactions among physical, chemical, and biological attributes of an ecosystem that lead to an outcome of change in character of the ecosystem and its components (i.e., changes in ecosystem state).

The nearshore processes that influence the marine and estuarine shorelines of Puget Sound occur and vary over diverse spatial and temporal scales. These nearshore processes are classified into three general scales of influence on nearshore ecosystems: regional influences, broad physiographic processes, and local geochemical and ecological processes. The large-scale, long-term regional influences form the backdrop for the broad physiographic processes, within which occur even more local, fine-scale geochemical and ecological processes. *Regional influences* include factors such as climate, wave exposure, geology, inherited physiography, sea level history, and tidal regime. *Broad physiographic processes* are landscape-forming processes, which are embedded within regional influences and vary considerably on scales of kilometers or fractions thereof. Examples of broad physiographic processes include sediment input to beaches and distributary channel formation. The *local geochemical and ecological processes* that occur within a given landscape structure and vary within the local structure of nearshore ecosystems are shaped by the combined effect of the regional influences and broad physiographic processes. They vary on the order of meters, within the local structure of nearshore ecosystems, and thus are spatially and temporally complex. Examples of local geochemical and ecological processes include geochemical reactions that lead to nutrient cycling, primary production of plants, and food web interactions.

The PSNERP assessment of nearshore ecosystem conditions tends to focus on the broad physiographic processes because they are responsible for creation and maintenance of the shoreforms and energy regimes that characterize Puget Sound's shorelines. The broad physiographic processes that were identified by the PSNERP NST as being most important to the creation, maintenance, and function of Puget Sound's shoreline ecosystems are listed in Table 2-2 (from Simenstad et al. 2011).

2.4 Data Organization

The analytical template underlying the PSNERP Change Analysis and this Strategic Needs Assessment relies on the spatial arrangement of ecosystem processes along Puget Sound's beaches, estuaries, and river deltas. To support spatially-explicit accounting of nearshore conditions, the Puget Sound shoreline was divided into geomorphic segments (shoreforms) based on the PSNERP *Geomorphic Classification* (Shipman 2008; Table 2-3). This geomorphic classification provided the basis for classifying both historic and current shoreforms that reflect the dominant controlling factors of: 1) shoreline sedimentation processes and 2) estuarine/deltaic freshwater inflow and tidal mixing processes.

In delineating the shoreforms along the shoreline, there is a need for an additional shoreform category to describe those areas where human alterations have completely changed the shape

Table 2-2

Nearshore Ecosystem Processes that are the Focus of PSNERP Analyses

Nearshore Ecosystem Process	Process Description
Sediment Input	• Delivery of sediment from bluff, stream, and marine sources into the nearshore; depending on landscape setting, inputs can vary in scale from acute, low-frequency episodes (hillslope mass wasting from bluffs) to chronic, high-frequency events (some streams and rivers). Sediment input interacts with sediment transport to control the structure of beaches.
Sediment Transport	• Bedload and suspended transport of sediments and other matter by water and wind along (longshore) and across (cross-shore) the shoreline. The continuity of sediment transport strongly influences the longshore structure of beaches.
Erosion and Accretion of Sediments	• Deposition (dune formation, delta building) of non-suspended (e.g., bedload) sediments and mineral particulate material by water, wind, and other forces. • Settling (accretion) of suspended sediments and organic matter on marsh and other intertidal wetland surfaces. These processes are responsible for creation and maintenance of barrier beaches (e.g., spits) and tidal wetlands.
Tidal Flow	• Localized tidal effects on water elevation and currents, differing significantly from regional tidal regime mostly in tidal freshwater and estuarine ecosystems.
Distributary Channel Migration	• Change of distributary channel form and location caused by combined freshwater and tidal flow. Distributary channel migration affects the distribution of alluvial material across a river delta.
Tidal Channel Formation and Maintenance	• Geomorphic processes, primarily tidally driven, that form and maintain tidal channel geometry. • Natural levee formation.
Freshwater Input	• Freshwater inflow from surface (stream flow) or groundwater (seepage) in terms of seasonal and event hydrography. Freshwater input affects the pattern of salinity and sediment and soil moisture content across the nearshore.
Detritus Import and Export	• Import and deposition of particulate (dead) organic matter. • Soil formation. • Recruitment, disturbance, and export of large wood.
Exchange of Aquatic Organisms	• Organism transport and movement driven predominantly by water (tidal, fluvial) movement.
Physical Disturbance	• Change of shoreline shape or character caused by exposure to local wind and wave energy input. • Localized and chronic disturbance of biotic assemblages caused by large wood movement, scour, and overwash.
Solar Incidence	• Exposure, absorption, and reflectance of solar radiation (e.g., radiant light and heat) and resulting effects. Solar incidence controls photosynthesis rates and temperature patterns in the nearshore.

and location of the shoreline. These areas are classified as "artificial" shoreforms. The delineation of artificial shoreforms is not based on habitat functions; rather, it is based on the extent of obvious modification, such as dredging and fill, to such a degree that the shoreline structure no longer reflects natural geomorphic processes. The methods used to delineate shoreforms and photographic examples of each shoreform type are presented in the *Geospatial Methodology* (Anchor QEA 2009). The geomorphic systems and components of the shoreforms as they have been delineated in Puget Sound are outlined in Table 2-3.

The Puget Sound geomorphic shoreforms are one of the primary units in a geospatial data structure that is organized into four related geographic scale units:

1. Shoreforms
2. Shoreline drainage units
3. Process units (drift cell or delta hydrogeomorphic components)
4. Various larger ("user defined") scales of shoreline-delta organization, such as political boundaries, large embayments, or sub-basins of Puget Sound

Because of the PSNERP emphasis on addressing change in nearshore ecosystem processes, the spatial data were organized based on two prominent processes that structure Puget Sound nearshore ecosystems: littoral sediment drift along the shoreline and tidal hydrology and mixing with fluvial inflow in large estuaries and deltas (Simenstad et al. 2011). Spatial data were organized into two types of "process units." The first type of process unit was *shoreline process units* (SPUs), which were areas dominated by shoreline marine processes, such as waves and tides. Each SPU contained a single littoral sediment drift cell that considered the "compartmentalization" of sediment delivery, transport, and deposition along the shoreline (Simenstad et al. 2011). The drift cell unit was typically composed of a sediment transport zone and adjacent divergence and convergence zones, and could include areas of no appreciable drift. SPUs included all upland area draining into the shoreline and extended out from shore to the 10-m depth contour. Throughout the PSNERP General Investigation study area, there were 812 SPUs. Two adjacent drift cells (and SPUs) often shared a common sediment source in a divergence zone and shared a sediment deposition area in a convergence zone.

Table 2-3
Geomorphic Systems and Components of Nearshore Shoreforms Delineated in Puget Sound[a]

Systems	Shoreforms	Components
Beaches Shorelines consisting of loose sediment and under the influence of wave action	*Bluffs:* Formed by landward retreat of the shoreline	Bluff face Backshore Beach face Low tide terrace
	Barriers: Formed where sediment accumulates seaward of earlier shoreline	Backshore Beach face Low tide terrace
Rocky coast Resistant bedrock with limited upland erosion	*Plunging:* Rocky shores with no erosion/deposition and no erosional bench or platform	Cliff/slope
	Platforms: Wave-eroded platform/ramp, but no beach	Cliff Ramp/platform
	Pocket beaches: Isolated beaches contained by rocky headlands	Cliff Backshore Beachface Low tide terrace
Embayments Protected from wave action by small size and sheltered configuration	*Open coastal inlets:* Small inlets protected from wave action by their small size or shape, but not significantly enclosed by a barrier beach	Stream delta Tide flats Salt marsh Channels
	Barrier estuaries: Tidal inlet largely isolated by a barrier beach and with a significant input of freshwater from a stream or upland drainage	Stream delta Tide flats Salt marsh Channels Tidal delta
	Barrier lagoons: Tidal inlet largely isolated by a barrier beach and with no significant input of freshwater	Tide flats Salt marsh Channels Tidal delta
	Closed lagoons and marshes: Back-barrier wetlands with no surface connection to Puget Sound	Salt marsh Pond or lake
Large river deltas[b] Long-term deposition of fluvial sediment at river mouths	*River-dominated deltas* *Wave-dominated deltas* *Tide-dominated deltas* *Fan deltas*	Alluvial floodplain Tidal floodplain Salt marsh Tide flats Subtidal flats Distributary channels Tidal channels
All	*Artificial*	Not applicable

Notes:
a) Table from Shipman 2008, modified to include artificial shoreforms
b) The large river deltas were not delineated to shoreform. Instead, they were only delineated to the system scale.

The second type of process unit was *delta process units* (DPUs), which were delineated in large river deltas. The PSNERP NST defined large river deltas as those identified as Fifth Level Hydrologic Code Units; there were 16 of these in the PSNERP General Investigation study area. A map showing the location and shoreline extent of the 16 DPUs is presented in Figure 2-3. (The large river deltas delineated as DPUs and the abbreviations used in report figures are listed in the legend provided after the Table of Contents.)

The delineation of geographic scale units included overlap between SPUs and DPUs. SPUs typically overlapped with each other at drift cell divergence or convergence zones. The reason for overlap in divergence zones was that sediment sources in divergence zones contribute sediment to the drift cells on either side. Similarly, convergence zones were overlap areas among adjacent SPUs because sediment from both drift cells is deposited in the zone. In the example presented in Figure 2-4, the divergence zone shared between SPU 4018 and SPU 4019 is show in pink lines. In blue lines are the convergence zones between SPU 4018 and the adjacent SPU 4017, as well as between SPU 4019 and the adjacent SPU 4020. The portions of SPU 4018 and SPU 4019 that were not shared (i.e., sediment transport zone) are shaded green. SPUs and DPUs often overlapped at the outer margins of large river deltas where shoreline and river processes interact. The zones of overlap for SPUs and DPUs were along the margin of the river delta where directional sediment drift was also mapped (i.e., not a no appreciable drift area). The *Geospatial Methodology* (Anchor QEA 2009) describes the SPU and DPU delineations and explains the areas of overlap in more detail. Maps of SPUs and DPUs are provided as Appendix A to this report.

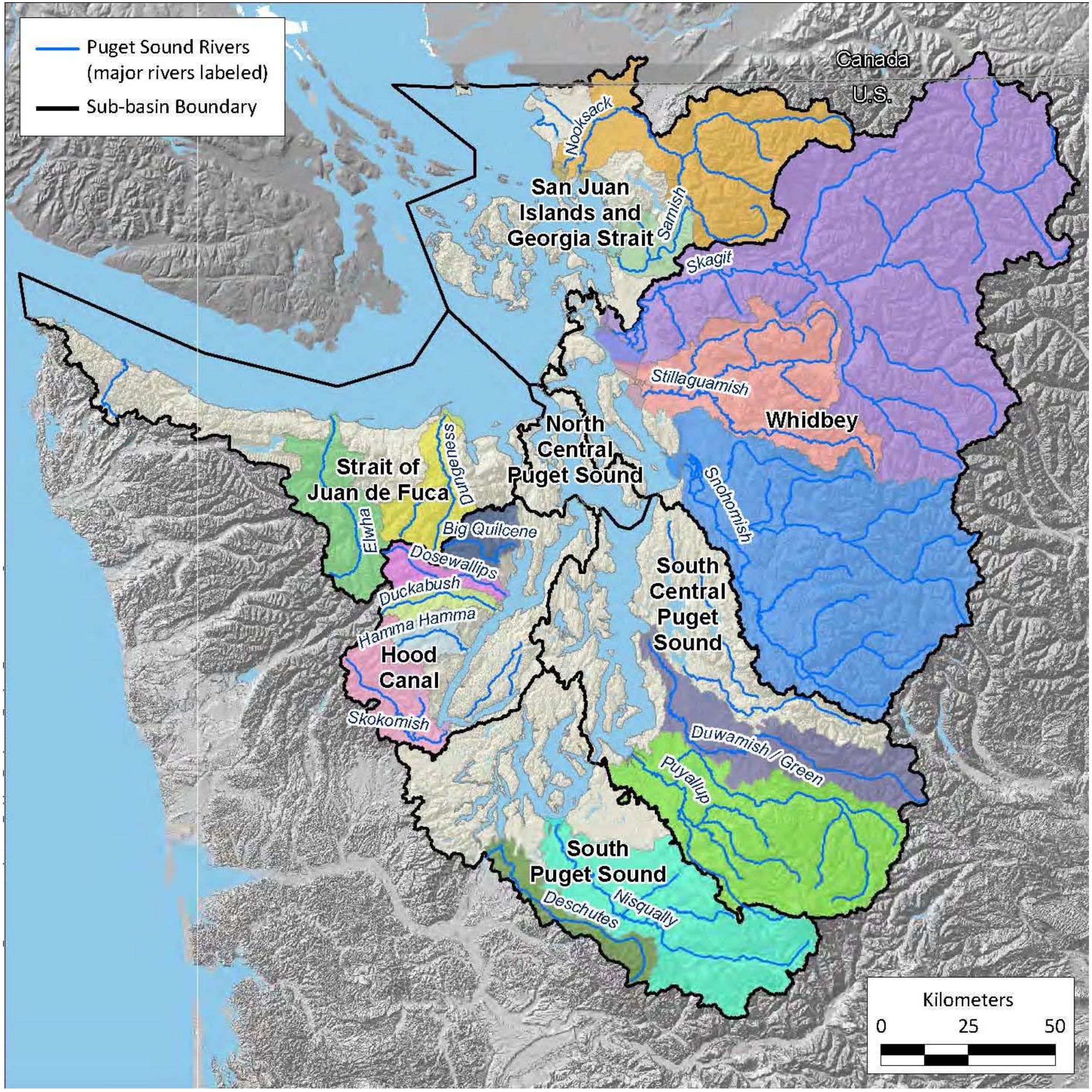

Figure 2-3

River Courses and Associated Watershed of the 16 Delta Process Units in Puget Sound

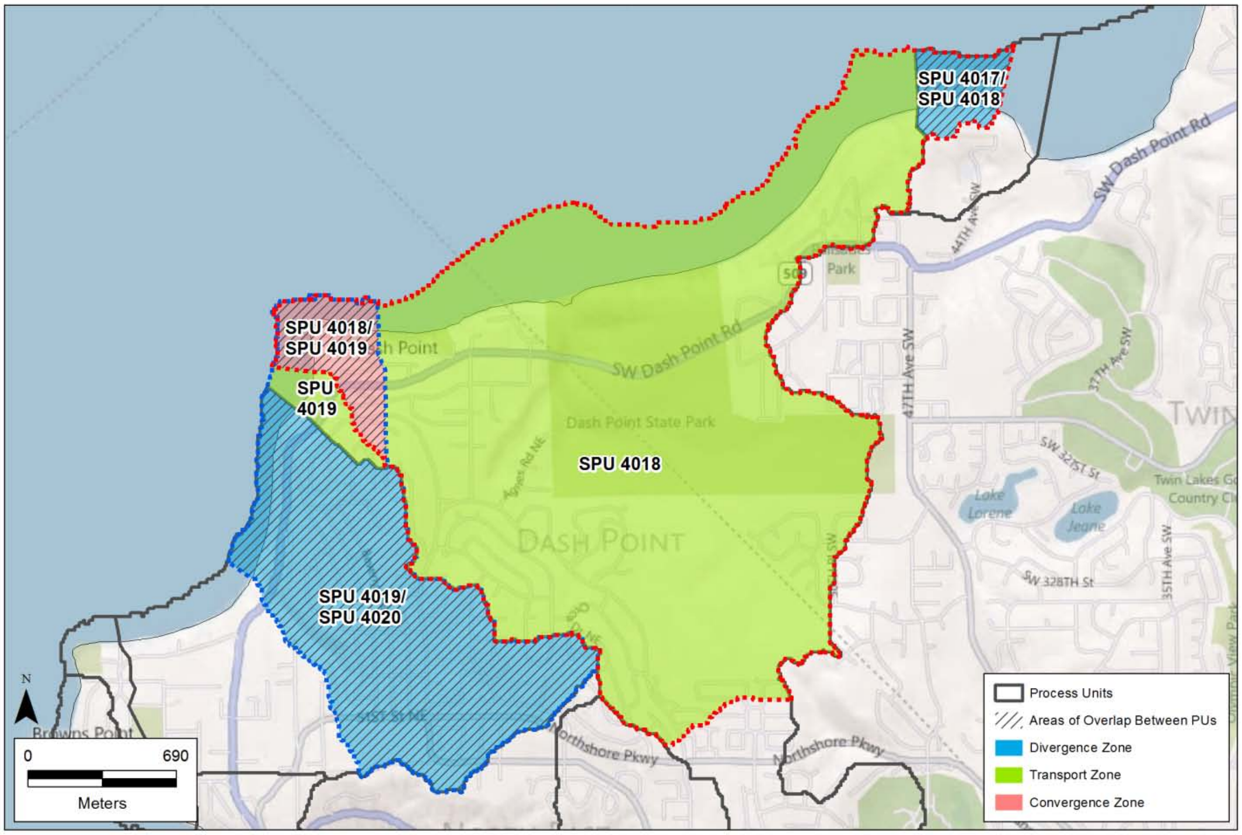

Figure 2-4

Example of Spatial Overlap between Shoreline Process Units

Lengths and areas of SPUs and DPUs are shown by sub-basin in Table 2-4. Because the Puget Sound sub-basins were not delineated based on SPU or DPU boundaries, there were some SPUs that were shared between two sub-basins. As a result of the overlap, the sums of the individual sub-basin data do not equal the calculation at the Puget Sound basin scale (i.e., the Puget Sound basin sums do not double count areas of overlap). This affects length, area, and percent calculations.

Table 2-4

Summary Information on Shoreline Process Units and Delta Process Units in Puget Sound Basin and its Sub-basins

Basin/Sub-basin	Number of SPUs[a]	Number of DPUs	Percentage of Sub-basin Shoreline Length		Percentage of Sub-basin Drainage Area	
			% SPUs	% DPUs	% SPUs	% DPUs
Strait of Juan de Fuca	31	2	95%	5%	43%	57%
San Juan Islands - Strait of Georgia	182	2	94%	6%	60%	40%
Hood Canal	77	5	91%	9%	60%	40%
Whidbey	67	3	59%	41%	95%	5%
North Central Puget Sound	42	0	100%	0%	100%	0%
South Central Puget Sound	151	2	88%	12%	59%	41%
South Puget Sound	294	2	96%	4%	57%	43%
Puget Sound Basin	812	16	88%	12%	72%	28%

Note: a) SPUs overlap between sub-basins (i.e., one SPU can occur across two sub-basins); therefore, the sum of SPUs among sub-basins does not equal the number calculated for the entire Puget Sound Basin.

2.5 Describing and Interpreting Changes in Puget Sound

2.5.1 Summary of Change Analysis Approach

To identify what human-induced changes have occurred in the nearshore and where those changes have occurred, the PSNERP NST conducted an analysis of change in nearshore ecosystems (referred to as the Change Analysis, a separate report by Simenstad et al. 2011). Requirements for datasets used in this analysis were as follows:

1. Directly related to physical and ecological change in ecosystem-scale processes
2. Spatially explicit
3. Comprehensive, complete, and uniform resolution and quality over the entire Puget Sound Basin
4. Well documented
5. In GIS format, or readily convertible to GIS format

The criterion that datasets had to be available and consistent Sound-wide meant that more detailed, local datasets could not be used. However, the main advantage of this approach was that it became possible to consistently and rigorously compare all places in Puget Sound to one another.

To assemble appropriate data, PSNERP surveyed restoration planners and scientists to identify and review available datasets that would meet these criteria. Review of these datasets resulted in the decision to focus on changes that had occurred between two broad time periods: the advent of United States territorial settlement of the region (circa 1850 to 1880) and the present day (circa 2000 to 2009). Datasets meeting the above criteria were then compiled from a variety of sources to document shoreline composition, potential anthropogenic stressors, and land use in these two time periods. These data provided a basin-wide comparison of selected attributes that could have changed between the historic and current periods. Historic conditions in Puget Sound were generated from General Land Office topographic maps from the mid- to late 1800s. Data on current conditions came from many sources and included data on shoreline stressors, conditions adjacent to the shoreline, and watershed conditions. A description of the datasets used, the data sources, and the steps taken to prepare the data for use in the Change Analysis database is in Anchor QEA (2009).

Historic change was analyzed for each process unit in Puget Sound, as well as at the scale of each sub-basin and Sound-wide, in four categories, also referred to as "tiers" in this report:

1. Shoreform Transition: changes from one shoreform type to another
2. Shoreline Alterations: changes in historical attributes, such as wetland area, or presence of anthropogenic modifications (stressors), such as bulkheads or docks, along the shoreline
3. Adjacent Upland Change: anthropogenic changes, such as roads or land cover development, in the upland areas within 200 m of the shoreline
4. Watershed Change: anthropogenic changes, such as roads or land cover development, in the drainage area (this area overlaps with the Adjacent Upland Change area)

These categories and the attributes included in the Change Analysis database to characterize physical conditions in each category are shown in Figure 2-5.

Shoreform Transition (Tier 1)

- Historic shoreforms
- Current shoreforms

Shoreline Alterations (Tier 2)

- Loss/gain in intertidal wetlands
- Armoring
- Tidal barriers
- Breakwaters/jetties
- Overwater structures
- Nearshore fill
- Marinas
- Roads[1]
- Railroads active[1]
- Railroads abandoned[1]

Adjacent Upland Change (Tier 3)

- Roads
- Railroads active
- Railroads abandoned
- Land cover
- Impervious surface
- Stream crossings

Watershed Area Change (Tier 4)

- Roads
- Railroads active
- Railroads abandoned
- Land cover
- Impervious surface
- Stream crossings
- Impounded drainage area (behind dams)
- Current drainage extent based on historic drainage extent

Figure 2-5

Four Categories (Tiers) and Associated Attributes Used to Describe Nearshore Ecosystem Change by PSNERP

Note: 1) The Shoreline Alterations analysis includes only nearshore roads, nearshore railroads-active, and nearshore railroads-abandoned that occur within 25 m of the shoreline.

The anthropogenic changes documented in the Change Analysis provided the basis for assessing the effect of altered ecosystem processes on nearshore structure. In order to translate structural change to actual changes in nearshore ecosystem processes, the PSNERP NST used a conceptual model (Simenstad et al. 2006) and expert opinion to link the observed anthropogenic changes to likely degradation of biotic and abiotic nearshore ecosystem processes. To further describe the ecological, social, and cultural importance of changes in nearshore ecosystem structures and processes, the PSNERP NST generated an assessment of the relative levels of ecosystem functions, goods, and services (EFG&S) provided in all four categories and how those services were likely to have been degraded by the observed changes.

Based on recent applications for restoration and protection planning (Leslie and McLeod 2007; NAS 2007; Halpern et al. 2008), the PSNERP NST adopted the Millennium Ecosystem

Assessment's EFG&S (MEA 2005; WRI 2005) as a template for ranking the level of cumulative impairment of nearshore ecosystem processes among the SPUs and DPUs. Using a Delphi process (similar to that described in Linstone and Turoff 2002), the PSNERP NST ranked EFG&S according to changes at each category (tier) of change and generated aggregate maps scaled for each Puget Sound sub-basin as well as Sound-wide.

2.5.2 Update on Change Analysis Shoreform Transition Results

2.5.2.1 Changes Made to Shoreform Transition Analysis

As already described, the Change Analysis (Simenstad et al. 2011) presents results for four tiers of change. Many of the results of the Change Analysis are included in this Strategic Needs Assessment to support findings. The results of the Change Analysis will not be summarized here, except for the shoreform transition data, which were updated during the development of this report. The shoreform transitions were reviewed because initial investigation of the results revealed that some of the shoreform transitions were likely identified due to a mapping data source discrepancy rather than an actual transition. That is, some of the shoreform transitions appeared to be due to the different level of detail between historic and current datasets.

The review of shoreform transitions was conducted only on transitions to one of the 10 natural shoreform categories defined in Shipman (2008). Shoreform transitions to artificial shoreforms or "shoreform absent" were not reviewed. The characterization of transitions as "real," "mapping data source discrepancy," or "undetermined" was conducted by the Strategic Needs Assessment Team using the same data sources as were used in the current and historic shoreform delineations (Anchor QEA 2009), as well as using additional historic aerial photography available from the Washington State Department of Ecology's (WDOE's) Digital Coastal Atlas (http://www.ecy.wa.gov/programs/sea/SMA/atlas_home.html).

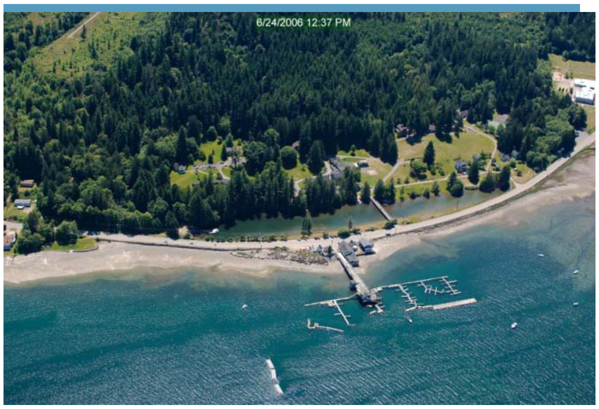

Photo 2-1
Example of shoreform transition where a historic barrier estuary has been disconnected by a road and associated armoring
(Photo courtesy of WDOE)

Shoreform transitions were attributed to mapping data source discrepancies if there was sufficient information to indicate missing mapping accuracy such as: 1) current embayments that appear natural but were not delineated on the historic shoreline; and 2) offshore shoreline features (e.g., rocky islands) that were not delineated in the historic shoreline mapping. Designating a shoreform transition as real does not imply that the transition is natural; the review of shoreform transitions did not evaluate whether transitions were natural or related to anthropogenic alterations.

Upon this closer review, many previously identified shoreform transitions appeared to be attributable to a mapping data source error rather than a real transition. Among the 126 shoreform transitions reviewed, only 54 were identified as real transitions (Table 2-5). Many of the shoreform transitions determined to be mapping data source errors were instances of small rocky formations or islands that were not included in the historic mapping of the shoreline. This discrepancy accounted for all 10 of the transitions from shoreform absent to plunging rocky shoreline and all 40 of the transitions from shoreform absent to rocky platform. Another common mapping data error was caused by the current shoreline not accurately extending into small embayments and instead continuing straight across the opening of the embayment. Another common mapping data error was caused by the current shoreline continuing straight across the opening of small embayments instead of extending into the embayment. In these cases, current embayments were mapped only when wetlands were present in the Puget Sound River History Project polygon dataset (see Anchor QEA 2009 for description of dataset). The mapping errors resulted if both the current shoreline and River History Projects datasets did not include embayment wetlands identified in the historical data.

2.5.2.2 Updated Summary of Historic and Current Shoreform Distributions

The historic and current counts of each shoreform type are presented in Figure 2-6. Rocky platform and pocket beaches are the most numerous shoreform types. The number of pocket beaches is nearly identical between historic and current conditions, but the number of rocky platform shoreform segments is higher in the current mapping. This is due to the more detailed mapping of small outcroppings and islands, particularly in the Strait of Juan de Fuca sub-basin. The next most abundant shoreforms are the two beach shoreform types: bluff-backed beaches and barrier beaches. Both beach shoreform types have slightly lower numbers currently than were mapped in the historic conditions analysis. The abundance of the four embayment shoreform types (barrier estuaries, barrier lagoons, closed lagoons/marshes, and open coastal inlets), are much lower than the rocky and beach shoreform types. In each of the 4 embayment shoreform types, the current number of occurrences has decreased markedly from historic counts. Overall among all 4 shoreform types, there are 35% fewer embayment shoreforms currently compared to historically. Additional information on the differences in historic and current distributions of embayments is provided in the report section describing embayments as an additional ecosystem component of value (Section 2.6.2.1). The number of artificial shoreforms[1] has increased significantly since historic conditions when there were already 13 artificial shoreform reaches. There are currently more than 300 artificial shoreforms in the Puget Sound General Investigation study area.

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[1] Artificial shoreforms are mapped in those areas where the shoreline modifications have been so extensive that the shoreline no longer resembles any of the natural shoreform types.

Table 2-5

Shoreform Transition Matrix Showing Original Change Analysis Results and Revised Results When Transitions Apparently Due to Mapping Data Source Discrepancy are Removed

(Revised results in parentheses; blank cells mean no shoreform transitions)

Historic Shoreform	Current Shoreform											
	Bluff-backed Beach	Barrier Beach	Barrier Estuary	Barrier Lagoon	Closed Lagoon /Marsh	Open Coastal Inlet	Pocket Beach	Plunging Rocky Shoreline	Rocky Platform	Delta	Artificial[a]	Shoreform Absent[a]
Bluff-backed Beach		14 (12)	2 (2)	1 (1)							124	
Barrier Beach	10 (4)		1 (0)	1 (1)							82	
Barrier Estuary				2 (1)	2 (7)						21	63
Barrier Lagoon					10 (7)						16	73
Closed Lagoon/ Marsh				1 (1)							5	163
Open Coastal Inlet			13 (13)								53	
Pocket Beach											5	
Plunging Rocky Shoreline											2	
Rocky Platform				1 (1)							21	
Delta											8	
Artificial		1 (1)									0	
Shoreform Absent				7 (4)	10 (4)			10 (0)	40 (0)		29	

Notes:

a) Shoreform transitions to artificial or shoreform absent were not reviewed for data source discrepancy.

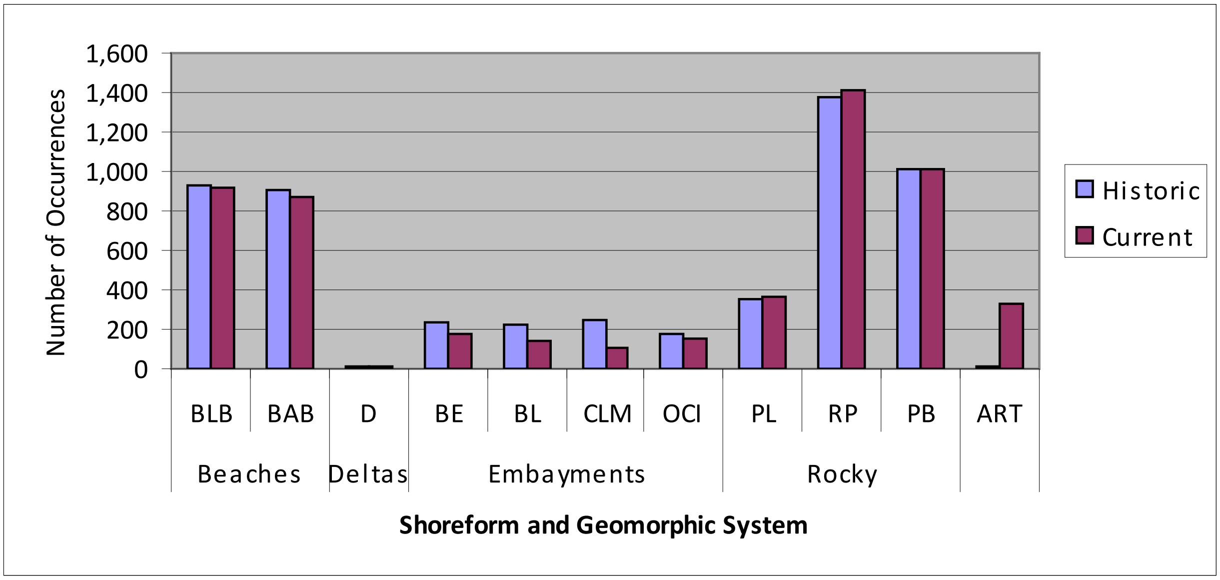


Figure 2-6

Historic and Current Counts of Each Shoreform Type

The historic and current lengths of each shoreform type are presented in Figure 2-7. Bluff-backed beaches comprise the longest lengths, as the shoreform comprised 2.5 to 3 times as much length as the next highest shoreform type. All of the natural shoreform types have decreased in length compared to historic conditions. In contrast, artificial shoreforms now comprise nearly 400 km of shoreline.

2.6 Valued Ecosystem Components

As the term suggests, Valued Ecosystem Components (VECs) refer to ecosystem components that have “value.” As described in Leschine and Petersen (2007), the types of values provided by the ecosystem components can be wide ranging and include ecological, economic, cultural, spiritual, and aesthetic values. The authors report that VECs are being applied increasingly in environmental management as they are frequently intertwined with ecosystem services.

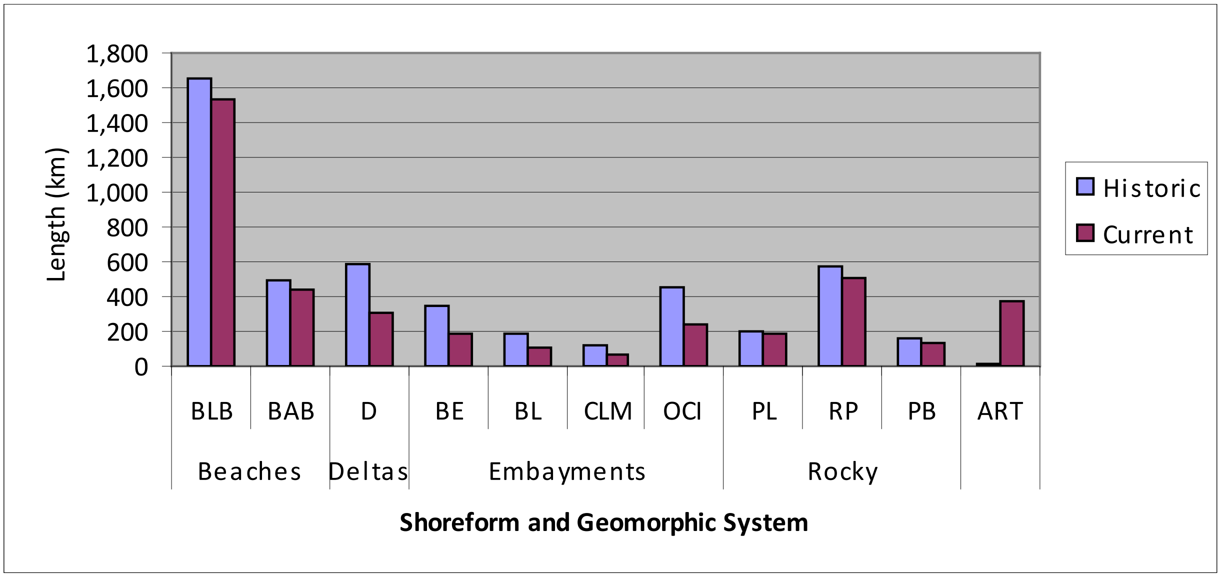


Figure 2-7
Historic and Current Lengths of Each Shoreform Type

2.6.1 PSNERP VECs

PSNERP identified a suite of VECs primarily to communicate the value of Puget Sound nearshore restoration to managers and the public (Leschine and Petersen 2007); they are a subset of a broader array of Puget Sound ecosystem components or biological communities that have value. The selected PNSERP VECs were intended to represent ecological and societal values and are considered among the most important, but not the only, potential beneficiaries of envisioned restoration actions (Leschine and Petersen 2007).

PSNERP identified VECs that share the three characteristics described by Leschine and Petersen (2007). First, each is judged likely to be enhanced by nearshore restoration. Second, each VEC has direct or indirect value to humans socially, culturally, or environmentally. Third, each component is already recognized by many people as emblematic of a “healthy” Puget Sound. The nine VECs identified by PSNERP are:

- Coastal forests (also referred to in this report as marine riparian vegetation)
- Beaches and bluffs
- Eelgrass and kelp

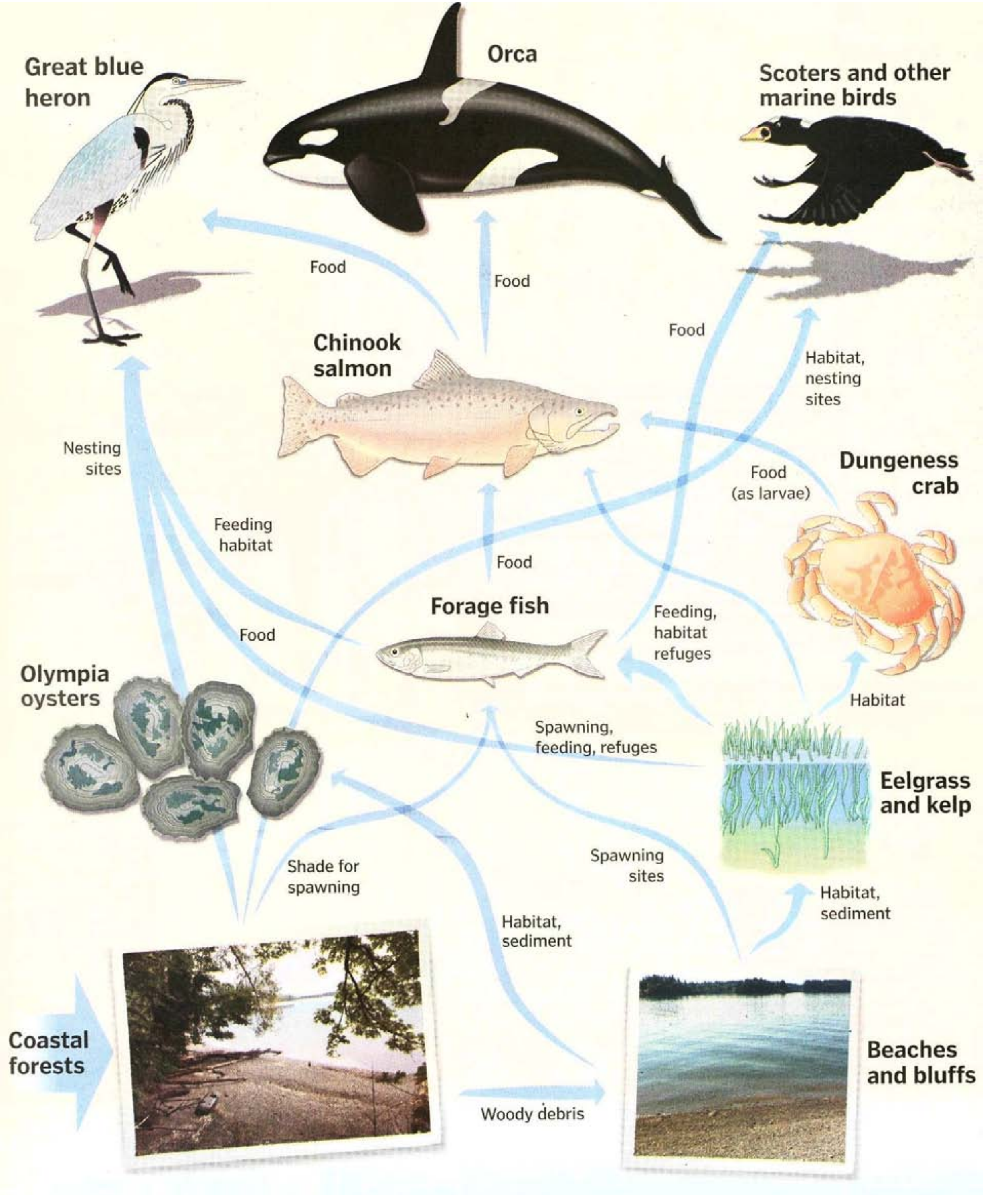
- Forage fish
- Great blue heron
- Juvenile salmon
- Orca whales
- Native shellfish
- Nearshore birds

For each of these VECs, PSNERP prepared technical reports that describe the habitat requirements (or in some cases contributions), distribution, status and trends, human effects on required habitats and the ecosystem processes that sustain the habitats, and data gaps. These reports are available at http://www.pugetsoundnearshore.org. The relationship of these VECs to the nearshore is also discussed in Section 4 of this report. A schematic of the relationship of VECs to the nearshore and each other is presented in Figure 2-8.

2.6.2 Additional Ecosystem Components of Value

During the development of the Strategic Needs Assessment approach, in addition to the nine VECs already identified, two ecosystem components were identified as important for assessing the impacts of human alterations on nearshore ecosystem processes. These additional ecosystem components—embayments and tidal wetlands—share the three characteristics described above as consistent among the PSNERP VECs in that they are likely to be enhanced by restoration, they have direct and indirect value to humans, and each is recognized as emblematic of a “healthy” Puget Sound. They are described here to document our understanding of their contributions to nearshore ecosystems and to characterize their distributions throughout Puget Sound.

Embayments and tidal wetlands are described in more detail in Sections 2.6.2.1 and 2.6.2.2. These sections include a description of each ecosystem component; the nearshore processes, structures, and functions supported by each ecosystem component; the PSNERP VECs supported by each ecosystem component; and the distribution of each ecosystem component throughout the Puget Sound Basin and its sub-basins.



Source: The Olympian, October 2006, reprinted with permission

Figure 2-8

Relationship of Valued Ecosystem Components to Puget Sound Nearshore and Each Other

2.6.2.1 Embayments

2.6.2.1.1 Description of Embayments

Embayment systems typically encompass shoreforms that are protected from wave action by their small size and sheltered configuration. These can occur at the mouths of streams and small rivers or in marine environments in association with barrier beaches. Marine embayments are dominated by tidal processes, while embayments associated with freshwater sources are subject to both upland basin and marine influences. Both commonly support tidal wetlands and tide flats. Most embayment shoreforms include a barrier waterward of the embayment. Those with freshwater inputs contribute bed load sediment and large wood to the nearshore.

Embayments in the Change Analysis included all stream and river mouths that were identified on historical records, except for the 16 large river deltas delineated in Puget Sound. Shipman (2008) identifies four different shoreform types in the embayment geomorphic system: open coastal inlets, barrier estuaries, barrier lagoons, and closed lagoons/marshes (see Table 2-2). Based on the shoreform delineation rules, a single embayment could include shoreline sections of more than one embayment shoreform (see Anchor QEA 2009).

2.6.2.1.2 Embayment Nearshore Processes, Structures, and Functions

Each embayment shoreform is created and sustained by nearshore processes that in turn provide nearshore habitat structure and functions (Figure 2-9). Embayments are characterized by sheltered conditions and are commonly associated with depositional environments, such as the formation and morphology of ebb tidal deltas, stream deltas, and salt marsh accretion. Sediment transport in embayments is typically influenced more by tidal and fluvial processes than by wave action, which is the predominant influence on open shores like barrier beaches and bluff-backed beaches.

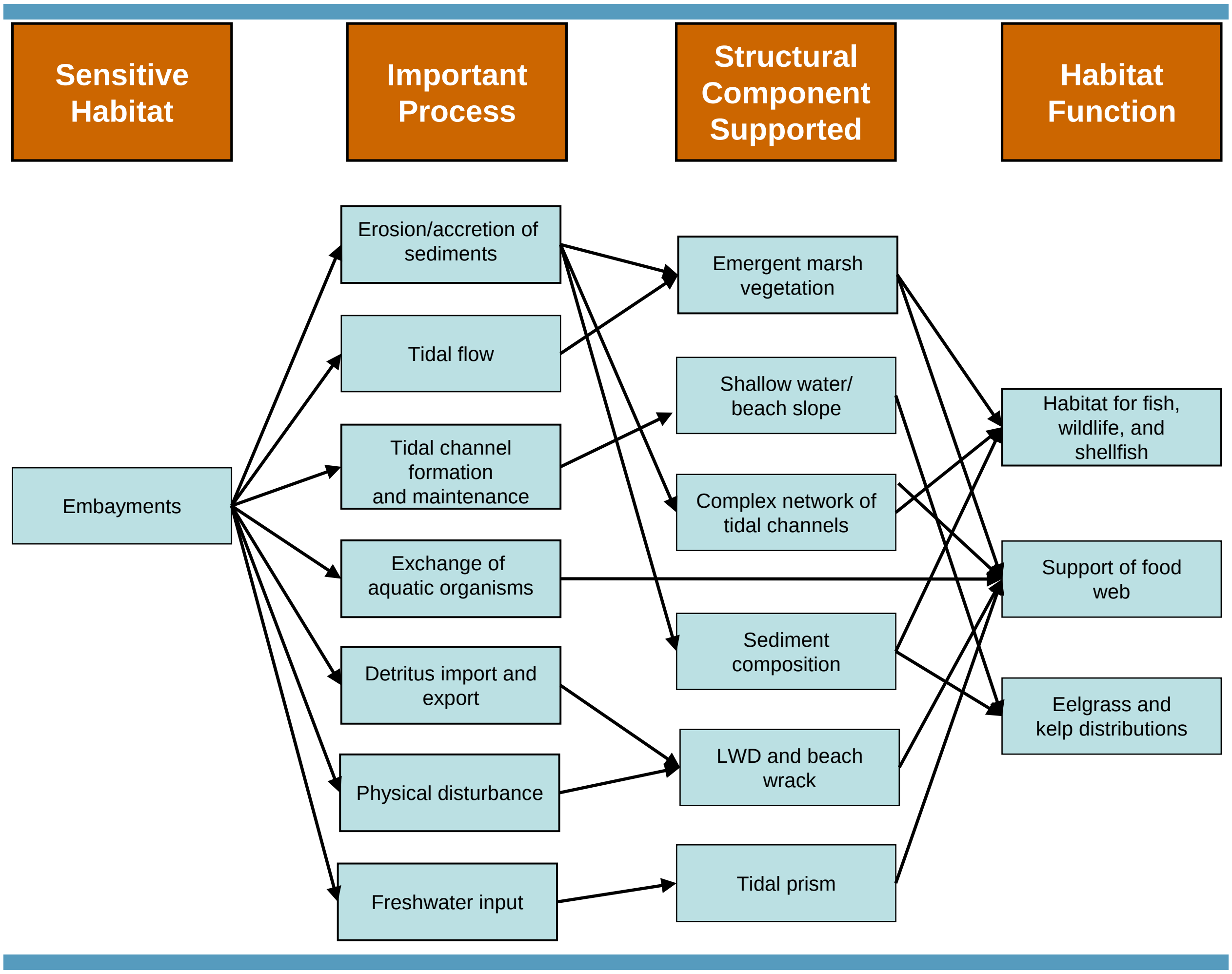


Figure 2-9

Conceptual Model of Embayments and Associated Nearshore Processes, Structure, and Functions

2.6.2.1.3 Importance of Embayments for Valued Ecosystem Components

Nearshore habitat assessments in Puget Sound and the North Straits have found that embayments provide high value nearshore habitat for juvenile salmon (Redman and Fresh 2005; Beamer et al. 2003). Redman and Fresh (2005) note in their review of Chinook and chum salmon use of nearshore habitats that young fry of these species typically migrate rapidly through their natal estuary and rear in and along estuarine embayments that can be relatively remote from their natal river. Beamer et al. (2003) found that pocket estuaries of the Skagit Bay are used by Chinook fry during late winter through spring as a predation and feeding refuge area that is more protective than the nearshore and offshore areas of Skagit

Bay. The sheltered condition that embayments provide can make them suitable for native shellfish, eelgrass and kelp beds, and shorebirds.

2.6.2.1.4 Distribution of Embayments throughout Puget Sound Basin and Its Sub-basins

Historically throughout Puget Sound, 884 embayment shoreforms were mapped (Table 2-6). The number of embayment shoreforms currently has been reduced to 579. Historically, open coastal inlets were the least abundant embayment shoreform, but due to the loss of several barrier lagoons and closed lagoons/marshes, open coastal inlets are currently the second most abundant embayment shoreform. Embayments historically comprised more than 1,100 kilometers (km) of shoreline whereas, currently, embayments account for only 600 km of shoreline. This 46 percent reduction in embayment shoreform length occurred nearly evenly among all embayment shoreform types, as all four lost between 44 and 48 percent of their historic shoreline length (see Table 2-6 and Figure 2-10).

Table 2-6

Historic and Current Distributions of Embayment Shoreforms In Puget Sound

Embayment Shoreform Type	Historic Number	Current Number	Historic Length (km)	Current Length (km)	Percent Gain/Loss in Length
Barrier Estuary	**240**	**179**	**342**	**190**	**-44**
Barrier Lagoon	**222**	**142**	**193**	**104**	**-46**
Closed Lagoon/Marsh	**249**	**101**	**124**	**64**	**-48**
Open Coastal Inlet	**173**	**157**	**450**	**246**	**-45**
Total[a]	**884**	**579**	**1,109**	**604**	**-46**

Note:

a) The total number of historic and current shoreforms cannot be compared to determine the number of embayment shoreforms lost. This is because a shoreform transition in the central portion of a shoreform (e.g., a new artificial shoreform due to a new marina) will result in one historic embayment shoreform being divided into two current embayment shoreforms separated by an artificial shoreform.

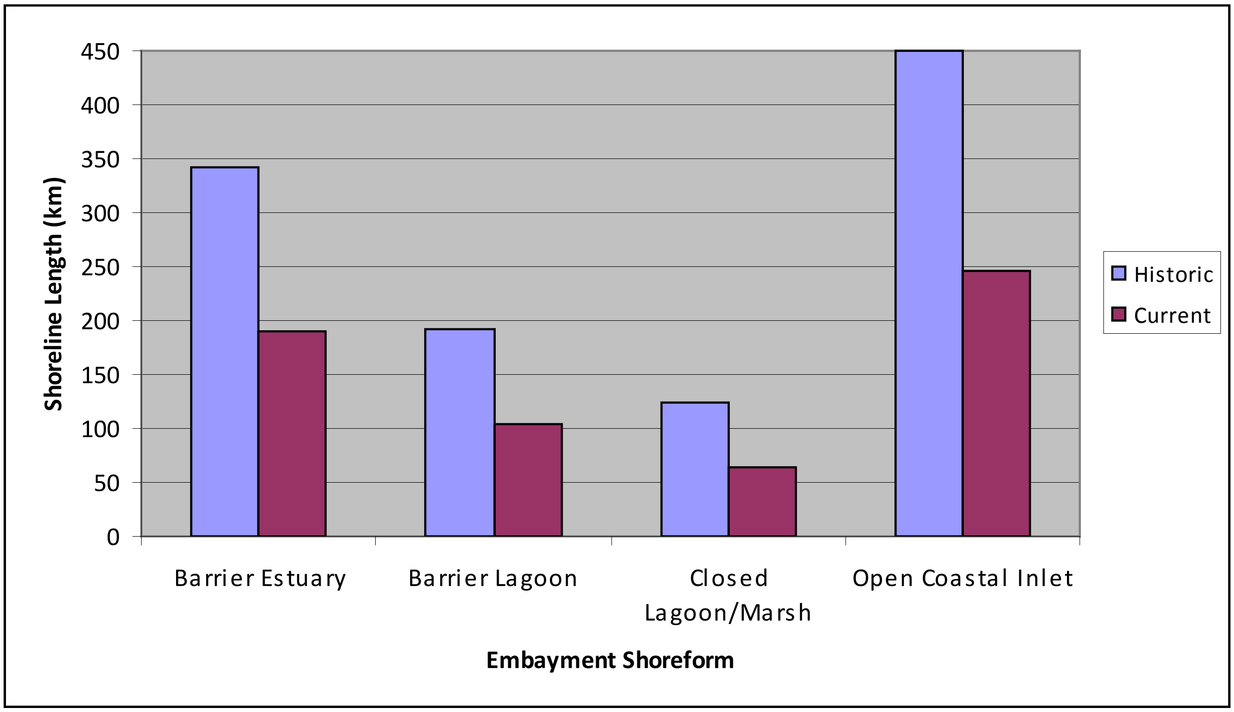


Figure 2-10

Historic and Current Shoreline Lengths of Embayment Shoreforms in Puget Sound

Among the sub-basins, relatively fewer embayment shoreforms occur in the North Central Puget Sound, Strait of Juan de Fuca, and Whidbey sub-basins. The San Juan Islands – Strait of Georgia sub-basin has a moderate quantity of embayment shoreforms, but also has highly variable levels of exposure. The Hood Canal and South Central Puget Sound sub-basins each have more embayment shoreforms. Embayment shoreforms are most abundant in the South Puget Sound sub-basin, with more than twice the occurrence of embayment shoreforms there as compared to other sub-basins.

In the Change Analysis, the loss of embayment shoreforms was analyzed both by reductions in shoreform count and linear extent. Historically and currently, the embayment shoreform that represents the greatest percent of Puget Sound shoreline is open coastal inlets. Closed lagoons/marshes were historically most abundant (by count), while barrier estuaries are currently the most frequently occurring embayment type.

Change Analysis results showed that the South Puget Sound sub-basin encompassed the greatest length of barrier estuary shoreline in both historic and current conditions, 85 and 59 km, respectively (see Table 2-7). The North Central Puget Sound sub-basin incurred the greatest loss of barrier estuaries among all sub-basins, with an 88 percent loss in barrier estuary shoreline, which is almost double the barrier estuary loss throughout Puget Sound (44 percent loss). The San Juan Islands – Strait of Georgia sub-basin and the Whidbey sub-basin also incurred large losses of barrier estuary shoreline (64 and 62 percent, respectively).

Photo 2-2
Example of barrier estuary
(Photo courtesy of WDOE)

Table 2-7
Barrier Estuaries Historic and Current Distribution Throughout Puget Sound and Sub-basins

Basin/Sub-basin	Historic No.	Current No.	Historic Length (km)	Current Length (km)	Percent Gain/Loss in Length
Strait of Juan de Fuca	15	13	25.7	20.4	-20.7
San Juan Islands – Strait of Georgia	14	6	34.4	12.5	-63.6
Hood Canal	49	37	59.1	44.3	-25.2
Whidbey	14	7	46.1	17.4	-62.3
North Central Puget Sound	17	6	64.0	7.5	-88.2
South Central Puget Sound	39	27	51.0	29.6	-41.9
South Puget Sound	100	84	84.5	59.1	-30.1
Puget Sound Basin	**240**	**179**	**342.2**	**190.4**	**-44.4**

The San Juan Islands – Strait of Georgia sub-basin historically contained and currently contains longer lengths of barrier lagoon shorelines (61 and 30 km, respectively) than other sub-basins (see Table 2-8). The greatest loss of barrier lagoon shoreline occurred in the South Central Puget Sound sub-basin (78 percent), followed by the North Central Puget Sound (53 percent), San Juan Islands – Strait of Georgia (51 percent), and Whidbey sub-basins (50 percent).

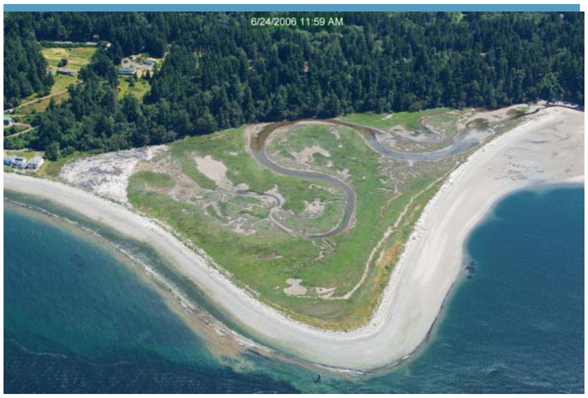


Photo 2-3
Example of barrier lagoon
(Photo courtesy of WDOE)

Table 2-8

Barrier Lagoons Historic and Current Distribution Throughout Puget Sound and Sub-basins

Basin/Sub-basin	Historic No.	Current No.	Historic Length (km)	Current Length (km)	Percent Gain/Loss in Length
Strait of Juan de Fuca	9	8	12.5	9.6	-22.8
San Juan Islands – Strait of Georgia	49	39	60.8	30.1	-50.6
Hood Canal	23	13	18.8	14.8	-21.1
Whidbey	24	13	36.1	18.0	-50.0
North Central Puget Sound	17	8	21.9	10.3	-52.8
South Central Puget Sound	31	10	24.3	5.4	-78.0
South Puget Sound	75	52	29.3	16.6	-43.3
Puget Sound Basin	**222**	**142**	**193.2**	**104.2**	**-46.1**

Photo 2-4
Example of closed lagoon/marsh
(Photo courtesy of WDOE)

Closed lagoons/marshes were historically the most abundant embayment type (by count), but are currently the least frequently occurring (249 historically, 101 currently; Table 2-9). The number and/or length of closed lagoons/marshes changed markedly in all sub-basins except the Strait of Juan de Fuca sub-basin. Historically, the South Puget Sound sub-basin contained the most closed lagoons/marshes (61) and all sub-basins other than the Strait of Juan de Fuca sub-basin contained 30 or more closed lagoons/marshes. Currently, no sub-basins have 30 or more closed lagoons/marshes. The greatest losses of closed lagoons/marshes were incurred in the South Central Puget Sound, South Puget Sound, and Whidbey sub-basins. In South Central Puget Sound, there was an 89 percent loss over 36 closed lagoons/marshes; in South Puget Sound, there was a 75 percent loss over 50 closed lagoons/marshes; and in the Whidbey sub-basin, there was a 64 percent loss over 19 closed lagoons/marshes. In terms of shoreline length, closed lagoons/marshes were historically most extensive in the Whidbey, San Juan Islands – Strait of Georgia, and North Central Puget Sound sub-basins (30, 25, and 24 km, respectively).

Table 2-9

Closed Lagoon/Marsh Historic and Current Distribution Throughout Puget Sound and Sub-basins

Basin/Sub-basin	Historic No.	Current No.	Historic Length (km)	Current Length (km)	Percent Gain/Loss in Length
Strait of Juan de Fuca	12	13	9.1	9.9	8.4
San Juan Islands – Strait of Georgia	42	28	24.5	22.2	-9.5
Hood Canal	46	23	16.2	10.3	-36.3
Whidbey	32	13	29.8	10.7	-64.1
North Central Puget Sound	30	18	24.4	19.0	-22.3
South Central Puget Sound	41	5	17.6	1.9	-89.1
South Puget Sound	61	11	12.1	3.0	-74.9
Puget Sound Basin	**249**	**101**	**123.9**	**63.9**	**-48.4**

Photo 2-5
Example of open coastal inlet
(Photo courtesy of WDOE)

Open coastal inlets were historically the least frequently observed embayment type throughout Puget Sound (173 open coastal inlets); in current conditions, however, Change Analysis results show that open coastal inlets are the second most abundant embayment type (180 open coastal inlets). Currently there are seven more open coastal inlets than there were historically, which is likely the result of mapping rules and errors in the mapping data sources, rather than the actual evolution of new open coastal inlets. The length of open coastal inlet shoreline incurred a (net) loss ranging from 13 to 57 percent among sub-basins, with an overall 43 percent loss throughout the Puget Sound Basin (Table 2-10). Open coastal inlets were far more abundant in the South Puget Sound sub-basin in both current and historic conditions; the same is true for the San Juan Islands – Strait of Georgia sub-basin.

Table 2-10
Open Coastal Inlets Historic and Current Distribution Throughout Puget Sound and Sub-basins

Basin/Sub-basin	Historic No.	Current No.	Historic Length (km)	Current Length (km)	Percent Gain/Loss in Length
Strait of Juan de Fuca	3	3	8.6	4.8	-44.6
San Juan Islands – Strait of Georgia	29	28	142.9	61.1	-57.2
Hood Canal	11	8	30.3	15.5	-48.9
Whidbey	2	2	1.1	1.0	-13.2
North Central Puget Sound	9	9	14.0	10.2	-27.2
South Central Puget Sound	31	24	61.9	29.7	-52.1
South Puget Sound	90	85	191.9	124.7	-35.0
Puget Sound Basin	**173**	**157**	**449.7**	**245.9**	**-45.3**

Throughout Puget Sound, a total of 418 embayments have transitioned either to artificial shoreforms or to another embayment shoreform type, or were absent (see Table 2-4). Artificial shoreforms are typically altered by a suite of co-located stressors including shoreline armoring, nearshore fill, overwater structures, roads, breakwaters and jetties, railroads, and tidal barriers. Among historic embayments, 53 open coastal inlets, 21 barrier estuaries, 16 barrier lagoons, and 5 closed lagoons/marshes had transitioned to artificial shoreforms in the current condition mapping.

In most cases where historic embayment shoreforms were determined to be “absent” in the current delineation, the loss can be attributed to the placement of nearshore fill. In other cases, this occurred as a result of the current shoreline used in the analysis not properly delineating the embayment feature (i.e., in some places the current shoreline goes straight across the mouth of a small embayment that was identified in the historic shoreform delineation).

2.6.2.2 Tidal Wetlands

2.6.2.2.1 Description of Tidal Wetlands

Tidal wetlands consist of areas of wetland hydrology, vegetation, and soils that are subject to tidal influence. In the Change Analysis, four classes of tidal wetlands were recognized. These include the following, which are ordered starting upstream and moving lower in the river (increasing salinity): tidal freshwater, oligohaline transition, estuarine mixing zone, and euryhaline unvegetated (Anchor QEA 2009). For the Change Analysis, tidal wetlands were defined as follows:

- **Tidal freshwater** areas have little to no salinity, but they do experience tidal water level fluctuation (to head of tide), including tidal swamps.
- **Oligohaline transition** wetlands encompass a brackish or low salinity zone that is typically bracketed by scrub-shrub vegetation.
- **Estuarine mixing** wetlands include the area of dominant salinity mixing, which is represented by emergent marsh.
- **Euryhaline unvegetated** wetlands are the mudflats and tideflats between the outer emergent marsh edge and the MLLW line.

In the Change Analysis, all four classes of tidal wetlands were assigned to the DPUs, while for the SPUs, the euryhaline transition class was not used because variability in the historical surveying of intertidal flats caused the change in unvegetated euryhaline wetlands to be extremely variable and inaccurate.

Data for historic tidal wetlands for the Change Analysis were sourced from historical topographical shoreline maps (called “T-sheets”). Current wetland data were sourced from available orthophotos and the U.S. Fish and Wildlife Service’s National Wetland Inventory (USFWS 2009) and additional sources.

2.6.2.2.2 Tidal Wetland Nearshore Processes, Structures, and Functions

Tidal wetlands support a broad variety of fish, shellfish, birds, and other wildlife and provide ecologically and economically important ecosystem services such as production of benthic invertebrates and insects, nutrient cycling, flood attenuation, and pollution abatement. These functions depend upon several key ecological processes such as freshwater input, sediment transport, erosion and accretion of sediments, tidal flow, tidal channel formation and maintenance, distributary channel migration, exchange of aquatic organisms, and detritus import and export.

Photo 2-6
Example of tidal wetlands that have been altered by a road across the embayment
(Photo courtesy of WDOE)

Extensive tidal wetlands are formed where river deltas accumulate sediment at the mouths of large rivers. Sediment and wood transported from the uplands into the nearshore create new marsh and shallow water habitats. As sediments build up, new marsh vegetation can grow, which in turn provides shade and a source of insects and detritus. Water flow and erosion create tidal and distributary channel networks of varying complexity, which then deliver nutrients and detritus to the nearshore for use by invertebrates, fish, nearshore birds, and other species. River systems also provide freshwater inputs to both estuaries and lagoons that affect the vegetation communities. Tidal wetlands provide transition, migration, and rearing areas for anadromous species between salt and freshwater systems.

Figure 2-11 provides a conceptual model that illustrates nearshore processes, including the importance of tidal wetlands to VECs.

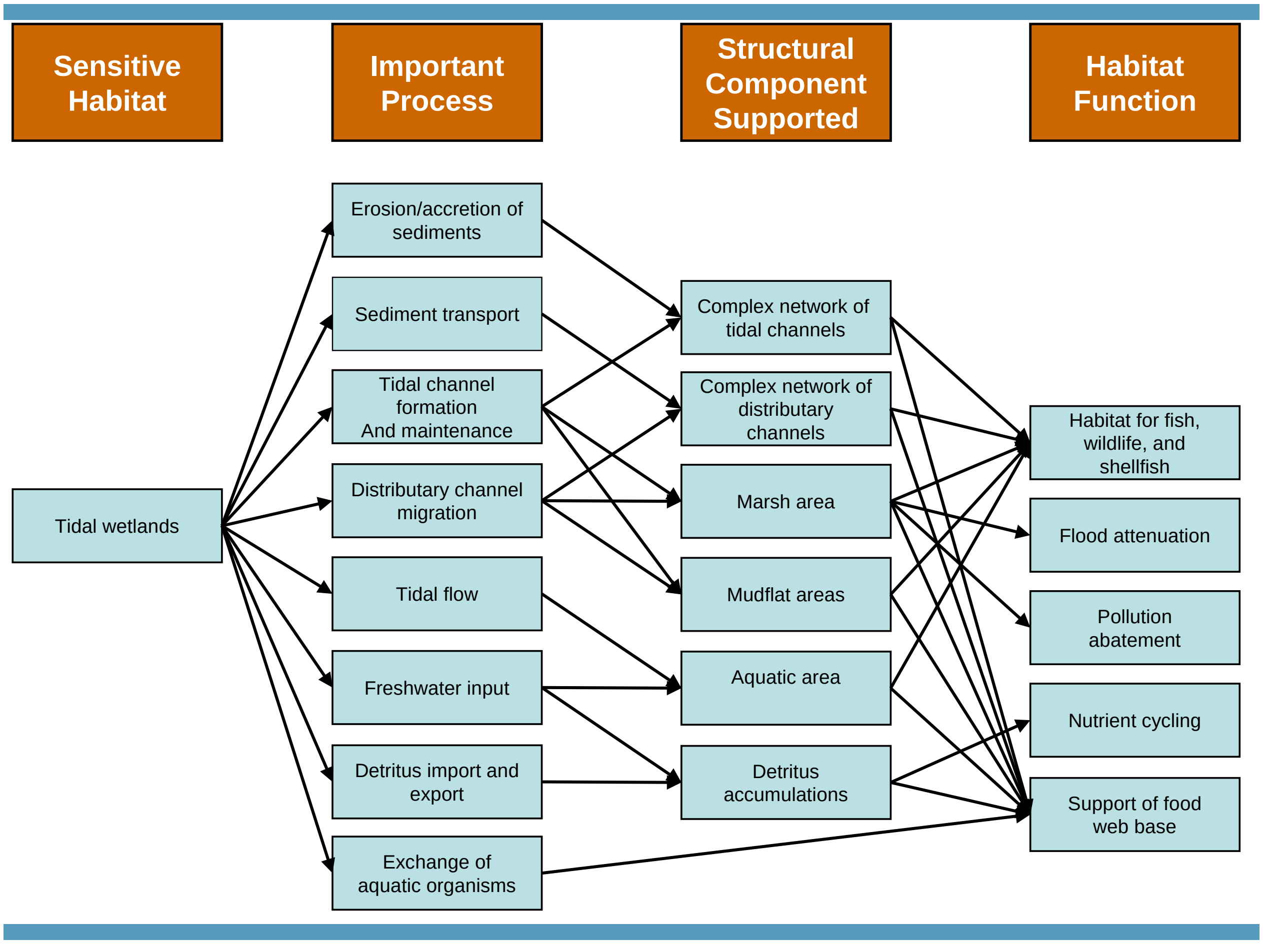


Figure 2-11

Conceptual Model for Processes and Functions in Tidal Wetlands

2.6.2.2.3 Importance of Tidal Wetlands for Valued Ecosystem Components

Tidal wetland habitat is important for several species that use nearshore habitats including juvenile salmon, forage fish, nearshore birds, great blue herons, and native shellfish. Compared to other shoreform types, these habitats provide among the highest levels of EFG&S.

Delta areas and tidal channel networks are some of the most important nearshore habitats used by juvenile salmon for rearing and foraging. In the Skagit River system, the largest river system in Puget Sound, loss of tidal channels has been linked to decreases in salmon population viability (Beamer et al. 2005).

Tidal wetlands that are fed by freshwater seeps provide localized freshwater input, which provides cooling water to the shore and supports species like native shellfish and forage fish that directly depend on the nearshore for one or more parts of their lifecycle.

Tidal wetlands are also important to shorebirds and great blue herons. In a study of estuarine use by nearshore birds in Puget Sound, the highest counts in all seasons were consistently recorded from four sites in northern Puget Sound (Padilla Bay, Port Susan Bay, Samish Bay, and Skagit Bay; Buchanan 2006). More than 30 species of shorebirds, including dunlins, use the Stillaguamish and Skagit deltas during migration or for overwintering. Dunlins and great blue herons use tide flats and mudflats to forage for fish and invertebrates. Dunlins typically return from the breeding grounds in mid- to late October (Paulson 1993), and from that time through mid-April, they generally make up more than 90 percent of the estuarine shorebird community (Buchanan 2006) and nearly exclusively use tide flats in marine estuaries.

2.6.2.2.4 Distribution of Tidal Wetlands throughout Puget Sound Basin and Its Sub-basins

Photo 2-7
Historic and current configuration of Duwamish DPU (red line shows historic shoreline)

To evaluate tidal wetland distributions throughout Puget Sound and the changes that have occurred, historic tidal wetland data from the University of Washington Puget Sound River History Project were compared to current tidal wetland data provided in the U.S. Fish and Wildlife Service's National Wetland Inventory database (USFWS 2009) and other current digital sources. The combination of the two datasets results in a moderate level of uncertainty for numerical calculations due to the different methods and data sources that were available to inform the historic and current datasets. Therefore, the distribution information presented below should be viewed as a general summary. Further, it must be noted that the losses of tidal wetlands include areas whose classification has changed from a historic tidal wetland to a current freshwater wetland, as well as areas in which the historic tidal wetland was converted to upland.

Puget Sound has experienced massive alterations at and near historically expansive estuaries of large rivers, which has included large-scale filling of wetlands during development of Puget Sound's major ports and industrial and urban centers. This process was accompanied by the destruction and alteration of marshes and wetlands associated with small rivers, tributaries, and lagoons.

In terms of losses of various wetland classes in Puget Sound, the most significant losses have been in tidal freshwater and oligohaline transition wetland classes. Figure 2-12 illustrates the area covered by historic and current wetland types in Puget Sound.

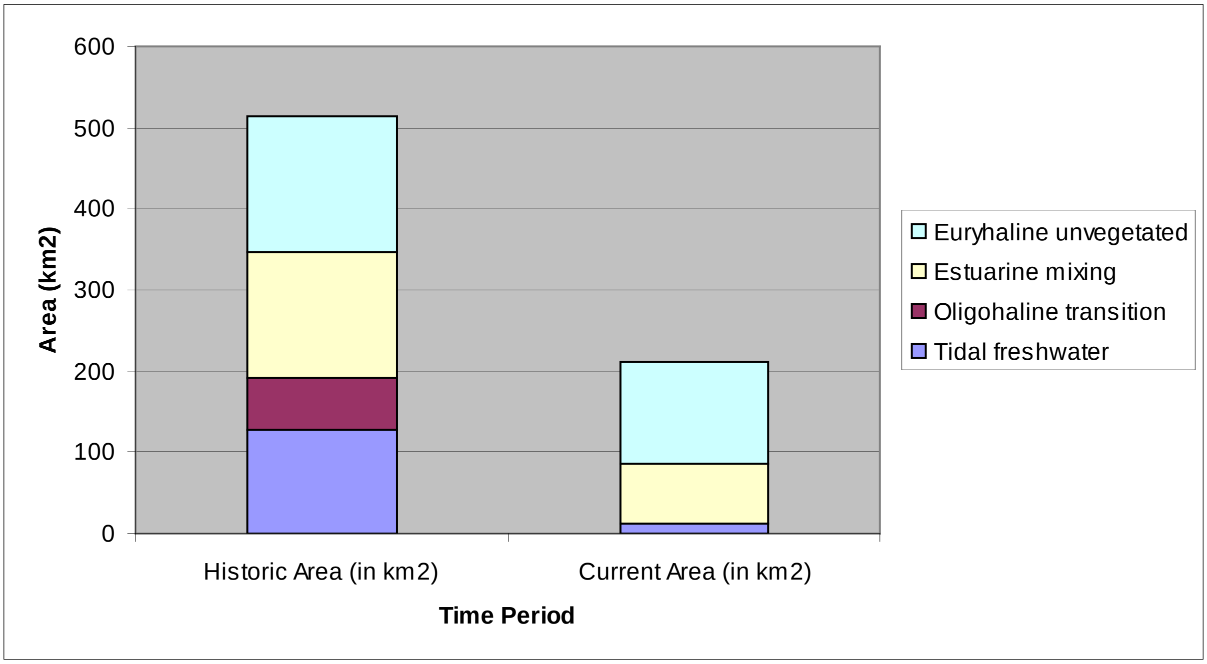


Figure 2-12
Area of Historic and Current Wetland Types in Puget Sound

At a sub-basin scale, the Whidbey sub-basin historically exhibited and currently exhibits the most wetland area, followed by the San Juan Islands – Strait of Georgia sub-basin. Figures 2-13 and 2-14 show historic and current wetland area by wetland type within each sub-basin.

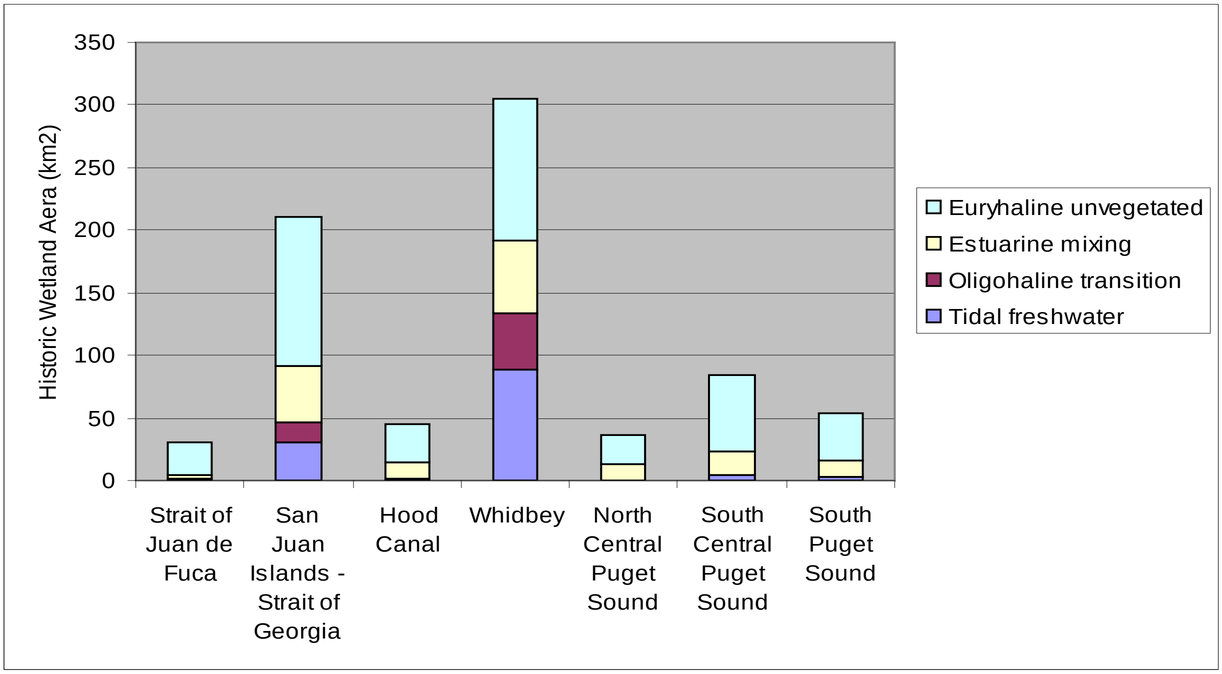


Figure 2-13

Historic Wetland Area by Wetland Type in Puget Sound Sub-basins

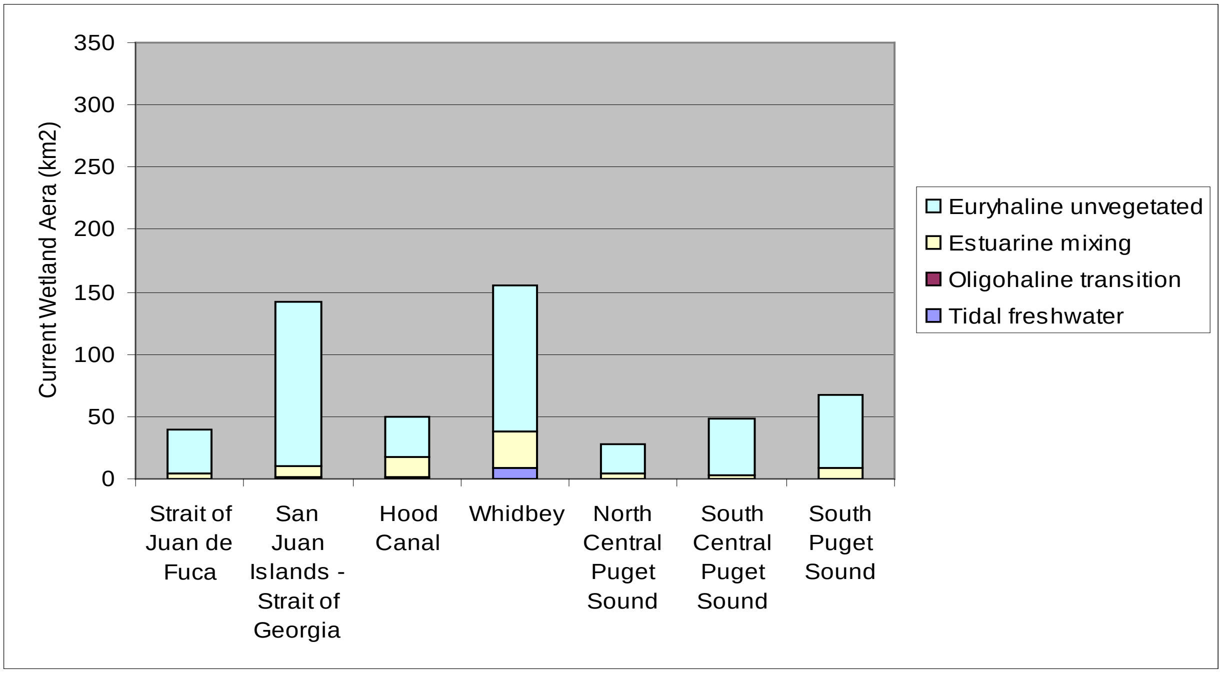


Figure 2-14

Current Wetland Area by Wetland Type in Puget Sound Sub-basins

Historically, the 514 square kilometers (km^2) of tidal wetlands in the nearshore of Puget Sound were broadly distributed within two major geomorphic systems: embayments and river deltas. DPUs have lost 56 percent of their historic extent (Table 2-11). This represents 77 percent of the total tidal wetland loss in Puget Sound. Within embayments, tidal wetlands have lost 71 percent of their historic extent.

Table 2-11

DPU and Embayment Wetland Loss

Tidal Wetland Loss	Historic Wetland Area (km^2)	Current Wetland Area (km^2)	Wetland Area (km^2) Lost	Percent Gain/Loss
DPUs	416	183	233	-56
Embayments	99	29	70	-71
TOTAL	**514**	**212**	**303**	**-59**

Table 2-12 shows changes in tidal wetland area between historic and current times for the 16 Puget Sound DPUs. Six of the 16 DPUs have lost more than 50 percent of their historic tidal wetland area. By percentage, the Duwamish and Puyallup DPUs have lost the most, 99 and 98 percent, respectively. The other four DPUs with losses of more than 50 percent are the Nisqually, Nooksack, Samish, and Snohomish. The largest total areal loss of tidal wetland habitat occurred in the large estuaries of the Whidbey sub-basin: the Skagit, Stillaguamish, and Snohomish DPUs. Five DPUs have shown an increase in wetland area (Dosewallips, Duckabush, Elwha, Hamma Hamma, and Big Quilcene); four of these are in the Hood Canal sub-basin, where the rate of delta progradation may be increased because of upstream processes[2]. The five DPUs that have more tidal wetlands than were historically present were five of the six smallest historic areas of tidal wetlands.

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[2] This progradation is viewed by some scientists as problematic and an indication that the deltas are out of balance due to upstream constraints on sediment distribution onto the floodplain, with subsequent unstable channels in the lower deltas. Some restoration efforts are now aimed at excavating these unnaturally prograded deltas.

Table 2-12
Tidal Wetland Changes in Puget Sound DPUs

DPU	Historic DPU Wetland Area (km^2)	Current DPU Wetland Area (km^2)	Percent Wetland Loss or Gain[a]
Nooksack	62.69	31.14	-50.3
Samish	50.83	24.41	-52.0
Skagit	186.68	97.03	-48.0
Stillaguamish	100.25	55.43	-44.7
Snohomish	98.05	28.31	-71.1
Duwamish	17.51	0.2	-98.9
Puyallup	21.71	0.54	-97.5
Nisqually	26.65	10.37	-61.1
Deschutes	2.69	1.51	-43.9
Elwha	0.51	0.95	86.3
Dungeness	11.72	7.93	-32.3
Big Quilcene	4.38	4.75	8.4
Dosewallips	1.59	2.94	84.9
Duckabush	1.6	2.37	48.1
Hamma Hamma	2.47	2.53	2.4
Skokomish	13.84	12.04	-13.0

Note:
a) The percent change calculation is based on the unrounded areas for current wetland and historic wetland areas. As a result, the percent change cannot be directly calculated from the table entries in the other columns.

Within embayments, tidal wetland losses have typically occurred via transitions to artificial shoreforms or through disappearance of embayment shoreforms (e.g., tidal wetland filling and development). Table 2-13 details the area of wetland change among the embayment shoreforms. All four embayment shoreform types have lost at least 50 percent of their historic wetland area. Open coastal inlets have lost the highest percentage (83 percent) and greatest area (27 km^2) of historic wetlands.

Table 2-13

Tidal Wetland Changes in Puget Sound Embayments

Shoreform Type	Historic Wetland Area (km^2)	Current Wetland Area (km^2)	Wetland Area (km^2) Lost	Percent Change
Barrier Estuary	28	9	19	-66
Barrier Lagoon	13	6	7	-53
Closed Lagoon/Marsh	7	3	4	-55
Open Coastal Inlet	32	5	27	-83

3 OVERVIEW OF THE STRATEGIC NEEDS ASSESSMENT APPROACH

The purpose of this Strategic Needs Assessment is to interpret change analysis (i.e., *structural* change) to define the restoration and protection needs of the Puget Sound nearshore. The PSNERP strategy is focused on restoration and protection of ecosystem *processes*. Thus, the structural changes documented in the Change Analysis (Simenstad et al. 2011) needed to be translated into estimates regarding the degradation of processes important to nearshore ecosystems. The seven steps described below and illustrated in Figure 3-1 were completed to estimate degradation of nearshore processes and interpret the major problems and restoration/protection priorities of Puget Sound:

1. Review results in the Change Analysis
2. Document impacts of stressors (human alterations) on nearshore processes
3. Develop an evaluation framework to estimate degradation of nearshore processes (Section 5)
4. Apply the evaluation framework to assess degradation of nearshore processes in each SPU and DPU (Sections 6.1 through 6.3)
5. Assess degradation of nearshore processes at multiple scales using landscape ecology principles (Section 6.4)
6. Identify major problems of Puget Sound (Section 7.1)
7. Identify priority recommendations for restoration and protection (Sections 7.2 and 7.3)

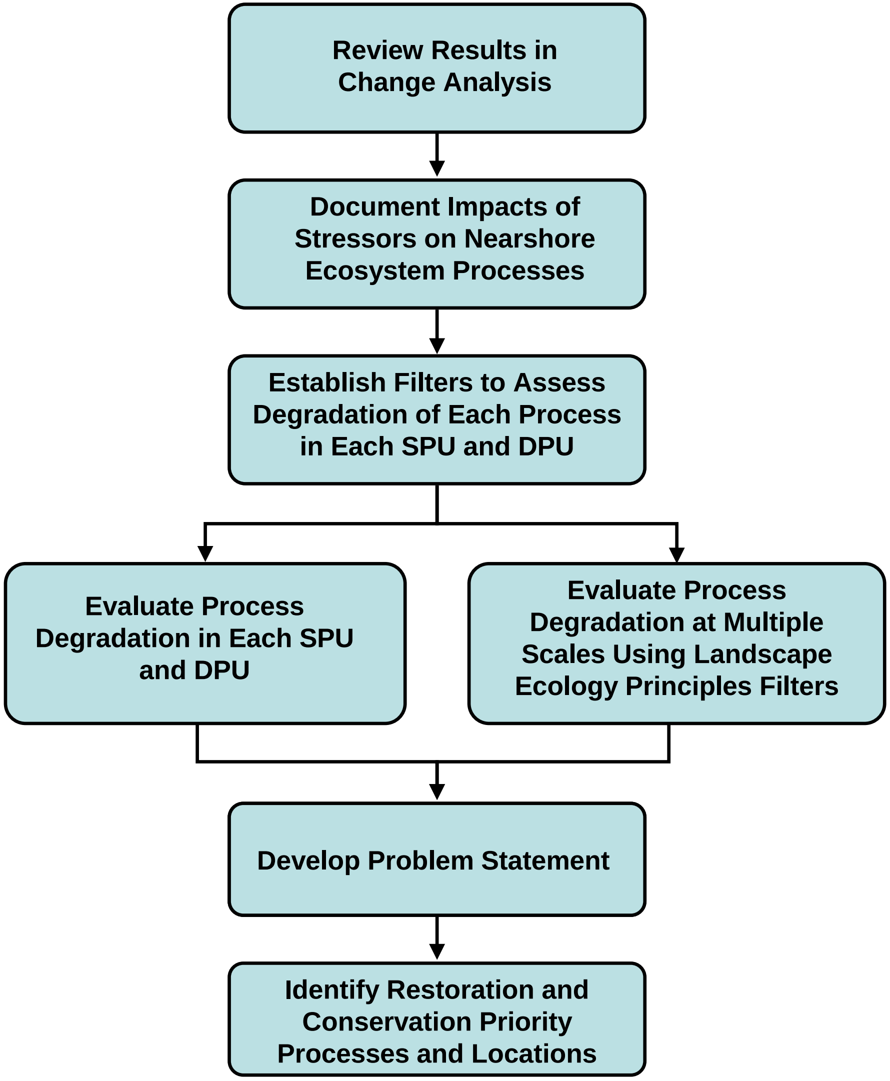


Figure 3-1

Strategic Needs Assessment Approach Flowchart

In the first step, the Change Analysis results were reviewed to understand the distribution of stressors and the relative impact of these stressors on the impairment analysis for EFG&S conducted by Simenstad et al. (2011). The analysis conducted for this review is presented in Sections 2.5 and 4.15.

In the second step, the understanding of the relationship between stressors and nearshore processes was developed and documented. This step entailed describing each of 12 stressors included in the Change Analysis database; documenting in a conceptual model and narrative text the current scientific understanding of the impacts that each stressor has on nearshore processes, habitat structure, and functions; characterizing stressor impacts on VECs; and documenting the distribution of the stressor through the PSNERP General Investigation study area. The stressors evaluated were limited to those physical stressors included in the Change Analysis database—those stressors for which there were consistent Sound-wide data. The effect of these stressors on nearshore processes, structures, and functions was a foundational component for the remainder of the Strategic Needs Assessment. The stressor information is presented in Sections 4.1 through 4.14.

Next, a spatially explicit evaluation framework (Framework) was created to characterize the extent to which each of the 11 nearshore ecosystem processes was likely degraded as a result of the observed physical alterations. The rules developed in this Framework were based on the implied relationships between a stressor and ecological processes as described in the conceptual models, as well as on an understanding of which shoreform types would suffer the greatest impact from a particular stressor. The Framework was developed to evaluate process degradation at the scale of a process unit and to differentiate areas of high, medium, and low degradation. Due to the different influences affecting processes along shorelines versus within river deltas, different metrics were used to assess process degradation in SPUs and DPUs. The Framework is explained in Section 5.

In the fourth step, the Framework was applied to estimate the degree of degradation of each of the nearshore processes in each SPU and DPU. These results are presented in Sections 6.1 through 6.3.

In addition to the analysis of degradation in individual SPUs and DPUs, the outputs of the Framework and additional information on the distribution of shoreforms were interpreted to investigate broader landscape-scale conditions throughout the PSNERP General Investigation study area. This investigation was conducted using filters to apply the protection and restoration principles prepared for the PSNERP General Investigation at the landscape scale and site-specific scale (Greiner 2010). The findings of this investigation are presented in Section 6.4.

In the sixth step, results from the SPU and DPU analysis of process degradation and the landscape-scale investigation, as well as the key findings from the Change Analysis, were interpreted to prepare a "problem statement" describing the major changes that have occurred in the Puget Sound General Investigation study area. The problem statement is presented in Section 7.1.

In the seventh and final step, priority restoration and protection recommendations were identified to address the factors described in the problem statement. These recommendations describe general locations and nearshore processes on which to focus in restoring Puget Sound. These recommendations are presented in Sections 7.2 and 7.3. Specific project sites or projects were not identified in this report because they are to be identified in subsequent steps as the Feasibility Study report is prepared.

4 STRESSORS IMPACTING NEARSHORE PROCESSES AND VECS

The Change Analysis methodology was designed to identify, describe, and quantify shoreline alterations from anthropogenic modifications inferred to impair nearshore process. To complete this task, the Change Analysis geospatial database was populated with information on the predominant stressors that were thought to affect nearshore processes and that were available in consistent, Sound-wide datasets. The Change Analysis stressor data include information on the amount, frequency, distribution, and, in some cases, size of stressors. Stressors that were part of the Change Analysis that are considered in this report include the following:

- Tidal barriers
- Nearshore fill
- Shoreline armoring
- Railroads
- Nearshore roads
- Marinas
- Breakwaters and jetties
- Overwater structures
- Dams
- Stream crossings
- Impervious surfaces
- Land cover development

These stressors vary significantly in their characteristics, size, frequency, and spatial distribution across the nearshore and are measured in varying units ranging from line segments, to areas, to counts. Some of the stressors are primarily associated with historic patterns of shoreline development, including extensive nearshore fill, diking, and railroads. Other stressors continue to be built in the nearshore, such as docks and armoring.

This report attempts to draw conclusions, based on conceptual models, about causes of impairment to ecological processes and VECs based on the stressor dataset and our understanding of the relationship between nearshore processes, structures, and functions. As described in Sections 4.1 through 4.12, many of these stressors often co-occur (e.g., roads and armoring) and are associated with specific shoreform types. Some stressors are found across nearly all shoreform types (e.g., roads and armoring), whereas others are found primarily in one shoreform type (e.g., tidal barriers in deltas). The nature and extent of impairments will differ depending on shoreform, co-occurring stressors, and position in the landscape. The following sections describe each stressor, discuss impacts, and summarize the current distribution of the stressor in Puget Sound.

4.1 Tidal Barriers

4.1.1 Description of Tidal Barriers

Tidal barriers consist of structures (e.g., dikes and levees) designed to impede tidal flow to and from specific areas. They can also include roads or railroads constructed across wetlands. Dikes are one type of tidal barrier in Puget Sound and are most commonly, although not exclusively, found in deltas where dikes allow conversion of river delta areas to agricultural farmland. Dikes are typically the longest type of tidal barrier. Maintaining dikes often requires the use of larger rock materials to prevent erosion from flood flows and storm events, particularly along distributary channels. Many tidal barriers include tide gates designed to allow drainage of agricultural land inside the barriers. Tide gates are typically designed to prevent tidal water movement into diked lands.

The tidal barrier dataset was created for the Change Analysis based on information provided by the Salmon and Steelhead Habitat Inventory and Assessment Project (SSHIAP). The final dataset contains only barrier information in the deltas, barrier estuaries, barrier lagoons, and open coastal inlets, and within the extent of historic wetland polygons (as delineated by the University of Washington's Puget Sound River History Project). Tidal barrier mapping, and therefore tabulation of length, was limited to only the first, or "primary," structure (e.g., road or dike) that the tide would encounter upon an incoming tide, and does not include cross dikes inside the barriers. In this way, the dataset provides a reliable delineation of areas or shoreline lengths impacted by tidal barriers, but will underestimate the total length of the tidal barrier network present at a site.

4.1.2 Impacts of Tidal Barriers on Nearshore Processes, Structures, and Functions

Tidal barriers impact the nearshore through alterations to the dynamics of sediment, water, detritus, and organisms. Lack of tidal flow prevents water and sediment from reaching marshes, causing geomorphic and vegetation changes both within and outside of diked areas (Thom 1992; Bryant and Chabreck 1998; Barrett and Niering 1993; Brockmeyer et al. 1997; Hood 2004). In the absence of tidal flooding, areas outside dikes dominated by organic soils subside (decline in surface elevation) and fill in with sediment. Estuarine vegetation growing in these areas no longer has the estuarine water source or elevation to support its growth and survival. Inside dikes, tidal channel formation and maintenance stalls in the absence of tidal flushing. Channels inside dikes are disconnected and frequently destroyed to facilitate agricultural operations, and those outside dikes are reduced in size and complexity. These losses in marsh acreage and expansion contribute to limited shoreline resilience against sea level rise. Additionally, with limited or no tidal flow and tidal energy, nutrients produced from decaying material (detritus) within the marsh are no longer transported into the nearshore and aquatic organisms are precluded from using former marsh areas for foraging and refuge.

Tidal barriers are frequently co-located with roads; however, these roads are typically gravel-surfaced and are used for transport of farm and/or other maintenance equipment, as opposed to the automobile use common to most roads. These gravel roads present fewer impacts than paved roads due to somewhat greater permeability, which reduces stormwater runoff typical of paved surfaces; infrequent use of these roads also reduces inputs of heavy metals and hydrocarbons that are commonly associated with conventional automobile traffic. In a restoration context, gravel roads located on dikes are easier and less costly to remove and do not typically impact vehicle traffic patterns. These roads, therefore, present less of an impediment to restoration than paved, frequently used, public

Photo 4-1
Example of delta area in which tidal barriers have restricted the river's connection to the floodplain and led to the loss of tidal wetlands
(Photo courtesy of Coastal Geologic Services)

roads. However, the value of these roads to pedestrians for recreational uses, particularly if roads are located on public land, can present a challenge to restoration.

Tidal barriers can also co-occur with armoring and fill, particularly in cases where residential development is established landward of the tidal barrier. In this case, paved roads may be constructed along tidal barriers to access developments. This increased modification presents additional challenges to restoration.

The conceptual model shown in Figure 4-1 describes the links between tidal barriers and nearshore processes, structural changes, and functional responses.

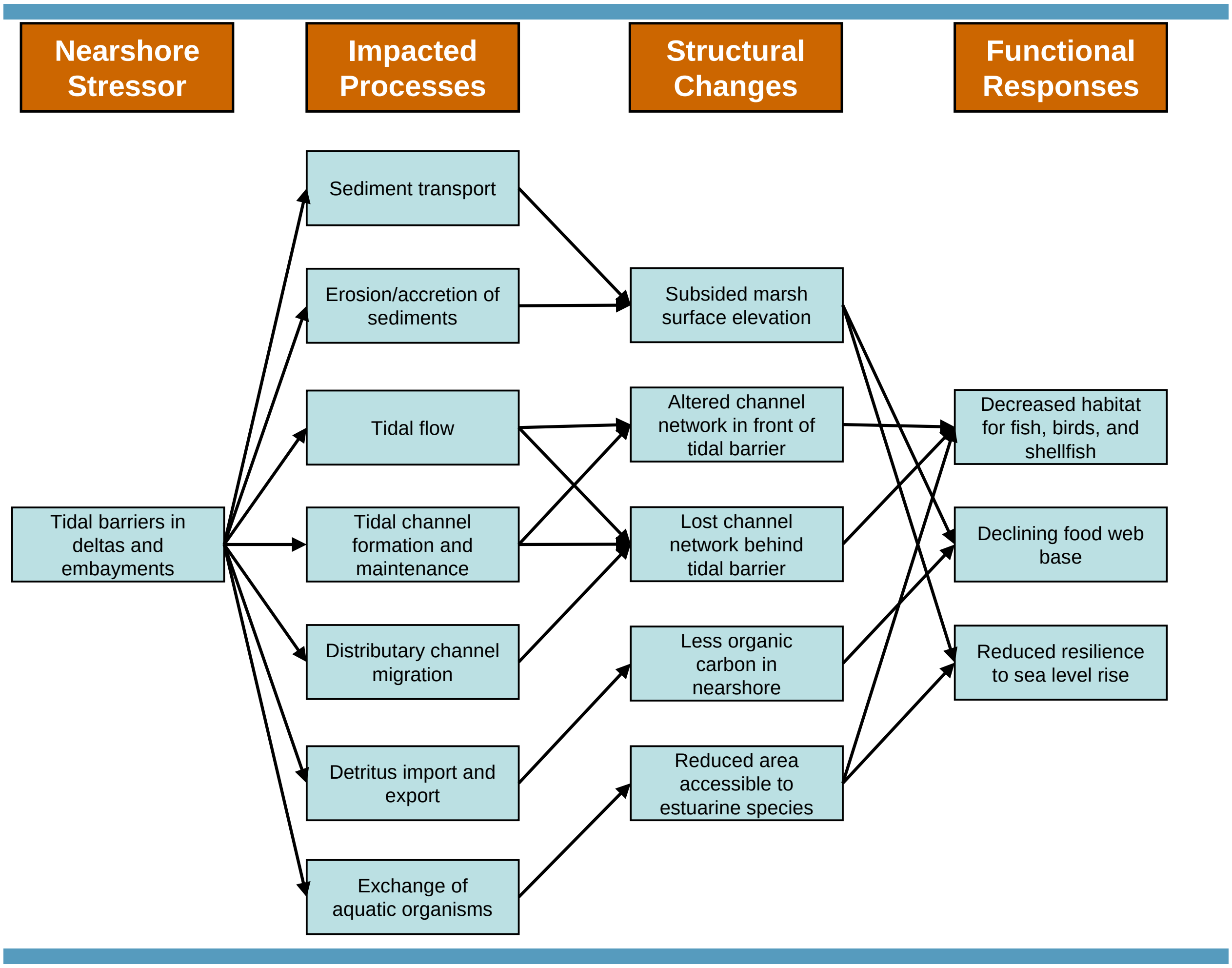


Figure 4-1

Conceptual Model Diagram Showing the Impacts of Tidal Barriers on Nearshore Processes, Structures, and Functions

4.1.3 Impacts of Tidal Barriers on Valued Ecosystem Components

Processes impaired by tidal barriers can result in direct impacts to juvenile salmon, native shellfish, nearshore birds, great blue heron, eelgrass and kelp. Indirect effects to forage fish, and orca whales can be inferred from direct impacts.

Juvenile salmon are heavily impacted by tidal barriers. The key impact for these juveniles is a loss of access to estuarine areas for rearing and foraging. Tidal barriers constrain tidal channel development and channel migration and limit development of complex channel networks. Tidal channels within deltas have specifically been shown to be important rearing habitat for juvenile Chinook during their outmigration from freshwater habitats (Healey 1980); juvenile Chinook have been known to rear for periods of up to 120 days in river deltas (Simenstad et al. 1982; Beamer et al. 2005). Loss of tidal channels can thus result in changes to salmon population viability, as shown by studies in the Skagit River system (Beamer et al. 2005).

Tidal barriers also limit or prevent nutrient delivery and transport that supports existing emergent tidal marsh vegetation. As marsh is lost, benthic invertebrates and insects that require tidal marsh areas for growth and survival diminish, and juvenile salmon lose access to marsh food resources.

Diking also triggers functional changes and loss of habitat for animals that depend on mudflat and intertidal marsh areas. This can occur through direct or indirect loss of food resources produced in mudflats. Detritus from marsh systems fuels the food web that many birds rely upon. Shorebirds such as dunlin typically use estuarine tide flats for foraging (Buchanan 2006), and great blue heron forage on mudflats in estuarine areas during low tides, seeking fish and invertebrate prey (Eissinger 2007). Many species of native shellfish rely on intertidal areas for essential life history phases, including feeding and reproduction (Dethier 2006). Decreased marsh habitat as a result of diking is therefore expected to diminish prey availability for these organisms.

Eelgrass and kelp beds can also be adversely affected by the significant changes to sedimentation processes associated with the presence of tidal barriers. Observations indicate that high quality eelgrass beds (i.e., dense, continuous beds) are often found adjacent to the margins of river deltas in Hood Canal and northern Puget Sound (Mumford 2007). Because eelgrass and kelp each have specific substrate requirements, significant changes in sedimentation near river deltas have the potential to stress eelgrass and kelp growth and survival.

Forage fish such as herring that depend on eelgrass for spawning would be affected by decreased eelgrass survival. Orca whales in Puget Sound may be indirectly affected by tidal barriers because the species is sensitive to stressors that decrease survival of salmonids. Puget Sound orca whales have been shown to prefer salmonids above other prey items (Ford et al. 1998, 2000; Saulitis et al. 2000).

4.1.4 Distribution of Tidal Barriers Throughout Puget Sound Basin and Its Sub-basins

Tidal barriers are present along 11 percent (418 km) of the shoreline in the Puget Sound Basin and impact a total area of 206 km^2, according to the Change Analysis. Large-scale wetland loss has occurred due to construction of these barriers and conversion of wetlands to agricultural production and other uses (see Section 2.6.2.2). Tidal barriers make up 263 km (63 percent) of all tidal barriers throughout Puget Sound.

Within DPUs, the Skagit, Snohomish, and Stillaguamish exhibit the largest wetland areas (freshwater and tidal) impacted by tidal barriers with 58, 58, and 20 km^2 impacted, respectively (Table 4-1). All three of these DPUs are located in the Whidbey sub-basin, representing 66 percent of the total wetland area impacted due to tidal barriers throughout Puget Sound. These three DPUs have lost 31 to 68 percent of their historic wetland area. They also exhibit the longest tidal barrier lengths compared to other DPUs. Outside of the Whidbey sub-basin, the Nooksack, Samish, Duwamish and Puyallup DPUs also have lost relatively large areas of former wetlands due to tidal barriers: 49, 44, 68, and 76 percent, respectively. DPUs in the Hood Canal and the Strait of Juan de Fuca are considerably less impacted by tidal barriers; wetland areas impacted in these DPUs range from 0.03 (Elwha) to 1 km^2 (Skokomish), with losses of 8 and 15 percent of historic wetland area, respectively. In South Central and South Puget Sound, wetland areas impacted by tidal barriers range from 2 (Deschutes) to 11 km^2 (Duwamish), a relatively small area compared to some of the other sub-basins, but in terms of historic wetland losses, these sub-basins have lost approximately 70 percent of their total wetland area.

Table 4-1
Wetland Losses due to Tidal Barriers in Puget Sound DPUs

DPU	Tidal Barrier Length (km)	Historical Wetland Area (km^2)	Wetland Area Impacted by Tidal Barriers (km^2)	Lost Wetland Percent
Nooksack	13.6	40.6	19.9	49.0
Samish	17.0	32.9	14.4	43.8
Skagit	51.6	120.9	58.2	48.2
Stillaguamish	43.8	64.9	20.2	31.1
Snohomish	93.6	84.6	57.5	67.9
Duwamish	22.5	15.1	10.9	72.3
Puyallup	40.2	18.7	14.3	76.0
Nisqually	10.3	17.3	4.7	27.1
Deschutes	4.1	3.5	2.4	69.9
Elwha	0.2	0.3	0.03	8.1
Dungeness	3.7	7.6	1.1	14.4
Big Quilcene	4.0	2.8	0.3	9.4
Dosewallips	1.2	1.0	0.04	3.8
Duckabush	1.3	1.0	0.2	14.5
Hamma Hamma	2.1	1.6	0.2	9.7
Skokomish	11.2	9.0	1.3	14.5

Note: The tidal barrier analysis of wetland losses included freshwater and tidal wetlands.

For tidal wetlands associated with embayments outside of the large river deltas, the San Juan Islands – Strait of Georgia sub-basin has lost the most wetland area (39 km^2), which corresponds to 83 percent of the historic wetland area (Table 4-2). The North Central Puget Sound sub-basin lost the second largest amount of wetlands by area and percent (7 km^2 and 59 percent).

The large-scale occurrence of tidal barriers, and the consequent loss of tidal inundation to the former marsh plain, has disrupted important processes within the deltas such as sediment and wood movement, tidal channel formation and maintenance (both inside and outside the

Table 4-2
Wetland Losses due to Tidal Barriers in Puget Sound Embayments

Basin/Sub-Basin	Tidal Barrier Length (km)	Historical Wetland Area (km^2)	Wetland Area Impacted by Tidal Barriers (km^2)	Lost Wetland Percent
Strait of Juan de Fuca	8.2	3.0	0.7	24
San Juan Islands – Strait of Georgia	40.7	32.3	38.7	83
Hood Canal	10.6	9.1	1.1	12
Whidbey	11.8	9.7	3.5	36
North Central Puget Sound	8.2	12.5	7.4	59
South Central Puget Sound	12.9	4.9	1.2	25
South Puget Sound	10.1	6.5	1.1	17
Puget Sound Basin	**100.3**	**80.0**	**44.3**	**55**

Note: The tidal barrier analysis of wetland losses included freshwater and tidal wetlands.

dike), and nutrient cycling from the former marsh surface. In addition, the loss of tidal prism to these deltas has significantly changed wetland distribution and composition in these areas. For example, tidal freshwater, oligohaline transition, and estuarine mixing zones have decreased by 90 percent, 99 percent, and 47 percent, respectively (also see information on change in wetland classes in Section 2.6.2.2). Documented changes to vegetation composition, species use, and tidal channel extent and complexity have also occurred (Hood 2004).

4.2 Nearshore Fill

4.2.1 Description of Nearshore Fill

Nearshore fill consists of material placed below the ordinary high water mark (OHWM) in order to create upland area. Historically, filling along Puget Sound shorelines has occurred as a consequence of industrial, commercial, and residential development, including transportation corridors. Early industrial development of Puget Sound beginning in the mid-1800s was often associated with sawmills and ports, and by the late 1800s, dredging to facilitate vessel traffic was common around mills and other industrial centers. Dredged material from shallow water areas was often used to fill adjacent wetland and intertidal areas to create uplands where development was desired. In downtown Seattle, hillsides were removed hydraulically and the material was sluiced into the Duwamish River tide flats and Elliott Bay to create dry land for development interests. Roadways and railroad grades were often placed on fill along the upper intertidal zone parallel to the shoreline. More recently, nearshore fill has been placed in association with shoreline armoring in the upper intertidal area, typically along bluff-backed beach and barrier beach shoreforms. This armoring is often used to support shoreline development, including single-family residences, and cumulatively affects a substantial portion of the Puget Sound shoreline.

The fill dataset used for this report is based on the Coastal Zone Atlas of Washington (WDOE 1980). It is recognized that the atlas has several key gaps. The atlas does not include the historical (i.e., mid-late 1800s) maps that provide information on the location of wetlands prior to most shoreline development (e.g., fill), and therefore does not capture the presence of fill in many less obvious fill areas. It also does not include fill along many shorelines where armoring buries a portion of the upper intertidal zone, an omission that may be important, as approximately 79 percent of shoreline armoring in WRIA 9 occurs below the OHWM (Anchor 2006). Lastly, the atlas does not include fill associated with many embayment systems and some smaller river deltas. Thus, this dataset significantly underestimates the extent of fill throughout Puget Sound.

4.2.2 Impacts of Nearshore Fill on Nearshore Processes, Structures, and Functions

Nearshore fill in deltas and many embayment systems has resulted in the loss and disconnection of estuarine wetlands (Fresh 2006) and streams. Fill along bluff-backed beaches and barrier beaches can bury upper and lower intertidal zones (Penttila 2007; Dethier 2006). The direct burial of intertidal areas also destroys beach and tide flat habitats (Buchanan 2006; Eissinger 2007).

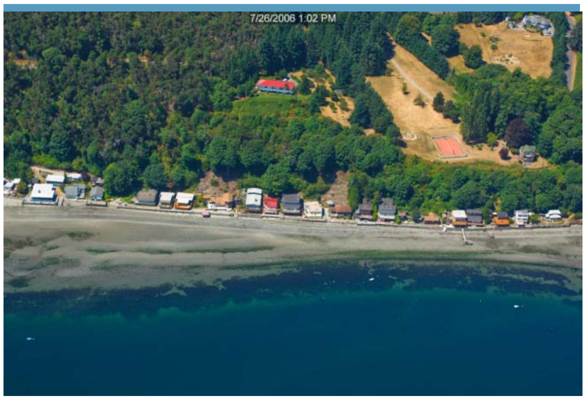


Photo 4-2
Example of shoreline area with fill at base of a bluff
(Photo courtesy of WDOE)

Nearshore fill, when associated with armoring, reduces sediment and wood supply to drift cells. When fill occurs along bluff-backed beach shoreforms, it is often associated with armoring. Armoring results in lower wave dissipation, which causes heightened erosion in the area waterward of bluffs. This prevents bluff sediment and wood from reaching drift cells and leads to eroded intertidal areas. Grain size and hydrology change because the substrate that is left often consists of a homogenous larger grain size or rests at a different elevation.

In addition to sediment supply, sediment transport can also be disrupted as a result of nearshore fill. Where fill occurs along either bluff-backed beach or barrier beach shoreforms, depending on the extent of fill below mean higher high water (MHHW), fill can act as a groin that traps sediment on the up-drift side and prevents sediment from reaching down-drift sections of drift cells.

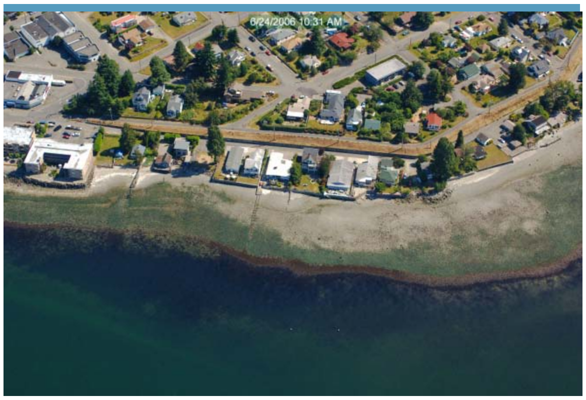


Photo 4-3
Example of shoreline area with fill extending into intertidal zone
(Photo courtesy of WDOE)

Fill indirectly impacts tidal processes by reducing the amount of tidal prism (the volume of water flowing in and out during a tide cycle), particularly in delta and embayment systems. The loss of tidal prism also disrupts or reduces sediment and wood distribution to affected shoreforms and associated habitats. The reduction of tidal and sediment processes affects sediment accretion, wood accumulation, and marsh development, and results in the loss or attenuation of tidal channels and the alteration of distributary channel migration. With these changes in marsh area, habitat is reduced or simplified, which decreases potential use by fish and wildlife. In addition, marsh losses limit shoreline resilience against sea level rise.

Photo 4-4
Example of embayment that has been partially filled
(Photo courtesy of WDOE)

Fill can disrupt the ecological linkages between upland coastal forest and backshore habitats and the adjacent nearshore and marine environment by reducing or eliminating large woody debris (LWD), nutrient, detritus, and invertebrate and insect inputs to the nearshore. On wave-dominated beaches, fill and armoring reduce wrack and detritus accumulation and truncate the continuum of habitats from subtidal to bluff that supports invertebrate populations. Fill can also disrupt the link between beaches and surface- and groundwater inputs.

The conceptual model shown in Figure 4-2 describes the links between nearshore fill and nearshore processes, structural changes, and functional responses.

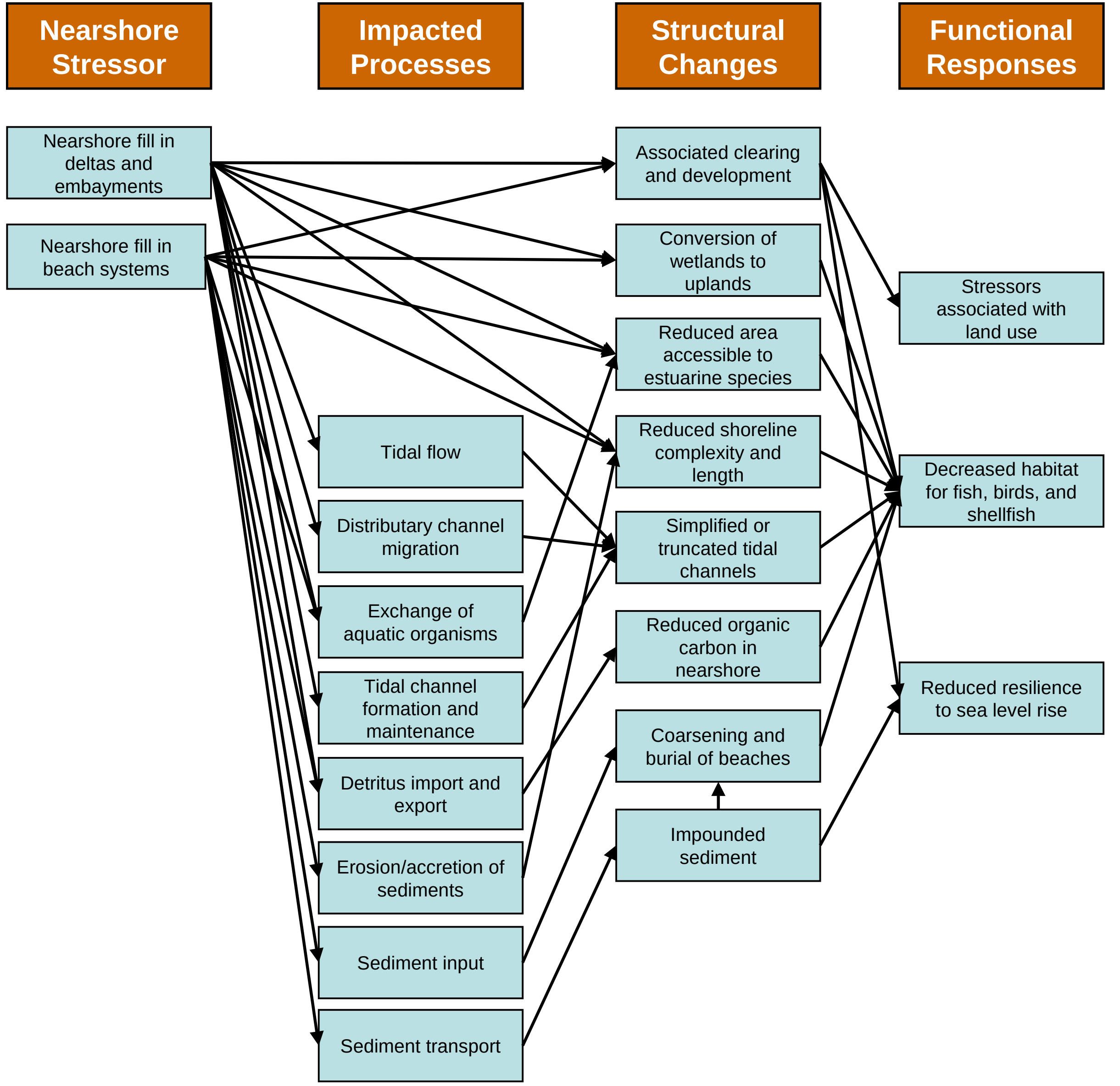


Figure 4-2
Conceptual Model Diagram Showing the Impacts of Fill on Nearshore Processes, Structures, and Functions

4.2.3 Impacts of Nearshore Fill on Valued Ecosystem Components

Processes impaired by nearshore fill can result in direct impacts to juvenile salmonids, forage fish, nearshore birds, great blue heron, and beaches and bluffs. Indirect effects to coastal forests, native shellfish, and orca whales can be inferred from direct impacts.
Juvenile salmon are impacted by nearshore fill because wetland and shallow water habitats are buried and lost. Migrating and rearing juveniles require shallow water habitat for their growth and survival (Fresh 2006).

Bluffs and beaches are impacted by nearshore fill as sediment supply processes are interrupted or stopped. This impact was previously described in Section 4.2.2. Beach spawning forage fish, such as surf smelt and sand lance, are impacted through interruptions in sediment processes and the subsequent coarsening of beach sediment or the direct burial of high beach areas that results from nearshore fill.

Shorebirds that depend upon shallow water and wetland habitats for feeding and nesting are impacted because these habitats can be lost with nearshore fill. These include shorebirds such as sandpipers, plovers, and similar birds, as well as other wading birds such as great blue heron (Eissinger 2007).

Marine riparian vegetation in the backshore is indirectly impacted by nearshore fill, as removal of shoreline vegetation commonly accompanies fill placement. Both juvenile salmonids and forage fish are impacted by this vegetation removal, as vegetation that overhangs beaches helps to maintain suitable temperature and moisture regimes in beach substrates and shallow water habitat (Penttila 2007). Additionally, this vegetation serves as a source of terrestrial insects, an important prey item for juvenile salmon in the nearshore (Fresh 2006).

Native shellfish are impacted by changes in substrate size, as their normal habitat consists of intertidal areas of small grain size. Shellfish are also impacted by alterations in tidal regimes. They are susceptible to extreme heat and desiccation events (Dethier 2006); therefore, changes to tidal regime are particularly damaging to them.

4.2.4 Distribution of Nearshore Fill Throughout Puget Sound Basin and Its Sub-basins

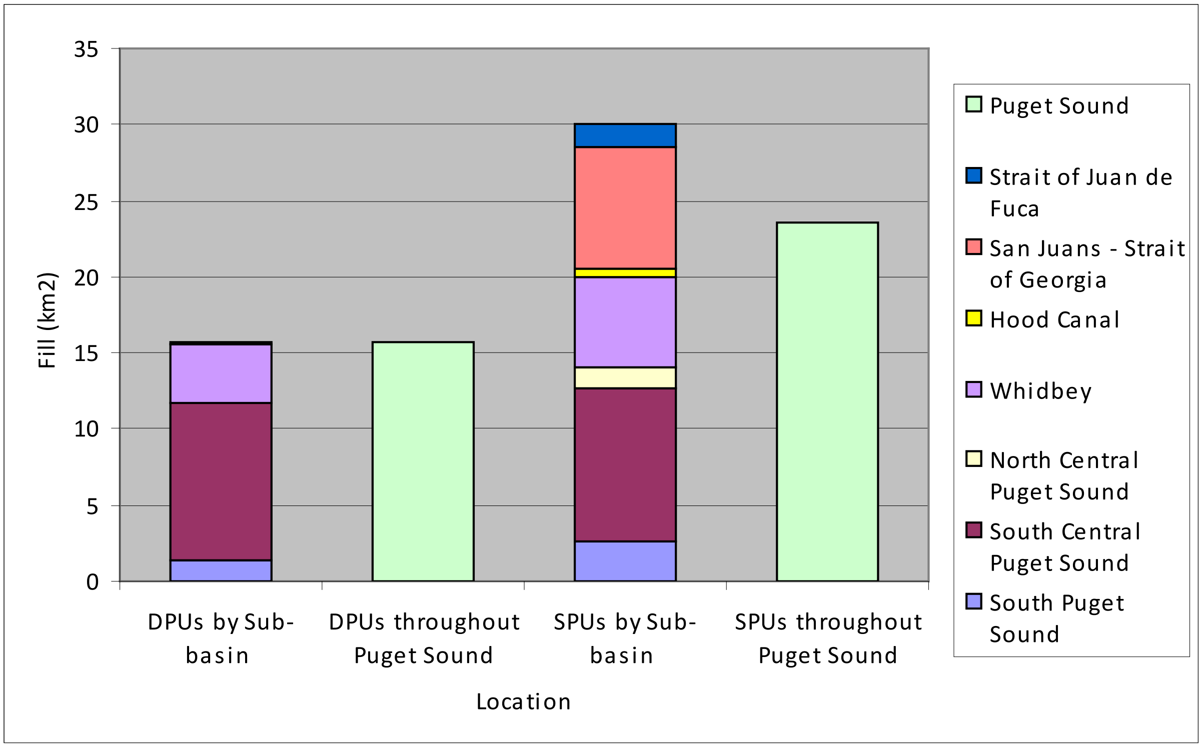
In the Puget Sound Basin, nearshore fill is mapped in 2 percent of the nearshore zone (39 km^2 of 2,036 km^2). However, a review of the existing fill dataset, the River History Project historic wetland dataset, and contemporary air photos in the Whidbey sub-basin suggests that the Change Analysis may have substantially underestimated the actual area of nearshore fill (see discussion in Section 4.2.1).

The occurrence of mapped fill is relatively uncommon compared with some other stressors (e.g., armoring). An exception is that fill was mapped along 62 percent of the length of artificial shoreforms. Fill was mapped much less frequently in other shoreforms, including 10 percent of the length of barrier beaches, 9 percent of barrier lagoons, 6 percent of deltas, 4 percent of open coastal inlets, and just 3 percent of each of bluff-backed beaches and barrier estuaries.

Of the mapped fill area, 60 percent is associated with SPUs and 40 percent is in DPUs (see Table 4-3 and Figure 4-3). The South Central Puget Sound and Whidbey sub-basins together account for 77 percent of the mapped fill in the Puget Sound Basin. Five DPUs (Duwamish, Puyallup, Snohomish, Deschutes, and Skagit) collectively account for almost 39 percent of the mapped fill in the Puget Sound region, and just two of these (Duwamish and Puyallup) combined account for more than 26 percent of the mapped fill in the region. One quarter of nearshore fill is in the Whidbey sub-basin; the majority of intertidal fill in the Whidbey sub-basin occurred outside of the three DPUs. Nine of the 16 DPUs have minimal or no fill mapped (for example, Dosewallips and Duckabush each have 0.06 km^2 of mapped fill).

Table 4-3
Percentage of Nearshore Fill in Puget Sound Sub-basins

Basin/Sub-basin	Nearshore Zone Area (km^2)	Area of Nearshore Fill (km^2)	Percent of Nearshore Zone Impacted by Fill (%)	Area of DPU Fill (km^2)	Area of SPU Fill (km^2)
Strait of Juan de Fuca	181.4	1.58	0.9	0.00	1.58
San Juan Islands – Strait of Georgia	580.3	7.93	1.4	0.00	7.93
Hood Canal	154.5	0.72	0.5	0.12	0.60
Whidbey	549.5	9.86	1.8	3.92	5.94
North Central Puget Sound	112.8	1.34	1.2	0.00	1.34
South Central Puget Sound	262.9	20.38	7.8	10.33	10.05
South Puget Sound	287.3	3.98	1.4	1.37	2.61
Puget Sound	**2,035.8**	**39.3**	**1.9**	**15.74**	**23.56**



Note: Summing SPUs within each sub-basin may result in greater values than reported for Puget Sound due to the spatial overlap of process units.

Figure 4-3

Nearshore Fill Area Distribution by Process Unit Types (DPUs and SPUs) in Puget Sound Sub-basins

4.3 Shoreline Armoring

4.3.1 Description of Shoreline Armoring

Shoreline armoring is a general term used to describe shore-parallel erosion control structures, such as bulkheads (also referred to as seawalls) and rock revetments. Armoring is typically constructed to prevent wave-induced erosion and to retain fill in shoreline and intertidal areas. Armoring is extensive in industrial and heavily urbanized areas, is often employed to protect roads and railroads along the water's edge, and is a common element of residential shoreline development.

The shoreline armoring dataset used for this report is a compilation of data sources that provides a spatially explicit delineation of the start and end points of armoring throughout the Puget Sound General Investigation study area (see Anchor QEA 2009). The dataset does not contain information about the waterward position of armoring structures relative to ordinary high water.

4.3.2 Impacts of Shoreline Armoring on Nearshore Processes, Structures, and Functions

Shoreline armoring impacts the nearshore by decreasing tidal area and by altering nearshore sediment, water, organic matter, and wave energy conditions.

Photo 4-5
Example of shoreline armoring disconnecting a bluff-backed beach
(Photo courtesy of Coastal Geologic Services)

Impacts due to armoring are generally related to the degree to which the structure interacts with wave energy, specifically whether the structure extends below MHHW. The presence of armoring on the upper beach impounds sediments and wood from backshore bluffs and interrupts sediment supply to the upper beach (Canning and Shipman 1995) or berm. The loss of a backshore berm, due either to the presence of a structure or due to resulting erosion, reduces the potential of accumulating drift wood (LWD) and beach wrack (detritus). Below the MHHW line, armoring results in a coarsening of beach substrate, as wave energy reflected from bulkheads causes an increase in erosion waterward of the structure (MacDonald et al. 1994). These changes to substrate cause lower substrate moisture and higher temperatures, which affect forage fish that spawn on this material. At the same time, armoring below MHHW also alters sediment transport rates and volumes (Miles et al. 2001; Johannessen and MacLennan 2007).

Armoring is primarily associated with bluffs and barrier beaches, but can also impact other landforms. In tidal marsh areas, armoring causes reduced sediment and organic deposition, which stalls the formation and maintenance of tidal channels and discourages distributary channels from migrating across the marsh surface. Lost tidal channels ultimately lead to degraded habitat for estuarine species (as discussed in Section 4.3.3). In addition, when marshes degrade, shoreline resistance to sea level rise is reduced.

The presence of armoring near stream mouths or in constricted tidal flow areas can also alter the character and distribution of flows and LWD to the shoreline. This alteration results in loss of backshore vegetation, which in turn increases erosion and decreases habitat for shorebirds. In some cases, armoring can function as a tidal barrier, with associated impacts (as described in Section 4.1).

Armoring is also typically associated with other clearing and development for shoreline areas. The combined changes to the shoreline structure from these activities can lead to increased risks of erosion and more degraded habitats along the length of the altered shore.

The conceptual model shown in Figure 4-4 describes the links between armoring and nearshore processes, structural changes, and functional responses.

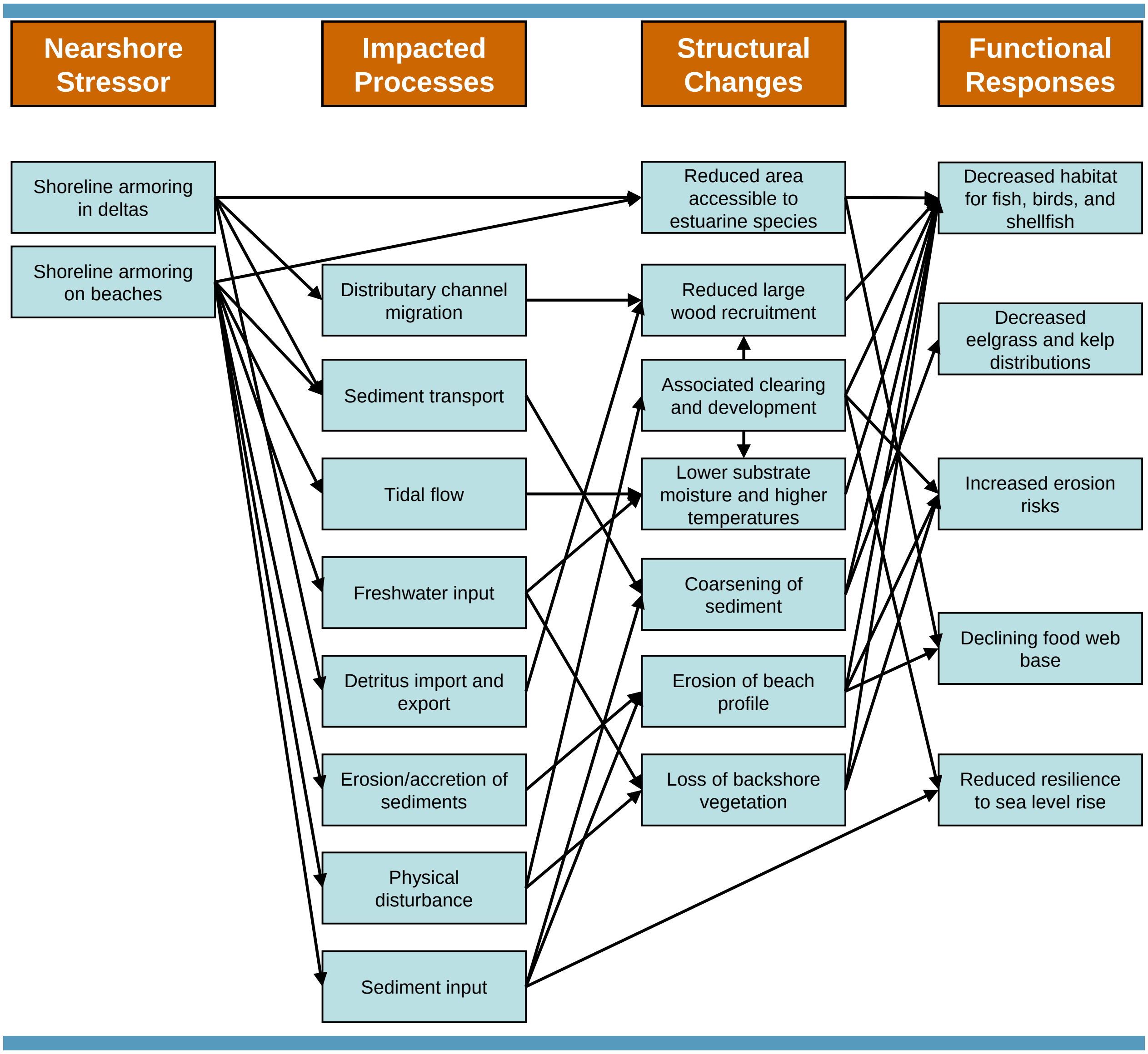


Figure 4-4

Conceptual Model Diagram Showing the Impacts of Armoring on Nearshore Processes, Structures, and Functions

4.3.3 Impacts of Shoreline Armoring on Valued Ecosystem Components

Processes impaired by armoring result in direct impacts to beaches and bluffs, forage fish, juvenile salmon, native shellfish, eelgrass and kelp, nearshore birds, and great blue heron. Indirect effects to coastal forests and orca whales can be inferred from direct impacts. Beaches are lost as upper intertidal beach substrate is buried by the armoring structure, which may also include nearshore fill. Additionally, shoreline armoring contributes to beach loss via the coastal squeeze, which is due to sea level rise along armored shores via a process called passive erosion. Beach loss resulting from the coastal squeeze is incurred as the waterline gradually migrates landward against a static, armored shoreline. Armoring precludes the natural process of shoreline transgression, which enables beaches to adapt to changing conditions.

Bluffs are impacted by armoring, as they are the primary source of beach sediment. When bluffs no longer erode, sediment available to down-drift beaches is reduced (Johannessen and MacLennan 2007). This loss of sediment supply reduces or degrades habitats for animals and plants that depend on the input of fine sediments, such as forage fish, shellfish, eelgrass, and birds. Forage fish are impacted by armoring when spawning habitat is lost due to the burial of the upper beach, as a result of the sediment processes described above (Griggs 2005). In addition, increased wave reflectivity and the structural footprint of the armoring preclude the deposition of driftwood and beach wrack, both of which are known to reduce substrate temperature and increase the moisture content of sediment that aids in forage fish spawn survival and benthic invertebrate production (Tonnes 2008). Native shellfish (such as clams) and eelgrass, both of which require fine substrates, are also affected when substrates change (Mumford 2007; Dethier 2006). Changes in substrate characteristics and loss of beach area also impact shorebirds, some of which use intertidal mudflat habitats for feeding on important invertebrate prey items (Buchanan 2006).

Juvenile salmon are impacted by armoring because armoring alters migration corridors and renders young salmonids more susceptible to predation (Heiser and Finn Jr. 1970). Shore armoring also typically reduces cross-shore and alongshore connectivity, both of which adversely affect habitats used by juvenile salmon and other important nearshore species (Fresh 2006).

Juvenile salmon, forage fish, eelgrass and kelp, native shellfish, and shorebirds are impacted due to reduced shallow water habitat area resulting from armoring (often associated with fill). These species require abundant shallow water habitat for their growth and survival (Fresh 2006; Penttila 2007; Buchanan 2006; Dethier 2006). As the substrate at the toe of armoring erodes, the toe elevation lowers and shallow water habitat area decreases.

Vegetation is often indirectly impacted, as shoreline armoring is commonly associated with wetland and marine riparian vegetation clearing. This vegetation provides shade to intertidal habitats, recruits LWD, and acts as a source of terrestrial insects for foraging migrating salmonids. Vegetation also helps maintain suitable temperature and moisture regimes in beach substrates and shallow water habitat for juvenile salmon and forage fish (Penttila 2007). Marsh areas provide foraging habitat for great blue heron.

4.3.4 Distribution of Shoreline Armoring Throughout Puget Sound Basin and Its Sub-basins

Shoreline armoring cumulatively occurs along 27 percent of the study area (Table 4-4). The percent of armored shoreline varies considerably (10 to 63 percent) across the sub-basins that comprise the study area. The South Central Puget Sound sub-basin has the most armoring, accounting for close to 63 percent of the sub-basin's shoreline. Other sub-basins with considerable shoreline armoring include the South Puget Sound (35 percent), Whidbey (23 percent), and Hood Canal (21 percent) sub-basins. The sub-basins with the least shoreline armoring include the North Central Puget Sound (10 percent), San Juan Islands – Strait of Georgia (14 percent), and Strait of Juan de Fuca (16 percent) sub-basins.

Table 4-4

Length and Percent of Shoreline Armoring in Puget Sound Sub-basins

Basin/Sub-Basin	Total Shoreline Length (km)	Total Shoreline Length Armored (km)	Percent of Shoreline Armored
Strait of Juan de Fuca	329.2	53.0	16.1
San Juan Islands – Strait of Georgia	1,186.5	166.5	14.0
Hood Canal	395.2	83.7	21.2
Whidbey	634.3	142.4	22.5
North Central Puget Sound	249.4	24.4	9.8
South Central Puget Sound	648.4	407.5	62.8
South Puget Sound	724.8	249.8	34.5
Puget Sound	**3,969.2**	**1,070.7**	**27.0**

Different shoreforms have varying degrees of armoring (Table 4-5). Artificial shores have the highest percent armoring, measuring 74 percent armored across Puget Sound. Bluff-backed beaches are the most frequently armored natural shoreform; 33 percent of all bluff-backed beaches across the Puget Sound region are armored. Twenty-seven percent of all barrier beaches are also armored. Other shoreforms are less frequently armored, or data limitations did not adequately capture armoring along those shoreforms. Barrier estuaries (7 percent) and rocky platforms (4 percent) are infrequently armored. The least armoring was mapped along plunging rocky shoreline (0.5 percent) throughout the Puget Sound Basin.

Table 4-5
Length and Percent of Shoreline Armoring along Puget Sound Shoreforms

Current Shoreform	Total Shoreline Length (km)	Total Shoreline Length Armored (km)	Percent of Shoreline Armored
Artificial	378.4	278.7	73.6
Barrier Beach	440.3	119.9	27.2
Bluff-backed Beach	1,529.2	511.3	33.4
Barrier Estuary	163.6	11.2	6.8
Barrier Lagoon	61.7	9.2	15.0
Open Coastal Inlet	245.9	54.9	22.3
Pocket Beach	138.8	11.4	8.2
Plunging Rocky	186.4	0.9	0.5
Rocky Platform	509.6	21.7	4.3
Delta	310.3	51.5	16.6
TOTAL	3969.2	1070.7	27.0

Note: Closed lagoons/marshes (CLM) do not occur on the shoreline; therefore, no shoreline alterations are associated with them. Other shoreform types are delineated waterward of CLM shoreforms and have the shoreline alterations attributed to them.

Studies of potential sediment supply have been carried out in more detail in a number of local areas and suggest that bluff-backed beaches are primary sources of nearshore sediment (Johannessen et al. 2005; Johannessen and Chase 2005; and others, as cited in Johannessen and MacLennan 2007). This result was also evident in the Change Analysis (Simenstad et al. 2011). Shoreline armoring along these shoreforms results in impoundment of nearshore sediment sources (reduced sediment supply) as well as the other adverse impacts of shore armoring (as described in previous sections). Shoreline armoring along bluff-backed beaches is somewhat similar in distribution to armoring among divergent zones, with a considerable number of bluffs being either completely free of armoring or completely armored (Figure 4-5). Thirty-four percent of all bluff-backed beaches are armored along more than 50 percent of the shore unit. Twenty-five percent of all bluff-backed beaches are completely unarmored. Across the larger study area, bluff-backed beaches are most frequently armored in the South Central Puget Sound (61 percent) and South Puget Sound (41 percent) sub-basins. Twenty-six percent of the bluff-backed beaches in the Hood Canal sub-basin have greater than 50 percent of the shoreline length armored. The San Juan Islands – Strait of Georgia, Whidbey, and Strait of Juan de Fuca sub-basins' bluff-backed beaches have a lower frequency of highly armored (greater than 50 percent armored) bluff-backed beaches.

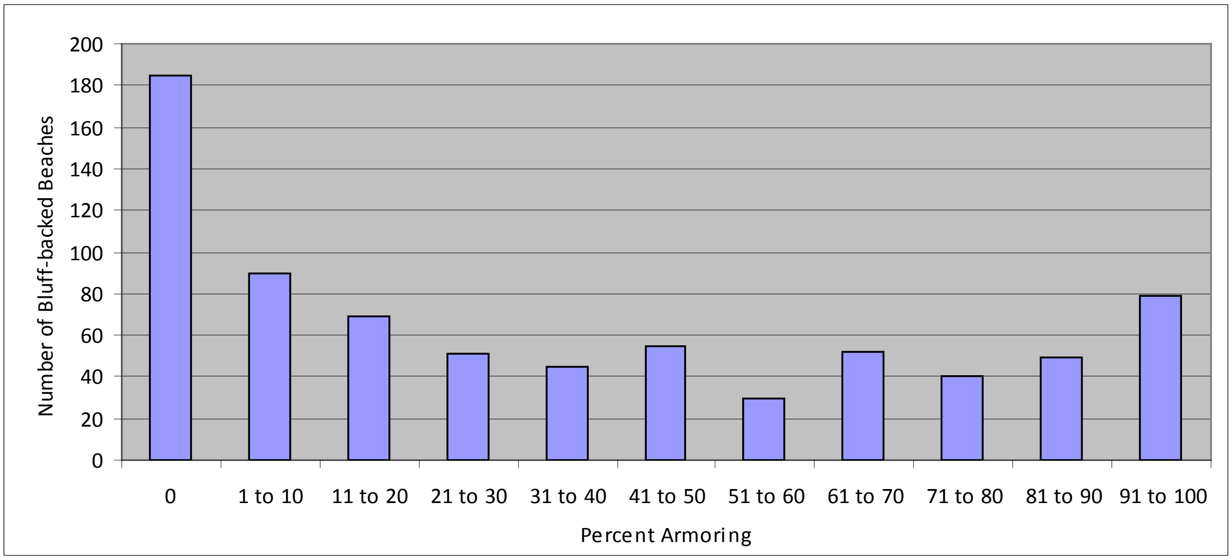


Figure 4-5

Frequency Distribution of Armoring among Bluff-backed Beaches

The location of armoring within drift cells can affect the proportion of the drift cell that could be impacted by the armoring. The divergent zone component of drift cells is at the "start" of two drift cells where sediment can be transported along the shore in either direction. Shoreline armoring in divergent zones that transport material in two directions therefore has the potential to affect sediment distribution in not only one, but two drift cells. In the study area, there were 350 mapped divergent zones. Approximately 59 percent of all divergent zones were armored partially or entirely. The median percent armoring within divergent zones throughout the Puget Sound Basin is 18 percent. Thirty-five percent of all divergent zones in the study area have armoring along more than half of their length (51 percent or more). A substantial number (18 percent) of divergent zones have a very high amount (91 to 100 percent) of their shoreline armored. The frequency of divergent zones in areas of varying armoring coverage is shown in Figure 4-6.

Armoring within divergent zones was most frequently mapped in the South Central Puget Sound sub-basin where 64 percent of the divergent zone shoreline length was armored. The South Puget Sound (35 percent) and Hood Canal (30 percent) sub-basins contained the next highest percentages of armored divergent zone shorelines. The smallest average percent of shoreline armoring is in the divergent zones of the North Central Puget Sound sub-basin, which has 6 percent of the divergent zone shoreline length armored.

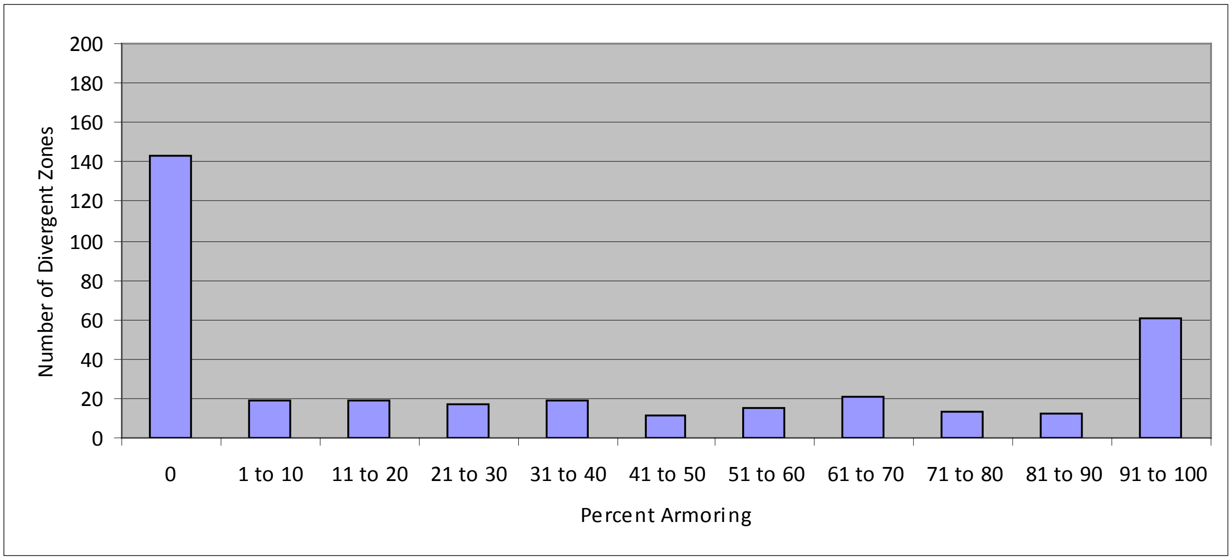


Figure 4-6

Frequency Distribution of Armoring in Drift Cell Divergent Zones

Geology is influential to the distribution of shoreline armoring. Sub-basins such as the Strait of Juan de Fuca and the San Juan Islands – Strait of Georgia, which include extensive rocky shorelines, have less armoring due to the reduced need for erosion control.

Surprisingly, exposure does not appear to substantially influence the prevalence of armoring, as sub-basins with (relatively) high exposure are some of the least armored areas (e.g., the North Central Puget Sound sub-basin, which has high exposure, is only 10 percent armored). The sub-basins with the most armoring include some of the most protected shores across the region (South Puget Sound and South Central Puget Sound sub-basins). Parcel density does not appear to be of particular influence to the occurrence of armoring.

4.4 Railroads

4.4.1 Description of Railroads

The railroads stressor includes active and abandoned railroads within 25 m of the shore. In Puget Sound, railroads within this nearshore zone have typically been built on fill material placed in upper intertidal or backshore areas. Intersections with coastal streams have been accommodated by culverts passing through the railroad fill. In some cases, these culverts have been fitted with tide gates. Larger streams and rivers have required bridge crossings. While the rail line often follows the shoreline closely, smaller coastal embayments have been crossed by building on pilings or a prism of fill material. In some locations, ditches running parallel and on the upland side of the rail line direct surface water runoff to discharge locations.

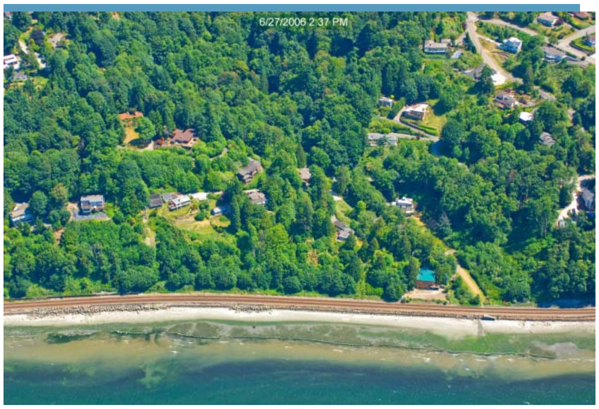


Photo 4-6
Example of railroad along Puget Sound shoreline
(Photo courtesy of WDOE)

The railroad dataset was created for the Change Analysis based on information on active and abandoned rail lines from Washington State Department of Transportation (WSDOT).

4.4.2 Impacts of Railroads on Nearshore Processes, Structures, and Functions

The presence of railroads impacts the nearshore through direct loss of habitats, and through alteration of sediment, water, organic matter, light, and energy conditions. The most obvious impact from railroads is the direct loss of nearshore habitats from burial associated with fill placement in nearshore areas. For beaches, changes include steepening of the profile and coarsening of sediment due to increased wave energy and altered tidal hydrology. Coastal streams can become isolated from nearshore marine areas. In addition, areas of riparian and other backshore vegetation are often reduced in the presence of railroads, with concomitant increases in temperature from solar radiation.

Interruption of bluff sediment input and transport processes occurs due to the presence of nearshore fill and bulkheads necessary to protect rail lines against bluff erosion. Below the bluffs, passive beach erosion processes and landward accretion are interrupted, leading to loss of intertidal/shallow subtidal beach area. Depending on the geographic setting and location along the beach slope, the railroad fill can also impact wave energy and associated littoral sediment transport.

In areas where they cross deltas and embayments, railroads interrupt the migration of any distributary channels that exist. Tidal flow to marshes landward of the rail line can also be constricted or disconnected. These changes limit the flow of sediment, detritus, and organisms from the embayments to marine areas, and lead to changes in marsh channel structure, nearshore food webs, and the beach profile. In addition, as discussed previously for other stressors, degraded and subsided marsh and shoreline habitats have less resistance to sea level rise.

The presence of railroads also disrupts connectivity between nearshore aquatic ecosystems and adjacent terrestrial systems. Tidal influence can be reduced in coastal streams, as can the tidal hydrology of coastal embayments crossed by rail lines. Groundwater seeping from the base of coastal bluffs may not reach beaches where it historically discharged.
Backshore vegetation is physically separated by the rail line from nearshore areas that otherwise collect inputs from terrestrial ecosystems. The movement of aquatic organisms across the aquatic/terrestrial ecosystem interface is disrupted. Fish movement is impacted by culverts, loss of shallow water areas, and barriers to areas that were previously accessible.

Areas that served as sources of detrital and LWD material may be isolated from locations where this material might otherwise collect and be processed by detritivores. An additional effect is that creosoted railroad ties can provide a source for contaminants to nearshore areas.

Photo 4-7
Example of railroad along Puget Sound shoreline
(Photo courtesy of Anchor QEA)

It is important to note that most impacts to nearshore environments occurred during initial railroad construction. However, operation of the rail lines and associated ongoing maintenance results in continued disturbance to aquatic organisms, terrestrial and aquatic vegetation, wood accumulation, and sediment processes. Vegetation is kept clear of rail lines. Material from periodic landslides is generally removed and disposed of at off-site locations. Emergency repairs may result in the unplanned disposal of landslide debris into adjacent aquatic areas.

The conceptual model in Figure 4-7 describes the links between railroads and nearshore processes, structural changes, and functional responses.

4.4.3 Impacts of Railroads on Valued Ecosystem Components

Processes impaired by railroads can result in direct impacts to juvenile salmon, forage fish, native shellfish, beaches and bluffs, and coastal forests. Indirect effects to orca whales, nearshore birds, and great blue herons can be inferred from railroad impacts.

Juvenile salmon are impacted by the disconnection of upland and nearshore habitats that occurs in the presence of railroads. This disconnection diminishes the production and delivery of important terrestrial insect prey. In addition, salmonid behavior and the behavior and survival of forage fish (salmon prey items) are affected, as discussed below.

Beaches are lost as upper intertidal beach substrate is buried. Connections between beaches, bluffs, and riparian vegetation are interrupted. For forage fish, impacts include direct loss of beach spawning area, gradual loss of beach area associated with passive erosion, loss of finer

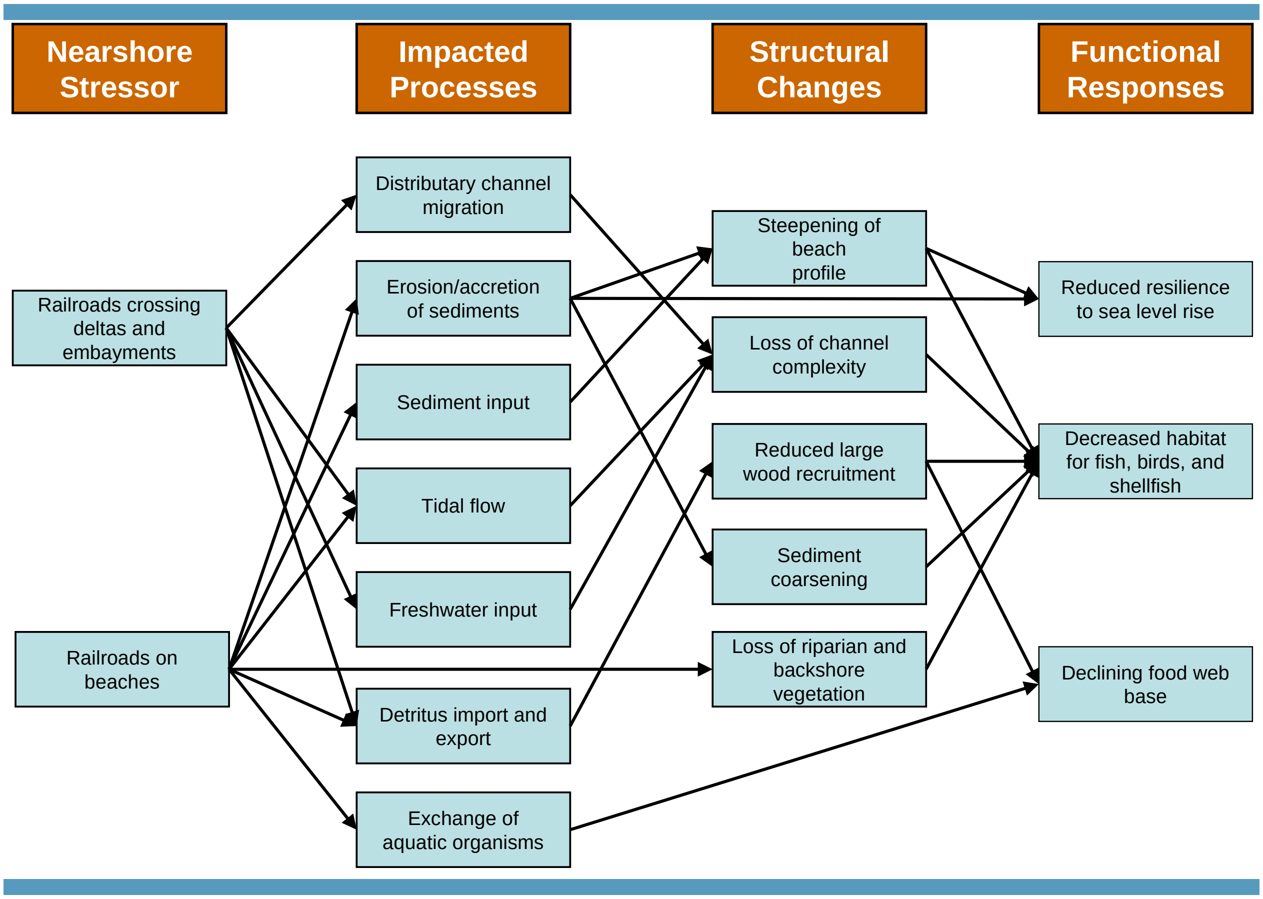


Figure 4-7

Conceptual Model Diagram Showing the Impacts of Railroads on Nearshore Processes, Structures, and Functions

grain materials necessary for spawning, and loss of overhanging vegetation and groundwater discharge that serve to moderate temperature and substrate moisture necessary for egg survival. Factors that lead to the loss of shallow water areas force small fish into deeper waters, increasing their exposure to potential predators. Fish movement into shallow embayments is impeded by culverts, tide gates, or fill material.

Juvenile salmonids and shorebirds are impacted by the decrease in LWD, loss of upper intertidal areas, and decreased detritus input stemming from the presence of railroads. The loss of these resources leads to decreased diversity and abundance of aquatic invertebrates used as food resources. While not documented, it is possible that the noise of a busy rail line creates conditions that discourage shorebird and heron use of shorelines for resting, refuge, and foraging.

4.4.4 Distribution of Railroads Throughout Puget Sound Basin and Its Sub-basins

Relative to other shoreline modifications documented in the Change Analysis geodatabase, railroads (active and abandoned) are less frequent and more highly variable in their distribution across Puget Sound. Sound-wide, active railroads occur along approximately 1.4 percent of the shoreline, while abandoned rail lines occupy 0.4 percent (Table 4-6). Taken together, this translates to 71 km of railroads along the nearly 4,000 km of Puget Sound (approximately 2 percent). By comparison, other shoreline features mapped as a percentage of shoreline length ranged from 8 percent (roads) to 27 percent (armoring).

As a percentage of shoreline length, active and abandoned railroads combined are most prevalent in the South Central Puget Sound (2.8 percent) and South Puget Sound (2.6 percent) sub-basins. A continuous rail line runs along the northeast shore of South Central Puget Sound from north of Seattle to the sub-basin boundary near Edmonds. Portions of the South Central Puget Sound sub-basin south of Seattle do not contain railroads. Similarly, the South Puget Sound sub-basin shoreline contains an active rail line from near its northern boundary at Point Defiance that extends south to the Nisqually River. Few active railroads exist elsewhere in the sub-basin. The San Juan Islands – Strait of Georgia sub-basin has railroads along 2 percent of its 1,187 km of shoreline, yielding the largest single length of railroad (20 km). All of the reported railroad length in this sub-basin is along the eastern shore of the sub-basin adjacent to Samish and Bellingham Bays. In the Whidbey sub-basin, 1 percent of the shoreline length is occupied by a railroad, primarily between the sub-basin boundary near Edmonds northward through Everett and the Snohomish River estuary. No active railroads were reported for the Strait of Juan de Fuca sub-basin, but 4 percent (13.2 km) of its length is occupied by abandoned rail lines. This represents 87 percent of the total length of abandoned railroad in Puget Sound. The North Central Puget Sound and Hood Canal sub-basins were not reported to have active or abandoned railroads.

Table 4-6

Railroad Distribution in Puget Sound Sub-basins

Basin/Sub-basin	Total Shoreline Length (km)	Length of Shoreline that is Active Railroad (km)	Percent of Shoreline that is Active Railroad	Length of Shoreline that is Abandoned Railroad (km)	Percent of Shoreline that is Abandoned Railroad	Total Length of Shoreline Active + Abandoned Railroad (km)	Total Percent of Shoreline that is Active + Abandoned Railroad
Strait of Juan de Fuca	329.2	0.0	0.0	13.3	4.0	13.3	4.0
San Juan Islands – Strait of Georgia	1,186.5	19.5	1.6	1.3	0.1	20.8	1.8
Hood Canal	395.2	0.0	0.0	0.0	0.0	0.0	0.0
Whidbey	634.3	8.6	1.4	0.0	0.0	8.6	1.4
North Central Puget Sound	249.4	0.0	0.0	0.0	0.0	0.0	0.0
South Central Puget Sound	648.4	18.0	2.8	0.0	0.0	18.0	2.8
South Puget Sound	724.8	18.7	2.6	0.7	0.1	19.4	2.7
Puget Sound Basin	**3,969.2**	**55.9**	**1.4**	**15.3**	**0.4**	**71.2**	**1.8**

4.5 Nearshore Roads

4.5.1 Description of Nearshore Roads

Nearshore roads consist of roads along the shoreline itself and in the nearshore zone. The Change Analysis showed that approximately 8 percent of Puget Sound's shorelines contain roads as a shoreline modification.

The road dataset used for this report is the ShoreZone data (WDNR 2001), which includes roads within 25 m of shore.

4.5.2 Impacts of Nearshore Roads on Nearshore Processes, Structures, and Functions

The impacts of roads are generally considered as part of the effects of co-occurring stressors. These co-occurring stressors include armoring, fill, and tidal barriers that are constructed as part of development. Depending on the circumstance, the co-occurring stressor (e.g., shoreline armoring) may be the primary one causing the disruption of nearshore processes rather than the road itself. The impacts depend on the co-stressor, the location, and the configuration in the landscape.

Roads that occur near beaches are typically armored in order to stem shoreline erosion. These roads are usually situated directly on the shoreline and therefore the armoring is part of the road prism. The potential effect on nearshore processes of the construction and presence of such roads could include hydrologic disruption and an increase in wave energy across (perpendicular to) the shoreline; loss of riparian vegetation; and loading of contaminants associated with the road surface or routing along the road. In addition, input and accretion of sediment, wood, and detritus from bluff and riparian areas are interrupted. Thus, sediment from bluffs never reaches the shore, and intertidal and subtidal beach habitat is eventually lost. The beach profile is steepened and coarsened in the presence of this armoring. Roads would also be likely to disrupt freshwater flow patterns to the nearshore as they often transform surface sheet flow, especially in wetlands, to channelized flow through ditches and culverts.

Photo 4-8
Example of road along shoreline of Puget Sound
(Photo courtesy of Coastal Geologic Services)

For roads that occur within the nearshore zone, but lack a co-occurrence with armoring, the effect on longshore sediment transport is expected to be negligible unless the road occurs mid-slope along a bluff-backed beach. In this case, the road can affect the hydrology of the slope, and thus, the ultimate stability of the bluff-backed beach.

Nearshore roads can also co-occur with fill, typically in deltas and embayments. Fill in these areas directly buries shallow water and wetland areas and disrupts the exchange of aquatic organisms between wetland and nearshore areas, as discussed in Section 4.2. These changes lead to degraded and decreased habitat for fish and wildlife, and the prey base that supports them. As is typical with other stressors, degraded and subsided wetland habitats also offer less resistance to sea level rise.

Deltas and embayments also may have roads with tidal barriers, typically where bridges have been built to span mouths of embayments. In the most severe cases, this type of activity can cause a transition from an open coastal inlet to a barrier estuary, barrier lagoon, or closed lagoon/marsh. Roads spanning the mouth of an embayment can have the effect of reducing the cross-section of the opening, which in turn affects the tidal prism within the embayment.

As with railroads, it is important to note that most impacts to nearshore environments occur during initial road construction. Ongoing maintenance may be required, such as vegetation or landslide control, which results in continued disturbance to aquatic organisms, terrestrial and aquatic vegetation, large wood accumulations, and sediment processes.

The conceptual model shown in Figure 4-8 describes the links between nearshore roads and nearshore processes, structural changes, and functional responses.

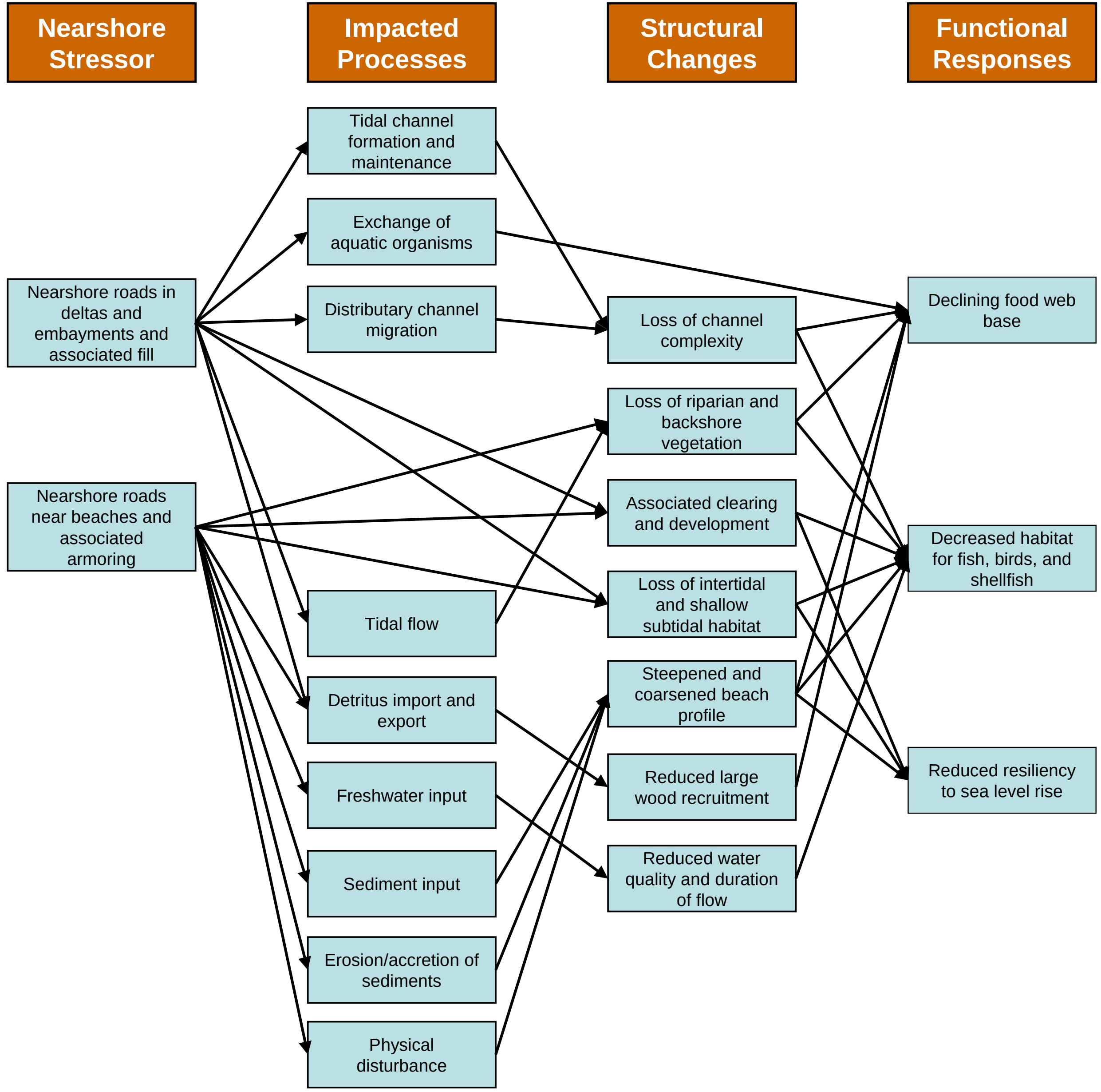


Figure 4-8

Conceptual Model Diagram Showing the Impacts of Nearshore Roads on Nearshore Processes, Structures, and Functions

4.5.3 Impacts of Nearshore Roads on Valued Ecosystem Components

Processes impaired by roads can result in direct impacts to juvenile salmon, forage fish, native shellfish, nearshore birds, great blue heron, beaches and bluffs, and coastal forests. Indirect effects to orca whales may also occur and can be inferred from direct impacts.

As discussed above, disruptions in tidal and freshwater flow can be caused by the presence of roads. This can have the effect of disrupting the input and exchange of certain resources from marine and riverine riparian vegetation to the nearshore, including aquatic insects and detritus. These resources are vital to the nearshore food web that supports juvenile salmon feeding and growth (Brennan et al. 2004).

Forage fish, native shellfish and other aquatic invertebrates, shorebirds, and great blue heron can all be impacted by roads that co-occur with fill and armoring, as tidal habitats for these species can be directly buried as part of road construction.

Beaches and bluffs are impacted by nearshore roads due to the disruptions to sediment processes, as discussed above.

Marine riparian vegetation is impacted by nearshore roads that co-occur with tidal barriers (such as levee roads); the extent of impact depends on the tidal elevations that the road and tidal barrier occupy. For example, levee roads in freshwater tidal segments of deltas are more likely to affect riparian vegetation than levee roads in the lower elevations of the delta.

4.5.4 Distribution of Nearshore Roads Throughout Puget Sound Basin and Its Sub-basins

Roads occur along 8 percent of Puget Sound's shorelines (Table 4-7). As a percentage of shoreline length, roads are most prevalent in the Hood Canal and South Central Puget Sound sub-basins (13 and 11 percent, respectively). Roads extend along approximately the same percent of shoreline in the Strait of Juan de Fuca, San Juan Islands – Strait of Georgia, Whidbey, and South Puget Sound sub-basins (approximately 6 to 7 percent). The North Central Puget Sound sub-basin has the fewest shoreline roads, with 3 percent of its 249 km of shoreline mapped as roads.

Table 4-7

Road Distribution in Puget Sound Sub-basins

Basin/Sub-basin	Total Shoreline Length (km)	Length of Roads (km)	Percent of Shoreline that is Road
Strait of Juan de Fuca	329.2	22.3	6.8
San Juan Islands – Strait of Georgia	1,186.5	72.1	6.1
Hood Canal	395.2	50.5	12.8
Whidbey	634.3	42.7	6.7
North Central Puget Sound	249.4	8.0	3.2
South Central Puget Sound	648.4	72.5	11.2
South Puget Sound	724.8	47.2	6.5
Puget Sound Basin	**3,969.2**	**311.9**	**7.9**

4.6 Marinas

4.6.1 Description of Marinas

Marinas consist of docks that contain boat slips, both temporary and permanent, and include both in-water facilities to accommodate vessel moorage and upland support facilities such as parking lots and vessel services. In Puget Sound, marinas comprise a diverse array of development activities and a wide range of spatial scales.

The marina dataset was created for the Change Analysis based on information on marinas and jetties from the Washington Department of Natural Resources (WDNR) overwater structures database. The marina dataset includes marinas at a minimum size of 12 slips as well as relatively large facilities such as Shilshole Marina that cover large acres of in- and over-water area and many acres of adjacent fill and impervious surface area. Accordingly, the impact of marinas on nearshore processes, structures, and functions can be highly variable depending on size and landscape context.

4.6.2 Impacts of Marinas on Nearshore Processes, Structures, and Functions

Marinas impact beach systems and deltas/embayments in different ways. In beach systems, the physical structure of marinas (and often the associated breakwaters and jetties) disturbs the delivery of sediment alongshore, affecting downdrift grain size and beach profiles. LWD and detritus transport are similarly interrupted. In addition, overwater structures at marinas cause disruptions in solar radiation to the substrate, which limits aquatic plant production and creates foraging problems for juvenile salmon (discussed in Section 4.6.3).

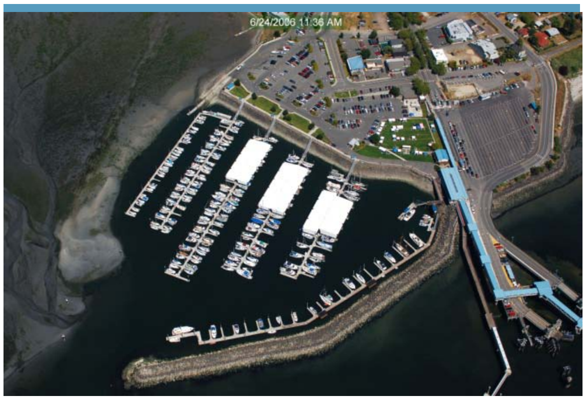


Photo 4-9
Example of a marina, including a breakwater/jetty and other stressors
(Photo courtesy of WDOE)

Marinas occurring in or near deltas and embayments can result in the destruction or reduction of nearby backshore ecosystems because upland facilities and armoring are often required. The connections between aquatic and terrestrial ecosystems are disrupted or eliminated with the construction of these facilities. These conditions lead to decreased and degraded habitat for wildlife that use backshore and other upland habitats.

Marinas can introduce environmental contaminants into the nearshore ecosystem. Piers and piling may include use of treated wood products. Anti-fouling compounds used to protect vessel hulls may leach into the water or accumulate in bottom sediments, and accidental spills may release petroleum or other contaminants into the nearshore environment. Parking lots and upland facilities may provide additional sources of contamination, delivered via stormwater and other site drainage. Contaminant delivery to nearshore areas can impact a wide range of ecological processes, including primary productivity, food web support, and exchange of aquatic organisms.

The conceptual model shown in Figure 4-9 describes the links between marinas and nearshore processes, structural changes, and functional responses.

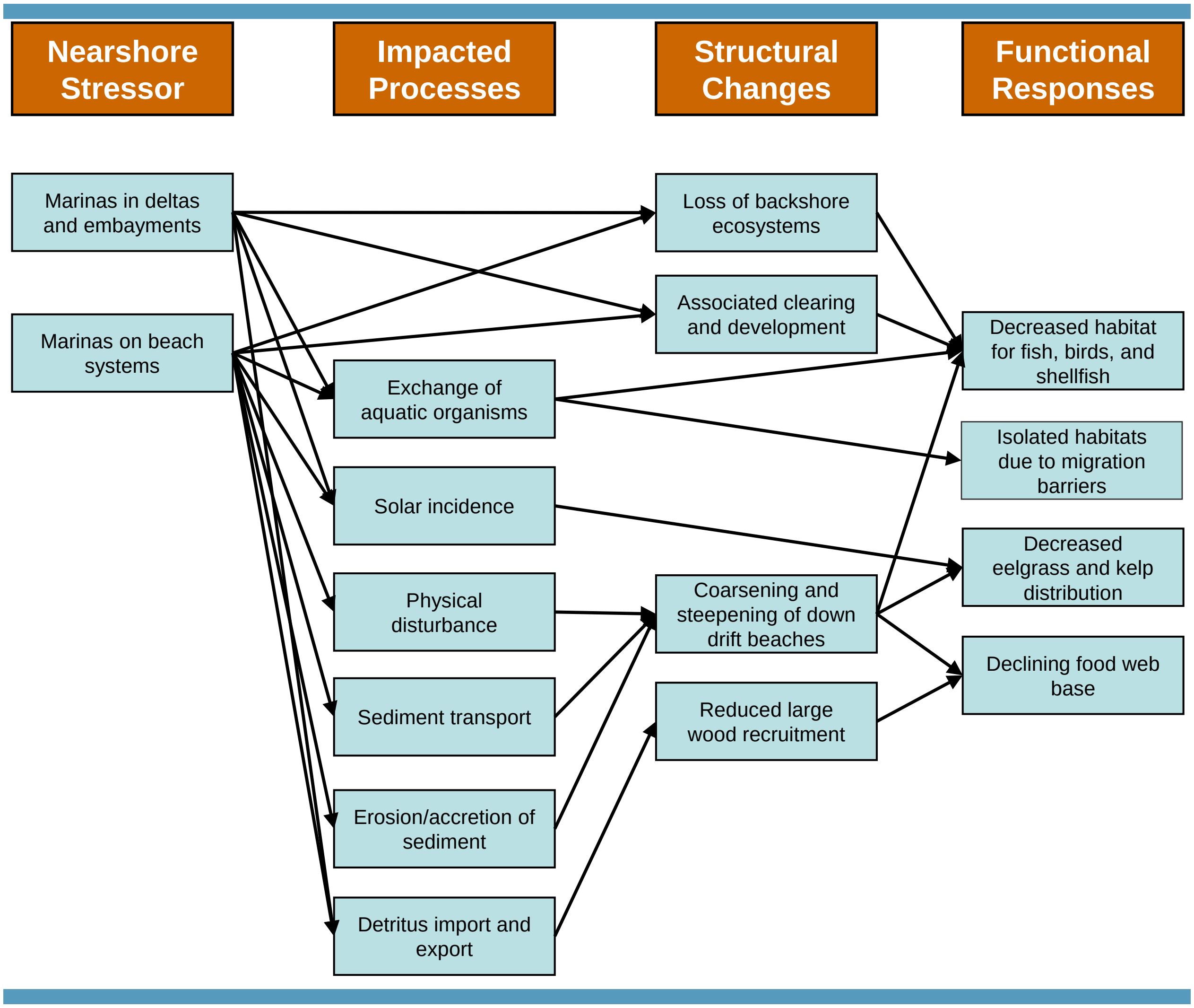


Figure 4-9

Conceptual Model Diagram Showing the Impacts of Marinas on Nearshore Processes, Structures, and Functions

4.6.3 Impacts of Marinas on Valued Ecosystem Components

Processes impaired by marinas can result in direct impacts to juvenile salmon, forage fish, native shellfish, eelgrass and kelp, beaches, and coastal forests. Great blue herons, nearshore birds, and orca whales may be indirectly affected by marinas.

Juvenile salmonids are impacted by marinas in a number of ways. First, shorelines with marinas that historically provided corridors for unimpeded movement in shallow water areas are fragmented by the physical placement of breakwaters and jetties and by shading from piers, docks, and other overwater structures. This interruption of shallow water habitat forces young fish into deeper water areas, increasing their exposure to predators and disrupting their foraging behavior (Nightengale and Simenstad 2001). Disconnection of shorelines from upland habitats limits the production and delivery of terrestrial insects that support food resources for juvenile salmonids and other aquatic organisms. Lastly, detritus movement in the nearshore is limited; this is important because detritus produced in the nearshore zone helps fuel the food web for juvenile salmon (Sibert et al. 1977; Sibert 1979).

If present, forage fish spawning can be impacted as a result of the coarsening of beach substrate due to the shoreline armoring that is associated with most marinas (see Section 4.3). These impacts include the direct loss of beach or eelgrass spawning area, the gradual loss of beach area associated with passive erosion, the loss of finer grained materials necessary for spawning, and the loss of overhanging vegetation, which moderates temperature and substrate moisture necessary for egg survival. Decreased LWD, loss of upper intertidal areas, and decreased detritus input can all lead to decreased diversity and abundance of aquatic invertebrates, including native shellfish and other invertebrates used as food resources by small fish (including juvenile salmonids) and shorebirds. Great blue herons may use floats as platforms for feeding or resting.

Eelgrass and kelp are impacted by the direct loss of nearshore area, as well as by shading from overwater structures, which limits plants' ability to photosynthesize. In addition, changes in substrate sizes result in inappropriate substrates for these plants.

4.6.4 Distribution of Marinas Throughout Puget Sound Basin and Its Sub-basins

Sound-wide, the Change Analysis geodatabase includes 171 marinas, covering 6 km^2, or 0.3 percent of the Puget Sound nearshore area (Table 4-8). More than one-third (67) of these are in the South Central Puget Sound sub-basin, where they cover 3 km^2., which is nearly half of the total Puget Sound area covered by marinas. More than 1 percent of the nearshore zone area of the South Central Puget Sound sub-basin is covered by marinas. The San Juan Islands – Strait of Georgia sub-basin also has a relatively large number of marinas (40) that cover 2 km^2, or 0.3 percent of the sub-basin nearshore area. Moderate numbers of marinas are in the Whidbey (28 total, 1 km^2) and South Puget Sound (26 total, 0.3 km^2) sub-basins. Relatively few marinas were mapped in the Hood Canal (8), North Central Puget Sound (6), and Strait of Juan de Fuca (4) sub-basins.

Table 4-8

Marina Distribution in Puget Sound Sub-basins

Basin/Sub-basin	Count	Nearshore Area (km^2)	Coverage Area (km^2)	Percent of Nearshore Area Coverage	Average Area per Marina (m^2)
Strait of Juan de Fuca	4	181.4	0.2	0.1	50,000
San Juan Islands – Strait of Georgia	40	580.3	2.0	0.3	50,000
Hood Canal	8	154.5	0.1	0.1	12,500
Whidbey	28	549.5	1.0	0.2	35,714
North Central Puget Sound	6	112.8	0.2	0.2	33,333
South Central Puget Sound	67	262.9	3.1	1.2	42,628
South Puget Sound	26	287.3	0.3	0.1	11,538
Puget Sound Basin	**171**[a]	**2,035.8**	**6.3**	**0.3**	**36,842**

Note:

[a] Sub-basins overlap, so a total count of marinas in Puget Sound cannot be arrived at by summing counts in sub-basins.

Overwater coverage per marina was calculated to roughly compare marina sizes across sub-basins. Larger overwater structures cover more area and impact more of the nearshore zone. Coverage per marina in the Strait of Juan de Fuca, San Juan Islands – Strait of Georgia, and South Central Puget Sound sub-basins is higher than in the other sub-basins (approximately 40,000 to 50, 000 m^2); in the Hood Canal and South Puget Sound sub-basins, per-marina coverage is generally less than in the other sub-basins (see Table 4-8).

4.7 Breakwaters and Jetties

4.7.1 Description of Breakwaters and Jetties

Breakwaters and jetties consist of structures designed to mitigate the impact of wave energy on vessel navigation, generally at the entrances to marinas and harbors. They can be perpendicular or parallel to the shoreline, and may or may not be structurally connected to the shore. These structures dampen wave energy either by using mass or an armored revetment slope. In Puget Sound, there is great variability in design and construction of breakwaters and jetties, including both free-floating and anchored structures made from a variety of materials. Because of this variability and the variety of nearshore environments where these structures are located, the impact of each individual breakwater and jetty varies. Therefore, this narrative addresses only those impacts of breakwaters and jetties that are generally applicable to all such structures, regardless of design and environment.

The dataset used for breakwaters and jetties was created for the Change Analysis based on an overwater structures dataset provided by WDNR (supplemented by Anchor 2008b), and includes area calculations for individual breakwater/jetty structures.

4.7.2 Impacts of Breakwaters and Jetties on Nearshore Processes, Structures, and Functions

Similar to other stressors, breakwaters and jetties impact beach systems and delta/embayment systems differently. In beach systems, these structures alter the nearshore through alterations to sediment, wood accumulation, water, and nutrient conditions. The presence of breakwaters and jetties causes physical energy shifts and initiates changes to sediment processes. For example, when breakwaters are offshore and parallel to the shoreline, the lowered wave energy causes sediment to deposit behind the breakwaters, creating artificial accretion beaches and changing the tidal prism. Lowered wave energy also results in diminished sediment erosion and transport along bluff-backed beaches. When breakwaters are perpendicular to shore, longshore sediment drift can become trapped updrift of the structure itself, often altering downdrift habitat by decreasing sediment deposition in those areas. The result is a coarsening and steepening of downdrift beaches, which leads to decreased fish, wildlife, and aquatic plant habitat, reduced LWD, and increased risk for erosion in these areas.

In deltas and embayments, the most significant impact of breakwaters and jetties is to disrupt connectivity between neighboring aquatic ecosystems, particularly when the structures physically connect to the bank. The structures themselves serve as barriers to that movement, interrupting aquatic organism and detrital exchange from freshwater areas and within and among intertidal areas. The detritus source is thus limited within the embayment and the detritus-based food web base declines.

Breakwaters and jetties are particularly significant when associated with overwater structures, marinas, dredging activity, and armoring. When grouped together, the maintenance of these structures involves continual disruption of the nearshore environment, potentially leading to decreases in water quality, changes in water temperature, changes in grain size distribution, and alterations to the beach profile.

Photo 4-10
Example of jetty along shoreline of Puget Sound
(Photo courtesy of Coastal Geologic Services)

The conceptual model shown in Figure 4-10 describes the links between breakwaters/jetties and nearshore processes, structural changes, and functional responses.

4.7.3 Impacts of Breakwaters and Jetties on Valued Ecosystem Components

Processes impaired by breakwaters and jetties result in direct impacts juvenile salmon, forage fish, eelgrass, and native shellfish. Indirect effects may impact nearshore birds, great blue herons, and orca whales.

Juvenile salmon are impacted by breakwaters and jetties because the presence of these structures decreases salmonid migratory and feeding habitat in shallow water areas. Eelgrass, forage fish, and shellfish are impacted by changes in sediment transport and supply, which can result in the coarsening of beach substrates and loss of suitable substrate for these organisms (see Section 4.3). Eelgrass and shellfish require small substrates for attachment and growth. Forage fish such as surf smelt and sand lance require small sand material in the upper intertidal zone for spawning.

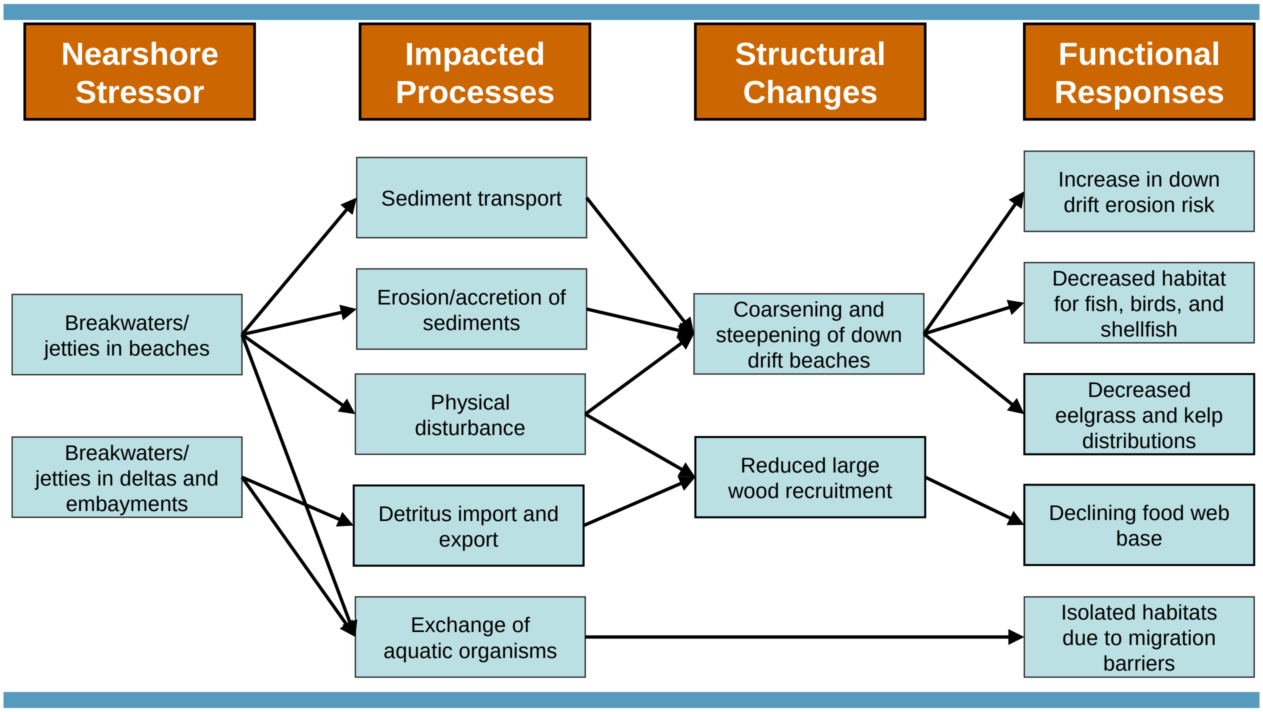


Figure 4-10

Conceptual Model Diagram Showing the Impacts of Breakwaters and Jetties on Nearshore Processes, Structures, and Functions

Shorebirds such as oystercatchers and surf scoters feed in sand flats or on invertebrates associated with eelgrass (Buchanan 2006), so these species could be affected by reductions in these habitats. Great blue herons also forage in tide flats potentially impacted by breakwaters and jetties.

4.7.4 Distribution of Breakwaters and Jetties Throughout Puget Sound Basin and Its Sub-basins

There are 136 breakwaters and jetties in the Puget Sound study area. The Whidbey and San Juan Islands – Strait of Georgia sub-basins account for more than half (65 percent) of the breakwaters and jetties in the Puget Sound Basin (Table 4-9). Six of the 16 DPUs contain breakwaters and jetties: the Snohomish, Skagit, Stillaguamish, Nooksack, Samish, and Big Quilcene DPUs.

Table 4-9
Breakwater/Jetty Distribution in Puget Sound Sub-basins

Basin/Sub-basin	Count of Breakwaters and Jetties	Percent of Total Breakwaters and Jetties in Puget Sound
Strait of Juan de Fuca	12	9
San Juan Islands – Strait of Georgia	34	25
Hood Canal	7	5
Whidbey	54	40
North Central Puget Sound	13	10
South Central Puget Sound	25	18
South Puget Sound	8	6
Puget Sound Basin	**136**	**100**

The structures range from 5 m to more than 5 km in length. The two largest are found in Neah Bay (3 km) and Lummi Bay (5 km). More than one-third of all breakwaters and jetties in Puget Sound are between 100 and 500 m in length (Figure 4-11).

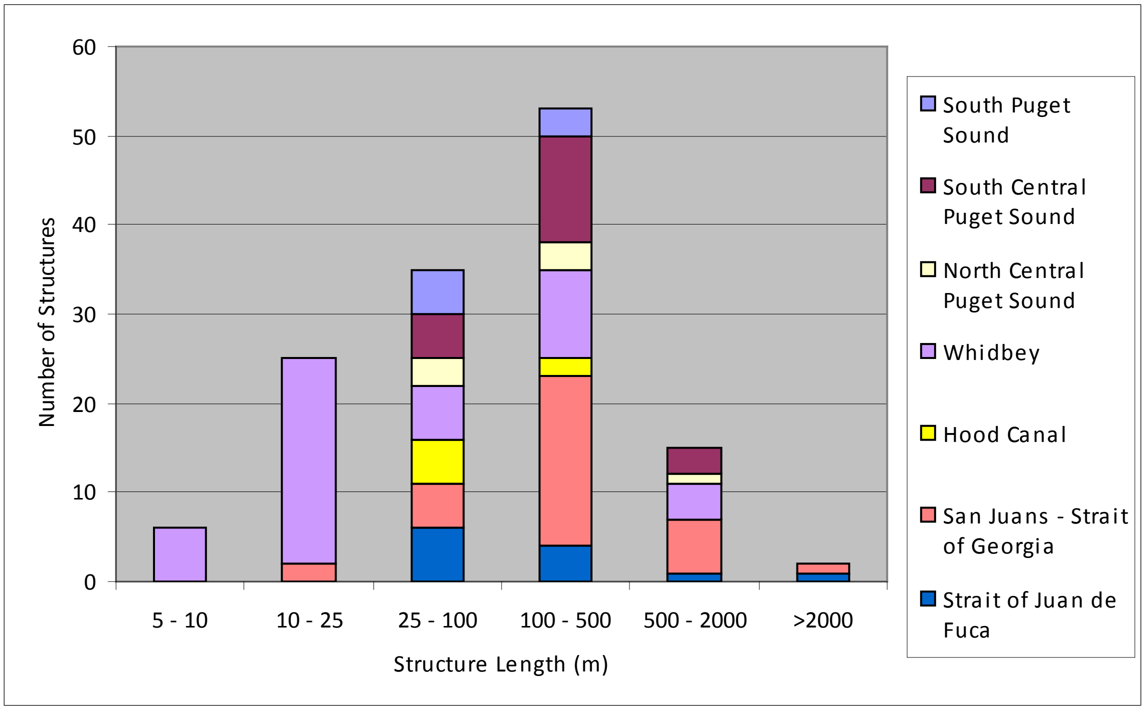


Figure 4-11

Breakwaters and Jetties Size Distribution in Puget Sound

Within Puget Sound, breakwaters and jetties are often associated with artificial shoreforms (Table 4-10). Thirteen of the 136 structures stand alone and are large enough that they define part of the "shoreline" within the WDNR ShoreZone database (WDNR 2001), and therefore are noted in the Change Analysis as shoreform transitions.

Table 4-10
Breakwaters and Jetties in Shoreforms of Puget Sound

Current Shoreform	Count of Breakwaters and Jetties
Artificial	71
Barrier Beach	12
Bluff-backed Beach	42
Barrier Estuary	1
Barrier Lagoon	0
Closed Lagoon/Marsh	0
Open Coastal Inlet	4
Pocket Beach	1
Plunging Rocky	1
Rocky Platform	1
Delta	9

Note: The table shows more than 136 structures because a single structure can have two shoreforms when that structure falls in two distinct process units (e.g., Neah Bay)

More than half of all breakwaters and jetties (71 of 136 structures) are found where transitions from other shoreforms to artificial shoreforms have been mapped, suggesting that the presence and possible co-occurrence of breakwaters and jetties with other stressors has a significant enough impact on the shoreline that shoreform type is no longer recognizable. Of these 71 structures, 35 were historically bluff-backed beaches or barrier beaches.

4.8 Overwater Structures

4.8.1 Description of Overwater Structures

The term "overwater structures" refers to a variety of structures along the shoreline that cast shade into nearshore habitats. The structures vary by shape, size, material, height above water, and purpose. These structures include large industrial/commercial docks, single-family residence docks, floating docks, fixed piers, bridges, floating breakwaters, moored vessels, and variations on these, including the use of piles for support and stabilization. Marinas are a shoreline modification that includes extensive numbers of overwater structures that are addressed in a separate narrative (Section 4.6).

The dataset used for overwater structures was refined for the Change Analysis based a dataset provided by WDNR, and includes area calculations for these structures.

4.8.2 Impacts of Overwater Structures on Nearshore Process, Structure, and Function

Overwater structures impact the nearshore through alteration of light, wave energy, sediment, and water conditions. Overwater structures cast shade on the substrate, which affects the distribution, behavior, growth, and survival of fish, wildlife, and plants in the vicinity of the structure (see Section 4.8.3).

Photo 4-11
Example of overwater structure along shoreline of Puget Sound
(Photo courtesy of Coastal Geologic Services)

The piling supporting overwater structures can affect wave energy dissipation. Individual piles can attenuate waves in a small area, and generally, more piling will lead to greater attenuation of wave energy. Multiple rows of piling or multiple structures in close proximity can further dampen wave energy to the shoreline in a cumulative fashion. Decreased wave energy leads to alteration in sediment transport patterns, namely substrate depositing under and inshore of the structures, which has the potential to negatively impact areas downdrift of the structure by diminishing the sediment supply. As a result, coarsening of substrate size can occur in downdrift areas, which can impact invertebrates that require small substrate and that are important to the food web base.

Depending on the materials used for the overwater structure decking and piling, water quality impacts could occur through the introduction of contaminants (Poston 2001).

Recently, there has been a shift away from creating new structures with creosote- and copper-treated wood; however, older structures containing creosote-treated wood may still leach contaminants. Creosote can leach polycyclic aromatic hydrocarbons (PAHs) in the water and sediment, and copper-treated wood in the form of ammoniacal copper zinc arsenate (ACZA) or chromated copper arsenate (CCA Type C) introduces contaminants into the aquatic system (Poston 2001). In recent years, contribution of contaminants via these materials has been reduced as new overwater structures are now installed with concrete or steel piling.

The impacts of the overwater structures on nearshore ecosystems depend on a wide variety of structure attributes including: size and shape of overwater structure; orientation relative to position of sun; height of structure above the water; type, size, and number of supporting structures (piles); location along shoreline; depth of water under the structure; presence of marine vegetation; and presence of other overwater structures in close proximity. As with other shoreline alterations, the cumulative effects of multiple overwater structures increase the associated degree of impact to the nearshore ecosystem. This is the case for marinas, which are a collection of overwater structures, and which have a much larger cumulative biologic impact due to the increased area of light reduction and due to structurally introduced changes in wave energy and longshore sediment transport (Nightengale and Simenstad 2001).

The conceptual model shown in Figure 4-12 describes the links between overwater structures and nearshore processes, structural changes, and functional responses.

4.8.3 Impacts of Overwater Structures on Valued Ecosystem Components

Processes impaired by overwater structures can result in direct impacts to juvenile salmon, forage fish, eelgrass and kelp, and native shellfish. Associated indirect effects may impact great blue heron, nearshore birds, and orca whales.

Juvenile salmon, forage fish, and native shellfish are all negatively impacted by the shading cast by overwater structure decking. The reduction in available light negatively impacts the

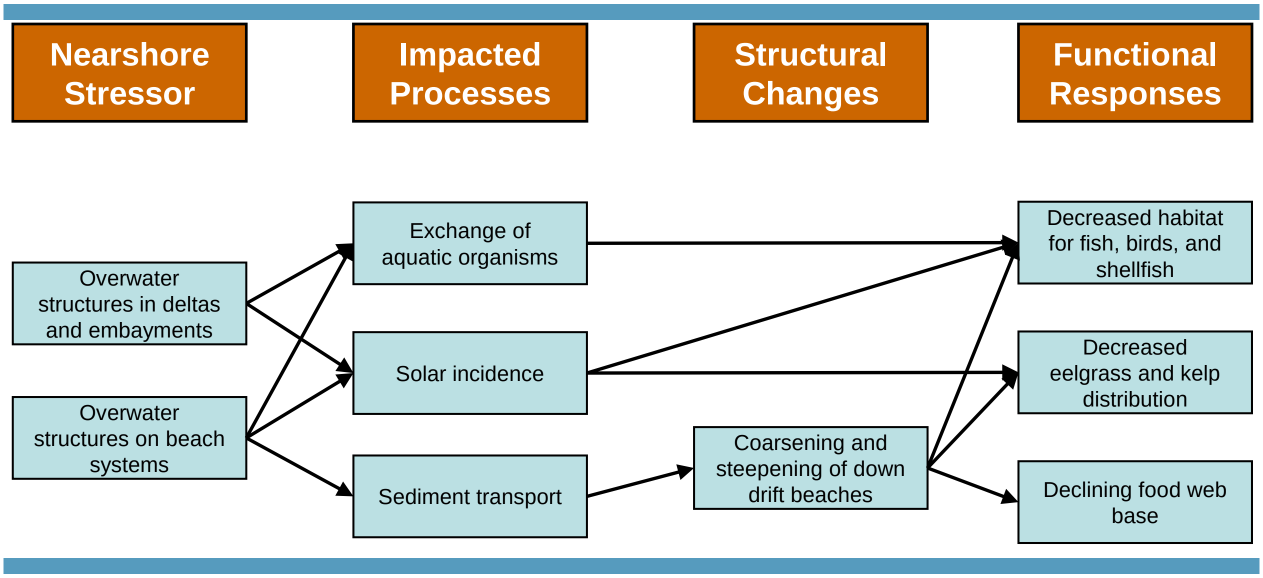


Figure 4-12

Conceptual Model Diagram Showing the Impacts of Overwater Structures on Nearshore Processes, Structures, and Functions

ability of visual feeders such as salmon, forage fish, and Dungeness crab to locate and capture prey (see Nightengale and Simenstad 2001; Jones and Stokes 2006 for review). The presence of overwater structures also creates a sharp contrast between light and dark environments that can alter fish behavior such as schooling, migration, and feeding. For example, Thom et al. (2006) documented altered movement patterns among juvenile salmon encountering large, wide docks, especially at higher tides when less ambient light penetrates under the docks compared to low tide conditions. Although there have not been specific studies that target large versus small docks and fish use, available research on fish behavior near overwater structures supports the hypothesis that smaller, narrower structures impact fish behavior less because the fully shaded area is reduced and no abrupt transition between light and dark is created. Another example has been documented among juvenile and larval sand lance, a forage fish species, in a study that found the fish showed reduced swimming and feeding behavior under overwater structures, attributed to low light conditions (Tribble 2000, as cited in Nightengale and Simenstad 2001). As Nightengale and Simenstad (2001) note, fish responses to overwater structures are complex. Light reductions associated with shade appear to be a primary factor affecting fish behavior near overwater structures. Similarly, changes to nighttime lighting associated with overwater structures also risk impacting fish migration behavior (Nightengale and Simenstad 2001).

Although often inferred, there is little direct evidence that overwater structures increase predation of juvenile salmonids (Nightengale and Simenstad 2001). Simenstad et al. (1999) found no studies attributing predation mortality to overwater structures. However, as is the case with marinas, shading from overwater structures can force young fish into deeper water areas, increasing their exposure to predators (Nightengale and Simenstad 2001).

Habitats for native shellfish are altered by changes in surrounding wave energy conditions and physical substrates available for use. Dissipated wave action results in lower energy environments that have benefits for certain species; for example, juvenile salmon use lower energy environments (Haas and Simenstad 2002), and bivalve shellfish production is increased under dock structures (Shreffler and Gardiner 1999). The piling supports also provide hard substrates that numerous fauna and flora species often colonize. These organisms include sessile encrusting organisms such as barnacles, mussels, and sponges, as well as mobile organisms such as Dungeness crabs and sea stars. Macroalgae and understory kelp species can also colonize these structures and the organisms growing upon the structures. Piles are also used as spawning substrate by herring. However, these benefits can be costly; study results on this topic from San Francisco Bay noted 100 percent mortality for herring embryos adhering directly to creosote-treated wood (Vines et al. 2000).

Eelgrass and kelp beds are also impacted as overwater structure decking casts shade into the water column, thus reducing light penetration. Light is the most important factor affecting plants; plant growth, survival, and depth of light penetration are directly related to light availability (Dennison 1987; Kenworthy and Haunert 1991). Thus, the reduction in light penetration associated with overwater structures limits the growth and survival of eelgrass, kelp, and macroalgae under the structure and in adjacent areas affected by shading. As a result, overwater structures typically create unvegetated areas along the shoreline, which fragment otherwise continuous or expansive vegetation beds.

Construction and use of overwater structures can result in the loss of adjacent marine riparian vegetation due to clearing for access to the structures and beach. Overwater structures also cause indirect effects to Dungeness crab, nearshore birds, great blue heron, and shorebirds by reducing foraging area. In addition, the diminished light conditions decrease production of benthic invertebrate communities, reducing the availability of juvenile salmon and forage fish prey items.

4.8.4 Distribution of Overwater Structures Throughout Puget Sound Basin and Its Sub-basins

In the Puget Sound Basin, 8,972 separate overwater structures are mapped in the nearshore zone. In aggregate, these overwater structures cover 9 km^2. The number, density, and area of overwater structures among sub-basins is presented in Table 4-11. The South Central Puget Sound sub-basin has the highest number (2,040), density (4 per km), and area of overwater structures (4 km^2) of all sub-basins. The South Puget Sound sub-basin has the second highest number (1,871) and density (3 per km), but only the fourth largest area of overwater structures (0.5 km^2). This disparity in area between the South Central Puget Sound and South Puget Sound sub-basins, despite the two having almost the same number of overwater structures, is consistent with the expectation that the structures in the South Puget Sound sub-basin would be more commonly associated with residential landowners (and hence typically smaller in size), while the South Central Puget Sound sub-basin includes concentrations of large industrial and commercial docks. While the South Puget Sound sub-basin has a high number of overwater structures, but a relatively small overwater structure area, the Whidbey sub-basin has approximately one-third as many overwater structures as the South Puget Sound sub-basin (654 versus 1,871), but substantially more area of overwater structures (0.8 versus 0.5 km^2). The number, density, and area of overwater structures in the Whidbey sub-basin rank fifth, fifth (tie), and third, respectively, among sub-basins. The North Central Puget Sound and Strait of Juan de Fuca sub-basins both have the smallest area of overwater structures (0.2 km^2) among sub-basins. The Strait of Juan de Fuca sub-basin has the lowest number of overwater structures (213) and the North Central Puget Sound sub-basin has the second lowest number (374). The Strait of Juan de Fuca sub-basin has the lowest density of overwater structures (0.8 per km).

Of the 9 km^2 of overwater structures in the Puget Sound Basin, approximately 23 percent of the area is contained within DPUs delineated at large river systems (2 km^2). Fourteen of the 16 DPUs have overwater structures; the exceptions are the Elwha and Stillaguamish DPUs. Overwater structures in DPUs account for approximately 8 percent (676 of 8,972) of the total number of overwater structures in the Puget Sound Basin.

Table 4-11

Number and Area of Overwater Structures in Puget Sound Sub-basins

Basin/Sub-basin	Number of Overwater Structures	Number of Structures Per Kilometer of Shoreline	Area of Overwater Structures (km^2)	Average Area per Structure (m^2)
Strait of Juan de Fuca	213	0.8	0.2	948
San Juan Islands/Strait of Georgia	1,180	1.2	1.2	1,033
Hood Canal	911	2.8	0.3	383
Whidbey	654	1.2	0.8	1,208
North Central Puget Sound	374	1.8	0.2	524
South Central Puget Sound	2,040	4.1	3.7	1,814
South Puget Sound	1,781	3.2	0.5	292
Puget Sound Basin[a]	**6,927**	**2.3**	**6.45**	**931**

Note:

[a] The Puget Sound Basin number and area of overwater structures is not a summation of the contributing sub-basins because the sub-basins overlap in shared divergence zones at sub-basin margins.

4.9 Dams

4.9.1 Description of Dams

Dams are barriers that block the flow of water in a stream or river channel. Dams included in the Change Analysis include those that capture and store at least 10 acre feet (about 3.2 million gallons) of water.

The dams dataset was created for the Change Analysis from data provided by WDOE. Each dam's drainage area is derived from values included in the WDOE source dataset. Because values in the source dataset are coarse, percent totals are approximate.

4.9.2 Impacts of Dams on Nearshore Processes, Structures, and Functions

Dams impact the nearshore by altering water, organic matter, and energy conditions. A dam slows the movement of water, thus reducing water's capacity to transport sediment and organic debris (including LWD). Dams also block the movement of this material, starving lower reaches and the nearshore, which depend on the material for beach development, and nutrient enrichment. The reservoirs created behind dams, and even the way in which the water from the reservoirs is released downstream, can alter the water temperature regime in streams, depending on the size of the reservoir. The severity of the impacts of damming rivers depends on grade, river morphology, land use, logging practices, and location of the dam in the drainage (the further downstream the greater the impact). By blocking this natural flow of sediment and materials, dams can cause significant reductions in nearshore habitat over time as well as a decline in the food web base downstream.

The conceptual model shown in Figure 4-13 describes the links between dams and nearshore processes, structural changes, and functional responses.

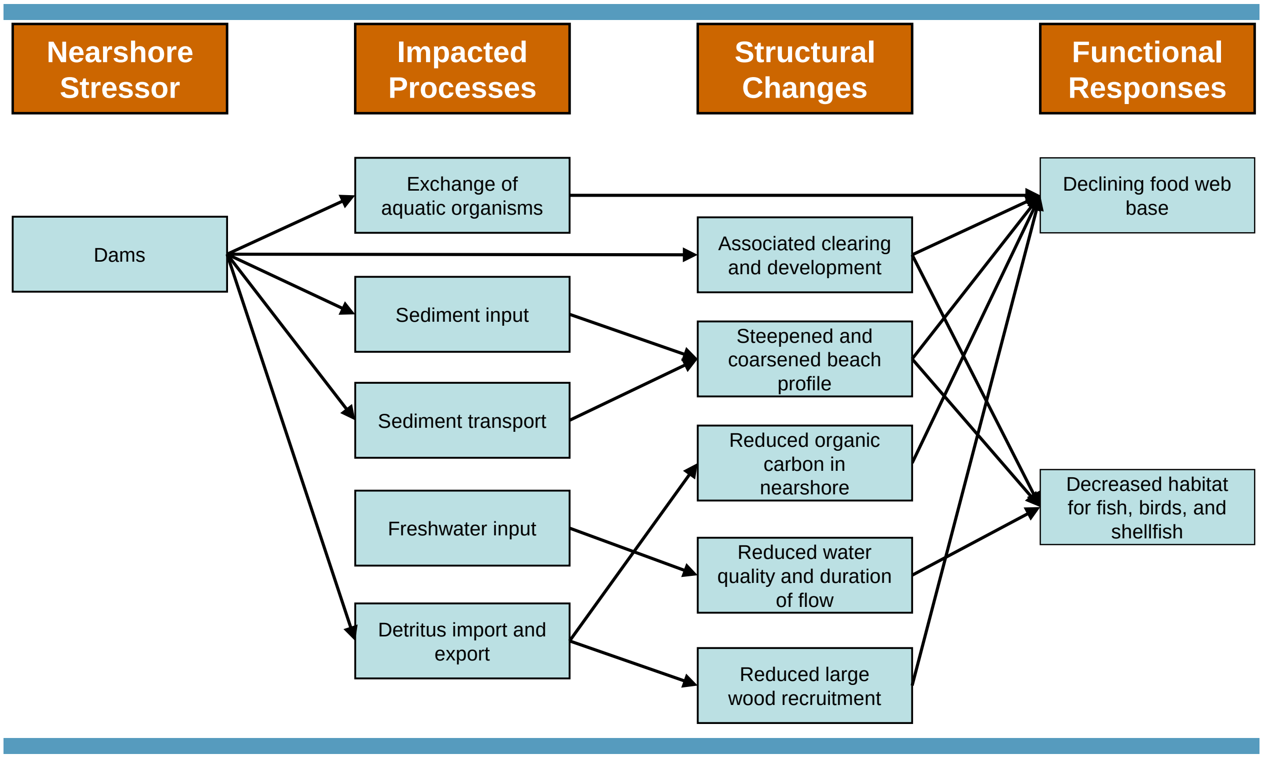


Figure 4-13

Conceptual Model Diagram Showing the Impacts of Dams on Nearshore Processes, Structures, and Functions

4.9.3 Impacts of Dams on Valued Ecosystem Components

Processes impaired by dams can result in direct impacts to juvenile salmon, forage fish, and native shellfish. Orca whales and eelgrass and kelp may be indirectly affected by dams.

Juvenile salmon and marine forage fish are negatively impacted by dams as large wood and sediment recruitment is reduced in the nearshore, which in turn decreases nearshore habitat area and complexity. Adult and juvenile salmon are also unable to migrate to or emigrate from habitats above dams without specialized passage facilities or operations. Some native shellfish are negatively impacted by a decrease in sediment inputs that results in a reduction in rearing habitat.

Kelp and eelgrass are indirectly impacted by dams as habitat area and nutrient availability are reduced. Depending on proximity to the nearshore zone and dam configuration and operations, impounded water can also increase or decrease water temperatures in the nearshore zone. Primary productivity and plant, fish, and shellfish production and survival are all impacted as a result of altered water temperatures.

4.9.4 Distribution of Dams Throughout Puget Sound Basin and Its Sub-basins

There are 436 dams in the Puget Sound Basin, impounding approximately 37 percent of the total drainage area of the basin. Impoundment areas were measured as the percentage of the overall drainage area above the furthest downstream dam in each drainage (Table 4-12). The South Central Puget Sound sub-basin is the most impacted by dams, with 154 dams and 54 percent of the drainage area impounded. The least impacted sub-basin is the North Central Puget Sound sub-basin, with four dams and 0.4 percent of the drainage impounded.

Table 4-12

Dam Distribution in Puget Sound Sub-basins

Basin/Sub-basin	Count of Dams	Area Impounded (km^2)	Sub-basin Drainage Area (km^2)	Percent of Drainage Area Impounded
Strait of Juan de Fuca	17	818	3,100.2	26
San Juan Islands – Strait of Georgia	89	272.8	3,782.9	7
Hood Canal	19	414.8	2,707.3	15
Whidbey	108	6,288.7	14,244.2	44
North Central Puget Sound	4	1.6	432.1	0
South Central Puget Sound	154	3,383.2	6,306.1	54
South Puget Sound	57	1,766.8	4,451.7	40
Puget Sound Basin	**436**	**12,926.8**	**34,710.4**	**37**

Among DPUs (see Table 4-13), the Deschutes DPU has nine dams and is the most impacted DPU in Puget Sound as measured by percent of drainage impounded (100 percent). The

Elwha DPU in the Strait of Juan de Fuca sub-basin runs a close second in terms of impacts from dams as measured by percent of drainage impounded—98 percent of the Elwha drainage is impounded above the Elwha Dam, the furthest downstream of the two dams in the drainage. The least impacted DPU in the Puget Sound Basin, as measured by the percent of drainage above the lowermost dam, is the Dungeness DPU, with only 0.01 percent of the drainage impounded; there are three dams in the Dungeness DPU.

The Snohomish DPU has the greatest number of dams (52) followed by the Puyallup DPU (41 dams), although only 53 and 43 percent of these drainages, respectively, are impounded in each DPU. For perspective, the Deschutes DPU has only 9 dams (among the DPUs with the fewest dams in Puget Sound) but its entire drainage is impounded behind the lowermost dam (104 percent). The Big Quilcene, Elwha, Dungeness, Skokomish, and Samish DPUs have the fewest dams in Puget Sound (2 to 4), though it is important to note the percent of the drainage impounded behind the lowermost dam in each drainage (0.4 percent, 98 percent, 0.01 percent, 42 percent, and 2 percent, respectively).

Table 4-13
Dam Distribution in Puget Sound DPUs

DPU	Count of Dams	Percent of Drainage Area Impounded above Lowermost Dam
Nooksack	10	0.2
Samish	4	1.7
Skagit	24	52.6
Stillaguamish	8	0.3
Snohomish	52	53.2
Duwamish	25	52.0
Puyallup	41	43.0
Nisqually	16	43.9
Deschutes	9	100.0
Elwha	2	97.6
Dungeness	3	0.01
Big Quilcene	2	0.4
Dosewallips	0	0.0
Duckabush	0	0.0
Hamma Hamma	0	0.0
Skokomish	3	41.8

4.10 Stream Crossings

4.10.1 Description of Stream Crossings

Stream crossings are defined as locations where transportation corridors (i.e., roads and railroads) cross rivers, streams, and estuaries. The size and type of crossings vary considerably, ranging from small forest roads or private road crossings where streams are conveyed through relatively narrow culverts or pipes to multiple-lane highway corridors that use bridges to span the width of streams, rivers, and other channels (e.g., tidal sloughs).

Photo 4-12
Example of culvert at stream crossing under railroad
(Photo courtesy of Coastal Geologic Services)

The stream crossing dataset was created for the Change Analysis based on WDNR's transportation and hydrography datasets, and included many smaller roads and forest roads that are not in other roads datasets.

4.10.2 Impacts of Stream Crossings on Nearshore Processes, Structures, and Functions

Stream crossings vary in their impact to nearshore systems, depending on their potential to impact nearshore processes. Crossings that alter water, nutrient, and sediment delivery conditions have the most impact. For example, at some stream crossings, due to upland development, stormwater and sediment can make their way downstream to the nearshore zone in high quantities. If there are significant stormwater and sediment inputs, stream crossings can be focal points for the introduction of contaminants that can disrupt the biological function of organisms, with the potential for bio-cumulative effects or magnification in the food web.

Constricted stream crossings that occur within tidal influence of DPUs or embayment systems limit the location and volume of tidal inundation landward of the crossing, which can decrease sediment transport and increase sediment deposition. This reduces habitat complexity both landward and seaward of the crossing. These types of crossings may also limit detrital and LWD inputs from upstream, leading to degraded fish and wildlife habitat and a reduced food web base.

The conceptual model shown in Figure 4-14 describes the links between stream crossings and nearshore processes, structural changes, and functional responses.

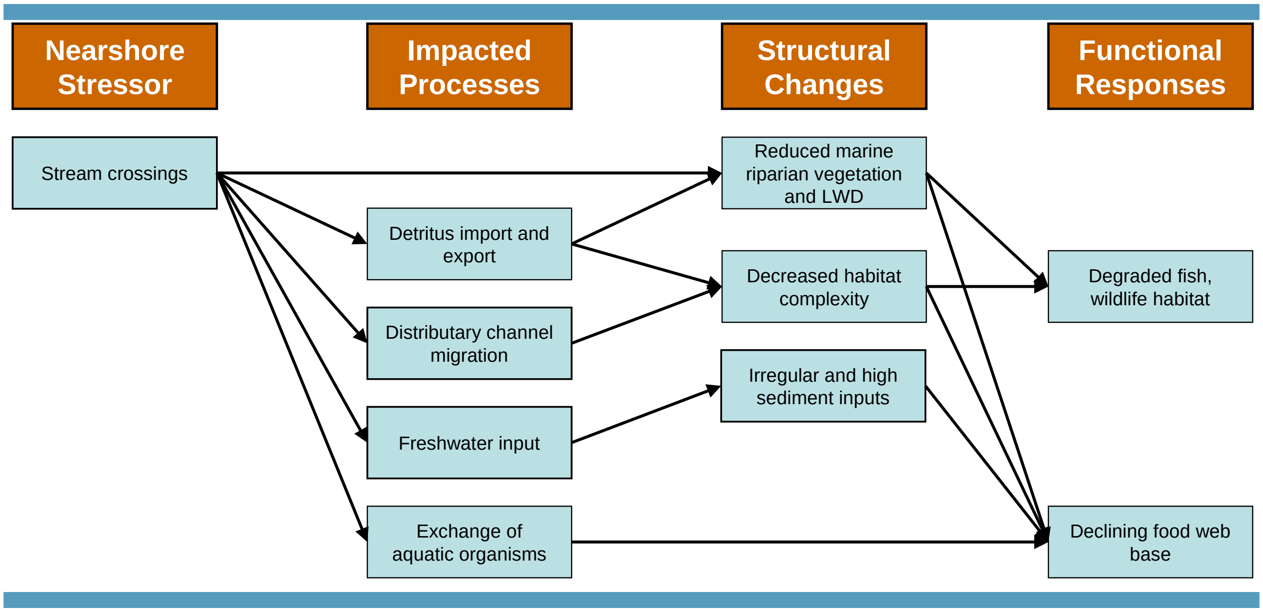


Figure 4-14

Conceptual Model Diagram Showing the Impacts of Stream Crossings on Nearshore Processes, Structures, and Functions

4.10.3 Impacts of Stream Crossings on Valued Ecosystem Components

Processes impaired by stream crossings can result in direct impacts to juvenile salmon. Forage fish, eelgrass and kelp, native shellfish, orca whales, and coastal forests are all potentially impacted by indirect effects of stream crossings, especially those effects associated with changes in sediment delivery.

Stream crossings directly impact the ability of animals to migrate upstream and downstream of a particular crossing, sometimes blocking passage entirely (WSDOT 1998; Warren and Pardew 1998). This effect is particularly notable for fish species that migrate into freshwater or estuarine systems for part or much of their life cycle, such as juvenile salmon.

Indirect impacts of stream crossings include the introduction of sediment particulate matter sourced from instream work, such as bridge and culvert construction, or stormwater runoff from upland portions of construction sites. Sediments suspended in the water column can have indirect adverse impacts on aquatic organisms (Bash et al. 2001), including juvenile salmon, forage fish, eelgrass, kelp, and native shellfish. In addition, indirect pathways of contamination exist via stormwater runoff and treated wood piles used for stream crossing structures (Poston 2001).

Marine riparian vegetation is often removed for construction of stream crossings close to the nearshore. Removal of large amounts of this vegetation alters the water temperature regime at the nearshore, reduces bank stability, alters cooling groundwater influences to the nearshore, and limits the input and subsequent transport of large and small woody debris and detritus downstream to the nearshore. In turn, these effects indirectly impact all of the other VECs via adversely modified habitat conditions. Increased water temperatures and modified banks affect salmon, forage fish, and shellfish by creating unsuitable temperature and physical substrate conditions. Loss of woody debris impacts fish as well, as the presence of LWD increases habitat complexity, affording fish cover, protection from currents, and foraging opportunities (Quinn 2005).

4.10.4 Distribution of Stream Crossings Throughout Puget Sound Basin and Its Sub-basins

The frequency of stream crossings (per nearshore zone area) is nearly double in the Hood Canal sub-basins compared to the other sub-basins (Table 4-14). In the Hood Canal sub-basin there were 3.2 stream crossings per km^2 of the nearshore zone area. The sub-basin with the second highest stream crossing frequency was the South Central Puget Sound (1.8 per km^2 of the nearshore zone area). The San Juan Islands – Strait of Georgia, Whidbey, and North Central Puget Sound sub-basins had less than 1.0 stream crossing per km^2 of the nearshore zone area (0.4, 0.5, and 0.7, respectively). The frequency of stream crossings (per drainage area) is highest in the South Puget Sound sub-basin (3.0 per km^2 of the drainage area) and lowest in the North Central Puget Sound and Whidbey sub-basins (1.3 and 1.4, respectively).

Table 4-14
Stream Crossings and Crossing Frequencies in Puget Sound Sub-basins

Basin/Sub-basin	Count in Nearshore Zone	Nearshore Zone Area (km^2)[a]	Freq. in Nearshore Zone (Count/ km^2 Nearshore Zone Area)	Count in Drainage Area	Drainage Area (km^2)[a]	Freq. in Drainage Area (Count/ Drainage Area)
Strait of Juan de Fuca	220	181.4	1.2	4,989	3,230.4	1.5
San Juan Islands - Strait of Georgia	249	580.3	0.4	7,193	4,175.6	1.7
Hood Canal	488	154.5	3.2	4,750	2,790.3	1.7
Whidbey	260	549.5	0.5	20,061	14,687.0	1.4
North Central Puget Sound	79	112.8	0.7	651	501.8	1.3
South Central Puget Sound	479	262.9	1.8	13,233	6458.7	2.0
South Puget Sound	406	287.3	1.4	13,682	4610.3	3.0
Puget Sound Basin	**2,140**	**2,035.8**	**1.1**	**64,383**	**36,080.1**	**1.8**

Table Notes:

a Nearshore Zone Area and Drainage Area were used to express stream frequency because stream length data were not available.

The frequencies of stream crossings, per nearshore area, are shown for the 16 DPUs in the Puget Sound Region (Table 4-15). Stream crossing frequency in the nearshore zone is higher, relatively speaking, in the Skokomish, Hamma Hamma, Dosewallips (all of which occur within the Hood Canal sub-basin), Puyallup, Deschutes, and Big Quilcene DPUs. The best explanation for the high percentages in the Hood Canal DPUs is the presence of Highway 101 and at least some level of development in the lower rivers and estuaries. The Puyallup and Deschutes River estuaries and lower river areas are heavily urbanized, and thus, they would be likely to have high frequencies of stream crossings.

Table 4-15

Stream Crossings and Crossing Frequencies in Puget Sound DPUs

DPU	Count in Nearshore Zone	Nearshore Zone Area (km^2) [a]	Freq. in Nearshore Zone (Count/ Nearshore Zone Area)
Nooksack	40	59.7	0.7
Samish	29	52.0	0.6
Skagit	43	162.8	0.3
Stillaguamish	17	75.1	0.2
Snohomish	91	112.9	0.8
Duwamish	15	18.9	0.8
Puyallup	30	23.0	1.3
Nisqually	22	19.6	1.1
Deschutes	26	7.0	3.7
Elwha	2	2.6	0.8
Dungeness	22	18.5	1.2
Big Quilcene	21	5.4	3.9
Dosewallips	2	3.4	0.6
Duckabush	7	2.4	2.9
Hamma Hamma	5	2.5	2.0
Skokomish	19	12.4	1.5

Note:

a Nearshore Zone Area was used to express stream crossing frequency because stream length data were not available.

4.11 Impervious Surfaces

4.11.1 Description of Impervious Surfaces

Impervious surfaces result from the conversion of forest, wetland, and other natural land cover types to pavement, buildings, and other largely impermeable areas.

The dataset for impervious surfaces was created for the Change Analysis based on the Multi-Resolution Land Characteristics Consortium 2001 National Land Cover Dataset (MRLC 2001). These data are based on 30-m Landsat TM satellite imagery. For the analysis, the data were grouped into four ranges of impervious coverage: 0 to 10 percent, 10 to 30 percent, 30 to 50 percent, and 50 to 100 percent.

Photo 4-13
Example of shoreline area with high percentage of impervious surfaces as well as other stressors
(Photo courtesy of WDOE)

4.11.2 Impacts of Impervious Surfaces on Nearshore Processes, Structures, and Functions

Impervious surfaces impact the nearshore by alterations to sediment, water, and light energy conditions. Impervious surfaces across the watershed alter hydrology by increasing the magnitude and frequency of peak flows and decreasing base flows (Booth et al. 2002). Increased peak flows result in greater stream channel erosion and increased silt and clay inputs in receiving estuarine and nearshore waters. Higher peak flows can also result in an increase in anthropogenic contaminants that can ultimately reach Puget Sound. Decreased base flows change the typical freshwater flow amount reaching nearshore waters, which can impact tidal wetlands, if present, as well as cause drying of seep areas.

The presence of impervious surfaces also affects the volume and rate of groundwater seepage and overland water delivery to the nearshore. In particular, areas with higher levels of impervious surface tend to concentrate freshwater into fewer channels and pipes. These outputs can result in dilution of saltwater in areas newly containing pipes/consolidated channels and increased salinities where freshwater inputs have been reduced.

Impervious surfaces directly along the shoreline (residential uses, roads, parking lots, and other pavement) can increase solar incidence, as marine riparian vegetation is typically cleared to make room for this development. The removal of this vegetation also reduces detrital and nutrient inputs to the shoreline, with impacts to the food web.

The conceptual model shown in Figure 4-15 describes the links between impervious surfaces and nearshore processes, structural changes, and functional responses.

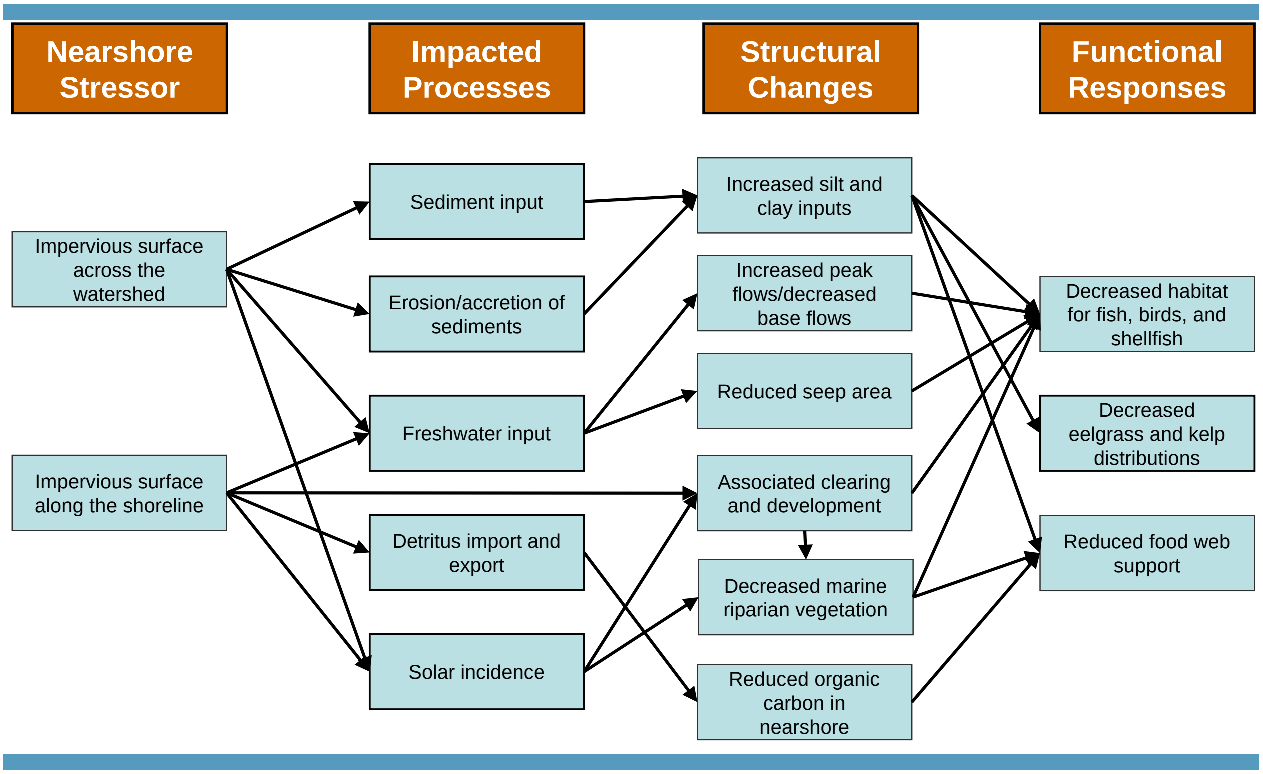


Figure 4-15

Conceptual Model Diagram Showing the Impacts of Impervious Surfaces on Nearshore Processes, Structures, and Functions

4.11.3 Impacts of Impervious Surfaces on Valued Ecosystem Components

Processes impaired by impervious surfaces result in direct impacts to juvenile salmon, forage fish, native shellfish, and eelgrass beds.

Juvenile salmon, forage fish, and native shellfish can be exposed to contaminants, sediments, and bacteria via runoff sourced from impervious surfaces. In juvenile salmon, such runoff has been linked to increased injury risk, reduced prey, and reduced habitat (Fresh 2006). Shellfish species and forage fish are impacted by the increased peak flows and sediment loading attributed to stormwater runoff, as it alters the sediment supply and size in the nearshore. While many shellfish species require fine sands and mud in shallow water areas, rapid increases in fine sediments to nearshore areas smother filter-feeders (Dethier 2006). These altered peak flows also change the delivery of surface water and groundwater to nearshore areas. Groundwater helps keep nearshore waters cool, while clean and regular inputs of surface water provide the water column salinity and temperature conditions that shellfish and forage fish require (Penttila 2007; Dethier 2006). Increases in stormwater runoff also impact flow patterns and channel formation in streams and rivers, potentially negatively impacting upstream salmon habitat.

Increased sediment deposition resulting from impervious surfaces (especially in the deltas, barrier estuaries, open coastal inlets, and barrier lagoons) can cause contaminant loading and eutrophication in receiving waters. This, in turn, causes impacts to shellfish productivity, and reduces dissolved oxygen, which negatively impacts juvenile salmon and their prey resources. Increased impervious surface within coastal watersheds has been documented to result in the closure of commercial and recreational shellfish beds due to increased bacterial loading (Glasoe and Christy 2004; Dethier 2006). Eelgrass beds can be smothered by excessive sedimentation, and are vulnerable to reduced light levels associated with eutrophic waters and high levels of suspended sediments.

4.11.4 Distribution of Impervious Surfaces Throughout Puget Sound Basin and Its Sub-basins

Impervious surface data were summarized for the nearshore zone and the drainage area zone by categories that reflect level of imperviousness (Table 4-16). Impervious surfaces are in the 0 to 10 percent (i.e., the lowest impervious level) category for the majority of the Puget Sound nearshore zone (76 percent) as well as the drainage area (90 percent) of Puget Sound. Therefore, 24 percent of the Puget Sound nearshore zone has impervious surface above the 10 percent level, and about 10 percent of the Puget Sound drainage area falls within this lowest category for level of impervious surface. In general, levels of impervious surface across the Puget Sound Basin are higher in the nearshore zone than across the entire drainage area. This reflects the relative concentration of human development near Puget Sound (e.g., larger cities such as Bellingham, Bremerton, Everett, Seattle, Tacoma, and Olympia all border the Puget Sound shoreline) and relatively protected lands that occur in the middle and upper watersheds across much of the region (e.g., federally-protected Wilderness Areas, National Parks, and large forest areas dedicated primarily to forestry and recreation).

Table 4-16
Coverage of Impervious Surfaces within the Nearshore Zone and Drainage Area of Puget Sound

Impervious Surface (%)	Percent of Nearshore Zone Area	Percent of Drainage Area
0 – 10%	76.1	89.9
10 – 30%	13.0	5.1
30 – 50%	5.4	2.5
50 – 100%	5.5	2.6

The level of impervious surface varies considerably across the sub-basins (Figures 4-16 and 4-17). The Hood Canal sub-basin has the highest percentage among the sub-basins of both nearshore zone (86 percent) and drainage area (97 percent) within the less than 10 percent impervious surface category, and the South Central Puget Sound sub-basin has the lowest percentage of both nearshore zone (57 percent) and drainage area (73 percent) within the less than 10 percent impervious surface category. Consistent with this pattern, the Hood Canal sub-basin has the lowest percentage among the sub-basins of nearshore zone (1 percent) and drainage area (0.2 percent) within the highest level of impervious surface (greater than 50 percent), and the South Central Puget Sound sub-basin ranks highest for percentage of nearshore zone (15 percent) and drainage area (9 percent) within the greater than 50 percent impervious surface category.

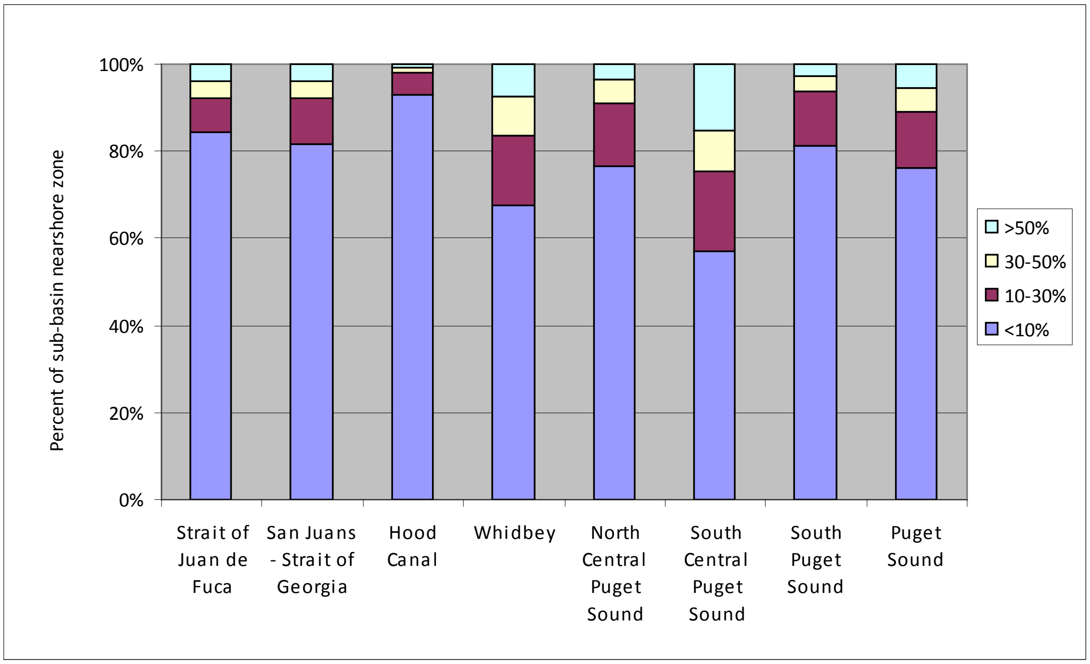


Figure 4-16

Percentage of Nearshore Zone Impervious Surface Area for Puget Sound Sub-basins

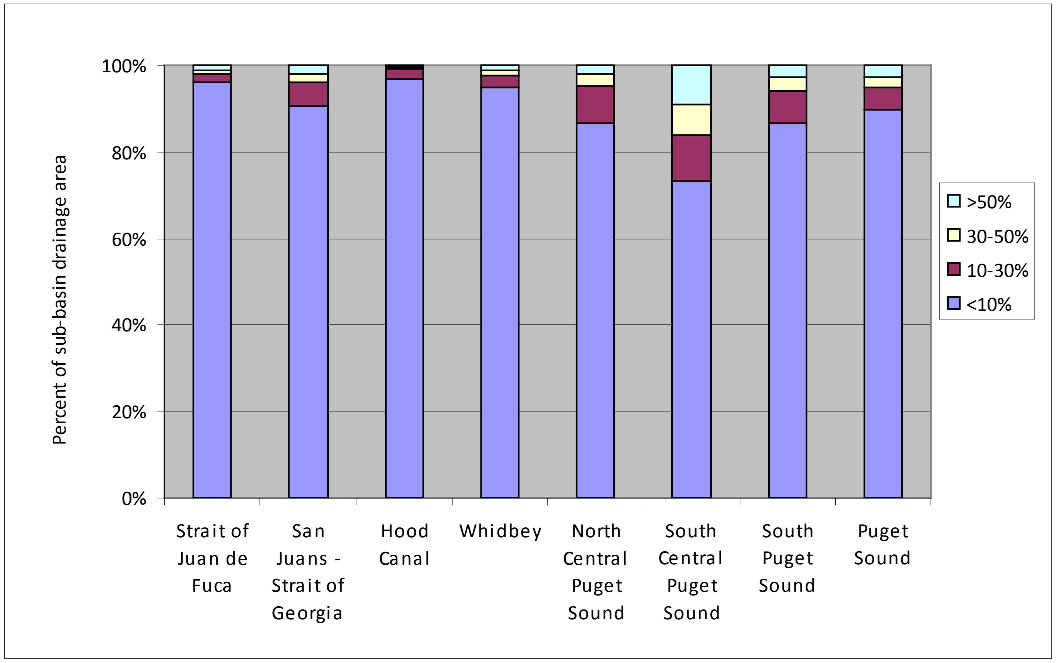


Figure 4-17

Percentage of Drainage Area Impervious Surface Area for Puget Sound Sub-basins

Levels of impervious surface varied among the 16 DPUs (Figures 4-18 and 4-19). None of the DPUs has particularly high levels of impervious surface at the drainage area scale. Even the most urbanized, the Deschutes, Duwamish, and Puyallup, have 83 percent, 77 percent, and 86 percent of their respective drainage areas within the less than 10 percent impervious surface category. These DPUs stand out as having considerably higher levels of impervious surface in their respective nearshore zones; the estuaries are heavily urbanized port areas (Olympia, Seattle, and Tacoma). Many of the DPUs have relatively low levels of impervious surface in the nearshore zone, including the Dungeness, Elwha, Hamma Hamma, Big Quilcene, Skokomish, Nisqually, Skagit, Nooksack, and Samish. Each of these DPUs also has relatively low levels of impervious surface in the drainage areas as well. The Dosewallips and Duckabush are similar in that they each have somewhat high levels (67 and 66 percent in the less than 10 percent category) of impervious surface in nearshore zones (associated with lower river floodplain development and highway crossings), but very low levels of impervious surface in drainage areas (99 percent in the less than 10 percent category). Large portions of these watersheds drain relatively protected federal lands, as is the case in most of the DPUs. The Snohomish and Stillaguamish also have moderate levels of impervious surface (56 and 69 percent within the less than 10 percent impervious surface category) in their respective nearshore zones. The Snohomish estuary/lower river occurs within the City of Everett and surrounding area, and the Stillaguamish estuary/lower river resides in a mostly agricultural but urbanizing area.

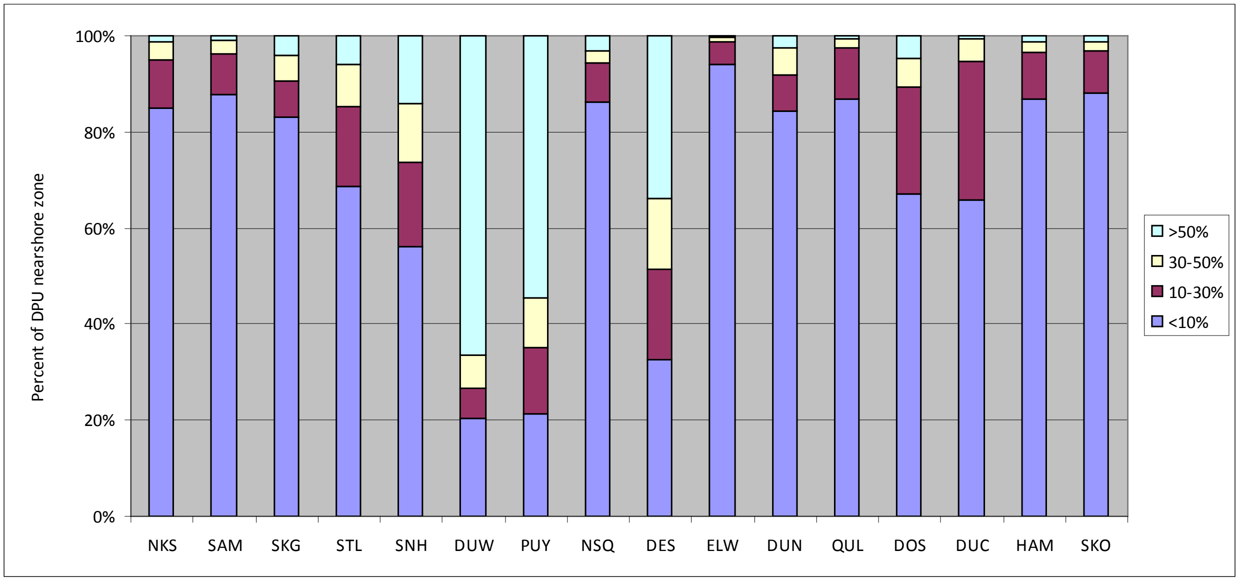


Figure 4-18

Percentage of Nearshore Zone within Selected Levels of Impervious Surface Area for Puget Sound DPUs

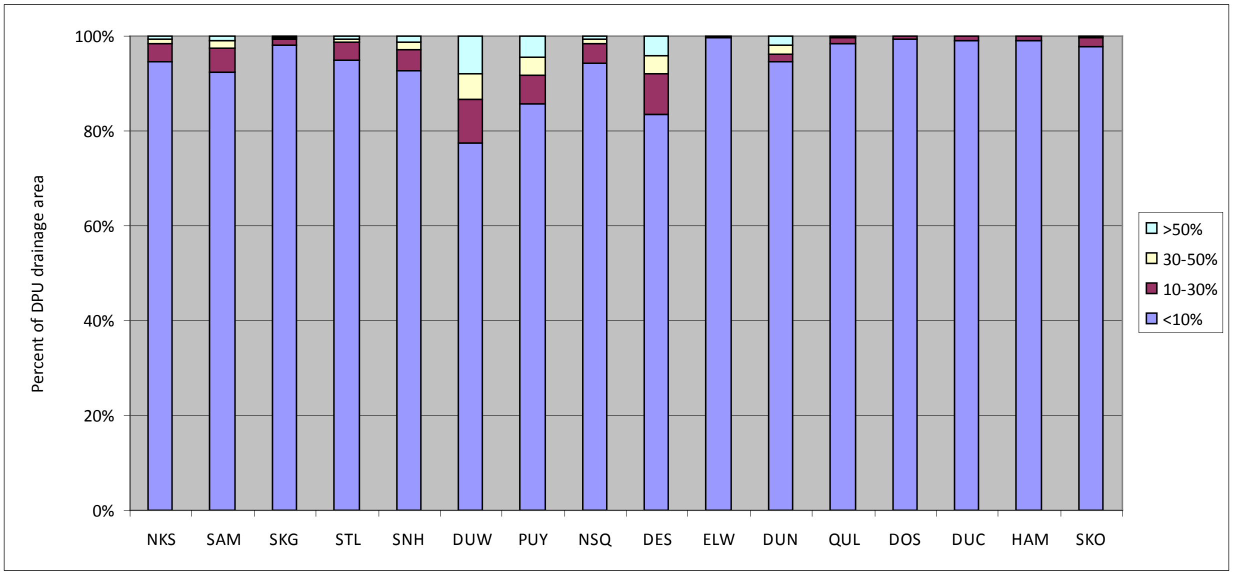


Figure 4-19

Percentage of Drainage Area within Selected Levels of Impervious Surface Area for Puget Sound DPUs

4.12 Land Cover Development

4.12.1 Description of Land Cover Development

Land cover refers to the type of feature present on the surface of the earth. For example, agricultural fields, lakes, rivers, forests, roads, open water, and parking lots are all land cover types. Land cover may refer to a biological categorization of the surface, such as grassland or forest, or to a physical or chemical categorization, such as concrete. Denoted by the physical state of the land, land cover includes the type and quantity of vegetation, water, and earth materials. Land cover development occurs when one land cover type is converted to another, or when a land cover type is modified, such as a change in agricultural composition. Land cover development is strongly influenced by land use due to human cultural, social, and economic activities. Understanding the significance and potential consequences of land cover development on climate, biogeochemistry, or ecological complexity requires land use information.

The land cover dataset was created for the Change Analysis from the Multi-Resolution Land Characteristics Consortium 2001 National Land Cover Data (MRLC 2001). The dataset depicts land cover and land use in the Puget Sound region. The land cover classes identified in the land cover data layer for the Puget Sound region are listed in Table 4-17.

Table 4-17
Puget Sound Region Land Cover Classes

LC_Class	LC_Group
Open Water	Natural
Perennial Snow/Ice	Natural
Developed, Open Space	Developed
Developed, Low Intensity	Developed
Developed, Medium Intensity	Developed
Developed, High Intensity	Developed
Barren Land	Natural
Deciduous Forest	Natural
Evergreen Forest	Natural
Mixed Forest	Natural
Shrub/Scrub	Natural
Herbaceous	Natural

LC_Class	LC_Group
Hay/Pasture	Developed
Cultivated Crops	Developed
Woody Wetlands	Natural
Emergent Herbaceous Wetlands	Natural

4.12.2 Impacts of Land Cover Development on Nearshore Processes, Structures, and Functions

Land cover development, i.e., changes to land cover classes, can impair important nearshore processes, structures, and functions in receiving waters (Simenstad et al. 2006; Alberti and Marzluff 2004; NWP 1995). Nearshore habitat and the plant and animal life that rely on this habitat for production and survival depend on the natural hydrologic, geomorphologic, and ecological processes that occur in the surrounding watersheds. Watersheds experience a cascade of effects among critical physical, chemical, and biological processes when land cover changes (NWP 1995; Thom and Borde 1998). For example, urbanization has sweeping impacts, altering natural habitats (Marzluff 2001) and species composition (Blair 1996), disrupting hydrological systems (Arnold and Gibbons 1996; Booth and Jackson 1997), and modifying energy flow and nutrient cycles (McDonnell and Pickett 1990; Vitousek et al. 1997; Grimm et al. 2000).

An increase in activities associated with urban development increases impervious surfaces, and the loss of wetland land cover types increases the delivery of pollutants from impervious surface runoff to nearshore environments. Upland development also results in changes in groundwater flow patterns and exchange, which can result in increased stream water temperatures in-stream and in the nearshore. Conversion of woody and herbaceous cover types to agricultural crops or pasture lands or to developed open space or light development increase the timing and quantity of runoff, and as a result, increase sediment inputs into nearshore zones. The conversion of marine riparian vegetation to a developed land cover class, or the removal of marine riparian vegetation to improve access or views to the marine environment, eliminates or reduces LWD, detritus, and aquatic organism input into the nearshore areas and destabilizes shorelines. The development of shoreline areas can result in decreases in or removal of distributary channels and a reduction in their function, which simplifies terrestrial and aquatic habitat quantity and quality for fish and wildlife.

Research has shown that once watersheds begin approaching or exceeding about 10 percent of their drainage area in an impervious or paved condition, there is a high potential for physical, chemical, and biological impairments to both water quality conditions and other aquatic resources. Related research has shown that watersheds, particularly those along the west side ranges of the Pacific Northwest, require about 65 percent forest cover to retain the hydrological processes that minimize surface water runoff during storms and infiltrate water into ground water and summer base flows in local streams and rivers (McMurray and Bailey 1998).

Model simulations show that current land cover development in the Puget Sound Basin results in higher fall, winter, and early spring streamflow but lower summer flow. Land cover development impacts in urban and partially urban basins have resulted in changes in annual flow, annual maximum flows, and fall and summer flows. For the upland portion of the basin, shifts in the seasonal distribution of streamflows (higher spring flow and lower summer flow) are clearly related to rising temperatures, but annual streamflow has not changed much. Key reasons for these different hydrologic sensitivities are the importance of snow in the seasonal hydrologic cycle of the uplands, and its general absence in the lowlands, and forest regrowth in the upland basins (Cuo et al. 2009).

The conceptual model shown in Figure 4-20 describes the links between land cover development and nearshore processes, structural changes, and functional responses.

4.12.3 Impacts of Land Cover Development on Valued Ecosystem Components

Processes impaired by land cover development can result in degradation, both directly and indirectly, to the following VECs: kelp and eelgrass, coastal forests, juvenile salmon, forage fish, native shellfish, nearshore birds, great blue herons, orca whales, and beaches and bluffs.

Kelp and eelgrass can be directly impacted by changes in land cover classes that increase sediment input into the nearshore zone because these plants need relatively high light levels to grow and reproduce. Increased turbidity in nearshore areas decreases light penetration while sediment is entrained in the water column. A reduction in kelp and eelgrass would also result in a reduction of the many small invertebrates and fishes that inhabit eelgrass and kelp beds, serving as prey for many other animal species.

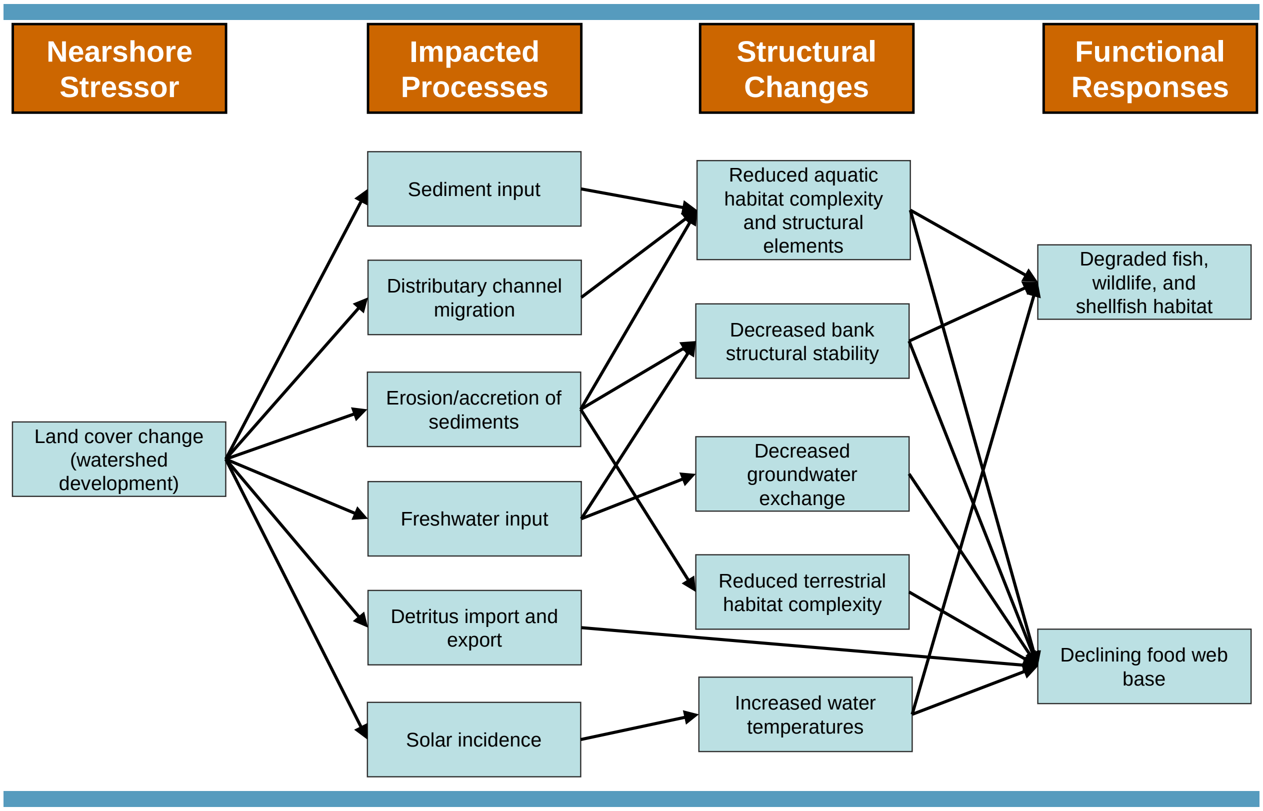


Figure 4-20

Conceptual Model Diagram Showing the Impacts of Land Cover Development on Nearshore Processes, Structures, and Functions

Removal of marine riparian vegetation is a type of land cover conversion that results in less stable shoreline conditions, a reduction in habitat structure, and potential local increases in water temperature in nearshore areas. Lost or degraded marine riparian vegetation also decreases the total exchange of aquatic organisms and detritus into the nearshore zone. Impacts to nearshore processes results in a loss of productivity of the nearshore zone. Bluffs and beaches are impacted by changes in land cover as land is converted from natural beach/bluff to developed shorelines.

Juvenile salmon, marine forage fishes, and native shellfish rely on runoff from surrounding drainages for the delivery of food and nutrients to the nearshore. Conversion of naturally vegetated land cover types to developed or agricultural land cover alters the natural conditions of live and dead organic material and nutrient input into the nearshore habitat.

Further up in the food web, great blue herons and nearshore birds prey on fish species in the nearshore ecosystem. These species rely on the production and arrival of juvenile salmonids from sub-basin habitats and on the production of marine forage fish in the nearshore environment. Conversion of sub-basin land cover types to development and agricultural use decreases the survival of salmon and disrupts the movement of salmon downstream to the marine environments. Alteration of natural land cover types also increases the delivery of pollutants and sediment into the nearshore zone, reducing survival and production of fish species in that habitat.

All VECs are impacted by changes in the land cover that alter the timing and quantity of freshwater input into the nearshore zone. Changes in the salinity and temperature of water in the nearshore area reduce the survival of all fish and wildlife species that rely on the production of the aquatic plant communities adapted to natural conditions.

4.12.4 Distribution of Land Cover Development Throughout Puget Sound Basin and Its Sub-basins

In the Puget Sound Basin drainage area, 84 percent of the land cover is in a natural condition, and 16 percent of the basin's drainage area has been developed (Table 4-18). In the nearshore zone, 66 percent is natural and 34 percent is developed. The South Central Puget Sound sub-basin is the most impacted sub-basin in the Puget Sound Basin as measured by the percent land cover alteration in the drainage area, with 34 percent of the sub-basin drainage area developed and 51 percent of the nearshore zone area developed. The Hood Canal sub-basin is the least impacted sub-basin in the Puget Sound Basin, with 5 percent of the drainage area developed and 10 percent of the nearshore zone area developed.

In terms of land cover types, cover is dominated by evergreen forest, with moderate contributions across all sub-basins from other land cover classes such as mixed forest and scrub-shrub. Figure 4-21 illustrates the land cover groups and coverage percent in sub-basins.

Table 4-18
Percent Nearshore Zone and Drainage Area with Developed or Natural Conditions in Sub-basins of Puget Sound

Basin/Sub-basin	Percent Nearshore Zone Area		Percent Drainage Area	
	Developed	Natural	Developed	Natural
Strait of Juan de Fuca	22.4	77.6	7.4	92.6
San Juan Islands - Strait of Georgia	28.6	71.4	26.6	73.4
Hood Canal	10.1	89.9	5.2	94.8
Whidbey	50.2	49.8	9.2	90.8
North Central Puget Sound	30.3	69.7	24.2	75.8
South Central Puget Sound	50.6	49.4	33.6	66.4
South Puget Sound	25.7	74.3	21.4	78.6
Puget Sound Basin	**33.6**	**66.4**	**16.4**	**83.6**

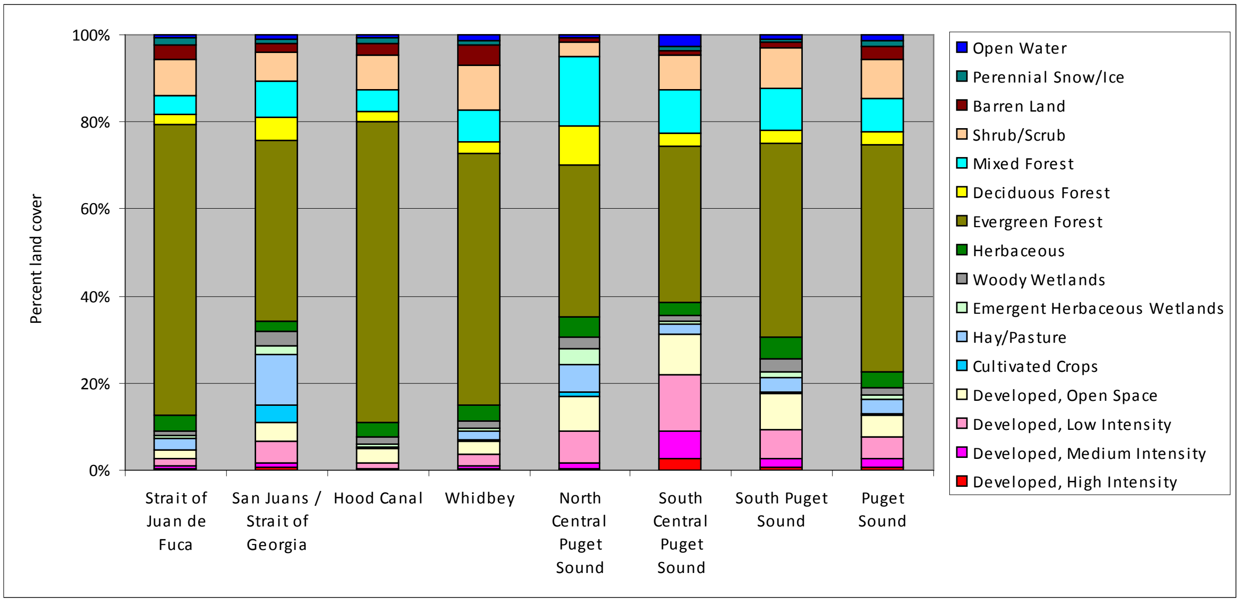


Figure 4-21
Land Cover Class Coverage in Puget Sound Basin and its Sub-basins

For DPUs (Figures 4-22 and 4-23; see Figure 2-3 for map of DPUs), the Duwamish DPU is the most highly impacted in the Puget Sound Basin, with 83 percent of the DPU's nearshore zone area developed and 31 percent of the drainage area developed. The Skokomish is the least impacted DPU overall, with 20 percent of the nearshore zone area developed and 4 percent of the entire drainage developed. The Elwha DPU has the lowest percent drainage area developed: 1 percent.

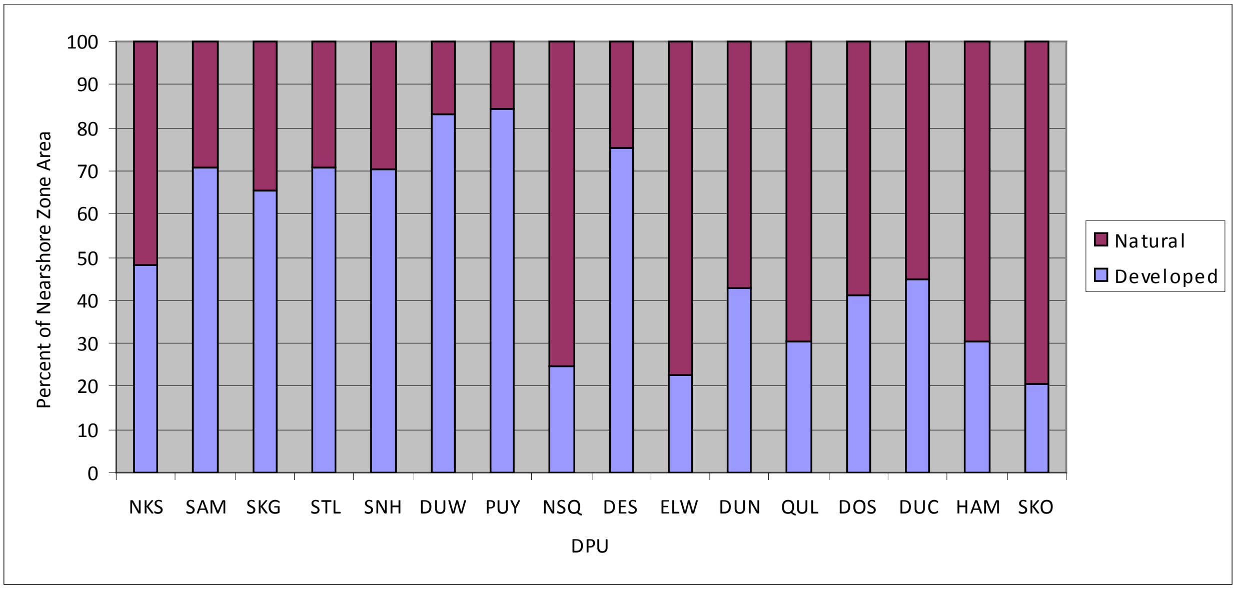


Figure 4-22

Percentage of Nearshore Zone Developed in Puget Sound DPUs

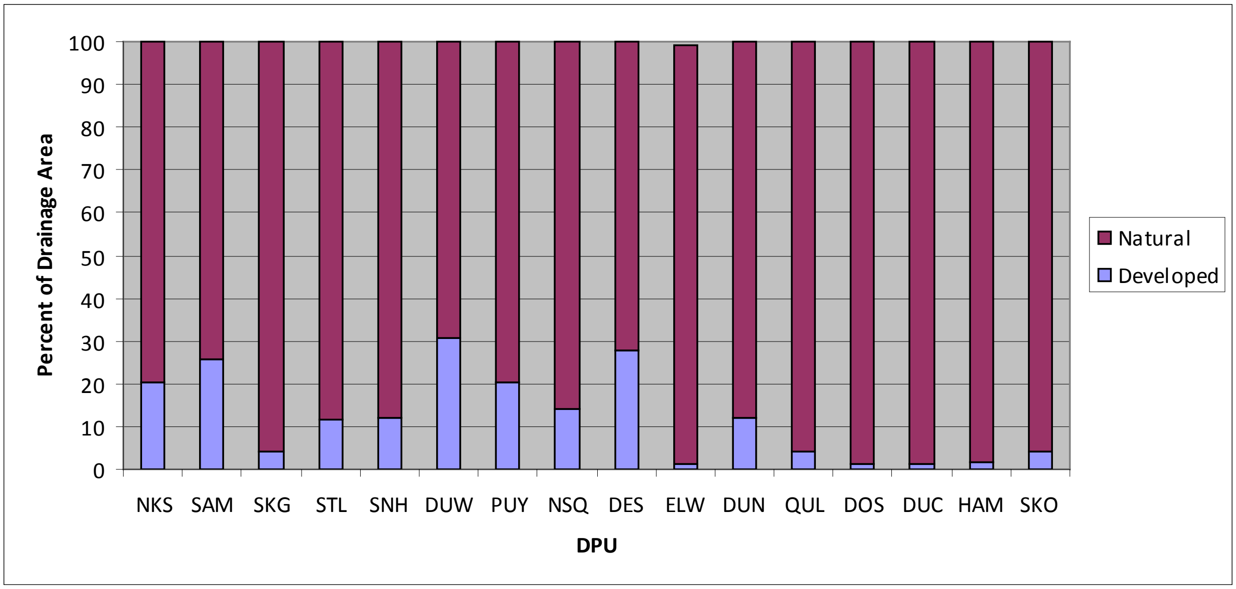


Figure 4-23

Percentage of Drainage Area Developed in Puget Sound DPUs

4.13 Summary of Stressor Impacts to Nearshore Processes

As described in Sections 4.1 through 4.12 for the individual stressors, stressor impacts vary between nearshore processes and shoreforms. A stressor along some shoreforms may affect many processes, while only affecting a single process along other shoreforms. Appendix B provides a table summarizing the relationships between stressors, nearshore processes, and shoreforms, as well as examples of ways that stressors degrade processes in each of the Puget Sound shoreforms. Table 4-19 is a simplified version of that table. Table 4-20 summarizes the relationships between stressors, nearshore ecosystem processes, and shoreforms.

Table 4-19

Nearshore Stressors and Impacts to PSNERP Nearshore Processes

Stressor (Change Analysis Categories [Tiers])	**PSNERP Nearshore processes**										
	Sediment Input	**Sediment Transport**	**Erosion/Accretion of Sediment**	**Tidal Flow**	**Tide Channel Formation and Maintenance**	**Distributary Channel Migration**	**Freshwater Input**	**Detritus Import and Export**	**Exchange of Aquatic Organisms**	**Physical Disturbance**	**Solar Incidence**
Shoreline Armoring (2)	✓	✓	✓	o	o	✓	o	✓	✓	✓	o
Breakwaters and Jetties (2)	o	✓	✓			o		o	✓	✓	o
Tidal Barriers (2)		✓	✓	✓	✓	✓		✓	✓	o	
Nearshore Fill (2)	✓	✓	✓	✓	✓	✓	o	✓	✓	✓	o
Roads (2, 3, 4)	✓	o	✓	✓	o		o	✓	✓	✓	o
Overwater Structures (2)	o	o	o					o	✓	o	✓
Marinas (2)	o	✓	✓	o	o		o	o	✓	✓	✓
Railroads (2, 3, 4))	✓	o	✓	✓	o	o	o	✓	✓	✓	o
Land Cover Development(3, 4)	o		o			o	o	✓			✓
Impervious Surface (3, 4)	o						✓	o			✓
Stream Crossings (3, 4)			o					o	✓		✓
Dams (4)	✓	✓	o			✓	✓	o	✓	o	

Note: ✓denotes a direct connection, or impact on process resulting from stressor
o denotes indirect or partial impact on process resulting from stressor

Table 4-20

Summary of Shoreforms in which Individual Stressors Impact Nearshore Ecosystem Processes

Stressors	Sediment Input	Sediment Transport	Erosion/Accretion of Sediment	Tidal Flow	Distributary Channel Migration	Tide Channel Formation and Maintenance	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence
Shoreline Armoring	D, BLB	BLB, BAB	D, BAB, BE, OCI, BL, CLM,	D, BE, BL, OCI, CLM	D	D	BLB, BAB, BE, OCI, D, PB	D, BLB, BAB, BE, BL, OCI, CLM, RP, PL, PB	D, BLB, BAB, BE, BL, OCI, CLM, RP, PL, PB	BLB, BAB, PB	BLB, BAB, OCI, BE, BL, RP, PB, D
Tidal Barriers		D, BE, OCI, BL,	BE, BL, OCI, CLM, D	D, OCI, BE, BL, CLM	D	OCI, BE, BL, D	OCI, BE, D	BE, BL, OCI, CLM, D	OCI, BE, BL, D		
Jetties and Breakwaters		BLB, BAB	BAB, BE, OCI, BL		D		D	D, BLB, BAB, BE, BL, OCI, CLM, RP, PL, PB	D, BLB, BAB, BE, BL, OCI, RP, PL, PB	BLB, BAB, PB	
Nearshore Fill	D, BLB	D, BLB, BAB, OCI, BE, BL	BAB, OCI, BE, BL, CLM, D	D, OCI, BE, BL, CLM	D	OCI, BE, BL, D	BLB, BAB, BE, OCI, D	D, BLB, BAB, BE, BL, OCI, CLM, RP, PL, PB	BLB, BAB, OCI, BE, BL, PL, RP, PB, D	BLB, BAB, PB	
Nearshore Roads	D, BLB	BLB, BAB, OCI, BE, BL, CLM, D	D, BAB, BE, OCI, BL, CLM	BE, BL, OCI, CLM. D	D	OCI, BE, BL, D	BLB, BAB, BE, OCI, D	BLB, BAB, BE, BL, OCI, CLM, RP, PL, PB	D, BLB, BAB, BE, BL, OCI, CLM, RP, PL, PB	BLB, BAB, PB	BLB, BAB, OCI, BE, BL, RP, PB, D

Stressors	Sediment Input	Sediment Transport	Erosion/Accretion of Sediment	Tidal Flow	Distributary Channel Migration	Tide Channel Formation and Maintenance	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence
Overwater Structures	BLB	BLB, BAB, OCI, BE, BL, CLM, D	BAB, OCI, BE, BL,					BLB, BAB, OCI, BE, BL, PL, PB, D	D, BLB, BAB, BE, BL, OCI, CLM, RP, PL, PB	BLB, BAB, PB	BLB, BAB, OCI, BE, BL, CLM, PL, RP, PB, D
Marinas	BLB	BLB, BAB, D	BAB, OCI, BE, BL, D	BE, BL, OCI, CLM. D		OCI, BE, BL, D	BLB, BAB, BE, OCI, D		D, BLB, BAB, BE, BL, OCI, RP, PL, PB	BLB, BAB, PB	BLB, BAB, OCI, BE, BL, PL, RP, PB, D
Railroads	D, BLB	BLB, BAB, OCI, BE, BL, CLM, D	D, BAB, BE, OCI, BL, CLM	D, OCI, BE, BL, CLM	D	OCI, BE, BL, D	BLB, BAB, BE, OCI, D	BLB, BAB, BE, BL, OCI, CLM, RP, PL, PB	BLB, BAB, BE, BL, OCI, CLM, RP, PB	BLB, BAB, PB	BLB, BAB, OCI, BE, BL, RP, PB, D
Wetland Loss		D, OCI, BE, BL, CLM	D, OCI, BE, BL, CLM	D, OCI, BE, BL, CLM		D, OCI, BE, BL		D, OCI, BE, BL, CLM		D	
Land Cover	D, BLB		D		D		D, BLB, BAB, OCI, BE, BL, CLM, PL, RP, PB	D, BLB, BAB, OCI, BE, BL, CLM, PL, RP, PB			BLB, BAB, OCI, BE, BL, CLM, RP, PB, D

Stressors	Sediment Input	Sediment Transport	Erosion/Accretion of Sediment	Tidal Flow	Distributary Channel Migration	Tide Channel Formation and Maintenance	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence
Impervious Surface	D, BLB, BE, BL, OCI	D, BLB, BAB, OCI, BE, BL, CLM, PL, RP, PB			D		D, BLB, BAB, OCI, BE, BL, CLM, PL, RP, PB	D, BLB, BAB, OCI, BE, BL, CLM, PL, RP, PB			D, BLB, BAB, BE, BL, OCI, CLM, RP, PL, PB
Stream Crossings				D, OCI, BE,	D	D	D	D, BE, OCI	D, BE, OCI		
Dams	D	D			D		D, BE, OCI	D	D	D	
Historic Drainage Area	D	D					D		D		

Shoreform abbreviations:

BE = Barrier Estuary
BL = Barrier Lagoon
CLM = Closed Lagoon/Marsh
OCI = Open Coastal Inlet
BLB = Bluff-backed Beach
BAB = Barrier Beach
RP = Rocky Platform
PL = Plunging Rocky
PB = Pocket Beach
D = Delta

4.14 Summary of Stressor Impacts to Valued Ecosystem Components and Additional Ecosystem Components of Value

Nearshore stressors impact VECs in a variety of ways, in addition to several ecosystems important to nearshore ecology. The following sections summarize these impacts and discuss their significance.

4.14.1 Stressor Impacts to VECs

A detailed discussion of stressor impacts to VECs was provided in Sections 4.1 through 4.12. Owing to the tight network of processes that control nearshore systems, virtually all of these relationships are linked; for example, orca whales preferentially feed upon salmon as prey, so any stressor that limits salmon is considered to have an indirect effect on orca whales. Likewise, adult salmon rely upon forage fish during their nearshore residence time, so impacts to forage fish are linked to salmon. Eelgrass provides habitat for some forage fish, so impacts to eelgrass would impact these fish.

4.14.2 Stressor Impacts to Additional Ecosystems of Value

Stressors affect nearshore processes, resulting in altered structure and lost or degraded habitat function. These effects are particularly evident in embayments and tidal wetlands. A detailed discussion of additional ecosystem components of value (embayments and tidal wetlands) is provided in Section 2.6.2.

4.14.2.1 Stressor Impacts to Embayments

The most prevalent stressors within embayments throughout the Puget Sound Basin are tidal barriers, nearshore fill, shoreline armoring, nearshore roads, railroads, and breakwaters/jetties. A detailed discussion of the impacts of these and other stressors on nearshore processes was provided in Sections 4.1 through 4.12. The discussion in this section focuses on structure and functions applicable to embayments.

Tidal barriers can impact embayments by restricting tidal flow to bays and associated marshes, which causes elevation changes and loss of tidal channels. Loss of these tidal channels results in decreased tidal prism, reduced tidal flushing, and isolation of formerly connected habitats. Placement of nearshore fill can directly bury embayment habitat, as well as cause disconnection of wetlands, streams, and sediment sources from bays. If sediment no longer accretes in embayments, beaches, barrier lagoons, and marshes erode and/or lose stability, leading to degraded fish, shellfish, and wildlife habitats. Shoreline armoring causes increased wave reflectivity that leads to coarsened substrates in embayments. In addition, armoring changes sediment, LWD, and detritus input and deposition in embayments, all of which are important for flora and fauna growth and survival. Nearshore roads impact embayments by disrupting the connectivity between bays and adjacent terrestrial systems, thus interrupting the flow of water, sediment, and organisms. Figure 4-24 provides a conceptual diagram of the processes that are impacted by these stressors in embayments, and the functional responses that result.

As discussed in Section 2.6.2.1, the major types of embayments found in the Puget Sound region are open coastal inlets, barrier estuaries, barrier lagoons, and closed lagoons/marshes. The Change Analysis indicated that the embayment types and sub-basins having the most co-occurring stressors included barrier estuaries and open coastal inlets in the San Juan Islands – Strait of Georgia sub-basin, barrier estuaries in the South Central Puget Sound sub-basin, and open coastal inlets and barrier lagoons in the Strait of Juan de Fuca sub-basin.

4.14.2.2 Stressor Impacts to Tidal Wetlands

The most prevalent stressors to Puget Sound tidal wetlands are tidal barriers such as dikes and levees, shoreline armoring, nearshore fill, and nearshore roads. A detailed discussion of the impacts of these stressors on nearshore processes was provided in Sections 4.1 through 4.12; this section gives a brief overview of impacts to the structure and function of tidal wetlands.

Construction of tidal barriers restricts or limits tidal flow in and out of river deltas and small estuaries, with impacts to water quality, wood accumulation, organism exchange, distributary channel migration, and sediment input, transport, and erosion/accretion. Filling of wetlands destroys wetland habitat altogether, eliminating transition areas between wetland classes, and reducing the quality of and accessibility to habitat. Large-scale filling significantly changes wetland distribution and composition of tidal areas. Shoreline

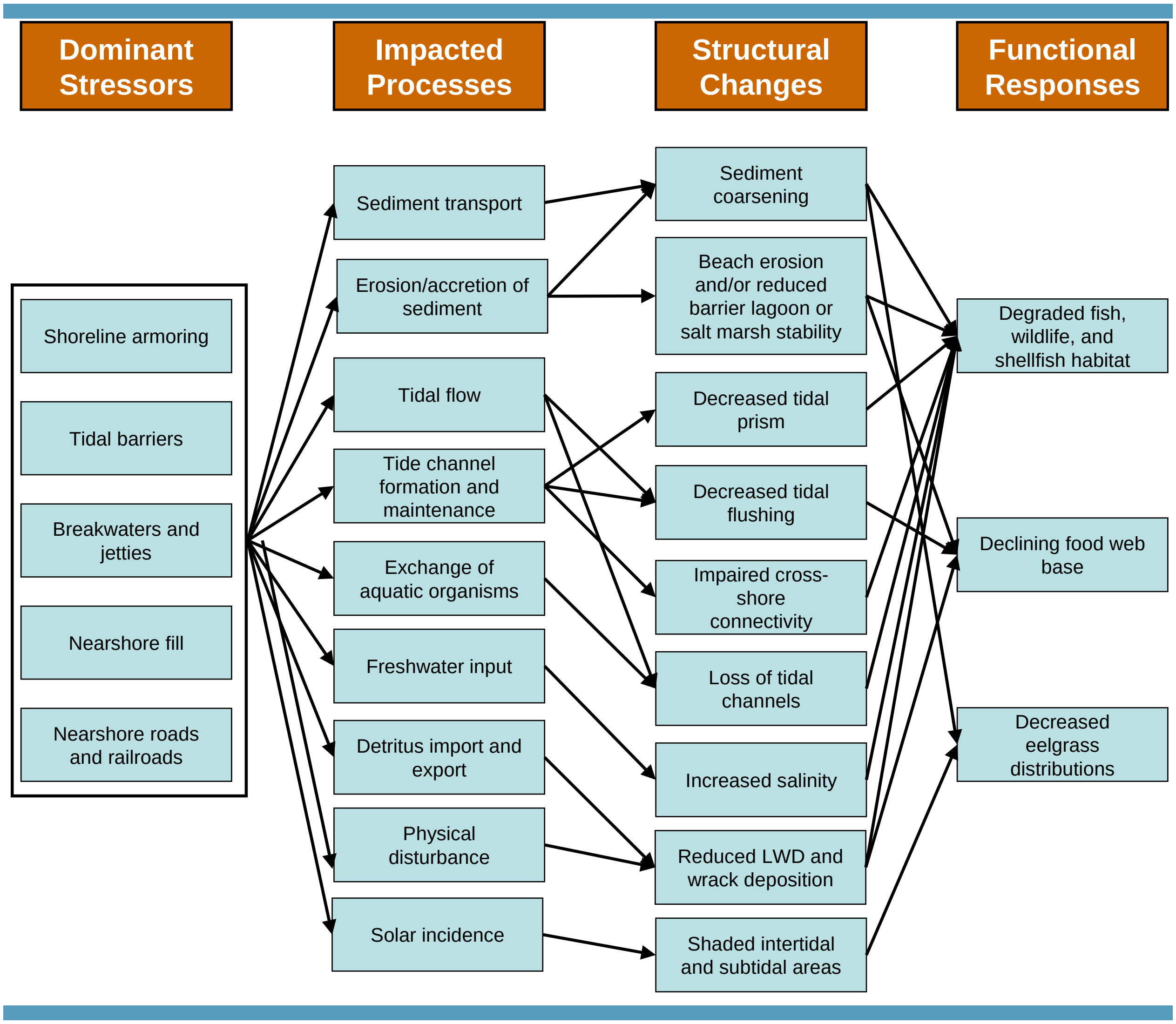


Figure 4-24

Conceptual Model Diagram Showing the Impacts of Key Stressors on Embayment Processes, Structures, and Functions

armoring reduces sediment and detritus/organic deposition that limits tidal channel formation and maintenance. Nearshore roads and armoring along small estuaries or lagoons can cut off the flow of fresh water, often in the form of small seeps, that provide a direct source of freshwater and moisture to the nearshore. Taken together, all of these impacts to processes and structure lead to a decline in the amount and quality of tidal wetlands for fish, wildlife, and humans. Figure 4-25 provides a conceptual diagram of the processes that are impacted by these stressors in tidal wetlands, and the functional responses that result.

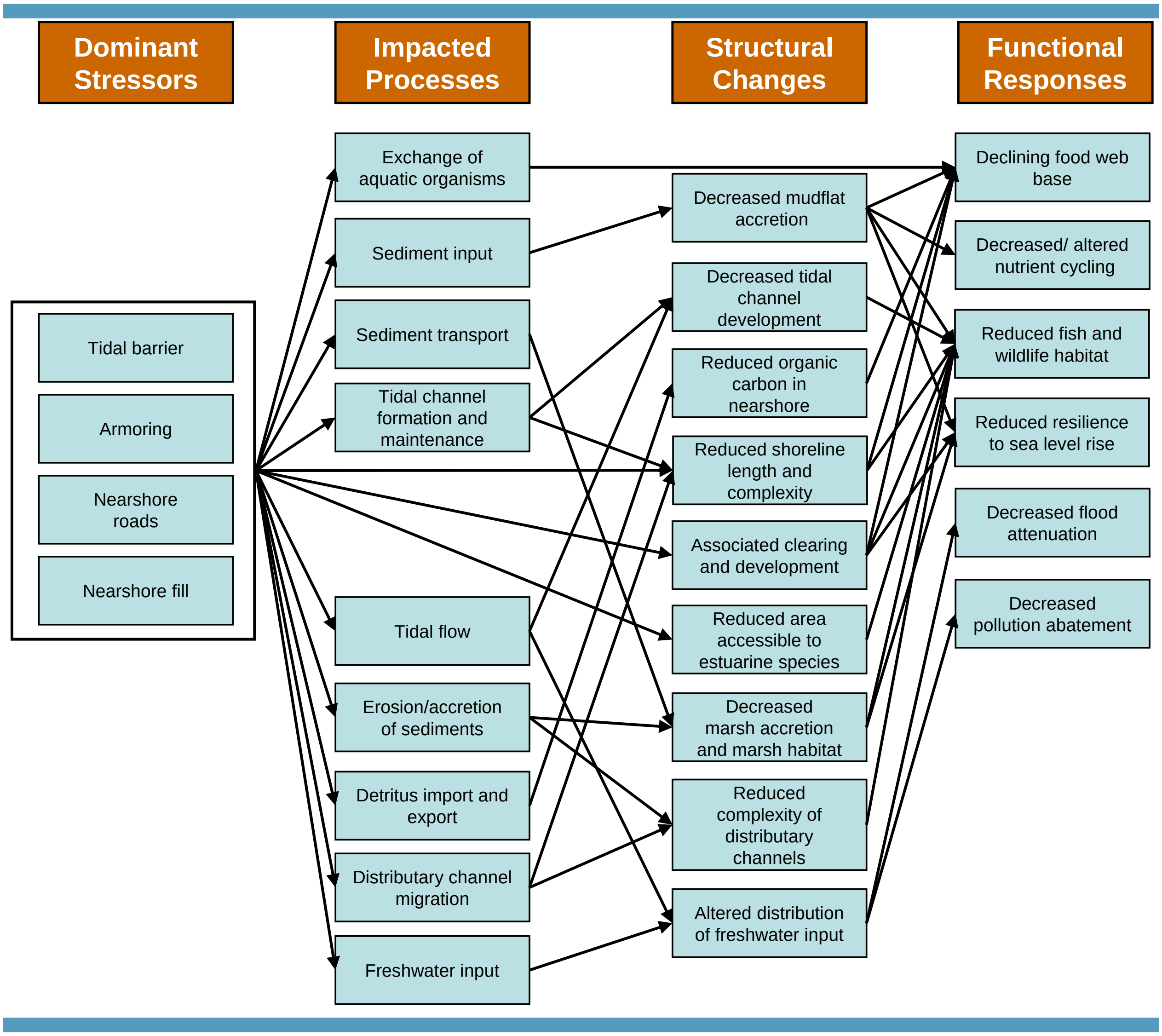


Figure 4-25

Conceptual Model Diagram Showing the Impacts of Key Stressors on Tidal Wetland Processes, Structures, and Functions

4.15 Co-location of Stressors throughout Puget Sound Basin and Sub-basin

Change Analysis data were explored to gain greater understanding of the patterns in the co-location of shoreforms and stressors, and of stressors with other stressors. Insights gained from this analysis helped in the development of a system to evaluate the degradation of nearshore processes (see Section 5). Results show that certain stressors are more commonly co-located with specific shoreforms, and that patterns of co-location vary among Puget Sound sub-basins.

Results of the Change Analysis show that multiple stressors are frequently co-located within an individual process unit. Patterns in the relative occurrence of co-located stressors and shoreforms are likely influenced by sub-basin characteristics, such as the scale of development, and other fundamental parameters, such as fetch, topography, tidal range, and geology.

The cumulative impact of co-located stressors varies by the stressors and shoreforms being affected, but process degradation is typically compounded by the occurrence of multiple stressors with associated impacts to nearshore structure and function. Impacts can often produce more systemic effects that extend beyond the reach or the extent of shore within which the stressors occur. This is due to process degradation within the shoreform or entire process unit (such as degraded sediment supply and sediment transport that will impact down-drift shoreforms). Section 4.15.1 summarizes the occurrence of stressors within specific shoreforms. Section 4.15.2 discusses multiple stressors within process units. Section 4.15.3 summarizes co-located stressors within Puget Sound sub-basins. Sections 4.15.1 through 4.15.3 focus on Shoreline Alteration (Tier 2) stressors (see Figure 2-6 in Section 2.5.1 for a list of these stressors). Section 4.15.4 provides evaluation of Change Analysis results on relative contributions of individual and co-located stressors to EFG&S.

Photo 4-14
Example of co-located stressors, including roads, fill, and armoring
(Photo courtesy of WDOE)

4.15.1 Co-located Shoreline Alteration (Tier 2) Stressors and Shoreforms

The co-location of stressors among specific shoreforms can inform which shoreforms are most vulnerable to specific stressors or anthropogenic alterations, which can aid in the development of restoration and protection strategies.

4.15.1.1 Puget Sound Basin

Change Analysis data for the Puget Sound Basin (Table 4-21) show that artificial shoreforms have the highest occurrence of stressors among all shoreforms; the most numerous alterations include shoreline armoring (74 percent), followed by nearshore fill (62 percent) and overwater structures (30 percent). Bluff-backed beaches are widely distributed across Puget Sound (encompassing the largest percent of Puget Sound shore [39 percent]), and are predominantly co-located with shoreline armoring (33 percent). Other stressors are much less widely co-located with bluff-backed beaches, which highlights the significance of shoreline armoring as the stressor most impacting these beaches. Barrier beaches are also frequently armored (27 percent). Nearshore fill (10 percent) and roads (10 percent) are less frequently observed along barrier beaches. Delta shores are most commonly co-located with tidal barriers (69 percent), with fewer nearshore roads (23 percent) and less armoring (17 percent). For embayment systems, the most frequently co-located stressors include shoreline armoring (7 to 22 percent), roads (13 to 22 percent), and tidal barriers (12 to 21 percent). Barrier lagoons and open coastal inlets exhibit similar patterns in the co-location of stressors, with a higher occurrence of each stressor in open coastal inlets (on the order of 4 to 7 percent). Among rocky systems, most stressors occur in relatively low amounts (0 to 4 percent). Plunging rocky shoreline has no occurrences of most stressor types, excluding armoring (1 percent) and overwater structures (1 percent). Rocky platform/bedrock ramp shores are more commonly co-located with shore armoring (4 percent) and roads (2 percent). Pocket beaches are commonly co-located with shoreline armoring (8 percent) and are also associated with nearshore roads (4 percent).

Table 4-21
Co-located Shoreline Alteration (Tier 2) Stressors and Shoreforms in Puget Sound Basin, Percent by Shoreform Length

	Current Shoreforms (Highest Percentage Among Natural Shoreforms is in Bold)									
Stressors	**Bluff-backed Beach**	**Barrier Beach**	**Delta**	**Barrier Estuary**	**Barrier Lagoon**	**Open Coastal Inlet**	**Plunging Rocky Shoreline**	**Rocky Platform**	**Pocket Beach**	**Artificial**
Armoring	**33%**	27%	17%	7%	15%	22%	1%	4%	8%	74%
BW/J	0%	0%	2%	1%	1%	**2%**	0%	0%	0%	16%
Marinas	0%	0%	0%	1%	0%	1%	0%	0%	1%	14%
Nearshore Fill	3%	**10%**	6%	3%	9%	4%	0%	0%	0%	62%
OWS	2%	2%	2%	5%	**7%**	5%	1%	1%	3%	30%
Roads	7%	10%	**23%**	22%	13%	17%	0%	2%	4%	23%
RR, Abandoned	1%	1%	0%	2%	**3%**	**3%**	0%	0%	0%	1%
RR, Active	1%	0%	1%	**3%**	1%	1%	0%	1%	0%	6%
Tidal Barriers	0%	0%	**69%**	21%	12%	16%	0%	0%	0%	0%

Note: Closed lagoons/marshes (CLM) do not occur on the shoreline; therefore, no shoreline alterations are associated with them. Another shoreform type is delineated waterward of CLM shoreforms and has the shoreline alterations attributed to it. BW/J = Breakwaters/Jetties, OWS = Overwater Structures, RR = Railroads

4.15.1.2 Strait of Juan de Fuca Sub-basin

The Strait of Juan de Fuca sub-basin has a similar distribution of commonly occurring stressors among the different shoreforms as the Puget Sound Basin (Table 4-22). Artificial shoreforms are most frequently armored (85 percent), and nearshore fill is common (48 percent). However, breakwaters and jetties are also often co-located (51 percent), which is likely due to the relatively higher wave energy within this sub-basin. Bluff-backed beaches (14 percent) are less frequently co-located with shoreline armoring, as are barrier beaches (24 percent). Tidal barriers remain the most frequent stressor in deltas (24 percent); however, they are also considerably less common than in the Puget Sound Basin. Stressors within embayment systems exhibit considerable contrast to the Puget Sound Basin. Barrier estuaries are most commonly altered by nearshore roads (18 percent), overwater structures (15 percent), and tidal barriers (13 percent). Barrier lagoons are commonly co-located with numerous stressors including: abandoned railroads (24 percent), shoreline armoring (22 percent), fill (22 percent), overwater structures (22 percent), tidal barriers (22 percent), and roads (21 percent). Open coastal inlets are frequently co-located with fewer stressors; the most frequent are abandoned railroads (44 percent) and tidal barriers (41 percent). Pocket beaches are commonly co-located with shoreline armoring (18 percent) and roads (8 percent). Rocky shores are infrequently co-located with stressors.

Table 4-22

Co-located Shoreline Alteration (Tier 2) Stressors and Shoreforms in Strait of Juan de Fuca Sub-basin, Percent by Shoreform Length

	Current Shoreforms (Highest Percentage Among Natural Shoreforms is In Bold)									
Stressors	**Bluff-backed Beach**	**Barrier Beach**	**Delta**	**Barrier Estuary**	**Barrier Lagoon**	**Open Coastal Inlet**	**Plunging Rocky Shoreline**	**Rocky Platform**	**Pocket Beach**	**Artificial**
Armoring	14%	**24%**	4%	0%	22%	4%	0%	4%	18%	85%
BW/J	0%	0%	0%	0%	0%	0%	0%	0%	0%	51%
Marinas	**1%**	0%	0%	0%	0%	0%	0%	0%	0%	13%
Nearshore Fill	2%	9%	0%	0%	**22%**	0%	0%	0%	0%	48%
OWS	1%	1%	6%	15%	**22%**	1%	0%	0%	1%	27%
Roads	4%	11%	12%	18%	**21%**	11%	0%	4%	8%	13%
RR, Abandoned	6%	5%	0%	4%	24%	**46%**	0%	0%	0%	10%
RR, Active	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Tidal Barriers	0%	0%	24%	13%	22%	**41%**	0%	0%	0%	0%

Note: Closed lagoons/marshes (CLM) do not occur on the shoreline; therefore, no shoreline alterations are associated with them. Another shoreform type is delineated waterward of CLM shoreforms and has the shoreline alterations attributed to it. BW/J = Breakwaters/Jetties, OWS = Overwater Structures, RR = Railroads

4.15.1.3 San Juan Islands – Strait of Georgia Sub-basin

The most frequent stressor among all shoreforms in the San Juan Islands – Strait of Georgia sub-basin (Table 4-23) is the presence of tidal barriers among barrier estuaries (82 percent), followed by stressors among artificial shoreforms. This result highlights the considerable level of degradation that has occurred to embayment systems in this sub-basin. Artificial shoreforms are predominantly co-located with shoreline armoring (60 percent), nearshore fill (57 percent), and breakwaters and jetties (32 percent). Bluff-backed beaches in the San

Juan Islands – Strait of Georgia sub-basin have a lower level of armoring (14 percent) than the Puget Sound Basin (33 percent), but are more frequently co-located with nearshore roads (7 percent in San Juan Islands – Strait of Georgia sub-basin, and 11 percent in the Puget Sound Basin). Barrier beaches are also less frequently armored than the Puget Sound Basin, with similar levels of nearshore fill and roads. The most commonly occurring stressors within the embayment systems are also variable and contrast with results from the Puget Sound Basin due to the regional prevalence of railroads and breakwaters and jetties. Barrier estuaries have the most co-located stressors of all shoreforms with alterations resulting from tidal barriers (82 percent), active railroads (50 percent), and breakwaters and jetties (40 percent). Barrier lagoons exhibit a lower occurrence of stressors in this sub-basin, largely resulting from nearshore roads (26 percent), shoreline armoring (21 percent), and tidal barriers (19 percent). Open coastal inlets are more heavily altered with co-located tidal barriers (41 percent), armoring (37 percent), and roads (34 percent). Rocky systems have minimal stressors and pocket beaches are infrequently co-located with stressors, with only 6 percent armored, 4 percent with roads, and 3 percent with overwater structures.

Table 4-23

Co-located Shoreline Alteration (Tier 2) Stressors and Shoreforms in San Juan Islands – Strait of Georgia Sub-basin, Percent by Shoreform Length

	Current Shoreforms (Highest Percentage Among Natural Shoreforms is In Bold)									
Stressors	**Bluff-backed Beach**	**Barrier Beach**	**Delta**	**Barrier Estuary**	**Barrier Lagoon**	**Open Coastal Inlet**	**Plunging Rocky Shoreline**	**Rocky Platform**	**Pocket Beach**	**Artificial**
Armoring	14%	20%	**47%**	34%	21%	37%	0%	2%	6%	60%
BW/J	0%	0%	5%	**40%**	4%	7%	0%	0%	0%	32%
Marinas	0%	0%	0%	0%	0%	0%	0%	0%	1%	23%
Nearshore Fill	2%	10%	0%	**12%**	2%	10%	0%	0%	0%	57%
OWS	1%	1%	3%	**12%**	10%	2%	1%	1%	3%	25%
Roads	11%	12%	11%	3%	26%	**34%**	0%	1%	4%	17%
RR, Abandoned	**1%**	0%	0%	0%	0%	0%	0%	0%	0%	0%
RR, Active	2%	0%	7%	**50%**	4%	5%	0%	1%	0%	10%
Tidal Barriers	0%	0%	49%	**82%**	19%	41%	0%	0%	0%	0%

Note: Closed lagoons/marshes (CLM) do not occur on the shoreline; therefore, no shoreline alterations are associated with them. Another shoreform type is delineated waterward of CLM shoreforms and has the shoreline alterations attributed to it. BW/J = Breakwaters/Jetties, OWS = Overwater Structures, RR = Railroads

4.15.1.4 Hood Canal Sub-basin

The distribution of stressors among shoreforms in the Hood Canal sub-basin in some ways contrasts with the Puget Sound Basin. For example, the most common stressor among all shoreforms in the Hood Canal sub-basin is tidal barriers among deltaic shores (66 percent), followed by nearshore fill (53 percent) and shoreline armoring (39 percent) on artificial shoreforms (Table 4-24). Bluff-backed beaches are more commonly associated with roads (13 percent) and overwater structures (3 percent) relative to the Puget Sound Basin. However, shoreline armoring among bluff-backed beaches (27 percent) and barrier beaches (27 percent) is similar in co-location. Deltas in the Hood Canal sub-basin are also commonly associated with nearshore roads (19 percent) and fill (13 percent). Barrier estuaries and open coastal inlets are commonly co-located with roads (24 and 16 percent, respectively) and tidal barriers (17 and 19 percent, respectively), while barrier lagoons are most commonly co-located with shoreline armoring (15 percent). Rocky systems were (relatively) more impacted by roads (plunging rocky shoreline [8 percent] and rocky platform [6 percent]) and armoring (plunging rocky shoreline [4 percent] and rocky platform [6 percent]) than the Puget Sound Basin. Pocket beaches are frequently co-located with shoreline armoring (24 percent) in the Hood Canal sub-basin.

Table 4-24
Co-located Shoreline Alteration (Tier 2) Stressors and Shoreforms in Hood Canal Sub-basin, Percent by Shoreform Length

	Current Shoreforms (Highest Percentage Among Natural Shoreforms is In Bold)									
Stressors	**Bluff-backed Beach**	**Barrier Beach**	**Delta**	**Barrier Estuary**	**Barrier Lagoon**	**Open Coastal Inlet**	**Plunging Rocky Shoreline**	**Rocky Platform**	**Pocket Beach**	**Artificial**
Armoring	**27%**	**27%**	3%	1%	15%	5%	4%	6%	24%	39%
BW/J	0%	0%	**5%**	0%	0%	2%	0%	0%	0%	0%
Marinas	0%	0%	0%	**2%**	0%	0%	0%	0%	0%	6%
Nearshore Fill	0%	3%	13%	2%	4%	**15%**	0%	0%	0%	53%
OWS	3%	4%	2%	4%	**6%**	1%	1%	2%	1%	20%
Roads	13%	8%	19%	**24%**	3%	16%	8%	6%	0%	16%
RR, Abandoned	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RR, Active	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Tidal Barriers	0%	0%	66%	17%	7%	**19%**	0%	0%	0%	0%

Note: Closed lagoons/marshes (CLM) do not occur on the shoreline; therefore, no shoreline alterations are associated with them. Another shoreform type is delineated waterward of CLM shoreforms and has the shoreline alterations attributed to it. BW/J = Breakwaters/Jetties, OWS = Overwater Structures, RR = Railroads

4.15.1.5 Whidbey Sub-basin

Change Analysis data show that the most common stressors among shoreforms in the Whidbey sub-basin are nearshore fill (78 percent) within artificial shoreforms and tidal barriers in deltas (Table 4-25). Nearshore fill is also frequent within barrier lagoons (30 percent), considerably more so than within the Puget Sound Basin (9 percent). Among natural shoreforms, shoreline armoring is most frequently occurring along bluff-backed beaches (29 percent) and barrier beaches (29 percent). Shoreline armoring is the most commonly occurring stressor affecting pocket beaches (11 percent). Barrier beaches are substantially more altered by nearshore fill (27 percent) relative to the Puget Sound Basin (10 percent). Marinas are predominantly located within artificial shoreforms (17 percent) and barrier lagoons (2 percent). Roads are most numerous in deltas (26 percent) closely followed by barrier estuaries (24 percent). Tidal barriers are also common among barrier estuaries (17 percent) and barrier lagoons (14 percent). Open coastal inlets are less common (n=2) in this sub-basin and are therefore free of alteration.

Table 4-25

Co-located Shoreline Alteration (Tier 2) Stressors and Shoreforms in Whidbey Sub-basin, Percent by Shoreform Length

	Current Shoreforms (Highest Percentage Among Natural Shoreforms is In Bold)									
Stressors	**Bluff-backed Beach**	**Barrier Beach**	**Delta**	**Barrier Estuary**	**Barrier Lagoon**	**Open Coastal Inlet**	**Plunging Rocky Shoreline**	**Rocky Platform**	**Pocket Beach**	**Artificial**
Armoring	**29%**	**29%**	8%	10%	12%	0%	0%	2%	11%	53%
BW/J	0%	0%	**1%**	**1%**	0%	0%	0%	0%	0%	17%
Marinas	0%	0%	0%	**2%**	0%	0%	0%	0%	0%	17%
Nearshore Fill	9%	27%	5%	7%	**30%**	0%	0%	0%	2%	78%
OWS	1%	2%	2%	**3%**	0%	0%	2%	1%	0%	24%
Roads	5%	7%	**26%**	24%	15%	0%	1%	1%	3%	5%
RR, Abandoned	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RR, Active	**1%**	0%	**1%**	0%	0%	0%	0%	0%	0%	3%
Tidal Barriers	0%	0%	**78%**	17%	14%	0%	0%	0%	0%	0%

Note: Closed lagoons/marshes (CLM) do not occur on the shoreline; therefore, no shoreline alterations are associated with them. Another shoreform type is delineated waterward of CLM shoreforms and has the shoreline alterations attributed to it. BW/J = Breakwaters/Jetties, OWS = Overwater Structures, RR = Railroads

4.15.1.6 North Central Puget Sound Sub-basin

The distribution of stressors among shoreforms in the North Central Puget Sound sub-basin has some unique characteristics that contrast with many other sub-basins as well as the Puget Sound Basin. For example, stressors on bluff-backed beaches occur considerably less frequently (Table 4-26). Barrier beaches are also relatively less frequently affected by stressors, particularly shoreline armoring and roads. Only 7 percent of bluff-backed beaches and 9 percent of barrier beaches are co-located with shoreline armoring. Nearshore fill is more frequent within barrier beaches (8 percent) as are roads (4 percent). Embayment shores encompass the most commonly occurring stressors in the entire sub-basin, including tidal barriers within barrier estuaries (22 percent) and open coastal inlets (18 percent). Overwater structures and armoring are also prevalent among open coastal inlets, occurring along 10 percent and 9 percent of those shoreforms, respectively. Open coastal inlets are the most altered shoreform in the sub-basin excluding artificial shoreforms. The most numerous alterations among rocky platforms occur relatively infrequently (4 percent) and include armoring and overwater structures. Pocket beaches have considerable stressor frequency, the most commonly occurring of which is shoreline armoring (12 percent) followed by marinas (7 percent), overwater structures (7 percent), fill (6 percent), and roads (2 percent).

Table 4-26

Co-located Shoreline Alteration (Tier 2) Stressors and Shoreforms in North Central Puget Sound Sub-basin, Percent by Shoreform Length

	Current Shoreforms (Highest Percentage Among Natural Shoreforms is In Bold)									
Stressors	**Bluff-backed Beach**	**Barrier Beach**	**Delta**	**Barrier Estuary**	**Barrier Lagoon**	**Open Coastal Inlet**	**Plunging Rocky Shoreline**	**Rocky Platform**	**Pocket Beach**	**Artificial**
Armoring	7%	9%	--	0%	0%	9%	0%	4%	**12%**	36%
	0%	0%	--	0%	0%	0%	0%	0%	0%	14%
Marinas	0%	0%	--	0%	0%	3%	0%	1%	**7%**	11%
Nearshore Fill	1%	**8%**	--	0%	0%	1%	0%	0%	6%	59%
OWS	0%	1%	--	1%	0%	10%	0%	4%	**7%**	31%
Roads	1%	4%	--	3%	3%	**9%**	0%	1%	2%	9%
RR, Abandoned	0%	0%	--	0%	0%	0%	0%	0%	0%	0%
RR, Active	0%	0%	--	0%	0%	0%	0%	0%	0%	0%
Tidal Barriers	0%	0%	--	**22%**	0%	18%	0%	0%	0%	0%

Note: Closed lagoons/marshes (CLM) do not occur on the shoreline; therefore, no shoreline alterations are associated with them. Another shoreform type is delineated waterward of CLM shoreforms and has the shoreline alterations attributed to it. BW/J = Breakwaters/Jetties, OWS = Overwater Structures, RR = Railroads

4.15.1.7 South Central Puget Sound Sub-basin

Shoreline alterations in the South Central Puget Sound sub-basin are typically more numerous than stressor occurrences in the Puget Sound Basin and other sub-basins (Table 4-27). As expected, stressors are most numerous within artificial shoreforms, particularly shoreline armoring (86 percent), nearshore fill (66 percent), overwater structures (33 percent), and roads (32 percent). Among natural shoreforms, shoreline armoring is most frequent within bluff-backed beaches (58 percent), followed by pocket beaches (53 percent), open coastal inlets (49 percent), rocky platforms (49 percent), and barrier beaches (48 percent). Barrier beaches are also co-located with nearshore fill (14 percent) and roads (11 percent). Of the shoreforms in embayment systems, barrier estuaries are most frequently altered by stressors in the South Central Puget Sound sub-basin, followed by open coastal inlets. Barrier estuaries are most widely altered by tidal barriers (45 percent) and roads (36 percent). Armoring is the most frequently occurring stressor within open coastal inlets followed by roads (49 percent) and roads (8 percent). Barrier lagoons are most widely altered by armoring (19 percent) and overwater structures (10 percent). Rocky platforms are commonly co-located with shoreline armoring (49 percent) and roads (29 percent). Armoring (53 percent) and roads (4 percent) are the most widely co-located with pocket beaches.

Table 4-27
Co-located Shoreline Alteration (Tier 2) Stressors and Shoreforms in South Central Puget Sound Sub-basin, Percent by Shoreform Length[a]

Stressors	Current Shoreforms (Highest Percentage Among Natural Shoreforms is In Bold)									
	Bluff-backed Beach	**Barrier Beach**	**Delta**	**Barrier Estuary**	**Barrier Lagoon**	**Open Coastal Inlet**	**Plunging Rocky Shoreline**	**Rocky Platform**	**Pocket Beach**	**Artificial**
Armoring	**58%**	48%	--	21%	19%	49%	--	49%	53%	86%
BW/J	0%	0%	--	0%	0%	0%	--	0%	0%	7%
Marinas	1%	0%	--	0%	0%	**3%**	--	0%	0%	11%
Nearshore Fill	8%	**14%**	--	8%	0%	4%	--	0%	0%	66%
OWS	3%	4%	--	5%	**10%**	7%	--	2%	4%	33%
Roads	8%	11%	--	**36%**	2%	8%	--	29%	7%	32%
RR, Abandoned	0%	0%	--	0%	0%	0%	--	0%	0%	0%
RR, Active	**2%**	0%	--	1%	0%	0%	--	0%	0%	6%
Tidal Barriers	0%	0%	--	**45%**	3%	3%	--	0%	0%	0%

Note:

a) Closed lagoons/marshes (CLM) do not occur on the shoreline; therefore, no shoreline alterations are associated with them. Another shoreform type is delineated waterward of CLM shoreforms and has the shoreline alterations attributed to it.

b) Although the South Central Puget Sound sub-basin includes two delta process units, there are no current delta shoreforms due to the major alterations that have occurred. The shorelines of the DPUs are classified as artificial shoreforms in the current shoreform delineation.

BW/J = Breakwaters/Jetties, OWS = Overwater Structures, RR = Railroads

4.15.1.8 South Puget Sound Sub-basin

Similar to the Puget Sound Basin, stressors are most frequently co-located within artificial shoreforms in the South Puget Sound sub-basin (Table 4-28). The most numerous alterations within artificial shoreforms include: nearshore fill (84 percent), shoreline armoring (82 percent), and overwater structures (27 percent). Tidal barriers (67 percent) and shoreline armoring (66 percent) within deltaic shores are the most frequent stressors across the different shoreforms. Forty-one percent of bluff-backed beaches are co-located with shoreline armoring. Barrier beaches are also commonly co-located with shoreline armoring (32 percent), as well as roads (9 percent) and nearshore fill (7 percent). Within embayment systems, common co-located stressors include armoring, roads, and tidal barriers. Among natural shoreforms, overwater structures are most commonly located within open coastal inlets (7 percent) followed by barrier lagoons (4 percent). Nearshore fill is most commonly co-located in deltas (20 percent), followed by barrier beaches (7 percent) and bluff-backed beaches (4 percent). Outside of deltas, tidal barriers are most numerous in barrier estuary shoreforms (10 percent).

Table 4-28

Co-located Shoreline Alteration (Tier 2) Stressors and Shoreforms in South Puget Sound Sub-basin, Percent by Shoreform Length

	Current Shoreforms (Highest Percentage Among Natural Shoreforms is In Bold)									
Stressors	**Bluff-backed Beach**	**Barrier Beach**	**Delta**	**Barrier Estuary**	**Barrier Lagoon**	**Open Coastal Inlet**	**Plunging Rocky Shoreline**	**Rocky Platform**	**Pocket Beach**	**Artificial**
Armoring	41%	32%	**66%**	3%	12%	12%	--	--	--	82%
BW/J	0%	0%	0%	0%	0%	0%	--	--	--	1%
Marinas	0%	0%	0%	0%	2%	0%	--	--	--	11%
Nearshore Fill	4%	7%	**20%**	2%	3%	1%	--	--	--	84%
OWS	2%	2%	1%	2%	4%	**7%**	--	--	--	27%
Roads	5%	9%	**35%**	19%	1%	12%	--	--	--	16%
RR, Abandoned	0%	0%	0%	3%	0%	**4%**	--	--	--	2%
RR, Active	3%	1%	0%	**4%**	1%	0%	--	--	--	19%
Tidal Barriers	0%	0%	67%	**10%**	4%	5%	--	--	--	0%

Note: Closed lagoons/marshes (CLM) do not occur on the shoreline; therefore, no shoreline alterations are associated with them. Another shoreform type is delineated waterward of CLM shoreforms and has the shoreline alterations attributed to it. BW/J = Breakwaters/Jetties, OWS = Overwater Structures, RR = Railroads

4.15.2 Multiple Shoreline Alteration (Tier 2) Stressors in Process Units

As reported in the Change Analysis, most SPUs (60 percent) have between two and four types of stressors, however no process unit contains all nine types of Shoreline Alteration (Tier 2) stressors (Figure 4-26). The most common number of stressors in an individual SPU is three (Simenstad et al. 2011). Looking at the number of Shoreline Alteration (Tier 2) stressors in each sub-basin (Figure 4-27), the most common number of stressors in SPUs is highest (five) in the Strait of Juan de Fuca sub-basin. In the Whidbey sub-basin, equal numbers of SPUs have four and five stressors. In contrast, in the San Juan Islands – Strait of Georgia sub-basin, the most common number of stressors in SPUs is two and nearly 60 percent of the SPUs have two or fewer Shoreline Alteration (Tier 2) stressors (Simenstad et al. 2011).

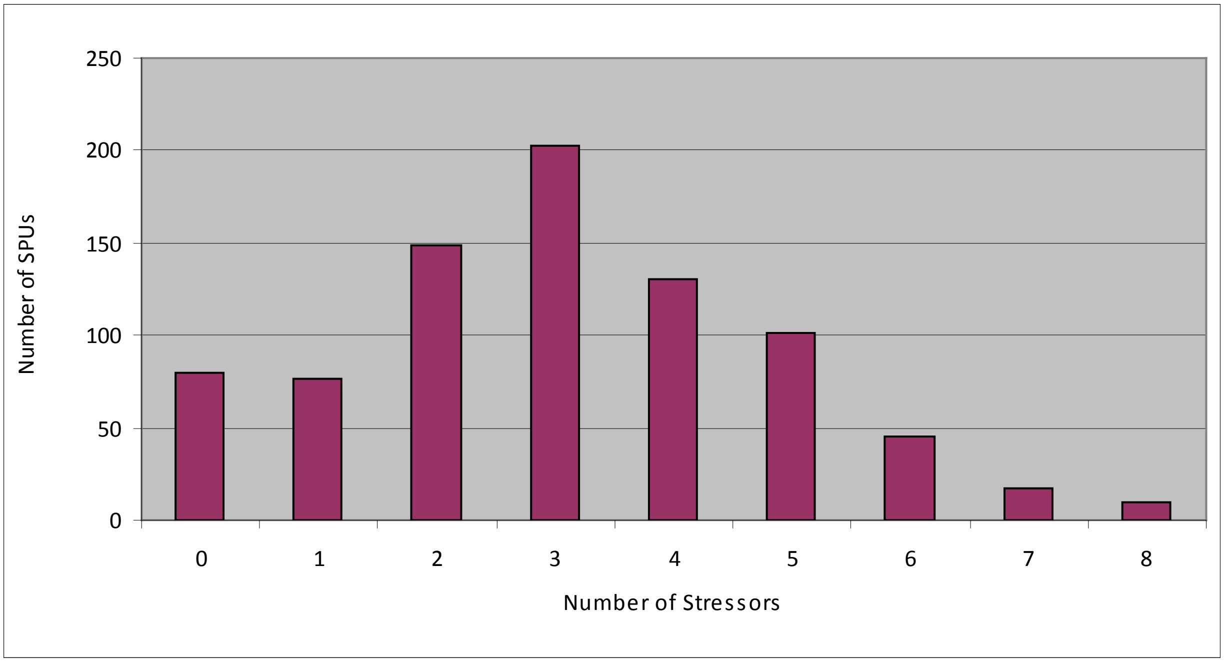


Figure 4-26

Number of Shoreline Alteration (Tier 2) Stressors Among SPUs Sound-wide

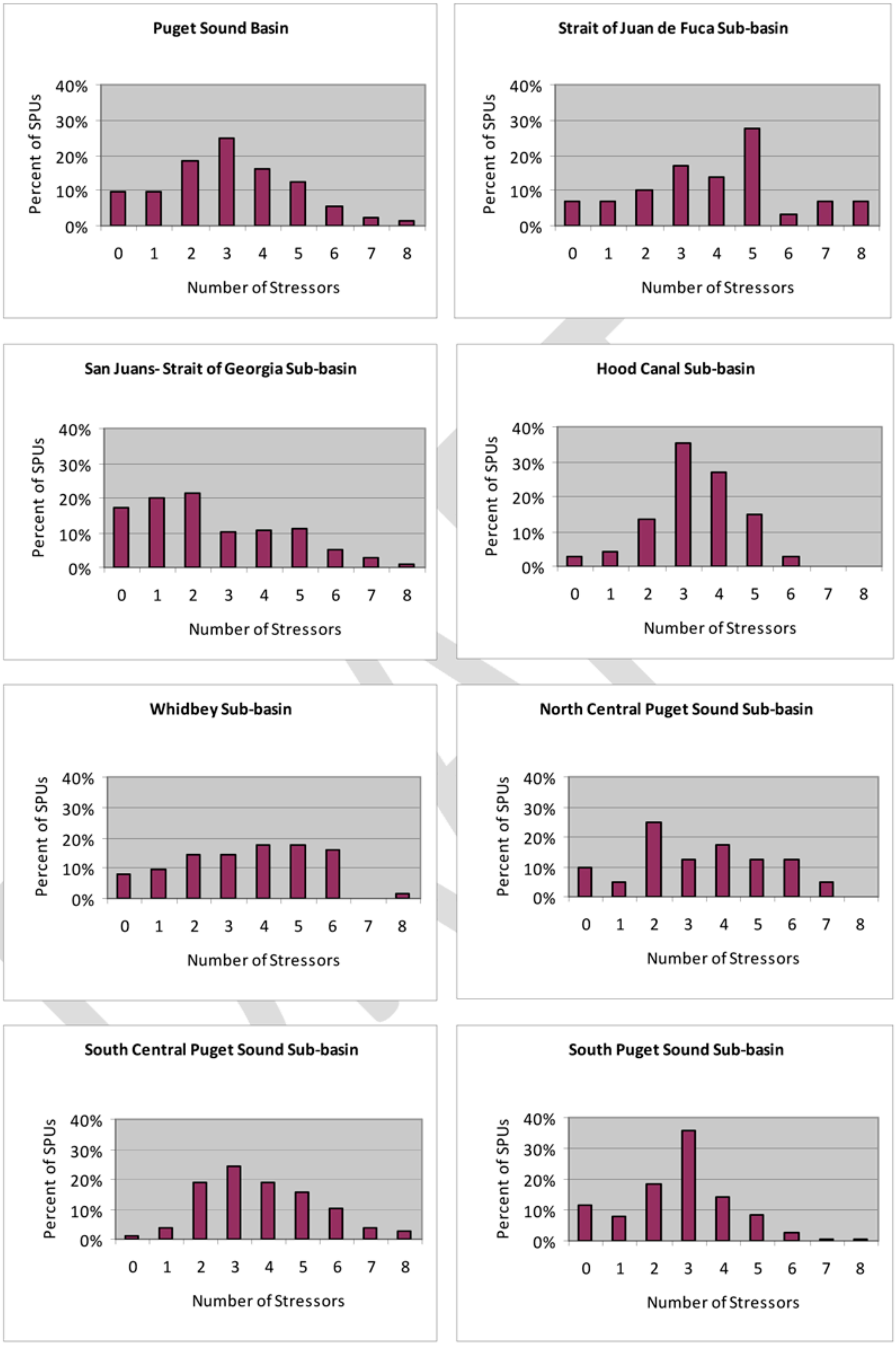


Figure 4-27

Number of Shoreline Alteration (Tier 2) Stressors, Percent SPUs Sound-wide and by Sub-basin

In general, DPUs contain more Shoreline Alteration (Tier 2) stressors than SPUs. Among DPUs, the highest number of stressors (eight) occurs in the Snohomish DPU (Figure 4-28). Three additional DPUs, the Skagit, Duwamish, and Puyallup, contain seven types of Shoreline Alteration (Tier 2) stressors.

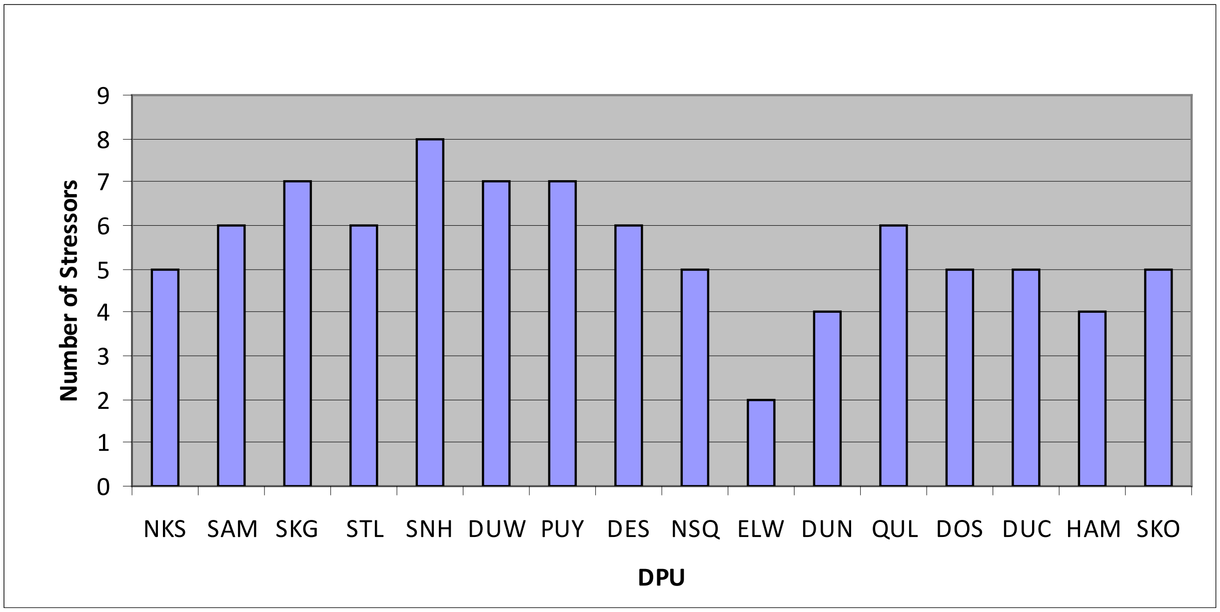


Figure 4-28
Number of Shoreline Alteration (Tier 2) Stressors Among DPUs

4.15.3 Co-located Shoreline Alteration (Tier 2) Stressors

The frequency and distribution of spatially coincident stressors were assessed to better understand patterns in amount of stressor occurrence throughout the Puget Sound Basin and sub-basins and areas of potentially compounded process degradation, to aid in the development of restoration and protection strategies.

The co-location of stressors is presented in a series of tables for the Puget Sound Basin and each of the sub-basins. These tables show stressors in columns across the top. The cells in each column show the percentage of the stressor's distribution that is co-located with each of the other stressors.

Change Analysis data show that shoreline armoring encompasses the greatest linear extent of shoreline and is frequently co-located with a secondary stressor. Throughout the Puget Sound Basin, shoreline armoring is most frequently spatially coincident with nearshore fill (23 percent; see Table 4-29) and roads (18 percent). The co-location of armoring and fill is unsurprising because armoring is often required to mechanically support an area of fill that has been placed in the nearshore. Armoring is prevalent within several other nearshore stressors including active railroads (72 percent), marinas (71 percent), nearshore fill (68 percent), overwater structures (64 percent) and breakwaters and jetties (63 percent). Other commonly occurring co-located stressors include nearshore fill within marinas (62 percent), active railroads (59 percent), and breakwaters and jetties (45 percent). Thirty-three percent of tidal barriers are co-located with roads, and 30 percent of abandoned railroads are coincident with tidal barriers. Abandoned railroads are more frequently co-located with overwater structures (31 percent) and roads (31 percent) than active railroads (10 and 22 percent, respectively). Roads are most commonly spatially coincident with armoring (40 percent) and tidal barriers (23 percent). Unsurprisingly, marinas have the greatest overlap with other stressors including armoring (71 percent), overwater structures (80 percent), nearshore fill (62 percent), and breakwaters and jetties (33 percent).

Table 4-29

Co-located Shoreline Alteration (Tier 2) Stressors in Puget Sound Basin

Co-located Stressors	Stressors								
	Armoring	BW/J	Marinas	Nearshore Fill	OWS	Roads	RR, Abandoned	RR, Active	Tidal Barriers
Armoring	100%	63%[a]	71%	68%	64%	46%	40%	72%	22%
BW/J	5%[b]	100%	33%	9%	10%	4%	2%	12%	4%
Marinas	4%	28%	100%	11%	27%	2%	2%	1%	0%
Nearshore Fill	23%	45%	62%	100%	43%	13%	14%	59%	9%
OWS	12%	27%	80%	23%	100%	10%	31%	10%	3%
Roads	18%	24%	16%	14%	20%	100%	31%	22%	33%
RR, Abandoned	1%	1%	1%	1%	4%	2%	100%	2%	3%
RR, Active	4%	10%	1%	10%	3%	3%	5%	100%	2%
Tidal Barriers	6%	14%	1%	7%	5%	23%	30%	9%	100%

Note: This table is organized such that each Shoreline Alteration stressor is shown in a separate column. The rows underneath indicate the percentage of the Shoreline Alteration stressor distribution that is co-located with the other Shoreline Alteration stressors. Thus, for the Sound-wide occurrence of breakwaters/jetties, 63% of the spatial extent is also impacted by armoring[a]. Conversely, for all armoring in Puget Sound, only 5% is associated with breakwaters/jetties. BW/J = Breakwaters/Jetties, OWS = Overwater Structures, RR = Railroads

Some variation in the magnitude of these relationships occurs among the sub-basins (see Sections 4.15.3.1 through 4.15.3.7) but the patterns remain relatively similar (Simenstad et al. 2011). Marinas have the greatest spatial coincidence with other alterations, including roads (16 percent), nearshore fill (62 percent), breakwaters and jetties (33 percent), overwater structures (80 percent), and armoring (71 percent). Breakwaters and jetties and active railroads are also frequently co-located with other stressors in the Puget Sound Basin.

4.15.3.1 Strait of Juan de Fuca Sub-basin

Co-located stressors in the Strait of Juan de Fuca sub-basin resemble the general patterns of the Puget Sound Basin, with some relationships being of greater magnitude (Table 4-30). For example, armoring is more commonly co-located with fill (31 percent) and roads (21 percent). Armoring is often more prevalent within other stressors including marinas (99 percent), breakwaters and jetties (94 percent), and nearshore fill (88 percent). Marinas also have a higher level of spatial coincidence with other stressors. Abandoned railroads are also more prevalently co-located with numerous stressors within the Strait of Juan de Fuca sub-basin, particularly armoring (55 percent), fill (21 percent), overwater structures (25 percent), roads (32 percent), and tidal barriers (25 percent).

Table 4-30
Co-located Shoreline Alteration (Tier 2) Stressors in the Strait of Juan de Fuca Sub-basin

	Stressors								
Co-located Stressors	**Armoring**	**BW/J**	**Marinas**	**Nearshore Fill**	**OWS**	**Roads**	**RR, Abandoned**	**RR, Active**	**Tidal Barriers**
Armoring	100%	94%	99%	88%	62%	43%	55%	--	18%
BW/J	17%	100%	78%	13%	23%	7%	4%	--	0%
Marinas	6%	25%	100%	10%	21%	5%	4%	--	0%
Nearshore Fill	31%	26%	60%	100%	37%	17%	21%	--	16%
OWS	15%	31%	87%	26%	100%	19%	25%	--	37%
Roads	21%	19%	40%	23%	37%	100%	32%	--	31%
RR, Abandoned	16%	6%	19%	17%	30%	20%	100%	--	39%
RR, Active	0%	0%	0%	0%	0%	0%	0%	--	0%
Tidal Barriers	3%	0%	0%	9%	28%	12%	25%	--	100%

Note: This table is organized such that each Shoreline Alteration stressor is shown in a separate column. The rows underneath indicate the percentage of the Shoreline Alteration stressor distribution that is co-located with the other Shoreline Alteration stressors. BW/J = Breakwaters/Jetties, OWS = Overwater Structures, RR = Railroads

4.15.3.2 San Juan Islands – Strait of Georgia Sub-basin

The co-location of stressors in the San Juan Islands – Strait of Georgia sub-basin resembles the general pattern of spatially coincident stressors in the Puget Sound Basin, with some distinct variations (Table 4-31). There are several patterns among co-located stressors in this sub-basin that are of greater magnitude than the Puget Sound Basin such as: 22 percent of armored shores co-occur with tidal barriers, 66 percent of tidal barriers are co-located with armoring, 18 percent of tidal barriers occur with roads, and 32 percent of active railroads are coincident with nearshore fill. Breakwaters and jetties are also more frequently co-located with roads (38 percent) and active railroads (18 percent). Overwater structures (37 percent) and nearshore fill (68 percent) are less commonly co-located with shoreline armoring, and abandoned railroads are less commonly associated with overwater structures, nearshore fill, and tidal barriers.

Table 4-31
Co-located Shoreline Alteration (Tier 2) Stressors in the San Juan Islands – Strait of Georgia Sub-basin

Co-located Stressors	Stressors								
	Armoring	**BW/J**	**Marinas**	**Nearshore Fill**	**OWS**	**Roads**	**RR, Abandoned**	**RR, Active**	**Tidal Barriers**
Armoring	100%	57%	53%	48%	37%	47%	100%	57%	66%
BW/J	13%	100%	37%	22%	10%	17%	0%	26%	12%
Marinas	8%	23%	100%	23%	43%	3%	0%	0%	0%
Nearshore Fill	21%	41%	67%	100%	37%	12%	0%	32%	10%
OWS	9%	11%	70%	21%	100%	7%	15%	10%	3%
Roads	24%	38%	11%	14%	15%	100%	23%	28%	18%
RR, Abandoned	1%	0%	0%	0%	0%	0%	100%	5%	0%
RR, Active	9%	18%	1%	12%	7%	9%	100%	100%	6%
Tidal Barriers	22%	17%	0%	8%	5%	12%	0%	13%	100%

Note: This table is organized such that each Shoreline Alteration stressor is shown in a separate column. The rows underneath indicate the percentage of the Shoreline Alteration stressor distribution that is co-located with the other Shoreline Alteration stressors. BW/J = Breakwaters/Jetties, OWS = Overwater Structures, RR = Railroads

4.15.3.3 Hood Canal Sub-basin

Spatially co-located stressors occur less frequently in the Hood Canal sub-basin relative to the Puget Sound Basin (Table 4-32). Only a few co-located stressors have greater spatial coincidence than the Puget Sound Basin including breakwaters and jetties (76 percent) and nearshore fill (23 percent) with tidal barriers. Shoreline armoring is more frequently coincident with roads than any other stressor (21 percent). Marinas and overwater structures are frequently co-located (84 percent), as are overwater structures with armoring (45 percent) and roads (17 percent). Tidal barriers are more frequently coincident with nearshore fill (14 percent) and roads (40 percent) than the Puget Sound Basin; however, they are considerably less frequently co-located with shoreline armoring (1 percent).

Table 4-32

Co-located Shoreline Alteration (Tier 2) Stressors in the Hood Canal Sub-basin

Co-located Stressors	Stressors								
	Armoring	BW/J	Marinas	Nearshore Fill	OWS	Roads	RR, Abandoned	RR, Active	Tidal Barriers
Armoring	100%	1%	19%	27%	45%	34%	--	--	1%
BW/J	0%	100%	0%	0%	0%	1%	--	--	5%
Marinas	0%	0%	100%	1%	9%	0%	--	--	0%
Nearshore Fill	5%	0%	10%	100%	11%	4%	--	--	14%
OWS	8%	0%	84%	10%	100%	4%	--	--	3%
Roads	21%	21%	4%	13%	17%	100%	--	--	40%
RR, Abandoned	0%	0%	0%	0%	0%	0%	--	--	0%
RR, Active	0%	0%	0%	0%	0%	0%	--	--	0%
Tidal Barriers	0%	76%	0%	23%	5%	19%	--	--	100%

Note: This table is organized such that each Shoreline Alteration stressor is shown in a separate column. The rows underneath indicate the percentage of the Shoreline Alteration stressor distribution that is co-located with the other Shoreline Alteration stressors. BW/J = Breakwaters/Jetties, OWS = Overwater Structures, RR = Railroads

4.15.3.4 Whidbey Sub-basin

Co-located stressors in the Whidbey sub-basin display a similar pattern to the Puget Sound Basin with some minor variation (Table 4-33). Armoring is more frequently coincident with nearshore fill (38 percent), but less so with roads (8 percent) in the Whidbey sub-basin. Breakwaters and jetties are co-located with less frequency with armoring (32 percent), marinas (15 percent), and roads (1 percent), but with greater frequency with nearshore fill (58 percent) relative to the Puget Sound Basin. Marinas are more frequently coincident with nearshore fill (88 percent) and overwater structures but with fewer breakwaters and jetties (17 percent). Nearshore fill is less frequently co-located with armoring (52 percent) as are overwater structures (56 percent). However, overwater structures in the Whidbey sub-basin are more frequently co-located with marinas (47 percent), fill (73 percent), and tidal barriers (67 percent). Roads are co-located with armoring (14 percent) with less frequency than the Puget Sound Basin, but are much more frequently spatially coincident with tidal barriers (67 percent). Active railroads are also more frequently co-located with tidal barriers (25 percent), but less so with nearshore fill (44 percent). Tidal barriers in the Whidbey sub-basin are also less frequently coincident with shoreline armoring (9 percent) relative to the Puget Sound Basin.

Table 4-33

Co-located Shoreline Alteration (Tier 2) Stressors in the Whidbey Sub-basin

Co-located Stressors	Stressors								
	Armoring	BW/J	Marinas	Nearshore Fill	OWS	Roads	RR, Abandoned	RR, Active	Tidal Barriers
Armoring	100%	32%	64%	52%	56%	14%	--	68%	9%
BW/J	3%	100%	17%	8%	15%	0%	--	0%	2%
Marinas	5%	15%	100%	10%	47%	1%	--	0%	0%
Nearshore Fill	38%	58%	88%	100%	73%	10%	--	44%	7%
OWS	8%	23%	88%	15%	100%	3%	--	9%	2%
Roads	8%	1%	7%	8%	12%	100%	--	20%	32%
RR, Abandoned	0%	0%	0%	0%	0%	0%	--	0%	0%
RR, Active	3%	0%	0%	2%	2%	1%	--	100%	1%
Tidal Barriers	11%	19%	6%	12%	13%	67%	--	25%	100%

Note: This table is organized such that each Shoreline Alteration stressor is shown in a separate column. The rows underneath indicate the percentage of the Shoreline Alteration stressor distribution that is co-located with the other Shoreline Alteration stressors. BW/J = Breakwaters/Jetties, OWS = Overwater Structures, RR = Railroads

4.15.3.5 North Central Puget Sound Sub-basin

The North Central Puget Sound sub-basin has similar patterns of co-located stressors with the Puget Sound Basin; however, it has additional coincident stressors in association with shoreline armoring, breakwaters and jetties, marinas, and active railroads (Table 4-34).

Armoring is more frequently co-located with breakwaters and jetties (15 percent) and nearshore fill (31 percent), and less coincident with roads (8 percent). The co-location of breakwaters and jetties and other stressors deviates from the distribution of coincident stressors in the Puget Sound Basin more so than other stressors in the North Central Puget Sound sub-basin. Breakwaters and jetties are more frequently co-located with armoring (99 percent), marinas (57 percent), nearshore fill (85 percent), and overwater structures (58 percent); however, they are less frequently coincident with roads (6 percent). Sixty-two percent of marinas are co-located with breakwaters and jetties in the North Central Puget Sound sub-basin, which is near double the spatial coincidence (33 percent) of these stressors in the Puget Sound Basin. Nearshore fill and armoring (37 percent) and active railroads (0 percent) are less frequently co-located. Overwater structures are less frequently co-located with armoring (26 percent) and roads (5 percent) in the North Central Puget Sound sub-basin relative to the Puget Sound Basin. Fewer roads are also co-located with armoring (28 percent) and tidal barriers (7 percent). Active railroads and armoring are 100 percent spatially coincident in the North Central Puget Sound sub-basin, as are overwater structures. Tidal barriers are less frequently co-located with shoreline armoring (3 percent) and roads (13 percent) than their coincidence in the Puget Sound Basin.

Table 4-34

Co-located Shoreline Alteration (Tier 2) Stressors in the North Central Sub-basin

Co-located Stressors	Stressors								
	Armoring	BW/J	Marinas	Nearshore Fill	OWS	Roads	RR, Abandoned	RR, Active	Tidal Barriers
Armoring	100%	99%	62%	37%	26%	28%	--	100%	3%
BW/J	15%	100%	62%	15%	20%	3%	--	0%	0%
Marinas	9%	57%	100%	10%	25%	6%	--	0%	0%
Nearshore Fill	31%	85%	63%	100%	52%	21%	--	0%	0%
OWS	12%	58%	80%	27%	100%	8%	--	100%	0%
Roads	8%	6%	12%	7%	5%	100%	--	0%	13%
RR, Abandoned	0%	0%	0%	0%	0%	0%	--	0%	0%
RR, Active	0%	0%	0%	0%	0%	0%	--	100%	0%
Tidal Barriers	0%	0%	0%	0%	0%	7%	--	0%	100%

Note: This table is organized such that each Shoreline Alteration stressor is shown in a separate column. The rows underneath indicate the percentage of the Shoreline Alteration stressor distribution that is co-located with the other Shoreline Alteration stressors. BW/J = Breakwaters/Jetties, OWS = Overwater Structures, RR = Railroads

4.15.3.6 South Central Puget Sound Sub-basin

The developed shorelines of the South Central Puget Sound sub-basin lead to the additional co-location of most stressors (Table 4-35) relative to the Puget Sound Basin. Shoreline armoring is more spatially coincident with nearshore fill (32 percent). Breakwaters and jetties are more frequently co-located with armoring (84 percent), marinas (52 percent), fill (71 percent), and overwater structures (70 percent); however, they are less frequent with roads (7 percent). Marinas are also more commonly co-located with armoring (87 percent). Similarly, nearshore fill (82 percent), overwater structures (89 percent), and roads (82 percent) are each more frequently coincident with shoreline armoring in the South Central Puget Sound sub-basin. Roads, however, are less frequently co-located with tidal barriers (8 percent). Ninety-four percent of the active railroad is co-located with armoring and 11 percent is associated with fill, both of which are considerably greater than in the Puget Sound Basin. Tidal barriers are also more commonly coincident with roads in the South Central Puget Sound sub-basin.

Table 4-35

Co-located Shoreline Alteration (Tier 2) Stressors in the South Central Sub-basin

Co-located Stressors	**Stressors**								
	Armoring	**BW/J**	**Marinas**	**Nearshore Fill**	**OWS**	**Roads**	**RR, Abandoned**	**RR, Active**	**Tidal Barriers**
Armoring	100%	84%	87%	82%	89%	82%	--	94%	15%
BW/J	3%	100%	30%	6%	12%	1%	--	2%	0%
Marinas	5%	52%	100%	9%	26%	4%	--	1%	0%
Nearshore Fill	-94%	71%	57%	100%	56%	19%	--	69%	16%
OWS	17%	70%	86%	28%	100%	18%	--	9%	2%
Roads	22%	7%	20%	13%	25%	100%	--	22%	67%
RR, Abandoned	0%	0%	0%	0%	0%	0%	--	0%	0%
RR, Active	4%	3%	1%	8%	2%	4%	--	100%	3%
Tidal Barriers	0%	0%	0%	1%	0%	8%	--	2%	100%

Note: This table is organized such that each Shoreline Alteration stressor is shown in a separate column. The rows underneath indicate the percentage of the Shoreline Alteration stressor distribution that is co-located with the other Shoreline Alteration stressors. BW/J = Breakwaters/Jetties, OWS = Overwater Structures, RR = Railroads

4.15.3.7 South Puget Sound Sub-basin

The South Puget Sound sub-basin has a number of variations (Table 4-36) to the general pattern of spatially coincident stressors in the Puget Sound Basin. Generally, shoreline armoring is co-located with fewer stressors relative to the Puget Sound Basin, excluding active railroads (7 percent). Breakwaters and jetties have the most overlap with other alterations, followed closely by marinas. Most stressors have a large ratio of co-located shoreline armoring of greater magnitude than the Puget Sound Basin, particularly breakwaters and jetties (94 percent), marinas (93 percent), nearshore fill (87 percent), and active railroads (81 percent). Active railroads are frequently co-located with nearshore fill (91 percent). Tidal barriers are commonly co-located with roads (50 percent) and shoreline armoring (34 percent), both of which are more frequent than in the Puget Sound Basin.

Table 4-36

Co-located Shoreline Alteration (Tier 2) Stressors in the South Puget Sound Sub-basin

Co-located Stressors	Stressors								
	Armoring	BW/J	Marinas	Nearshore Fill	OWS	Roads	RR, Abandoned	RR, Active	Tidal Barriers
Armoring	100%	94%	93%	87%	61%	36%	0%	81%	34%
BW/J	0%	100%	16%	0%	3%	0%	0%	0%	0%
Marinas	2%	86%	100%	6%	15%	0%	0%	3%	0%
Nearshore Fill	18%	25%	67%	100%	26%	12%	2%	91%	7%
OWS	7%	89%	95%	14%	100%	6%	47%	7%	2%
Roads	9%	4%	6%	14%	13%	100%	30%	6%	50%
RR, Abandoned	0%	0%	0%	0%	12%	4%	100%	0%	15%
RR, Active	7%	0%	13%	38%	6%	2%	0%	100%	4%
Tidal Barriers	3%	0%	0%	3%	2%	18%	46%	4%	100%

Note: This table is organized such that each Shoreline Alteration stressor is shown in a separate column. The rows underneath indicate the percentage of the Shoreline Alteration stressor distribution that is co-located with the other Shoreline Alteration stressors. BW/J = Breakwaters/Jetties, OWS = Overwater Structures, RR = Railroads

5 METHODS FOR ASSESSING NEARSHORE ECOSYSTEM PROCESS DEGRADATION

5.1 Development of a Framework to Assess Process Degradation

An evaluation framework (hereafter called the Framework) was developed to estimate degradation of nearshore processes based on the presence of stressors. The Framework estimates the degradation of each of the 11 nearshore processes separately for each of the process units in the project area. In addition, the Framework estimates the overall degradation of each process unit by summing the degradation results of the individual nearshore processes.

The metrics developed to estimate the degradation of individual processes are described in Section 5.1.1. The method for combining the individual process degradation results to estimate overall degradation in each process unit is described in Section 5.1.2.

5.1.1 Primary and Secondary Metrics of Degradation of Individual Processes

The Framework metrics used to estimate degradation of nearshore processes were based on previous PSNERP documents, including the Change Analysis (Simenstad et al. 2011), the Geomorphic Classification (Shipman 2008), the Management Measures Report (Clancy et al. 2009), as well as the best professional judgment of the Strategic Needs Assessment Team.

The Framework metrics for estimating degradation reflect the understanding that nearshore processes are impacted by stressors differently depending on the shoreform the stressors occur in. A summary of which stressors affect which processes was given in Table 4-20 and is further described in Appendix B. With this in mind, the metric to evaluate degradation could depend upon stressor distributions in either the entire process unit or in a subset of shoreforms in the process unit. Where specific shoreforms were evaluated for the presence of nearshore stressors (e.g., bluff-backed beaches in the evaluation of sediment input processes), the historic shoreform mapping of the Change Analysis was used. For many processes, the locations of artificial shoreforms were included in the degradation metric in order to augment the nearshore fill data layer, which was known to be incomplete.

Process degradation was assessed using different rules for DPUs and SPUs. For each nearshore process, degradation was assessed using a primary metric and in some cases a secondary metric. The secondary metric(s) was intended to characterize a different aspect of a nearshore process than the primary metric assessed. The secondary metric(s) refined the degradation estimate provided by the primary metric. Table 5-1 summarizes the stressors included in the process degradation metrics for SPUs and DPUs. Table 5-2 presents the metrics used to estimate the degradation of each nearshore process. Degradation metrics that were considered during development of the Framework, but ultimately not included, are provided in Appendix C.

Table 5-1

Primary Stressors Used to Characterize the Degradation of Nearshore Ecosystem Processes within DPUs and SPUs

	Stressors													
Nearshore Processes	**Tidal Barriers**	**Fill**	**Armor**	**Railroads**	**Roads**	**Marinas**	**Breakwaters/Jetties**	**Wetland Loss**	**Dams**	**Stream Crossings**	**Overwater Structures**	**Impervious Surfaces**	**Historic Drainage Area**	**Artificial Shoreform**
Sediment Input		DPU SPU	DPU SPU	DPU SPU	DPU SPU				DPU				DPU	DPU SPU
Sediment Transport	DPU SPU	DPU SPU	DPU SPU			DPU SPU	SPU		DPU					DPU SPU
Erosion and Accretion of Sediment	DPU SPU	DPU SPU	DPU SPU	DPU SPU	DPU SPU	DPU SPU	SPU							DPU SPU
Tidal Flow	DPU SPU	DPU SPU		DPU SPU	DPU			DPU SPU						DPU SPU
Distributary Channel Migration	DPU	DPU	DPU						DPU					DPU
Tidal Channel Formation and Maint.								DPU SPU						
Freshwater Input									DPU SPU			DPU SPU	DPU	
Detritus Import and Export	DPU SPU	DPU SPU	DPU SPU	SPU	SPU			DPU SPU						DPU SPU
Exchange of Aquatic Organisms	DPU SPU	DPU SPU	DPU SPU	DPU SPU	DPU SPU	DPU SPU	DPU SPU		DPU SPU		DPU SPU			DPU SPU
Physical Disturbance		DPU SPU	DPU SPU	DPU SPU	DPU SPU	DPU SPU	DPU SPU							SPU
Solar Incidence						DPU SPU					DPU SPU			

Table 5-2

Framework to Estimate the Degradation of Nearshore Ecosystem Processes

Nearshore Process	Metrics Applied in Delta Process Units (DPUs)	Metrics Applied in Shoreline Process Units (SPUs)
Sediment Input	Primary metric(s): Percent of total DPU area above lowermost dam in DPU Secondary metric(s): Percent of shoreline length with one or more of the following: • Fill • Armoring • Railroads • Roads • Artificial shoreform and Percent reduction in current drainage area compared to historic drainage area	Primary metric(s): Percent of bluff-backed beaches shoreline length in Divergent Zones and Transport Zones with one or more of the following: • Fill • Armoring • Railroads • Roads • Artificial shoreform Secondary metric(s): None
Sediment Transport	Primary metric(s): Percent of shoreline length with one or more of the following: • Tidal barriers • Fill • Armoring • Marinas • Artificial shoreform Secondary metric(s): Percent of total DPU area above lowermost dam in DPU	Primary metric(s): Combined percentage of bluff-backed beaches and barrier beaches shoreline length with one or more of the following: • Fill • Armoring • Down-drift of marina or breakwater/jetty in transport zone • Artificial shoreform and Barrier estuaries, barrier lagoons, and open coastal inlets shoreline length with one or more of the following: • Tidal barriers • Fill • Armoring • Artificial shoreform Secondary metric(s): None

Nearshore Process	Metrics Applied in Delta Process Units (DPUs)	Metrics Applied in Shoreline Process Units (SPUs)
Erosion and Accretion of Sediment	Primary metric(s): Percent of shoreline length with one or more of the following: • Fill • Armoring • Railroads • Roads • Marinas • Tidal barriers • Artificial shoreform Secondary metric(s): None	Primary metric(s): Combined percentage of barrier beaches shoreline length with one or more of the following: • Fill • Armoring • Railroads • Roads • Marinas • Breakwaters/jetties • Artificial shoreform and Barrier estuaries, barrier lagoons, closed lagoons/marshes, and open coastal inlets shoreline length with one or more of the following: • Fill • Armoring • Railroads • Roads • Marinas • Breakwaters/jetties • Tidal barriers • Artificial shoreform Secondary metric(s): None
Tidal Flow	Primary metric(s): Percent of shoreline length with one or more of the following: • Tidal barriers • Fill • Railroads • Roads • Artificial shoreform Secondary metric(s): Percent of historic tidal wetland area that has been impacted by tidal barrier or fill	Primary metric(s): Percent of barrier estuaries, barrier lagoons, and open coastal inlets shoreline length with one or more of the following: • Tidal barriers • Fill • Railroads • Artificial shoreform Secondary metric(s): Percent of historic tidal wetland area (excluding euryhaline unvegetated wetlands) that has been impacted by tidal barrier or fill

Nearshore Process	Metrics Applied in Delta Process Units (DPUs)	Metrics Applied in Shoreline Process Units (SPUs)
Distributary Channel Migration	Primary metric(s): Percent of shoreline length with one or more of the following: • Tidal barriers • Fill • Armoring • Artificial shoreform Secondary metric(s): Number of dams per km^2 of watershed area	N/A
Tidal Channel Formation and Maintenance	Primary metric(s): Percent of historic tidal wetland area that has been impacted by tidal barrier or fill Secondary metric(s): None	Primary metric(s): Percent of historic tidal wetland area (excluding euryhaline unvegetated wetlands) that has been impacted by tidal barrier or fill Secondary metric(s): None
Freshwater Input	Primary metric(s): Percent of total DPU watershed area above lowermost dam in DPU and Percent reduction in current drainage area compared to historic drainage area Secondary metric(s): Percent of adjacent upland area with 10 percent or more impervious surfaces	Primary metric(s): Percent of adjacent upland area with 10 percent or more impervious surfaces Secondary metric(s): Percent of total SPU watershed area above lowermost dam in SPU
Detritus Import and Export	Primary metric(s): Percent of shoreline length with one or more of the following: • Tidal barriers • Fill • Armoring • Artificial shoreform Secondary metric(s): Percent of historic tidal wetland area that has been lost	Primary metric(s): Percent of shoreline length with one or more of the following: • Tidal barriers • Fill • Railroads • Roads • Armoring • Artificial shoreform Secondary metric(s): Percent of historic tidal wetland area that has been lost

Nearshore Process	Metrics Applied in Delta Process Units (DPUs)	Metrics Applied in Shoreline Process Units (SPUs)
Exchange of Aquatic Organisms	Primary metric(s): Percent of shoreline length with one or more of the following: • Tidal barriers • Fill • Railroads • Roads • Armoring • OWS, including marinas • Breakwaters/jetties • Artificial shoreform Secondary metric(s): Percent of total DPU area above lowermost dam in DPU	Primary metric(s): Percent of shoreline length with one or more of the following: • Tidal barriers • Fill • Railroads • Roads • Armoring • OWS, including marinas • Breakwaters/jetties • Artificial shoreform Secondary metric(s): Percent of total DPU area above lowermost dam in SPU
Physical Disturbance	N/A	Primary metric(s): Percent of bluff-backed beaches, barrier beaches, and pocket beaches shoreline length with one or more of the following: • Fill • Armoring • Railroads • Roads • Marinas • Breakwaters/jetties • Artificial shoreform Secondary metric(s): None
Solar Incidence	Primary metric(s): Percent of aquatic area with overwater structures area, including marinas Secondary metric(s): None	Primary metric(s): Percent of aquatic area with overwater structures area, including marinas Secondary metric(s): None

For many of the processes, process degradation was estimated based on the percentage of the shoreline length with 1 or more of the specified stressors affecting that process. The percentage output is interpreted as the percentage of the process unit's capacity to provide a nearshore process that has been degraded by stressors. An example of this calculation is provided in Figure 5-1. Another type of metric used in the Framework estimates degradation by measuring the percent of the watershed area that is impacted by a specific stressor. It can be the percent of watershed area or percent of wetland area lost, depending on the process. For example, in DPUs, the degradation of tidal channel formation was estimated to be the percent of the historic wetland area that is impounded by existing tidal barriers or fill.

5.1.1.1 *Sediment Input*

In SPUs, nearshore sediment is predominantly supplied by eroding coastal bluffs (Downing 1983). In the Shipman (2008) geomorphic typology, the coastal bluffs that supply sediment to the nearshore would be expected to be delineated as a bluff-backed beach shoreform. To investigate whether this assumption was supported by the data, a comparison of nearshore sediment source data in Island County (part of the North Central Puget Sound and Whidbey sub-basins) from Johannessen and Chase (2005) was compared to bluff-backed beach areas delineated using the Shipman (2008) typology. As shown in Figure 5-2, this comparison indicated that bluff-backed beaches included 88 percent of the sediment source feeder bluffs delineated. The comparison also indicated that bluff-backed beaches include shorelines that were not determined to be feeder bluffs. In fact, only 61 percent of the bluff-back beach shoreline length was identified as sediment source feeder bluffs. For the purposes of this analysis, the comparison validates the assumption that bluff-back beaches encompass the sediment sources of SPUs.

Bluff-backed beaches located within divergent and transport zones of drift cells were determined by the Strategic Needs Assessment Team to be the areas where sediment input is most actively contributing to sediment inputs in SPUs.

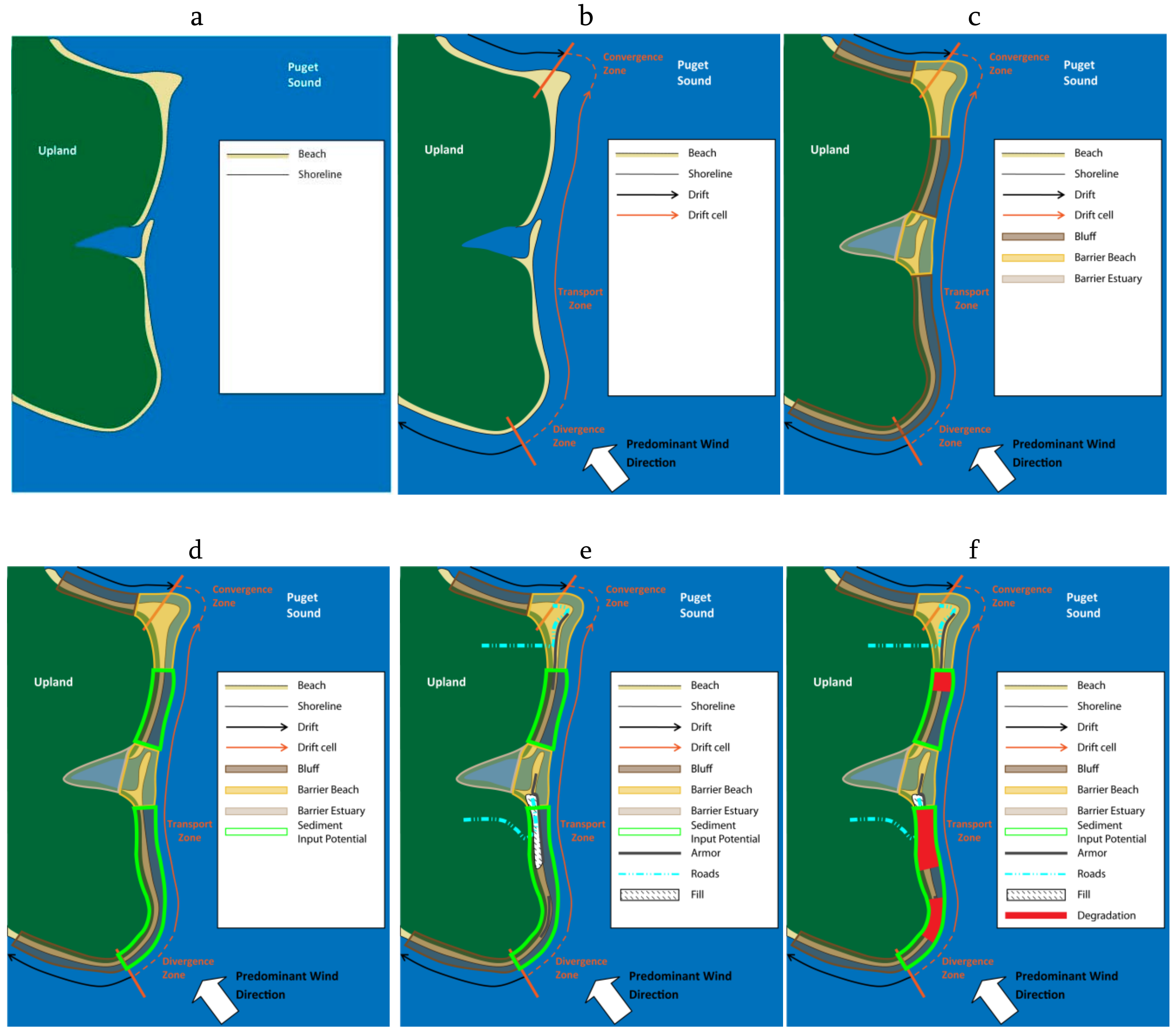


Figure 5-1

Schematic Example of Degradation Metric for Sediment Input in SPUs

Notes: Degradation of sediment input in SPUs is assessed by determining the percentage of bluff-backed beaches in the divergent zone or transport zone containing nearshore fill, shoreline armoring, roads, or railroads, or classified as artificial shoreform type. The six panels describe the steps taken to make this calculation.

a) Example shoreline
b) Identify boundaries of PU and drift cell zones within PU
c) Identify the shoreform types within the PU
d) Identify the potential sediment input areas (bluff-backed beaches in divergence zone or transport zone)
e) Determine the stressor distributions along the PU shoreline
f) Determine the extent of degradation—this is the percentage of the potential sediment input shoreline length (outlined in green) that has one or more stressors (outlined in red). If the green box encompasses 2 miles and the red box encompasses 1 mile, then the degradation calculation = (1 divided by 2) x 100%.

Credit: Johannessen, J. and M. Chase, Coastal Geologic Services, 2005. Island County Feeder Bluff and Accretion Shoreform Mapping. Prepared for Island County Marine Resources Committee.

Figure 5-2

Feeder Bluff and Bluff-backed Beach Mapping Documenting the Co-location of Feeder Bluffs and Bluff-backed Beaches

The Framework was originally designed to estimate degradation of sediment input in SPUs by only considering impairment of bluff-backed beaches that occur in divergent zones; however, additional investigation of Change Analysis data showed that many other shoreforms commonly occur within divergent zones; they do not exclusively comprise erosive (bluff-backed beach) shoreforms (Table 5-3). These investigations prompted the Strategic Needs Assessment Team to include bluff-backed beaches in both divergent and transport zones in order to estimate the degradation of the sediment input process.

Stressors included in the PSNERP geodatabase that cause direct effects on sediment delivery processes in SPUs were identified in order to establish metrics for evaluating degradation. These include nearshore fill, shoreline armoring, railroads, and roads. These features typically interrupt either the sediment erosion process or the delivery of bluff-derived sediments to drift cells. As discussed earlier, areas classified as artificial shoreforms were included in this rule set to augment the fill data layer.

Table 5-3

Shoreform Composition of Divergent Zones within the Puget Sound Basin and Sub-basins

	Shoreform Composition of Divergent Zones, Percent by Shoreline Length								
Basin/ Sub-basin	**Bluff-backed Beach**	**Barrier Beach**	**Barrier Estuary**	**Barrier Lagoon**	**Delta**	**Plunging Rocky**	**Rocky Platform**	**Pocket Beach**	**Artificial**
Strait of Juan de Fuca	77	2	0	0	8	0	0	2	11
San Juan Islands - Strait of Georgia	58	3	0	0	0	4	12	5	17
Hood Canal	80	9	0	0	1	0	9	0	1
Whidbey	97	1	0	0	0	0	1	0	1
North Central Puget Sound	79	8	0	0	0	0	10	0	3
South Central Puget Sound	66	3	1	0	0	0	1	0	28
South Puget Sound	91	6	2	0	0	0	0	0	1
Puget Sound Basin	**80**	**5**	**1**	**0**	**1**	**1**	**4**	**1**	**9**

In DPUs, most sediment comes from erosion occurring in portions of the watershed far upstream of the estuary. Dams impound sediment that would otherwise be transported downstream. For this reason, the selected metric to assess degraded sediment supply in DPUs is the percent of the total DPU area that is located upstream of the lowermost dam. Sediment is also commonly eroded from channel banks. Because this process can be precluded by the presence of stressors, secondary metrics were developed to assure that the Framework captured this potential source of sediment supply degradation. The secondary metrics include estimating the cumulative percent of the DPU shoreline with one or more of the following stressors: fill, armoring, railroads, roads, and artificial shoreforms.

5.1.1.2 Sediment Transport

In SPUs, sediment transport occurs along bluff-backed beaches and barrier beaches predominantly in the form of littoral drift, which is largely driven by waves; and within embayments (open coastal inlets, barrier estuaries, and barrier lagoons), sediment transport occurs via tidal channel hydrology. Therefore, different metrics were developed for the different shoreform types. Closed lagoon marshes were excluded from this definition as they typically lack tidal channel connections to adjacent systems. Stressors that are known to cumulatively alter sediment transport in wave-dominated environments (bluff-backed beaches and barrier beaches) include: nearshore fill; shore armoring; artificial shoreforms; and the percent of the process unit that is located within the transport zone down-drift of a breakwater, jetty, or marina. It was agreed upon by Strategic Needs Assessment Team members that the entire portion of a drift cell that is located down-drift of a cross-shore structure, such as a breakwater, has degraded sediment transport processes, as the sediment supplied from up-drift of the structure is no longer able to deposit along the entire down-drift shore and shoreforms; to the degree that these structures have been known to truncate and/or bifurcate drift cells in Puget Sound. The stressors selected to measure degraded sediment transport in tidally dominated embayment systems include: tidal barriers, nearshore fill, armoring, and artificial shoreforms. These stressors were selected because they impede sediment transport by reducing tidal prism and tidal flushing.

Sediment transport occurs throughout DPUs, distributed by tidal flows and river flows. This process is mainly degraded by features that disrupt movement of tidal waters, which include tidal barriers, nearshore fill, shoreline armoring, marinas, and artificial shoreforms. Marinas, which are typically associated with dense piles, overwater structures, and dredge areas, can alter sediment transport patterns by changing hydrodynamics. The percent of the DPU located above the lowermost dam was included as a secondary metric of degraded sediment transport, as the transport of sediment derived from upstream of the dam is largely precluded by the dam (and associated reservoir), resulting in degraded sediment transport through that reach of fluvial shore.

5.1.1.3 Erosion/Accretion of Sediment

The Strategic Needs Assessment Team interpreted this nearshore process to encompass only spit, dune, and marsh accretion, in an attempt to avoid redundancy with the sediment supply metric, which addresses bluff erosion. Due to the depositional nature of this process, this metric only evaluated depositional shoreforms: barrier beaches, deltas, and embayment shoreforms (barrier estuary, barrier lagoon, open coastal inlet, closed lagoon/marsh). Individual metrics were developed for each of these shoreform types, as each type is affected by a different suite of primary stressors. Primary stressors affecting sediment accretion along barrier beach shores are those that alter natural wave dissipation or preclude wave transport of sediment to supra-tidal beaches, where dunes and marsh vegetation develop. Tidal barriers can prevent accretion of sediment in large areas within DPUs. In addition to tidal barriers, sediment deposition along deltaic shores is degraded similarly to barrier beaches and includes the stressors that prevent or alter tidal flows and associated sediment movement: nearshore fill, shoreline armoring, railroads, and roads. Embayment shores are affected by the same primary stressors that occur within deltas and barrier beaches.

5.1.1.4 Tidal Flow

Degradation of tidal flow was estimated only within shoreforms where tidal processes most strongly affect ecosystem functions, such as within embayments and deltas. Primary stressors used to evaluate tidal flow within these shoreforms include tidal barriers, fill, railroads, and artificial shoreforms for both deltas and embayments, for similar reasons described previously in discussing factors affecting sediment transport. Nearshore roads were also selected to assess tidal flow, but in DPUs only, where they can function as dikes. Roads were not included in the metric applied to SPUs because the Strategic Needs

Assessment Team members determined that the dataset query would inadvertently include too many roads perpendicular to the shoreline, rather than those that truly impact tidal flow (i.e., roads running parallel to the shoreline). In addition, road-related impacts in SPUs would likely be captured by other nearshore stressors, such as artificial shoreforms, nearshore fill, or shoreline armoring. A secondary metric was also developed to calculate the percent of historic wetland loss that has resulted from tidal barriers and nearshore fill.

5.1.1.5 Distributary Channel Migration

The metric developed to evaluate impacts to the processes of distributary channel migration was applied to DPUs only and included stressors that would impede or constrain channel formation, migration, and avulsion. The stressors include: tidal barriers, nearshore fill, shoreline armoring, and artificial shoreforms. Dams typically alter downstream flows, often substantially reducing frequency and intensity of flood flows. Because of this effect on fluvial hydrology, number of dams normalized by watershed area was included as a secondary metric for distributary channel migration.

While distributary channels are associated with small coastal streams in some SPUs, they are not ubiquitous. Because the PSNERP geodatabase does not include comprehensive data for these coastal streams, it was not possible to limit application of the process evaluation framework to applicable areas, and SPUs were excluded from analysis for degradation of the processes of distributary channel migration.

5.1.1.6 Tidal Channel Formation and Maintenance

Degradation of the process of tidal channel formation and maintenance was measured only within shoreforms that have tidal channels including deltas, barrier estuaries, and barrier lagoons. Loss of vegetated wetlands, resulting from tidal barriers or fill, was selected as an effective indicator of process degradation because these two stressors impact both tidal flushing and the tidal prism, both of which drive the formation and maintenance of tidal channels.

5.1.1.7 Freshwater Input

Strategic Needs Assessment Team members agreed that the greatest source of degradation to freshwater input in DPUs could likely be attributed to the presence of dams. Secondary metrics to address degradation of freshwater input in DPUs included the reduction of the historic drainage area and the percent area of impervious surfaces. In SPUs, the percent area of impervious surfaces in adjacent uplands was identified as the primary metric for assessing impacts to freshwater inputs. Presence of dams was used as a secondary metric for SPUs. All of these stressors result in altered hydrography and ground water recharge.

5.1.1.8 Detritus Import and Export

Detritus import and export occurs within all geomorphic systems and shoreforms; therefore, the metric to evaluate process degradation was applied to the entire DPU or SPU. Stressors that impede the input, transport, and deposition of detritus were included in the metric. Along marine shores (SPUs), shoreline armoring, nearshore fill, roads, and railroads each degrade cross-shore connectivity and reduce the recruitment of terrestrial detritus (from leaf litter to LWD). These stressors also commonly bury the supra-tidal beach, which can prevent detritus, such as beach wrack, and small and large woody debris from depositing. These same stressors similarly affect DPUs; however, Strategic Needs Assessment Team members concluded that roads and railroads in deltas are typically elevated structures (such as bridges) that do not affect detritus input, and where they are not, they are likely tidal barriers. Roads and railroads were therefore not included as stressors to detritus import and export in DPUs. Tidal barriers degrade the transport and deposition of detritus into tidal wetlands and the transport of detritus produced in delta wetlands into the surrounding nearshore. Loss of wetlands reduces sources of detritus, and this factor was used as a secondary metric for evaluating degradation of this process.

5.1.1.9 Exchange of Aquatic Organisms

The metric for evaluating degraded exchange of aquatic organisms is applied to the entire process unit and includes a suite of nearshore stressors. Stressors that degrade either cross-shore or alongshore habitat connectivity were included, such as jetties and breakwaters, marinas, overwater structures, shoreline armoring, nearshore fill, roads, and railroads. Other stressors that preclude access to aquatic habitats such as tidal barriers, nearshore fill, and artificial shoreforms were also included in this metric. The percent of the watershed area above the lowermost dam was identified as a secondary stressor metric for both SPUs and DPUs. This secondary metric was identified in consideration of dams' impacts on upstream and downstream passage.

5.1.1.10 Physical Disturbance

This process was interpreted to include alterations to shorelines that alter the characteristics of wave energy on beaches—typically a reduction in the intensity of wave energy. As such, the process evaluation framework metric for evaluating degraded physical disturbance is applied only along wave-dominated shores including: barrier beaches, bluff-backed beaches, and pocket beaches. Stressors that directly alter wave conditions (such as jetties and breakwaters), or that alter natural wave dissipation (such as shoreline armoring, roads, railroads, and areas with nearshore fill [such as artificial shoreforms]) were included. Other stressors used in the metric include overwater structures and marinas, as they typically consist of piles, wharfs, and docks that attenuate wave energy and decrease the physical disturbance received by the landward beach.

5.1.1.11 Solar Incidence

Degraded solar incidence is evaluated in the Framework throughout each process unit as the percentage of the aquatic area that has overwater structures.

5.1.2 Interpretation of Overall Degradation of Individual Processes Based on Primary and Secondary Metric Outputs

The primary and, if applicable, secondary metrics described in the Framework (Table 5-2) produce numeric outputs for each nearshore process in each process unit. These outputs were combined to estimate the degradation of the individual nearshore processes separately. To characterize the degradation of individual nearshore processes, the numeric outputs of all primary and secondary metrics were used to assign one of five categories of degradation:

- High Degradation
- Medium Degradation
- Low Degradation
- No Degradation
- Not Applicable

The No Degradation category was assigned to process units where no degradation (0 percent) was detected due to the absence of any relevant stressors. The Not Applicable category was assigned to those process units where either the nearshore process does not apply, or the process unit does not include the shoreforms used in the evaluation. The high, medium, and low degradation categories of each nearshore process were assigned based on metric outputs among all process units. Categories were based on natural groupings of the outputs using the natural breaks tool of the ESRI ArcGIS 9.3 program[3]. In this way, the degradation categories are *relative* to degradation conditions in other process units, rather than *absolute* based on impact thresholds. Absolute categories were not used because the Strategic Needs Assessment Team determined that scientific justification for thresholds was not available for all processes and that the relative categories would provide the information needed to inform restoration priorities in the study area[4].

Once the categories were assigned to the primary and secondary metrics of each process, this information was combined to assign a degradation category for each process in each process unit. For nearshore processes evaluated using only one primary metric (i.e., no secondary metrics), the degradation category for the process was assigned based solely on the category assigned to the primary metric. For nearshore processes in which degradation was evaluated using more than one primary and one secondary metric, the category of process degradation assigned to each process unit was based on the combination of degradation categories assigned to each metric as shown in Table 5-4.

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[3] ESRI ArcGIS 9.3 determines result categories based on natural groupings inherent in the data. ArcMap identifies break points by picking the class breaks that best cluster similar values and that maximize the differences between classes. The features are divided into classes with boundaries set where there are relatively big jumps in the data values.

[4] Another "relative" categorization approach attempted, but ultimately not used, was to assign the High, Medium, and Low categories evenly by putting the most degraded one-third of results in the High category, the middle one-third in the Medium category, and the least degraded one-third in the Low category. This approach was not used because the category breaks did not occur at true breaks in results (i.e., two process units with the same result for a process metric could be assigned to different degradation categories to evenly distribute the number of process units in each category). Also, the Strategic Needs Assessment Team did not believe there were scientific data available in the literature to defend the assignment of nearly equal results (i.e., one percentage point difference) to different categories. The natural breaks approach taken would look for more distinct groupings of the data to make the classification.

Table 5-4
Rules Used to Combine the Degradation Category of Primary and Secondary Metrics in order to Assign a Process Degradation Category to Each Nearshore Process in Each Process Unit

Degradation Category of Most Degraded Primary Metric	Degradation Category of Most Degraded Secondary Metric	Process Degradation Category Assigned to SPU or DPU
High	High	High; no change to Primary Metric
High	Medium	High; no change to Primary Metric
High	Low	High; no change to Primary Metric
High	None	High; no change to Primary Metric
High	N/A	High; no change to Primary Metric
Medium	High	Medium; no change to Primary Metric
Medium	Medium	Medium; no change to Primary Metric
Medium	Low	Medium; no change to Primary Metric
Medium	None	Medium; no change to Primary Metric
Medium	N/A	Medium; no change to Primary Metric
Low	High	Medium
Low	Medium	Low; no change to Primary Metric
Low	Low	Low; no change to Primary Metric
Low	None	Low; no change to Primary Metric
Low	N/A	Low; no change to Primary Metric
None	High	Medium
None	Medium	Low
None	Low	Low
None	None	None; no change to Primary Metric
None	N/A	None; no change to Primary Metric
N/A	High	N/A; no change to Primary Metric
N/A	Medium	N/A; no change to Primary Metric
N/A	Low	N/A; no change to Primary Metric
N/A	None	N/A; no change to Primary Metric
N/A	N/A	N/A; no change to Primary Metric

5.1.3 Assignment of Overall Degradation Category to Each Process Unit

Using the numeric degradation outputs for the individual processes, an overall process degradation category was assigned to each process unit. The overall process degradation category was calculated by summing the numeric outputs of the primary metric of each nearshore process. Each primary metric was based on a percentage which was converted to a proportion (scale 0.0 to 1.0, where 0.0 indicates no degradation [0 percent] and 1.0 indicates full degradation [100 percent]). In each process unit, only 10 of the 11 nearshore processes were applicable[5]; thus, the range of the overall combined score was from 0.0 to 10.0 (with higher scores indicating higher degrees of degradation).

Six categories of overall process unit degradation were established:

- Most Degraded
- More Degraded
- Moderately Degraded
- Less Degraded
- Least Degraded
- Not Degraded

The Not Degraded category was assigned to process units where the summed score of all primary metrics was 0. The remaining categories were assigned using the same techniques as described above for assigning bins to the primary and secondary metric outputs for each nearshore process. Overall categories were assigned based on natural groupings of the metric outputs using the natural breaks tool of the ESRI ArcGIS 9.3 program[6]. In this way, the degradation categories were *relative* to degradation conditions in other process units, rather than *absolute* based on impact thresholds.

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[5] The distributary channel migration process does not apply in SPUs and the physical disturbance process does not apply in DPUs.

[6] ESRI ArcGIS 9.3 determines result categories based on natural groupings inherent in the data. ArcMap identifies break points by picking the class breaks that best cluster similar values and that maximize the differences between classes. The features are divided into classes with boundaries set where there are relatively big jumps in the data values.

5.2 Evaluation of Nearshore Ecosystem Process Degradation at Landscape Scale

To evaluate the problems affecting Puget Sound ecosystems and identify recommended priorities for restoration and protection, the strategic restoration and protection principles prepared for PSNERP by Greiner (2010) were considered. The principles highlighted in Greiner (2010) were derived from extensive research of peer-reviewed publications focusing on landscape ecology and protection biology. Greiner (2010) identified the following landscape-level and site-specific principles to consider in developing a large-scale restoration plan:

- Landscape-level principles:
    - The surrounding area has significant influence on the success of restoration efforts at a site.
    - Landscape connectivity should be restored to reduce fragmentation and facilitate the flow of energy, material, and biota between ecosystems.
    - Increased representation and redundancy of ecosystems contributes to landscape resiliency.
- Site-specific principles:
    - Heterogeneity on multiple scales supports a more resilient ecosystem.
    - Larger patches generally encompass more ecosystem components than smaller patches.
    - Rare or vulnerable species and habitats should receive high priority to preserve a region's biodiversity.
    - Ecological components that exert disproportionately greater influence on the integrity of an ecosystem should receive special attention.
    - Cumulative impacts must be considered in order to accurately assess ecosystem degradation.

The landscape principles identified by Greiner (2010) were assessed using several metrics that were designed to capture different aspects of connectivity at varying scales:

- Searches of extended shoreline sections (multiple process units) with little (least/less) process degradation

- The largest (longest) patches of each shoreform type at Sound-wide and sub-basin scales
- The average distance between shoreforms currently and historically to address the spatial distribution of uncommon shoreline types

The importance of landscape degradation, as emphasized by Greiner (2010), is that the function and resilience of a restoration project is reduced when the restoration site is located within a degraded environment. These data can also be used to identify large patches with the least process degradation in which protection efforts could be targeted. While generalized degradation is useful for making observations at a large spatial scale, each process operates over different spatial scales. A more thorough analysis of the influence of process degradation and patch size on restoration and protection prioritization has been conducted during subsequent restoration planning steps by PSNERP (e.g., the restoration and strategy plan analysis in Cereghino et al. 2011).

6 RESULTS

The results presented in this section include percentages of shoreline length and watershed area throughout the Puget Sound study area, as well as in each of the seven sub-basins. It is important to point out that the percentage calculations were based on the sum of the individual SPU or DPU values. These sums are greater than the actual shoreline length or watershed area in the analysis area because SPUs overlap with each other and with DPUs (see Section 2.4). In addition, two DPUs, the Stillaguamish and Samish River deltas, overlap each other. The portions of overlap are included twice in the calculation (i.e., once for each process unit the overlap area occurs in). Given the potential for differences in the conditions of the process units in which the overlap areas occur, the overlap areas may be assigned to two different categories of degradation. In maps presented in this section and in Appendix D, the areas of overlap are shown in colors depicting the higher of the two degradation categories assigned to the overlap area.

6.1 Degradation of Individual Nearshore Processes

In the following sections, the degradation results for individual processes are presented for the entire Puget Sound General Investigation study area (Section 6.1.1) and for each of the seven sub-basins (Sections 6.1.2 through 6.1.8).

6.1.1 Puget Sound Basin

6.1.1.1 Shoreline Process Unit Results for Individual Nearshore Processes

Maps depicting the Framework results for degradation of each of the 11 nearshore ecosystem processes are presented in Appendix D. The degradation categories assigned for each nearshore process in each process unit are presented in Appendix E. As described in the evaluation Framework methods (Section 5.1.2), the degradation category assignments were based on relative degradation compared to all other process units, rather than on absolute thresholds of degradation. Degradation categories were assigned based on natural breaks, which do not necessarily result in equal numbers of process units in each degradation category.

The percentage of the 812 SPUs assigned to each degradation category, by nearshore process, is presented in Figure 6-1. Among 8 of the 11 nearshore processes, the percentages of SPUs assigned to the High, Medium, and Low Degradation categories were generally evenly distributed with approximately 25 percent ± 5 percent of the SPUs assigned to those 3 categories. The three exceptions were distributary channel migration which was Not Applicable in SPUs, freshwater input which had many more Low Degradation SPUs than High Degradation SPUs, and solar incidence which had many more Low Degradation SPUs compared to the other categories.

The percentage of total shoreline length in SPUs within each degradation category (Figure 6-2) was generally similar to the distribution based on SPU counts (see Figure 6-1) although a smaller percentage of shoreline length was assigned to the Not Degraded and Not Applicable categories compared to the count of SPUs. In contrast, the percentage of total watershed area in SPUs within each degradation category (Figure 6-3) was markedly different from the distribution based on the percentage of SPUs by count (see Figure 6-1). Most notably, a much larger percentage of the total watershed area in SPUs High Degradation category compared to the percentage of SPUs by count assigned to the High Degradation category. The High Degradation category was assigned to SPUs comprising nearly 50 percent of the SPU watershed area, but those SPUs accounted for only approximately 25 percent by count and shoreline length. For example, for the sediment input process, nearly 50 percent of the SPU watershed area is in the High Degradation category, but only 28 percent of the SPUs (by count) are assigned to the High Degradation category. This indicates that SPUs of larger watershed areas tend to be more degraded than SPUs that are smaller in watershed area.

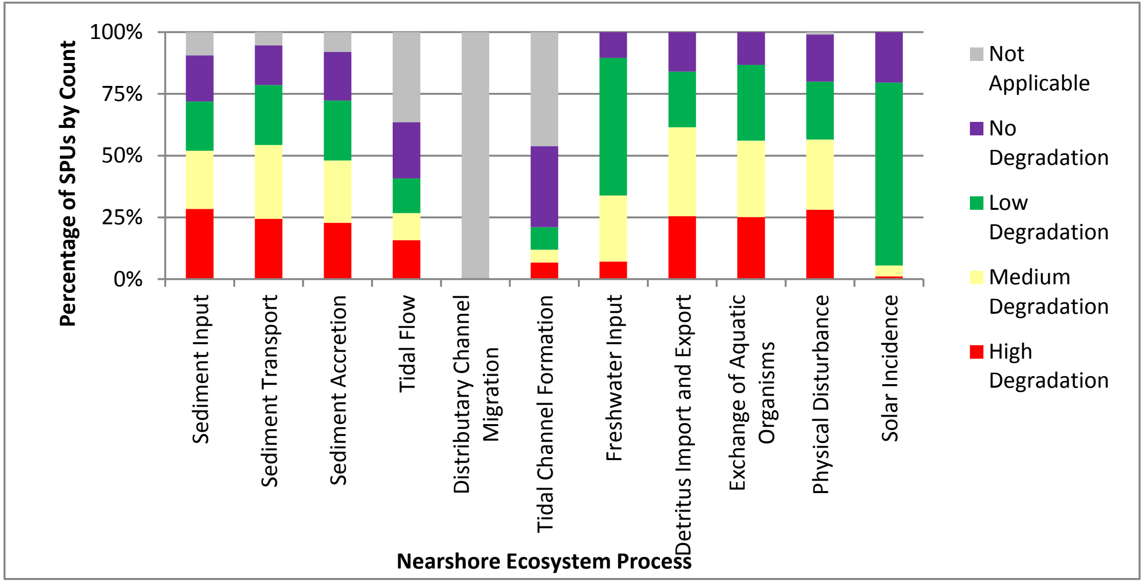

Figure 6-1

Sound-wide Nearshore Process Degradation by Percentage of SPUs

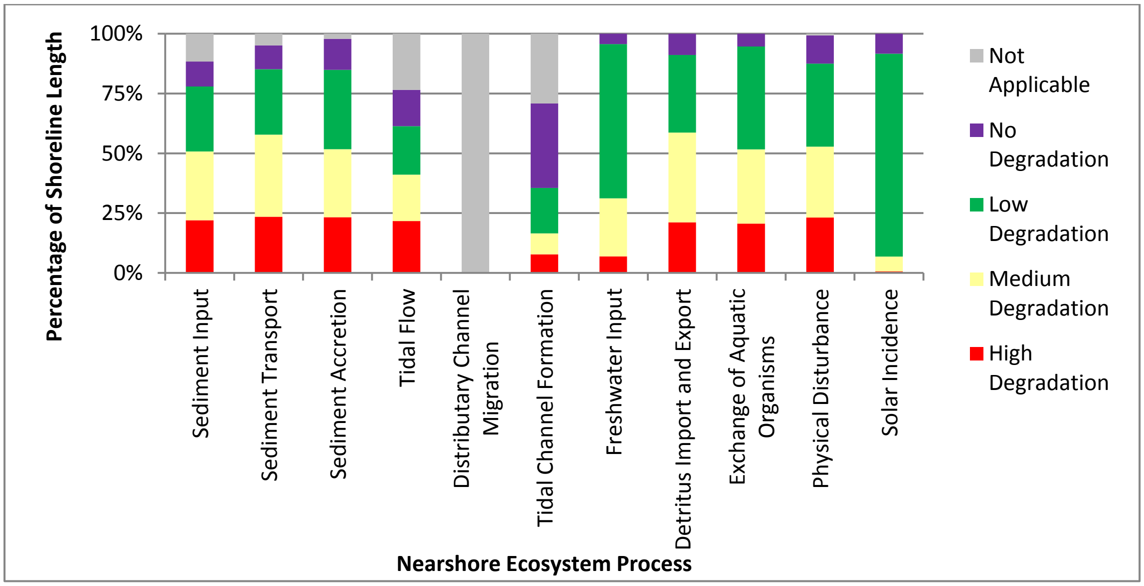

Figure 6-2

Sound-wide Nearshore Process Degradation by Percentage of Total SPU Shoreline Length

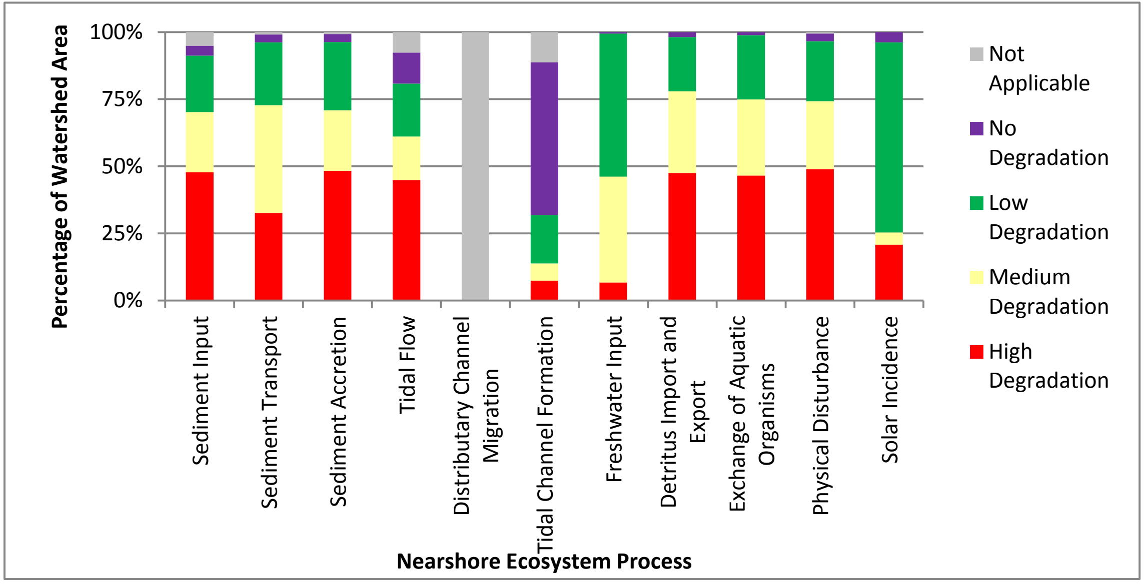

Figure 6-3

Sound-wide Nearshore Process Degradation by Percentage of Total SPU Watershed Area

6.1.1.2 Delta Process Unit Results for Individual Nearshore Processes

Fifty percent or more of the DPUs (i.e., 8 or more of the 16 DPUs) were assigned to the High Degradation category for five of the nearshore processes: sediment transport, sediment accretion, distributary channel migration, detritus import and export, and exchange of aquatic organisms (Figure 6-4). The five most degraded nearshore ecosystem processes in DPUs were those impacted primarily by shoreline alterations, including tidal barriers and armoring. The percentage of DPU shoreline length and watershed area in the High and Medium Degradation categories was disproportionately higher than the percentage of DPUs by count (Figures 6-5 and 6-6). This indicates that the larger DPUs in terms of watershed area and shoreline length tended to be more degraded than smaller DPUs. The degradation categories assigned for each nearshore process in each DPU are presented in Table 6-1.

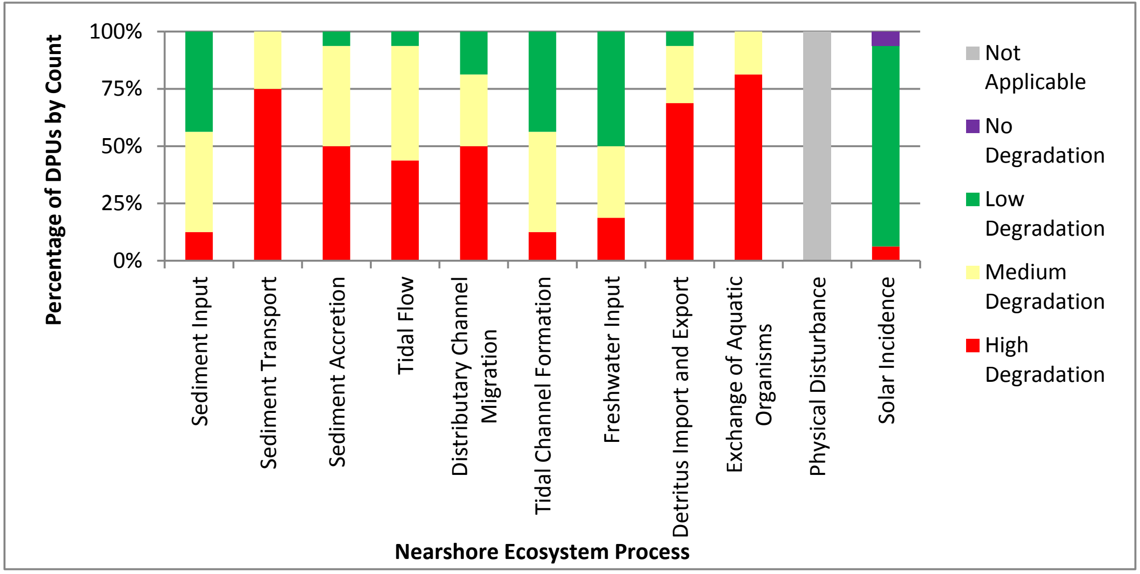

Figure 6-4

Sound-wide Nearshore Process Degradation by Percentage of DPUs

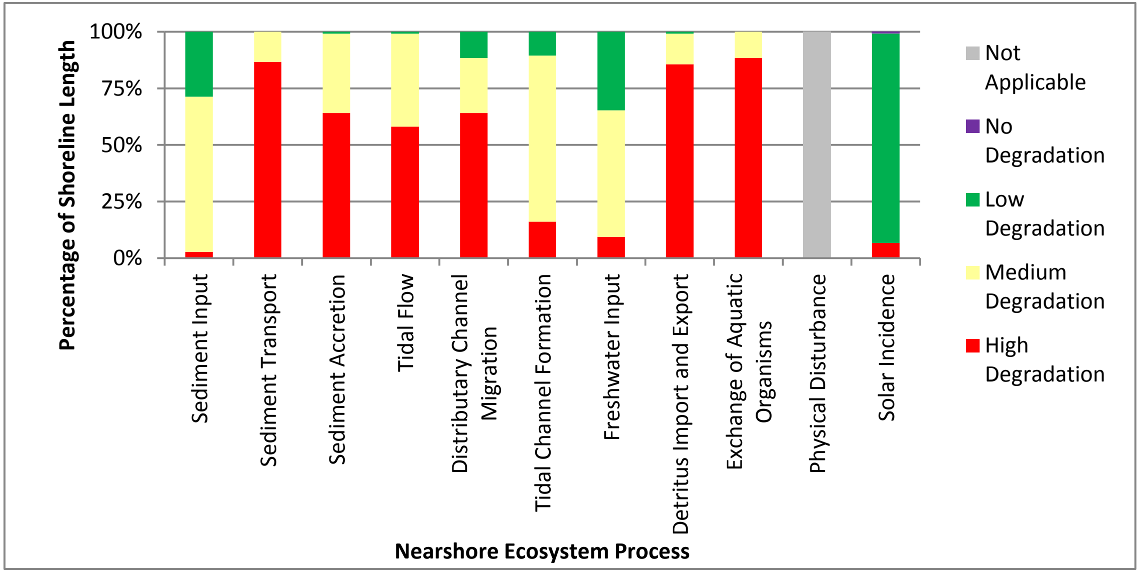

Figure 6-5

Sound-wide Nearshore Process Degradation by Percentage of Total DPU Shoreline Length

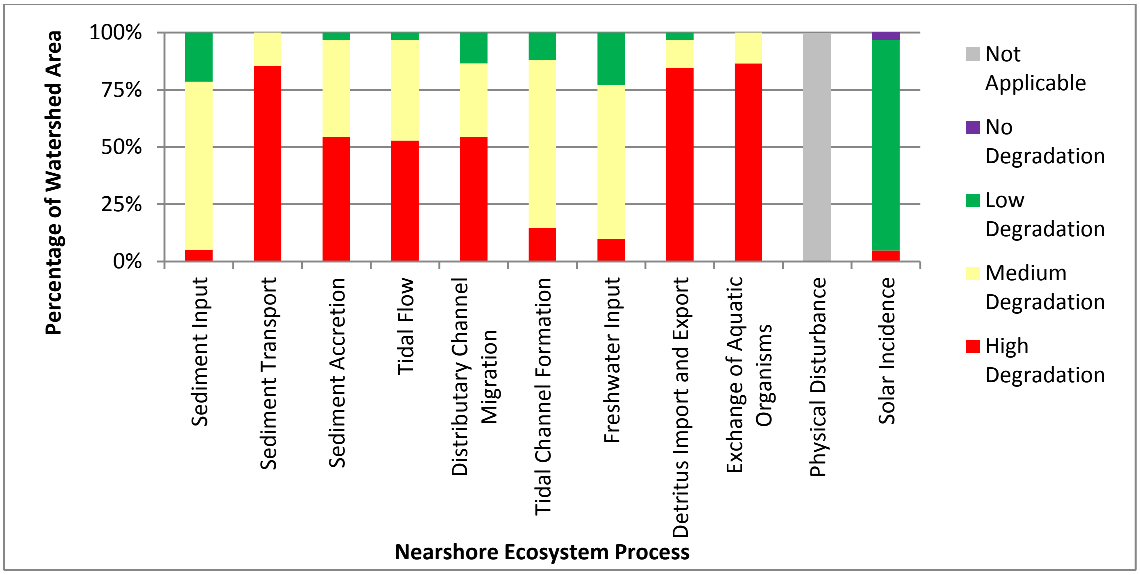

Figure 6-6

Sound-wide Nearshore Process Degradation by Percentage of Total DPU Watershed Area

Table 6-1
Process Degradation Categories of DPUs

DPU	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence
Nooksack	SJ	40.5	2,084	L	M	M	M	L	M	L	M	M	N/A	L
Samish	SJ	29.0	403	M	H	H	M	H	M	L	H	H	N/A	L
Skagit	WH	96.2	7,301	M	H	M	M	M	M	M	H	H	N/A	L
Stillaguamish	WH	65.5	1,876	L	H	H	H	H	M	L	H	H	N/A	L
Snohomish	WH	95.3	4,748	M	H	H	H	H	M	M	H	H	N/A	L
Duwamish	SC	32.5	1,257	M	H	H	H	H	H	H	H	H	N/A	H
Puyallup	SC	45.7	2,535	M	H	H	H	H	H	M	H	H	N/A	L
Nisqually	SP	20.2	2,160	M	H	H	H	H	M	M	H	H	N/A	L
Deschutes	SP	9.0	466	H	H	H	H	H	M	H	H	H	N/A	L
Elwha	JF	4.1	838	H	M	L	L	L	L	H	L	M	N/A	N
Dungeness	JF	11.6	564	L	M	M	M	L	L	L	M	M	N/A	L
Quilcene	HC	8.1	295	L	M	M	M	M	L	L	M	H	N/A	L
Dosewallips	HC	4.7	307	L	H	M	M	M	L	L	H	H	N/A	L
Duckabush	HC	3.9	204	L	H	M	M	M	L	L	H	H	N/A	L
Hamma Hamma	HC	5.1	222	L	H	M	M	M	L	L	M	H	N/A	L
Skokomish	HC	13.7	654	M	H	H	H	H	L	M	H	H	N/A	L

Note: H = High Degradation
M = Medium Degradation
L = Low Degradation
N = No Degradation
N/A = Not Applicable

6.1.2 Sub-basin Results

6.1.2.1 Strait of Juan de Fuca Sub-basin

The Strait of Juan de Fuca sub-basin is among the least degraded sub-basins in Puget Sound. Detritus import and export was the most widely degraded process in the sub-basin, as it was the only process in which more than 50 percent of the SPU shoreline length and SPU count were categorized as having High or Medium Degradation (Figure 6-7). Sediment transport and physical disturbance had the largest percentage of the shoreline length categorized as having High Degradation (24 and 21 percent, respectively). There were no SPUs categorized as having High Degradation for three processes: solar incidence, tidal channel formation, and freshwater input. Tidal flow and tidal channel formation processes had the smallest percentage of shoreline length and watershed area with some degree of degradation (i.e., assigned to the High, Medium, or Low Degradation category) as less than 60 percent of the shoreline length and less than 75 percent of the watershed area were degraded to some degree. (Figures 6-8 and 6-9). For 9 of the 11 nearshore processes, there was no degradation in 10 percent or more of the SPUs. The SPUs with no degradation tend to be smaller process units because they comprise a smaller percentage of the shoreline length and watershed area.

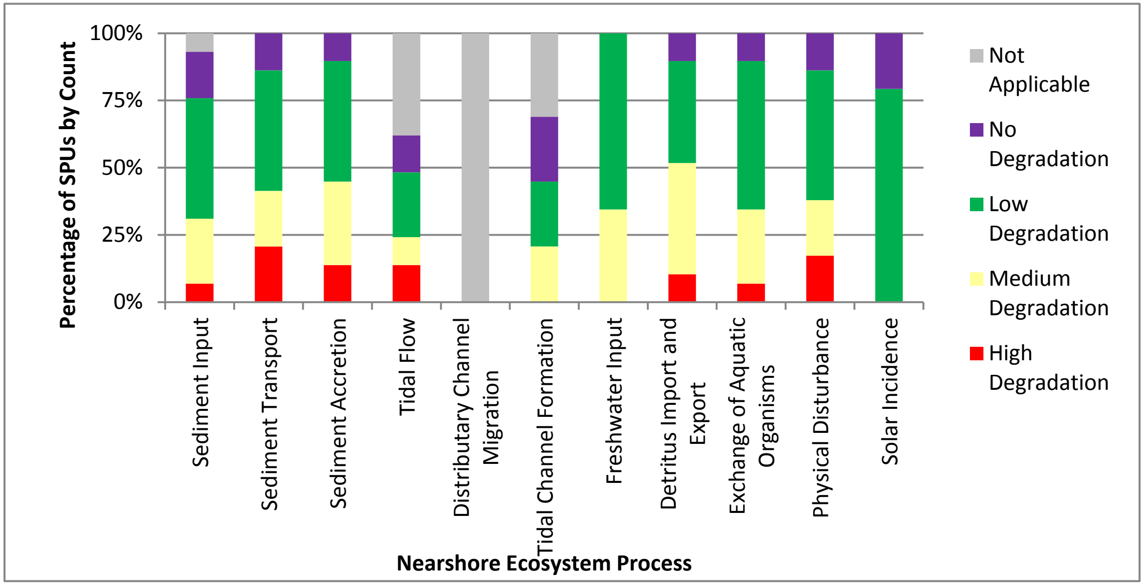

Figure 6-7

Nearshore Ecosystem Process Degradation in Strait of Juan de Fuca Sub-basin by Percent of SPU Count

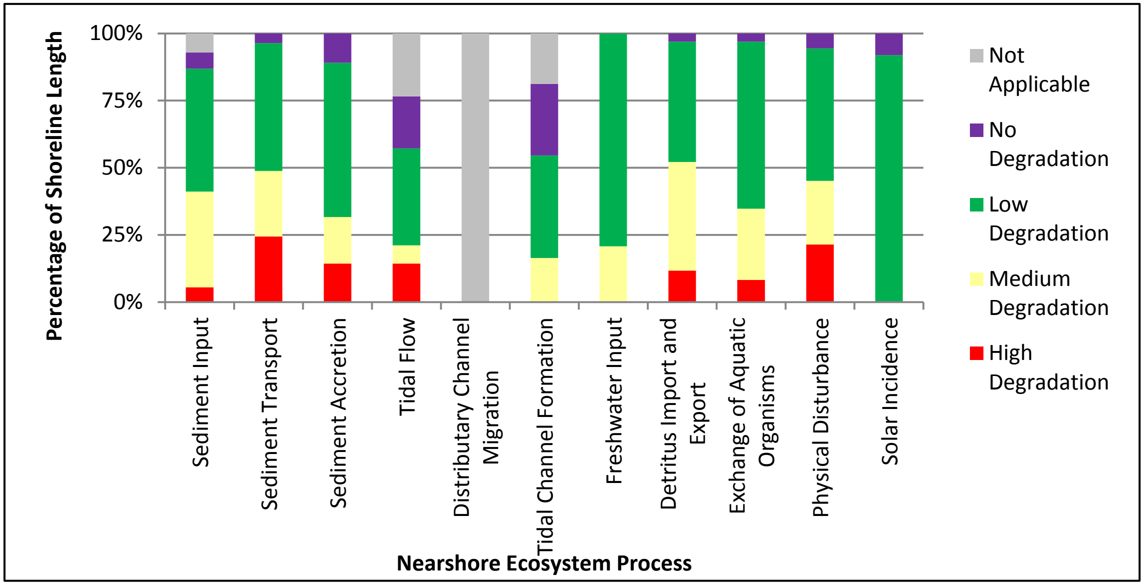

Figure 6-8

Nearshore Ecosystem Process Degradation in Strait of Juan de Fuca Sub-basin by Percent of Total SPU Shoreline Length

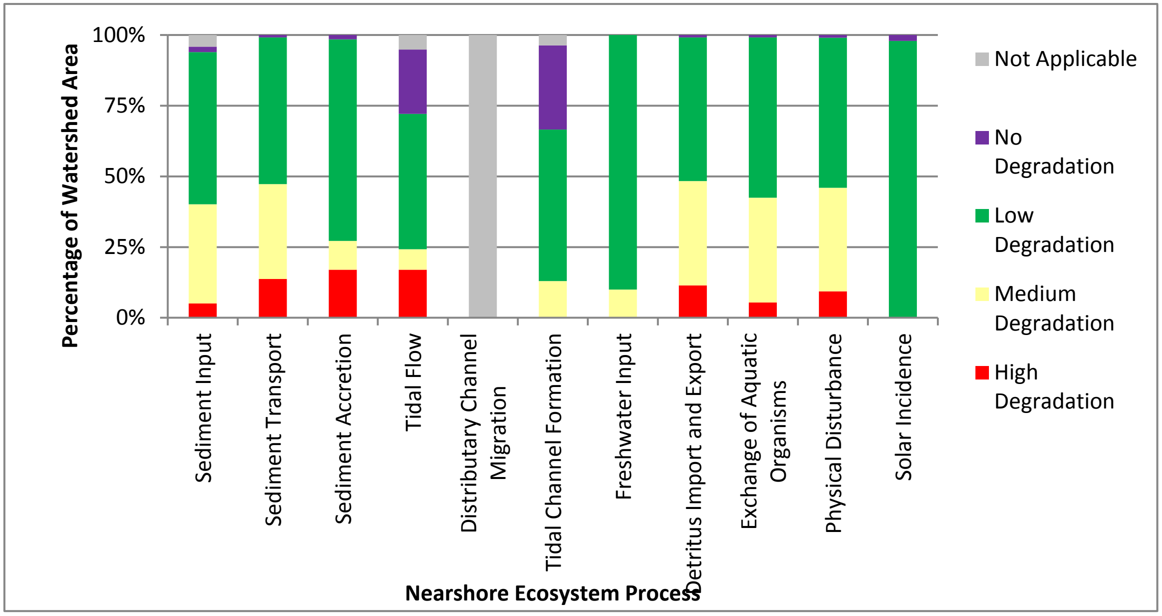

Figure 6-9

Nearshore Ecosystem Process Degradation in Strait of Juan de Fuca Sub-basin by Percent of Total SPU Watershed Area

6.1.2.2 San Juan Islands – Strait of Georgia Sub-basin

The San Juan Islands – Strait of Georgia sub-basin is among the less degraded sub-basins in Puget Sound. There were several processes that were classified as Not Applicable for several SPUs in the sub-basin because the Framework metrics focused on conditions in a subset of shoreforms that were not present in the SPUs (Figure 6-10). Specifically, several SPUs did not have bluff-backed beaches or embayments (e.g., barrier estuaries and barrier lagoons) in which to evaluate conditions. Six nearshore processes were classified as having High or Medium Degradation along more than 25 percent of the sub-basin shoreline length, including all three sediment processes, tidal flow, detritus import and export, and physical disturbance. Among those six nearshore processes, the SPUs categorized as having High or Medium Degradation comprised 25 percent or more of the shoreline length and 50 percent or more of the watershed area in the sub-basin (Figures 6-11 and 6-12).

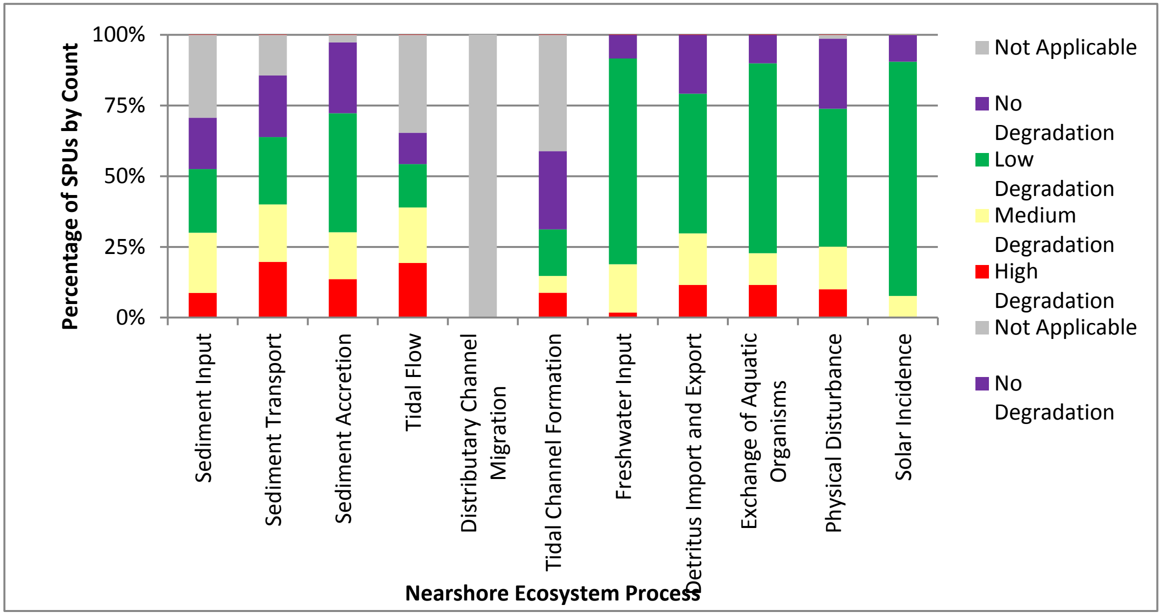

Figure 6-10

Nearshore Ecosystem Process Degradation in San Juan Islands – Strait of Georgia Sub-basin by Percent of SPU Count

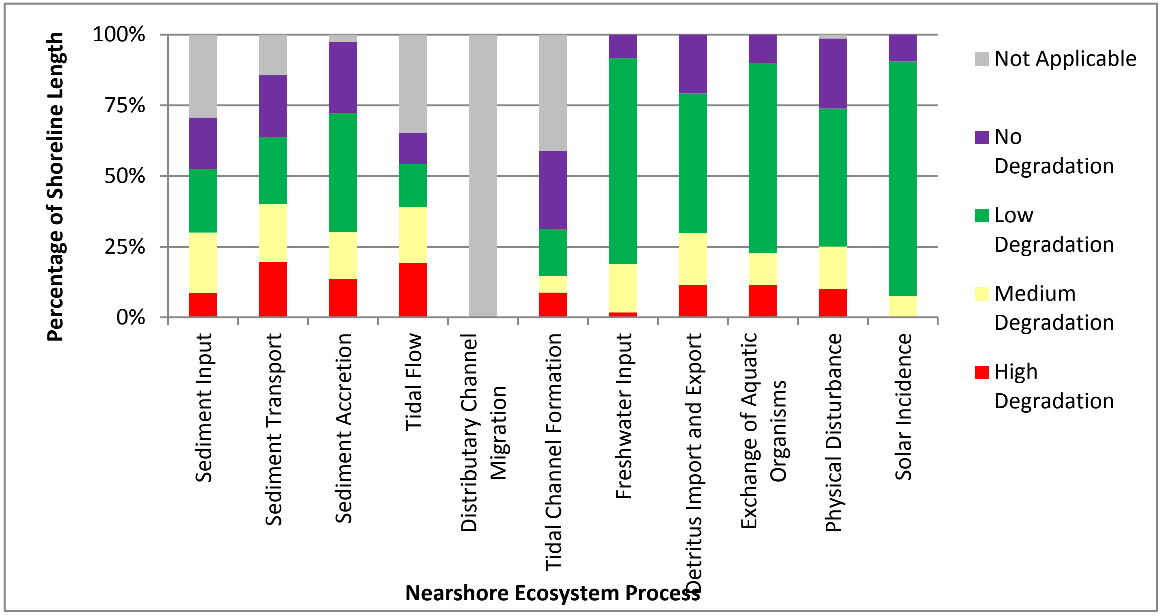

Figure 6-11
Nearshore Ecosystem Process Degradation in San Juan Islands – Strait of Georgia Sub-basin by Percent of Total SPU Shoreline Length

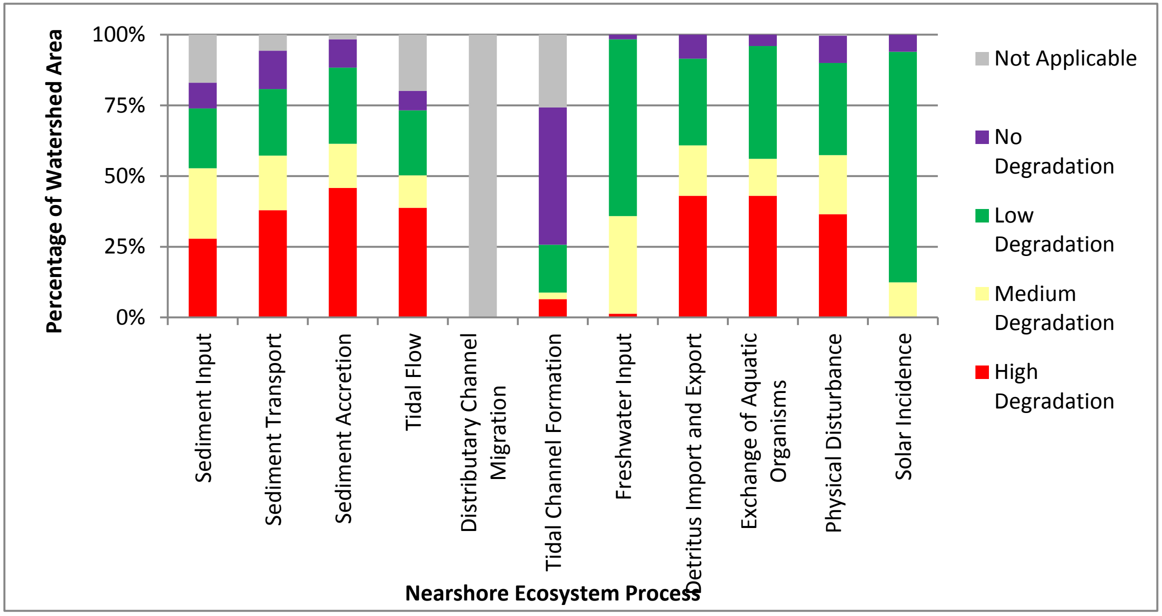

Figure 6-12
Nearshore Ecosystem Process Degradation in San Juan Islands – Strait of Georgia Sub-basin by Percent of Total SPU Watershed Area

6.1.2.3 Hood Canal Sub-basin

The Hood Canal sub-basin has several nearshore processes that have been widely degraded. Seven nearshore processes were classified as having High Degradation for between 23 and 30 percent of all SPUs (Figure 6-13), which corresponded to 16 to 21 percent of the total SPU shoreline length in the sub-basin (Figure 6-14). Five nearshore processes were categorized as having High or Medium Degradation along more than 50 percent of the SPU shoreline length and 69 percent or more of the watershed area of the sub-basin (Figures 6-14 and 6-15). The processes in this category were sediment transport, sediment accretion, detritus import and export, and exchange of aquatic organisms. The least degraded processes in the sub-basin were solar incidence, tidal channel formation, and freshwater input.

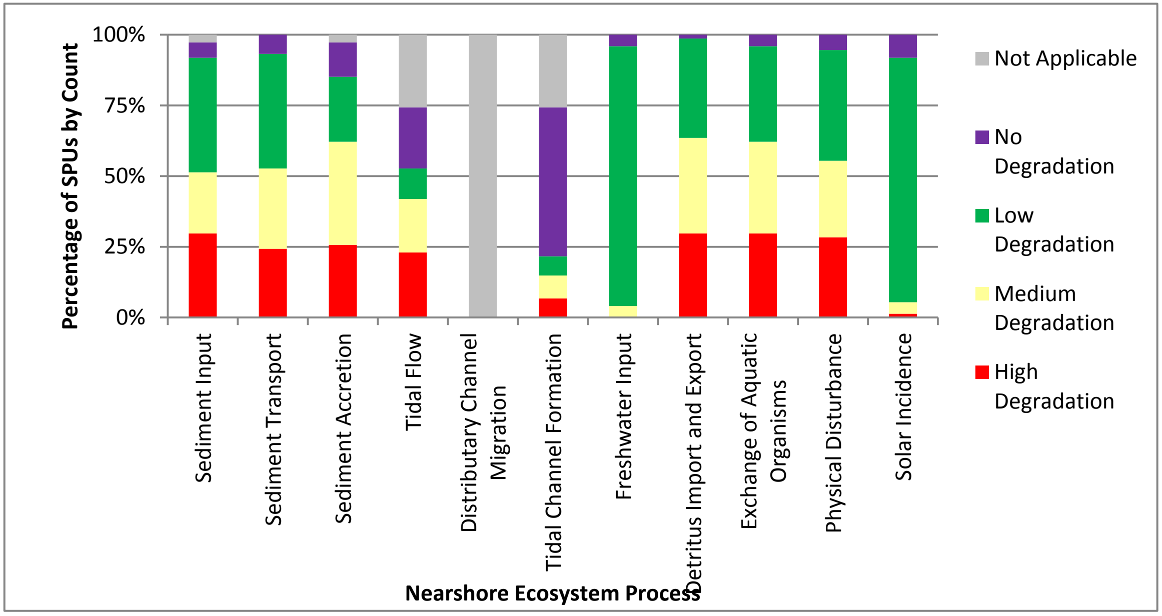

Figure 6-13
Nearshore Ecosystem Process Degradation in Hood Canal Sub-basin by Percent of SPU Count

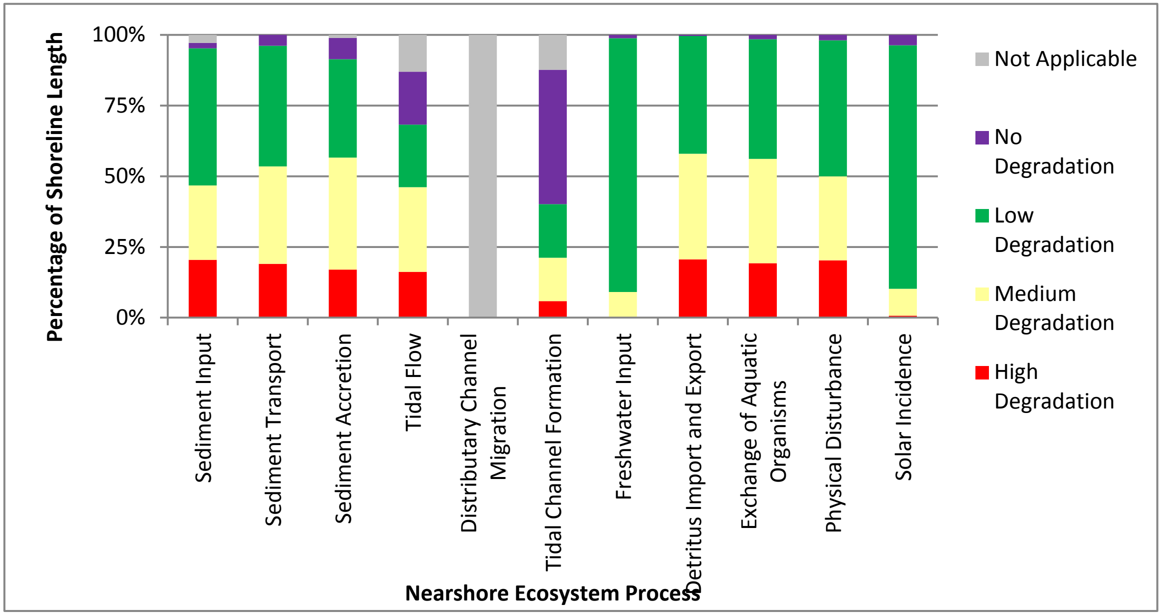

Figure 6-14
Nearshore Ecosystem Process Degradation in Hood Canal Sub-basin by Percent of Total SPU Shoreline Length

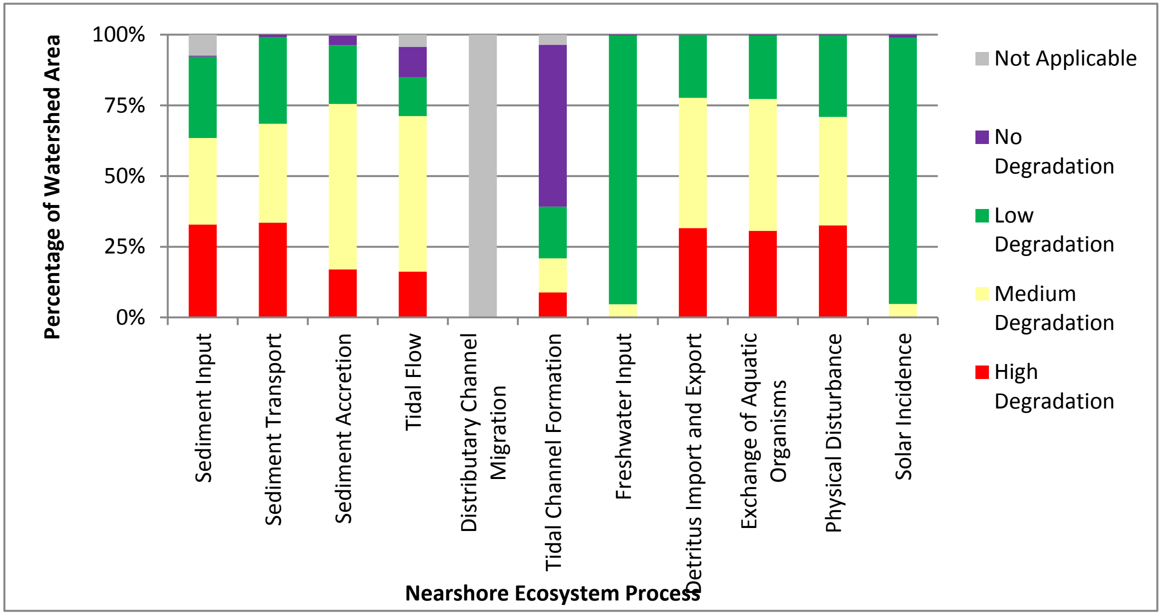

Figure 6-15
Nearshore Ecosystem Process Degradation in Hood Canal Sub-basin by Percent of Total SPU Watershed Area

6.1.2.4 Whidbey Sub-basin

The Whidbey sub-basin had widespread High and Medium Degradation across large portions of the sub-basin. Six nearshore processes in the Whidbey sub-basin have incurred High or Medium Degradation along 65 percent or more of the shoreline length and watershed area in the sub-basin (Figures 6-16, 6-17, and 6-18). The processes in this group include all three sediment processes, detritus import and export, exchange of aquatic organisms, and physical disturbance. Sediment accretion and tidal flow were the only nearshore processes for which the High Degradation category was assigned to more than 25 percent of the shoreline length or watershed area. The least degraded processes in the sub-basin were solar incidence and tidal channel formation.

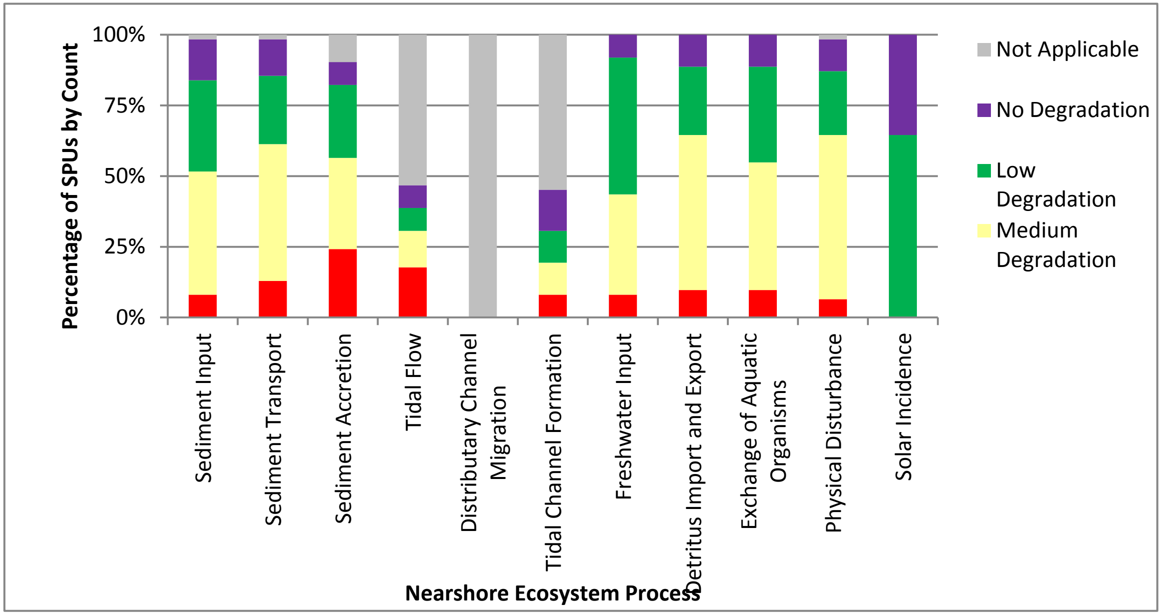

Figure 6-16
Nearshore Ecosystem Process Degradation in Whidbey Sub-basin by Percent of SPU Count

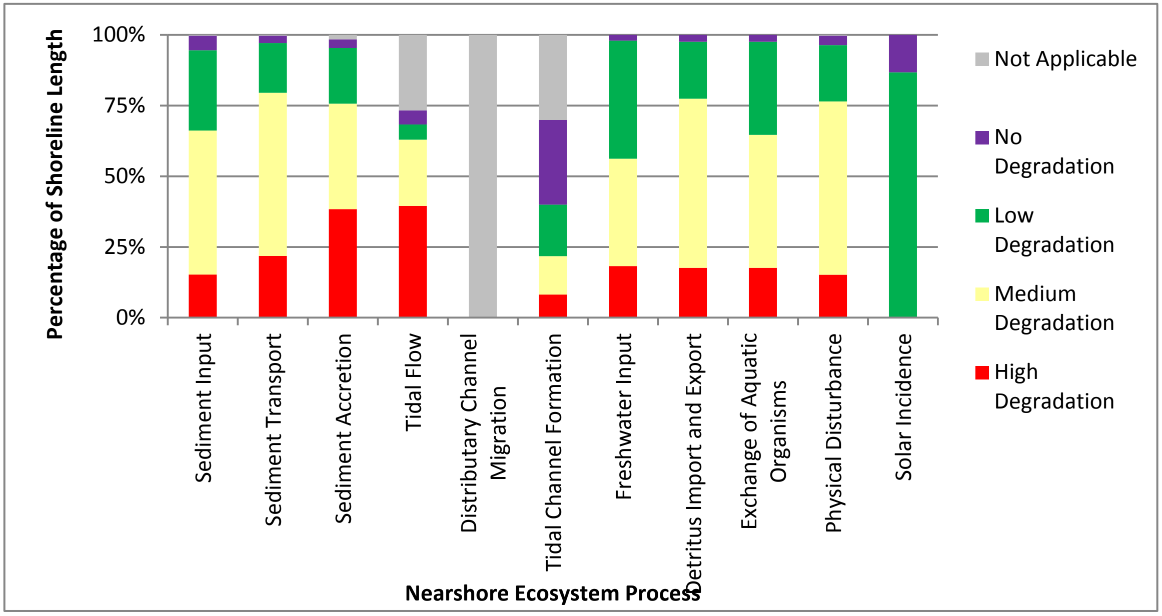

Figure 6-17
Nearshore Ecosystem Process Degradation in Whidbey Sub-basin by Percent of Total SPU Shoreline Length

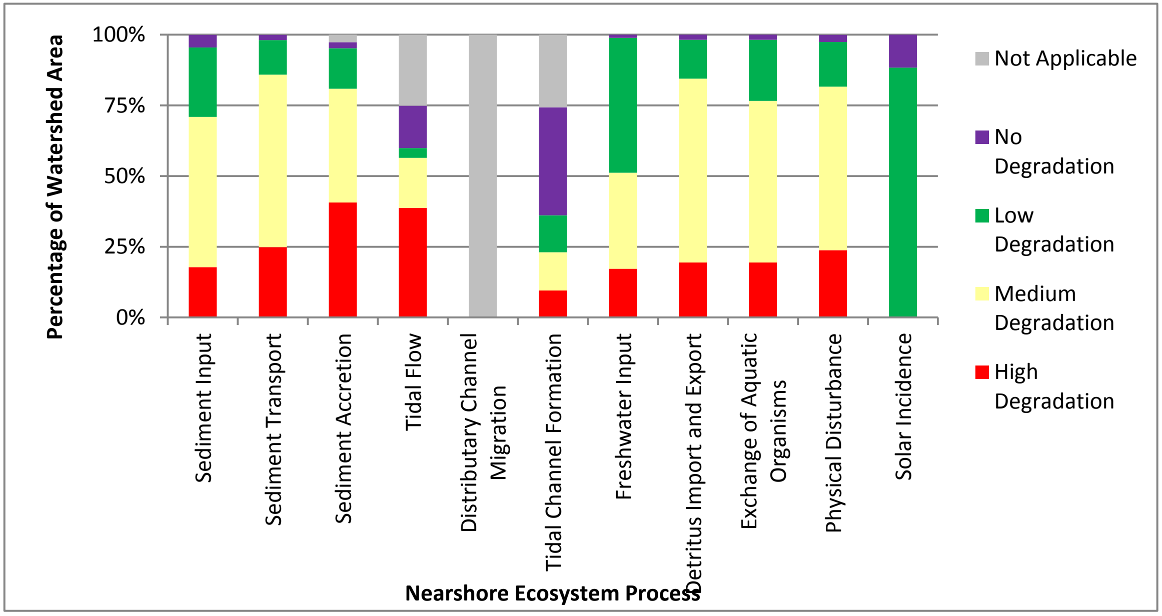

Figure 6-18
Nearshore Ecosystem Process Degradation in Whidbey Sub-basin by Percent of Total SPU Watershed Area

6.1.2.5 North Central Puget Sound Sub-basin

The North Central Puget Sound sub-basin is among the less degraded sub-basins in Puget Sound. Only four nearshore processes in the sub-basin (sediment transport, sediment accretion, tidal flow, and detritus import and export) were categorized as having High or Medium Degradation along more than 50 percent of the shoreline length and watershed area in the sub-basin (Figures 6-19, 6-20, and 6-21). Further, sediment accretion, tidal flow, and tidal channel formation were the only nearshore processes for which more than 10 percent of the shoreline length and watershed area of the sub-basin were classified in the High Degradation category. The least degraded processes were solar incidence, sediment input, and freshwater input.

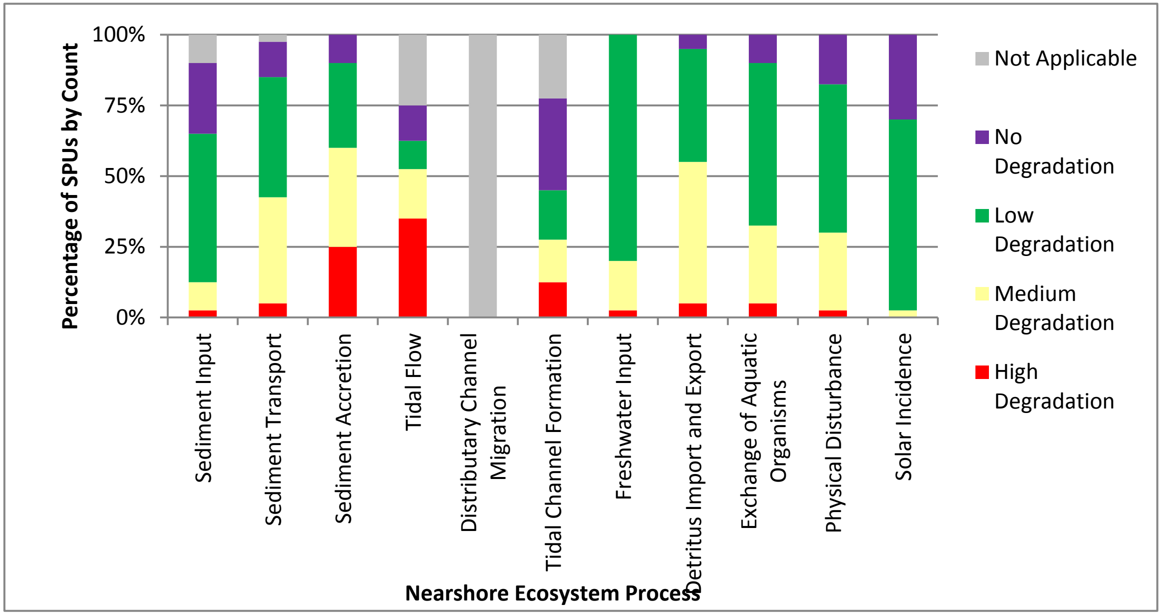

Figure 6-19
Nearshore Ecosystem Process Degradation in North Central Puget Sound Sub-basin by Percent of SPU Count

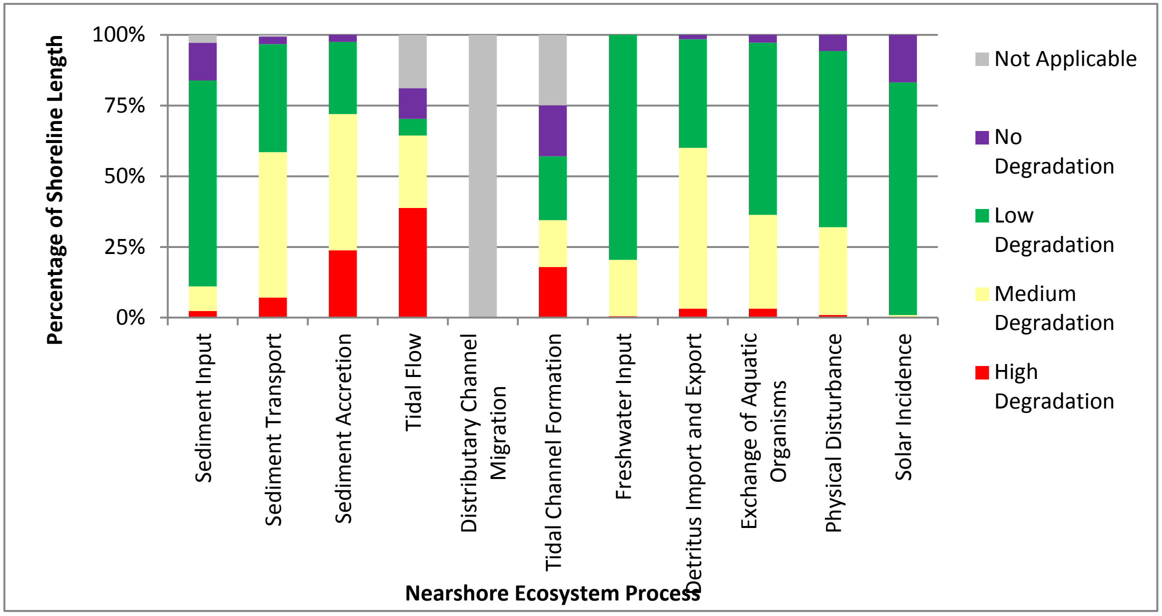

Figure 6-20
Nearshore Ecosystem Process Degradation in North Central Puget Sound Sub-basin by Percent of Total SPU Shoreline Length

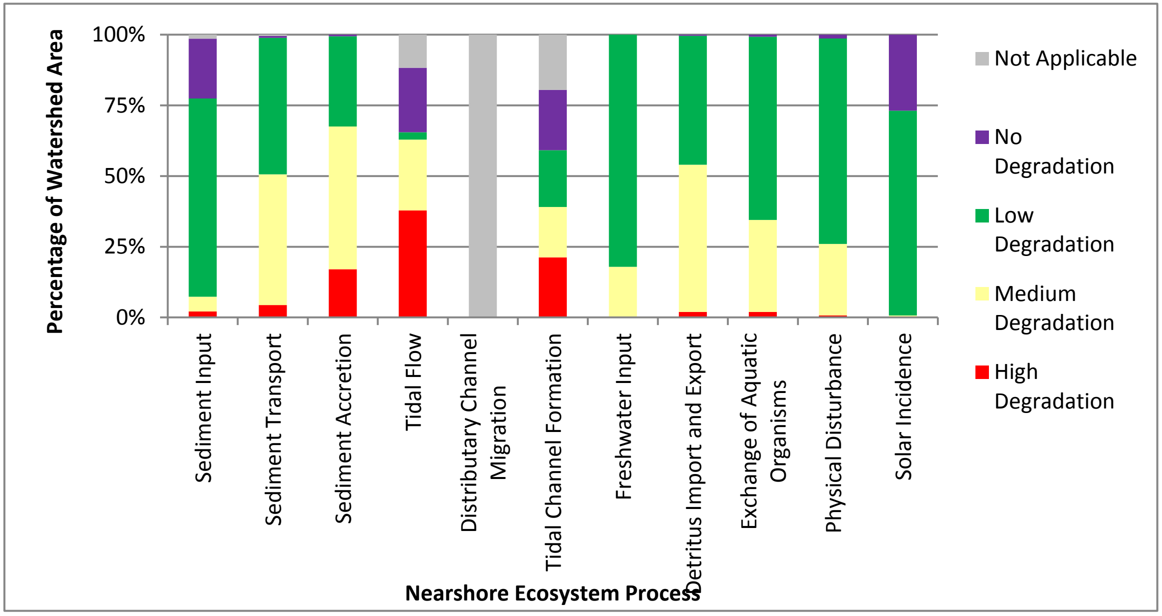

Figure 6-21
Nearshore Ecosystem Process Degradation in North Central Puget Sound Sub-basin by Percent of Total SPU Watershed Area

6.1.2.6 South Central Puget Sound Sub-basin

The South Central Puget Sound sub-basin is among the most degraded sub-basins in Puget Sound. More than 80 percent of the sub-basin shoreline length and watershed area has incurred High or Medium Degradation for six nearshore processes including all three sediment processes, detritus import and export, exchange of aquatic organisms, and physical disturbance (Figures 6-22, 6-23, and 6-24). These processes were all classified as High Degradation for more than 50 percent of the shoreline length. The least degraded processes in the sub-basin were solar incidence and tidal channel formation.

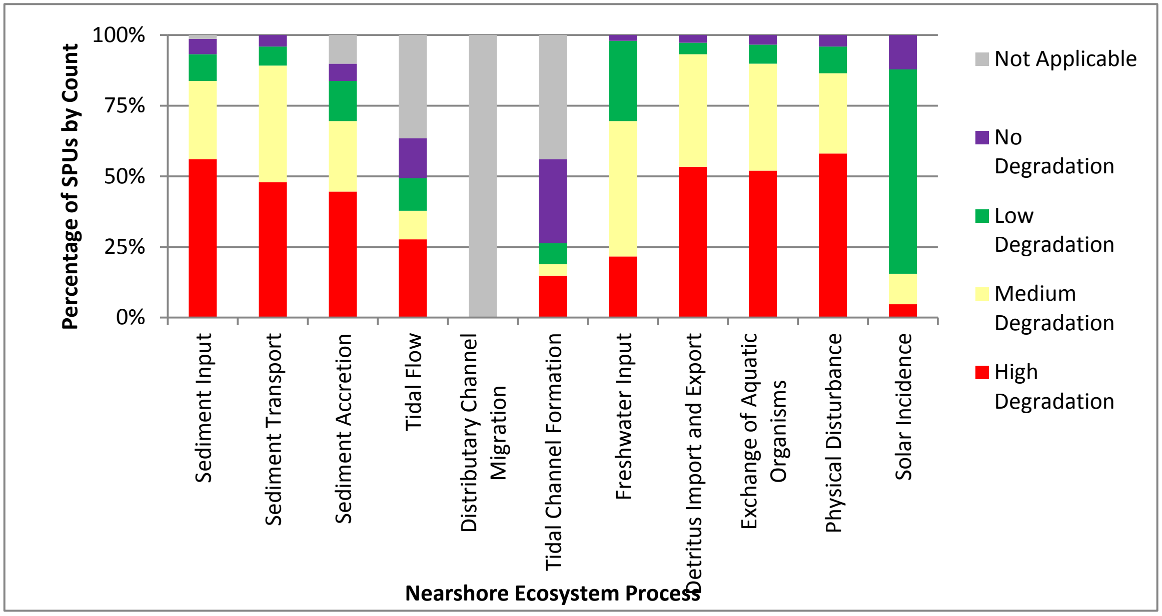

Figure 6-22
Nearshore Ecosystem Process Degradation in South Central Puget Sound Sub-basin by Percent of SPU Count

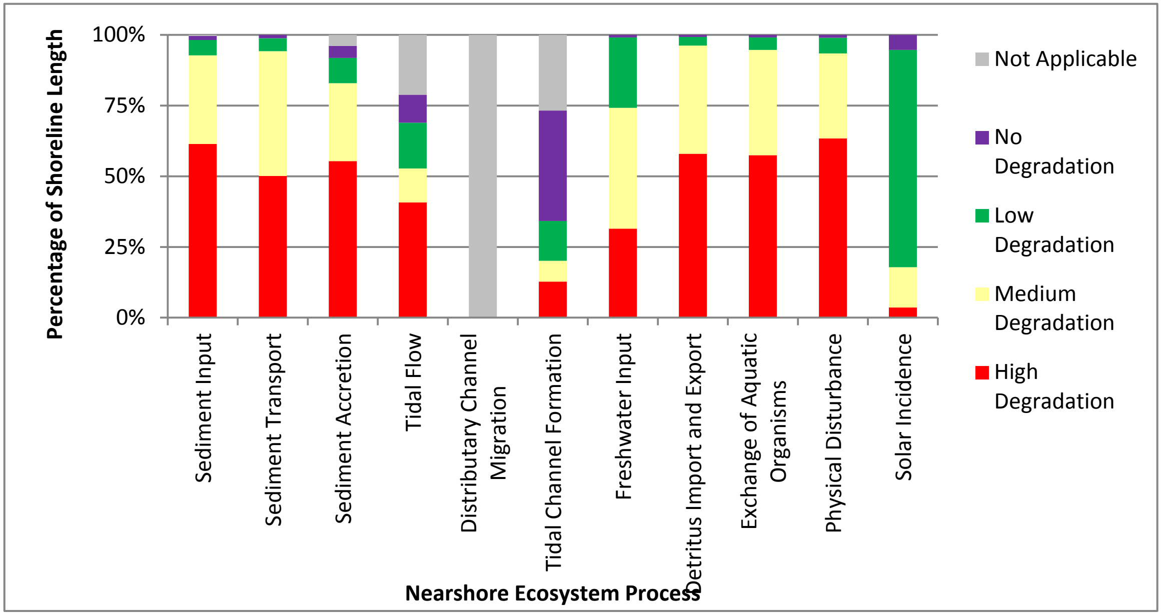

Figure 6-23
Nearshore Ecosystem Process Degradation in South Central Puget Sound Sub-basin by Percent of Total SPU Shoreline Length

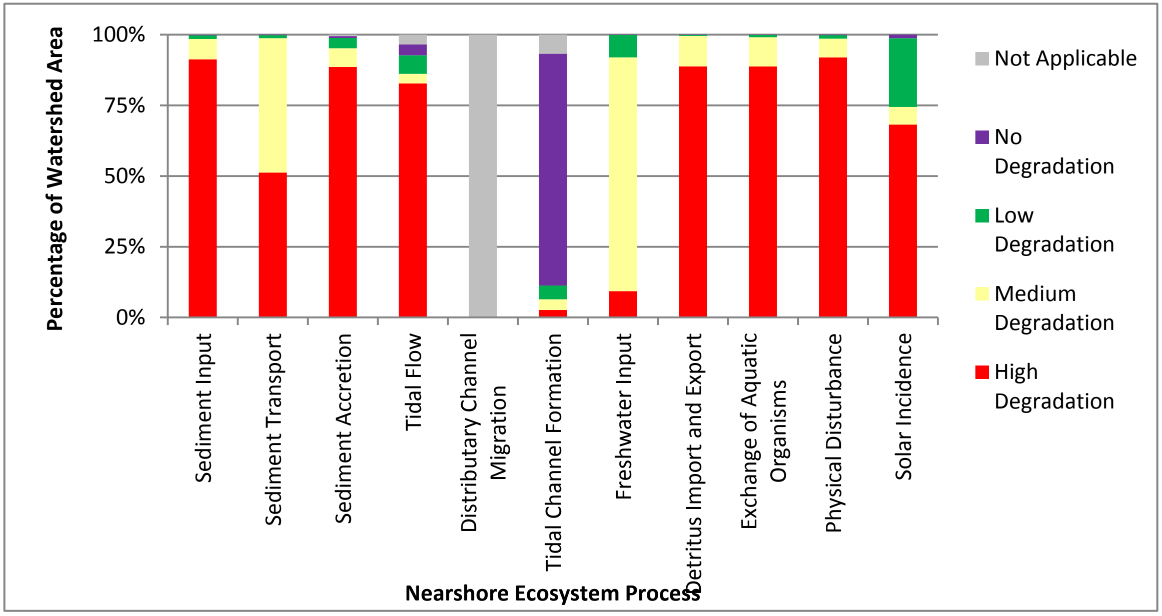

Figure 6-24
Nearshore Ecosystem Process Degradation in South Central Puget Sound Sub-basin by Percent of Total SPU Watershed Area

6.1.2.7 South Puget Sound Sub-basin

The South Puget Sound sub-basin is among the most degraded sub-basins in Puget Sound. Six nearshore processes have incurred High or Medium Degradation along 50 percent or more of the sub-basin shoreline length (Figures 6-25 and 6-26). The processes in this group include: sediment input, sediment transport, sediment accretion, detritus import and export, exchange of aquatic organisms, and physical disturbance. The same six nearshore processes, as well as tidal flow, were classified as having High or Medium Degradation in more than 50 percent of the watershed area of the sub-basin (Figure 6-27). Only sediment input and physical disturbance were assigned to the High Degradation category for more than 25 percent of the shoreline length (34 and 30 percent, respectively). The least degraded processes in the sub-basin were solar incidence and tidal channel formation.

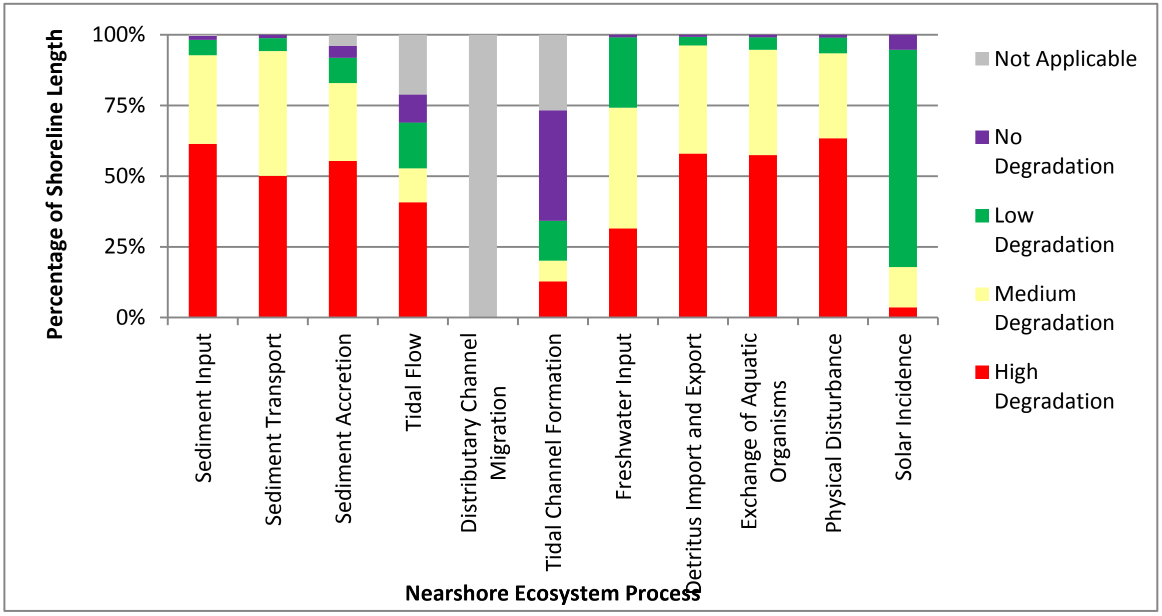

Figure 6-25
Nearshore Ecosystem Process Degradation in South Puget Sound Sub-basin by Percent of SPU Count

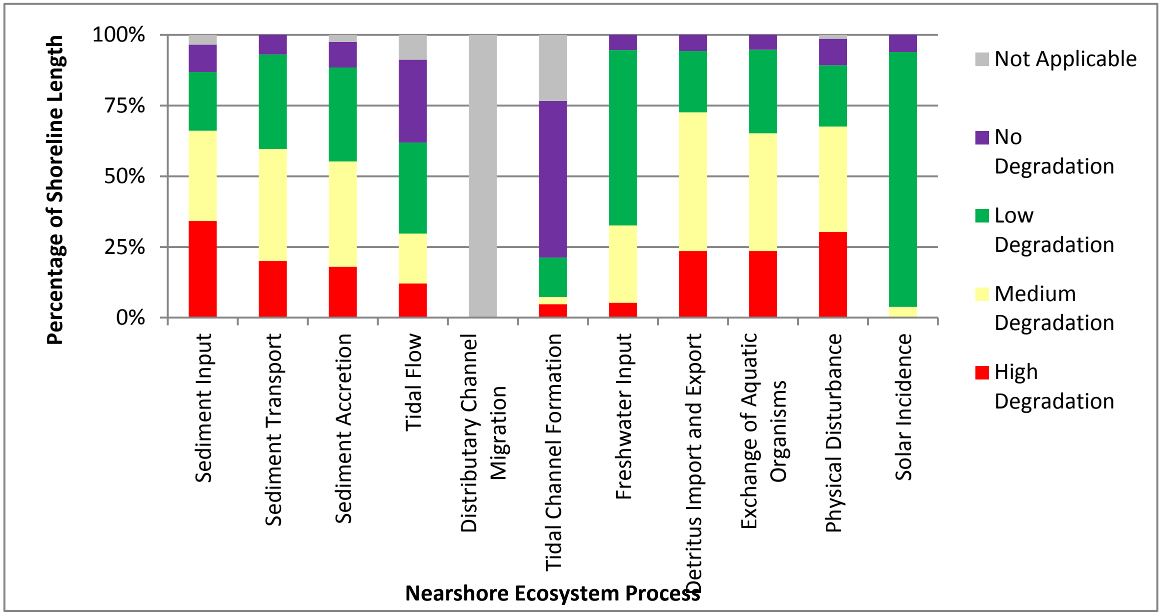

Figure 6-26
Nearshore Ecosystem Process Degradation in South Puget Sound Sub-basin by Percent of Total SPU Shoreline Length

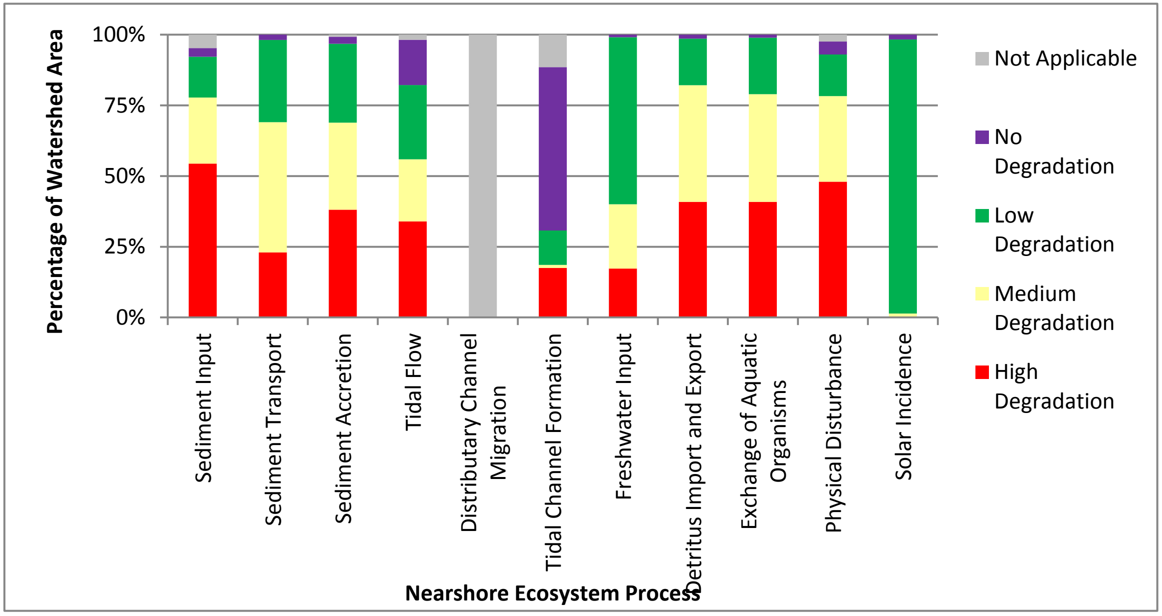

Figure 6-27
Nearshore Ecosystem Process Degradation in South Puget Sound Sub-basin by Percent of Total SPU Watershed Area

6.2 Overall Degradation in Process Units

In the following sections, the overall degradation results for process units in the entire Puget Sound General Investigation study area (Section 6.2.1) and for each of the seven sub-basins (Sections 6.2.2 through 6.2.8).

6.2.1 Puget Sound Basin

The overall degradation categories assigned to process units reveal geographic differences in terms of where higher degradation occurs compared to lesser degradation (Figure 6-28). The eastern shoreline of Puget Sound, spanning from the United States-Canada border in the north to the shoreline west of the Deschutes River in South Puget Sound, was entirely composed of process units of moderate degradation or worse. Within this portion of Puget Sound, from the Nooksack River in the north to the Nisqually River in the south, almost all of the process units were in the Most Degraded or More Degraded categories. These process units were in areas that were among the most populated and developed in the study area, and as a result, multiple shoreline and watershed stressors were contributing to the degradation of nearshore processes. Other portions of the study area with extended stretches in the Most Degraded or More Degraded categories included[7]:

- Southern Hood Canal
- The Kitsap Peninsula shoreline between Southward and Dyes Inlet in the South Central Puget Sound sub-basin
- The eastern shoreline of Carr Inlet and the peninsula shared by Eld and Budd Inlet in the South Puget Sound sub-basin
- The Anacortes area in the San Juan Islands – Strait of Georgia sub-basin
- The Port Angeles area in the Strait of Juan de Fuca sub-basin

Process units categorized as Less Degraded and Least Degraded included:

- Widely distributed in the islands of the San Juan Islands – Strait of Georgia sub-basin
- The Strait of Juan de Fuca sub-basin
- The northwestern parts of the Hood Canal sub-basin
- Portions of the eastern and western shorelines on Whidbey Island
- The southernmost portions of the South Puget Sound sub-basin

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[7] The landmarks identified in this section are more clearly located in the sub-basin scale maps presented in Section 6.2.2.2 through 6.2.2.8.

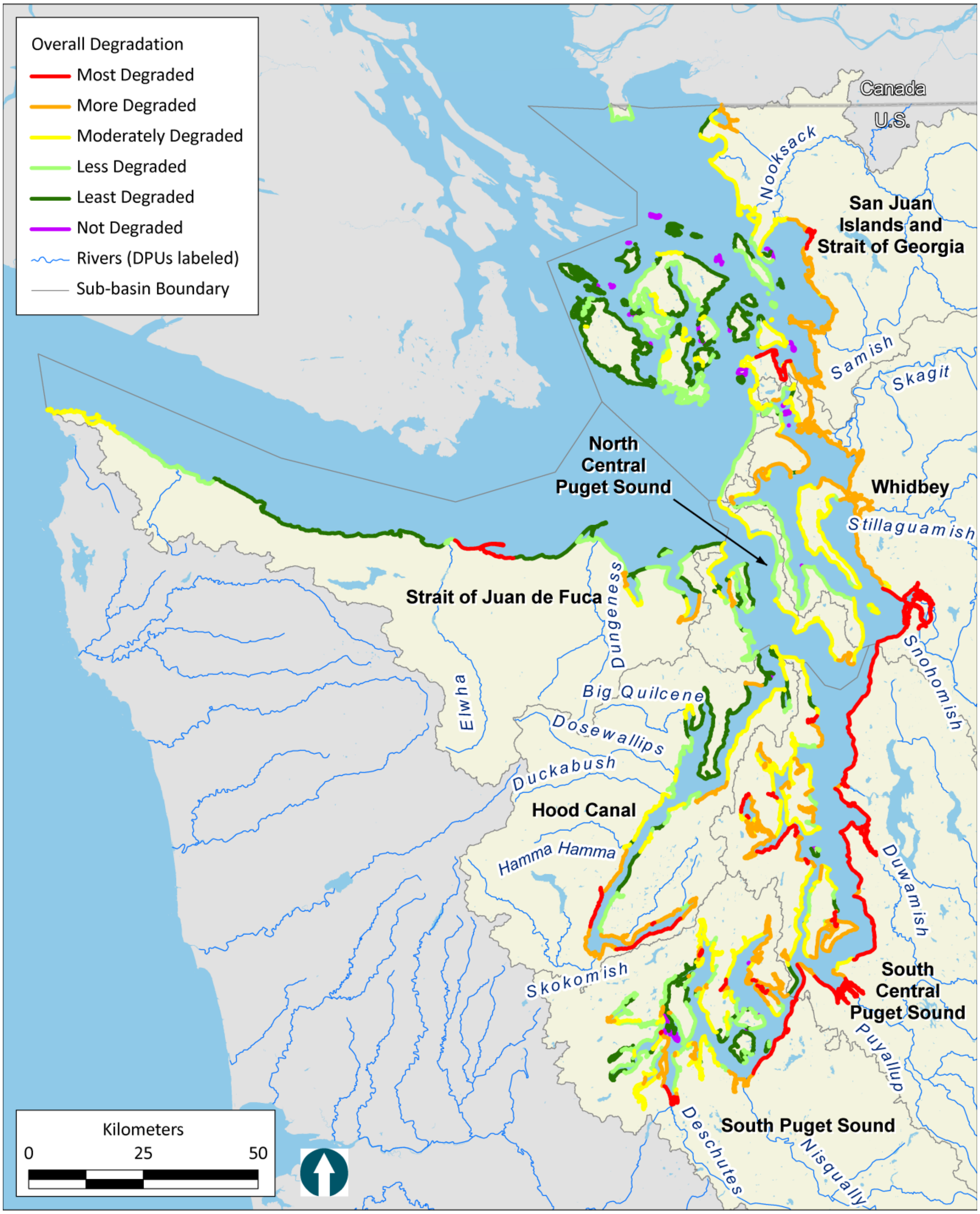


Figure 6-28
Map of Overall Process Degradation by Process Unit

Based on the number of SPUs, the highest percentage of SPUs throughout Puget Sound was assigned to the Least Degraded category (27 percent, 215 of 812) (Figure 6-29). Next most numerous were the Less Degraded and Moderately Degraded categories, which comprised 22 percent (176 SPUs) and 21 percent (170 SPUs) of the SPU count, respectively. Only 7 percent of the PUs (59 SPUs) were in the Most Degraded category. Approximately 6 percent of the SPUs in Puget Sound (52 SPUs) had no degradation.

The percentages of SPU shoreline length assigned to each overall degradation category were similar to the percentages of SPU count (see Figure 6-29), although compared to the number by count, a smaller percentage of shoreline length was assigned to the Not Degraded category. This indicates that the SPUs categorized as Not Degraded tend to be small SPUs with short lengths of shoreline.

The percentages of SPU watershed area assigned to each overall degradation category were markedly different than the distribution by count or shoreline length. Based on watershed area, 33 percent of SPUs were in the Most Degraded category. The More Degraded and Moderately Degraded categories comprised approximately another 33 percent of the watershed area in SPUs throughout the Puget Sound General Investigation study area. Likewise, the Less Degraded and Least Degraded categories comprised the remaining approximately 33 percent of the watershed area in SPUs throughout the Puget Sound General Investigation study area. The SPUs assigned to the Not Degraded category comprised only approximately 0.3 percent of the total watershed area in SPUs.

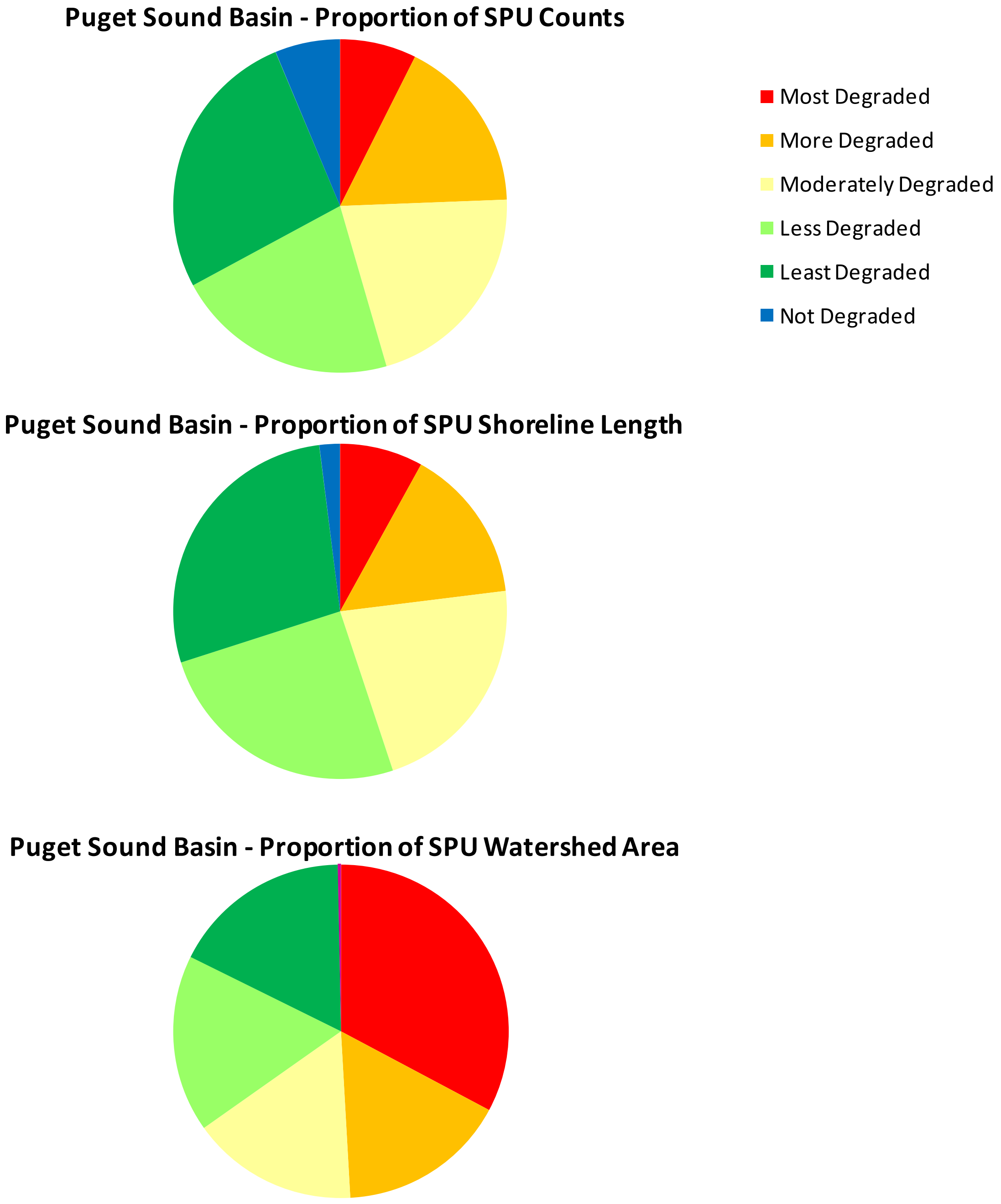


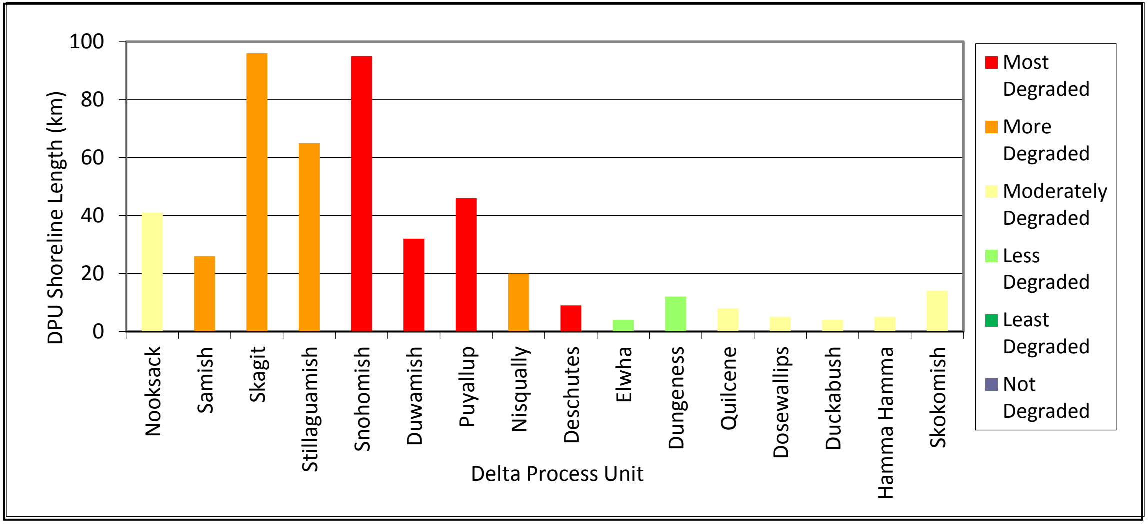
Figure 6-29

Proportion of SPUs Assigned to Each Overall Degradation Category

Among DPUs, 4 of the 16 were among the most degraded process units in the Puget Sound study area (Figure 6-30). Those five DPUs included river deltas on the eastern shoreline between the City of Everett and the City of Olympia: Snohomish, Duwamish, Puyallup, and Deschutes. In this portion of Puget Sound, only the Nisqually River was not among the most degraded. The Nooksack DPU is the only DPU along the eastern shoreline of the Puget Sound study area that is not categorized as Most Degraded or More Degraded. The Elwha and Dungeness DPUs were the only DPUs not in the Moderately Degraded category or worse. Seven of the eight DPUs comprising the longest shorelines were among the Most Degraded or More Degraded process units, with the exception being the Nooksack. Six of the eight DPUs comprising the longest shorelines were among the Most Degraded or More Degraded process units.

Figure 6-31 presents the proportion of shoreline length in SPUs versus DPUs assigned to each degradation category. DPUs comprised successively smaller portions of the degradation when considering each category between Most Degraded and Not Degraded. Figure 6-32 presents the proportion of watershed area in SPUs versus DPUs assigned to each degradation category. DPUs made up more than half of the Puget Sound watershed area that was assigned to the Most Degraded, More Degraded, and Moderately Degraded categories.

(a) Shoreline Length



(b) Watershed Area

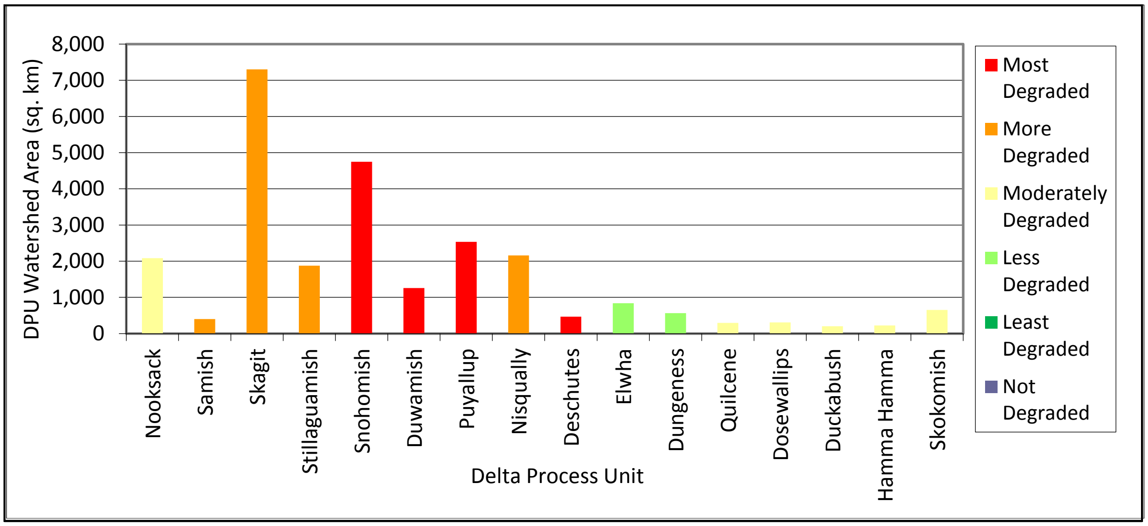


Figure 6-30

Overall Degradation Categories of Delta Process Units with (a) Shoreline Lengths and (b) Watershed Area

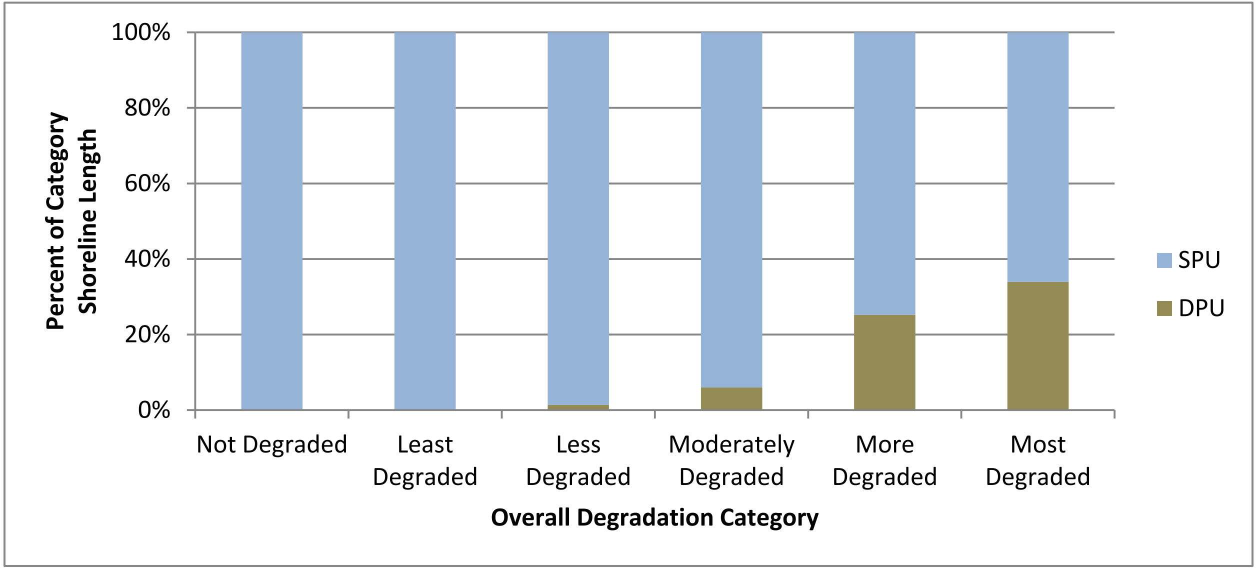


Figure 6-31

Percent of Process Unit Shoreline Length Assigned to Each Overall Degradation Category that is Comprised of DPUs or SPUs

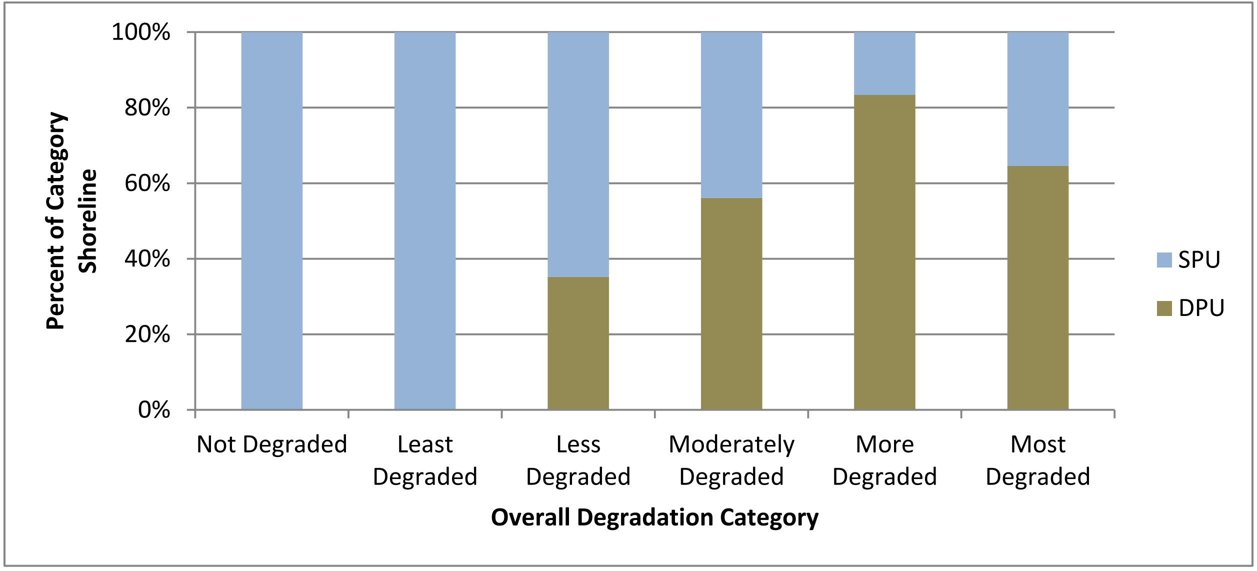


Figure 6-32

Percent of Process Unit Watershed Area Assigned to Each Overall Degradation Category that is Comprised of DPUs or SPUs

6.2.2 Sub-basin Results

6.2.2.1 Comparison Among Sub-basins

By process unit count, the South Central Puget Sound and South Puget Sound sub-basins had the highest combined numbers of process units in the Most Degraded and More Degraded categories (77 and 73, respectively; Figure 6-33). South Central Puget Sound and Whidbey sub-basins had the combined longest shoreline lengths in the Most Degraded and More Degraded categories (1,056 and 872 km, respectively; Figure 6-34). Similarly, the South Central Puget Sound and Whidbey sub-basins had the largest extents of watershed area in the Most and More Degraded categories (7,871 and 14,247 km^2, respectively; Figure 6-35).

The South Puget Sound and the San Juan Islands – Strait of Georgia sub-basins had the highest combined numbers of process units in both the Not Degraded (24 and 21, respectively) and Least Degraded (67 and 90, respectively) categories (Figure 6-33). Those two sub-basins contained 86 percent of the total number of process units in the Not Degraded category and 73 percent of the total number of process units in the Least Degraded category. The Least Degraded process units in these sub-basins comprised 187 km in the South Puget Sound sub-basin and 656 km in the San Juan Islands – Strait of Georgia sub-basin (Figure 6-34). The 656 km of Least Degraded shoreline in San Juan Islands – Strait of Georgia sub-basin comprised 53 percent of the total shoreline length in the Puget Sound study area categorized as Least Degraded. The largest amounts of watershed area in the Least Degraded and Less Degraded categories occurred in the Strait of Juan de Fuca sub-basin (1,098 and 1,944 km^2, respectively; Figure 6-35). In four of the seven sub-basins, process units in the Least Degraded and Less Degraded categories made up more than 50 percent of the sub-basin's shoreline length (Figure 6-36). Based on watershed area, only two of the seven sub-basins had 50 percent or more classified in the Least Degraded and Less Degraded categories (Figure 6-37).

The Not Degraded category comprised 52 km (3 percent) of the shoreline length in the Strait of Juan de Fuca and San Juan Islands – Strait of Georgia sub-basins and 23 km (2 percent) of the shoreline length in the South Puget Sound sub-basin, but was 1 percent or less of the shoreline length in the five other sub-basins. In considering watershed area, the Strait of Juan de Fuca sub-basin included 24km^2 of Not Degraded watershed area. Whidbey sub-basin had the second largest watershed area in the Not Degraded category (11 km^2) while the South Puget Sound sub-basin included 10 km^2 of Not Degraded watershed area.

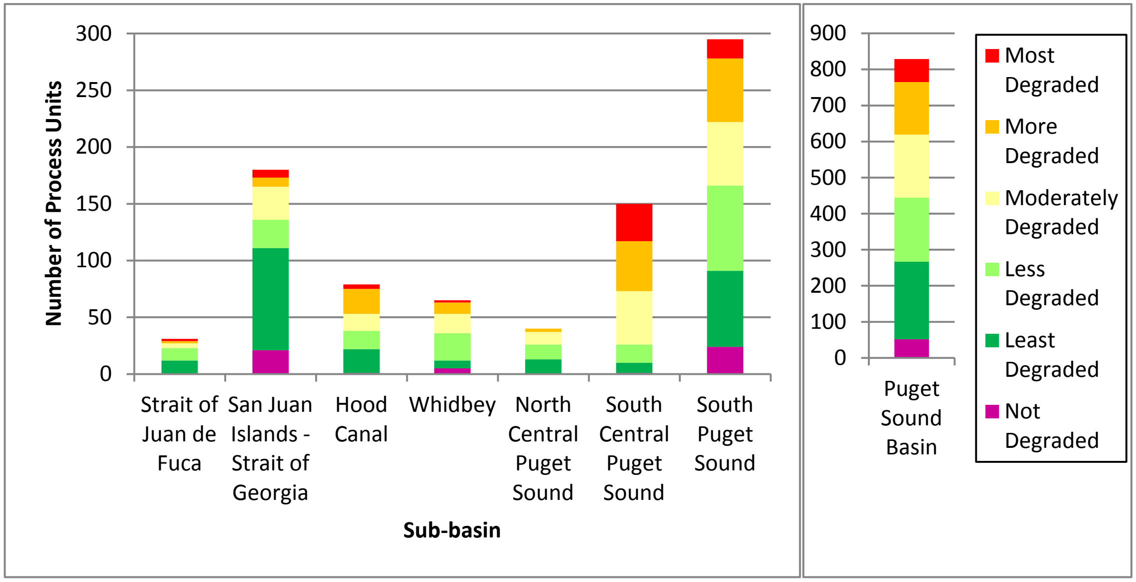


Figure 6-33

Number of Process Units in Each Sub-basin and Sound-wide Assigned to Each Overall Process Degradation Category

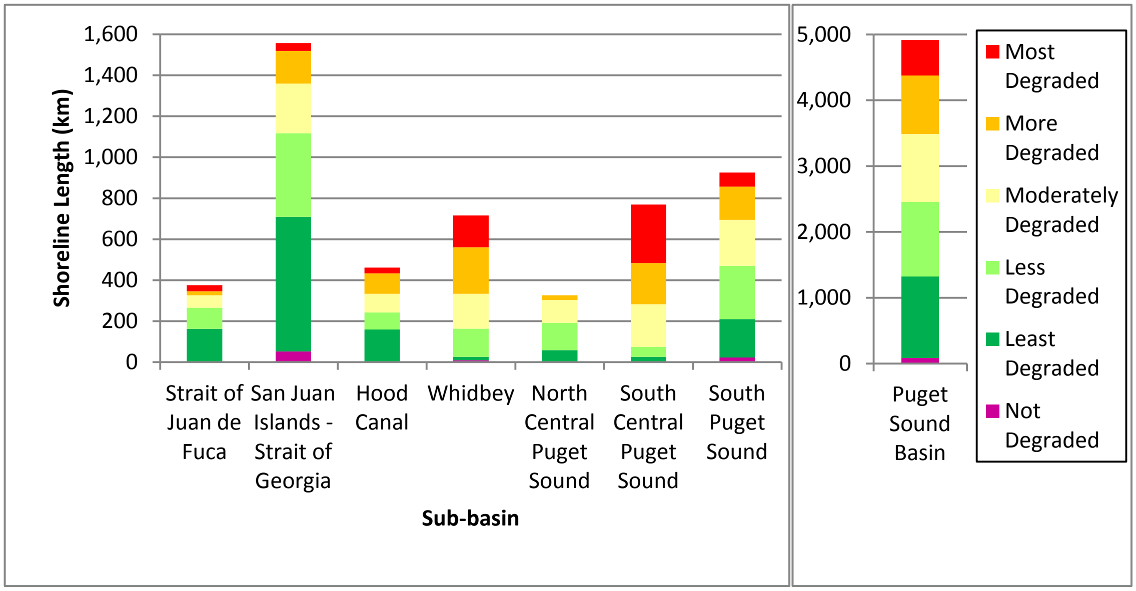


Figure 6-34

Shoreline Length Among Overall Process Degradation Categories in Process Units by Sub-basin and Sound-wide

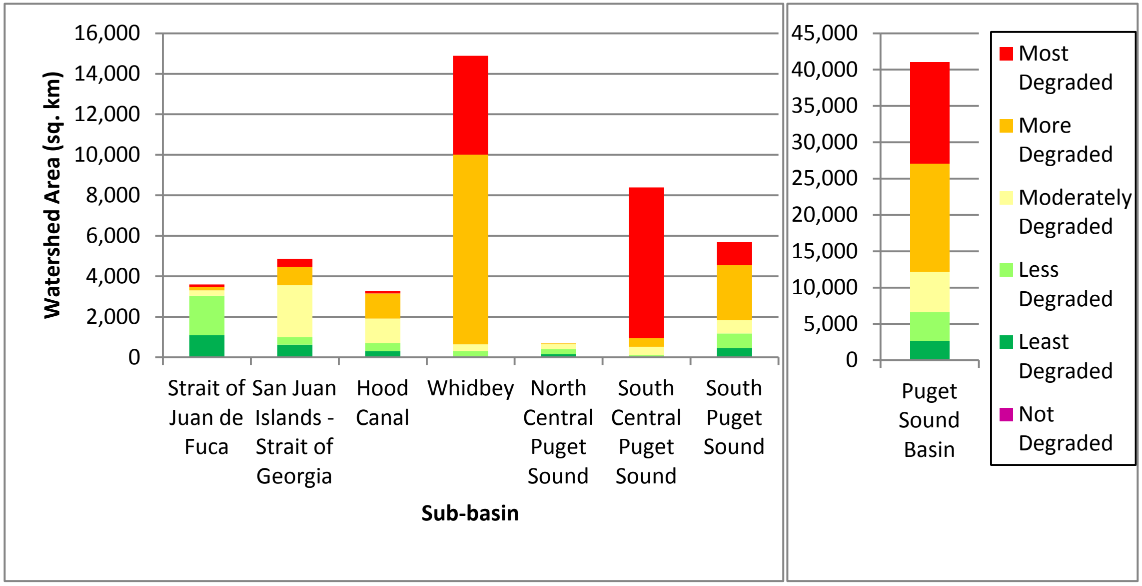
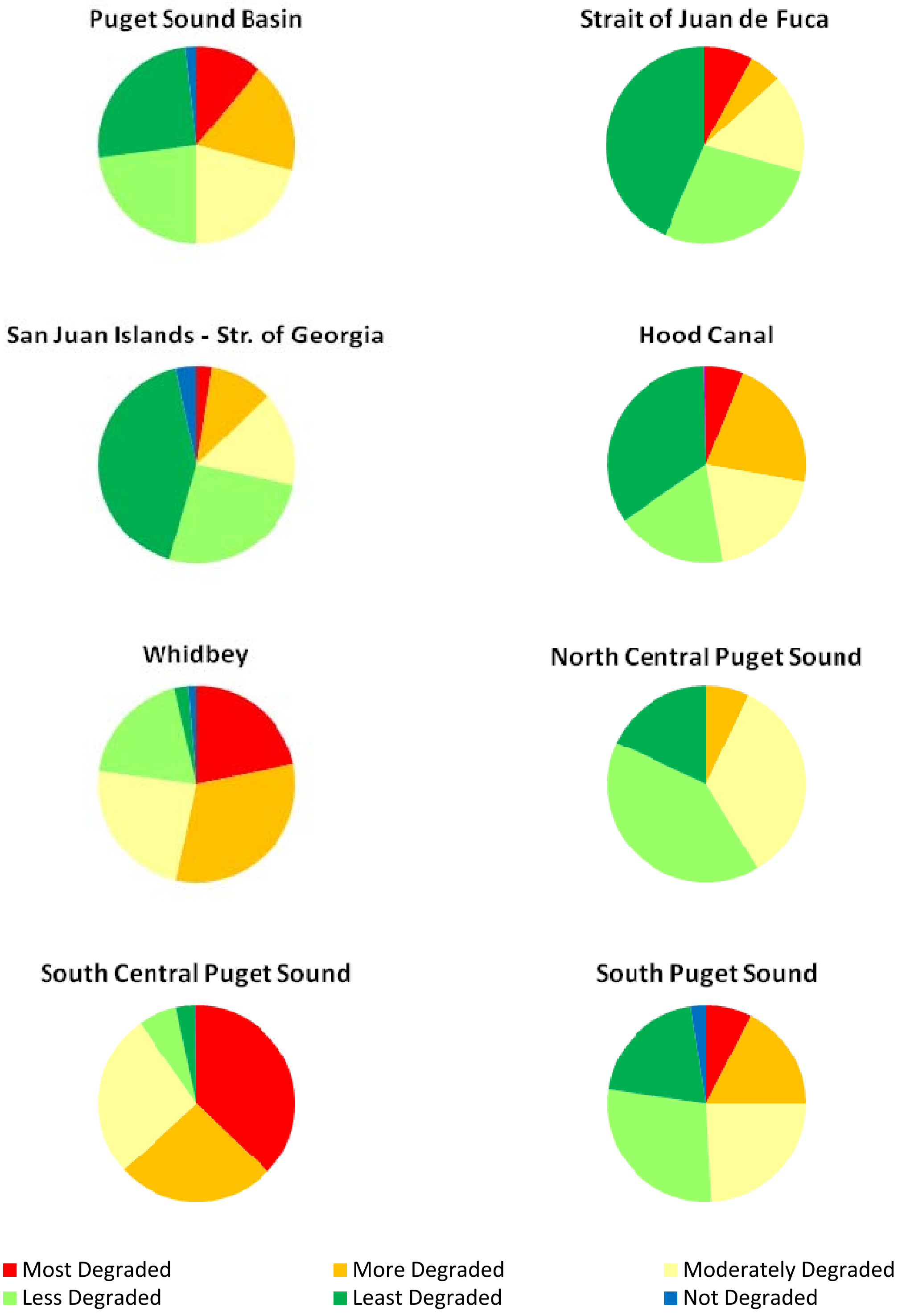


Figure 6-35

Watershed Area Among Overall Process Degradation Categories in Process Units by Sub-basin and Sound-wide



Puget Sound Basin

Strait of Juan de Fuca

San Juan Islands - Str. of Georgia

Hood Canal

Whidbey

North Central Puget Sound

South Central Puget Sound

South Puget Sound

Figure 6-36

Proportion of Sub-basin Process Unit Shoreline Length in Each Overall Degradation Category

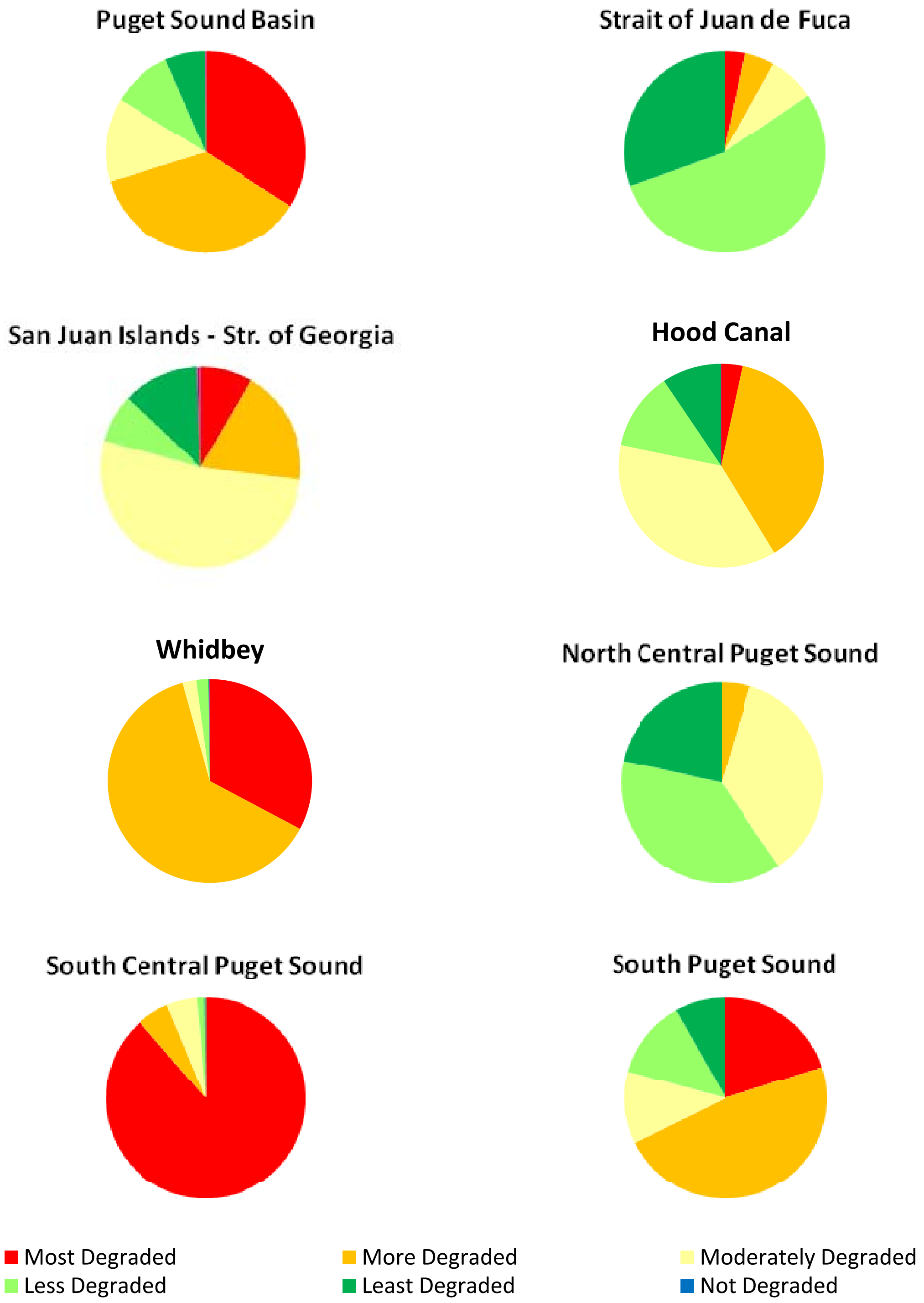


Figure 6-37

Proportion of Sub-basin Process Unit Watershed Area in Each Overall Degradation Category

6.2.2.2 Strait of Juan de Fuca Sub-basin

Within the Strait of Juan de Fuca sub-basin, long portions of shoreline were in the Less Degraded or Least Degraded categories (Figure 6-38). The only process units classified as Most Degraded encompassed Port Angeles and Ediz Hook. The process units in the Moderately Degraded and More Degraded categories were limited to the interior portions of Discovery Bay and Sequim Bay, as well as the Neah Bay area.

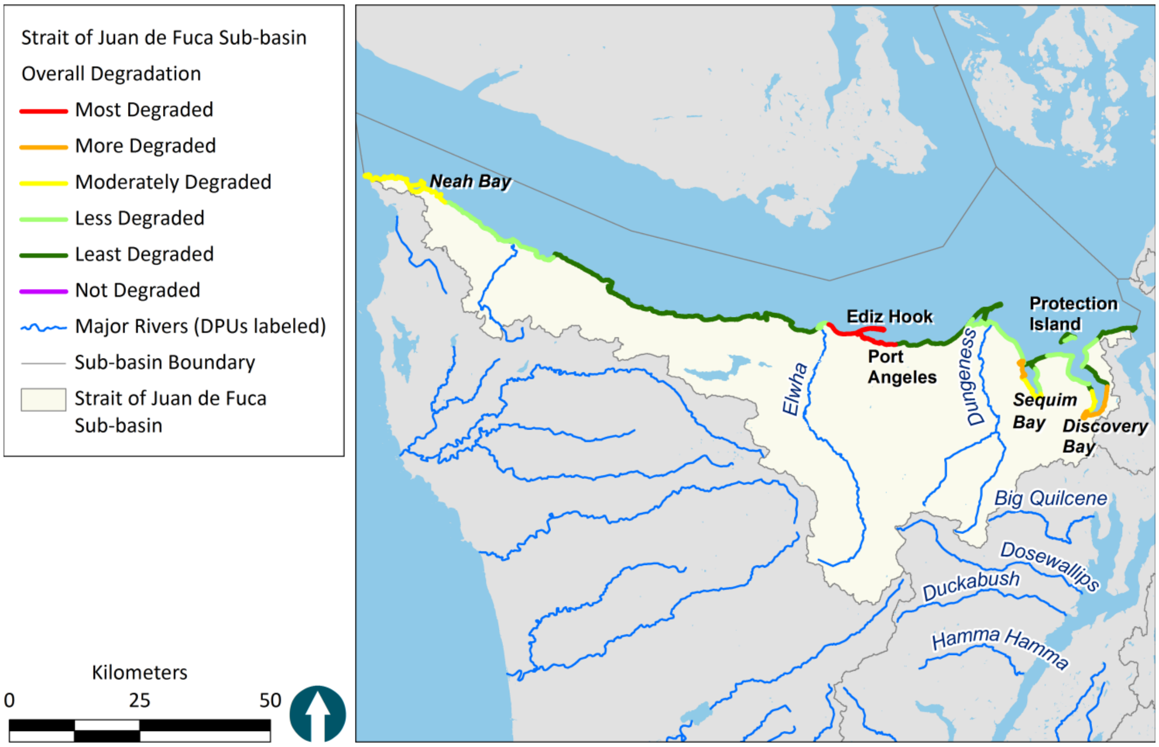


Figure 6-38

Sub-basin Scale Categories of Degradation in the Strait of Juan de Fuca Sub-basin

6.2.2.3 San Juan Islands – Strait of Georgia Sub-basin

In the San Juan Islands – Strait of Georgia sub-basin, much of the degradation had occurred along the mainland areas (Figure 6-39). Process units from Anacortes to the inner Bellingham Bay were entirely classified as Most Degraded or More Degraded. The northernmost process unit near the Canadian border in Drayton Harbor was the only other process unit in the sub-basin categorized as More Degraded. The San Juan Islands were primarily classified as Less Degraded or Least Degraded, although several islands included one or more process units categorized as Moderately Degraded. Process units classified as Not Degraded were small islands and some small shorelines on Shaw Island.

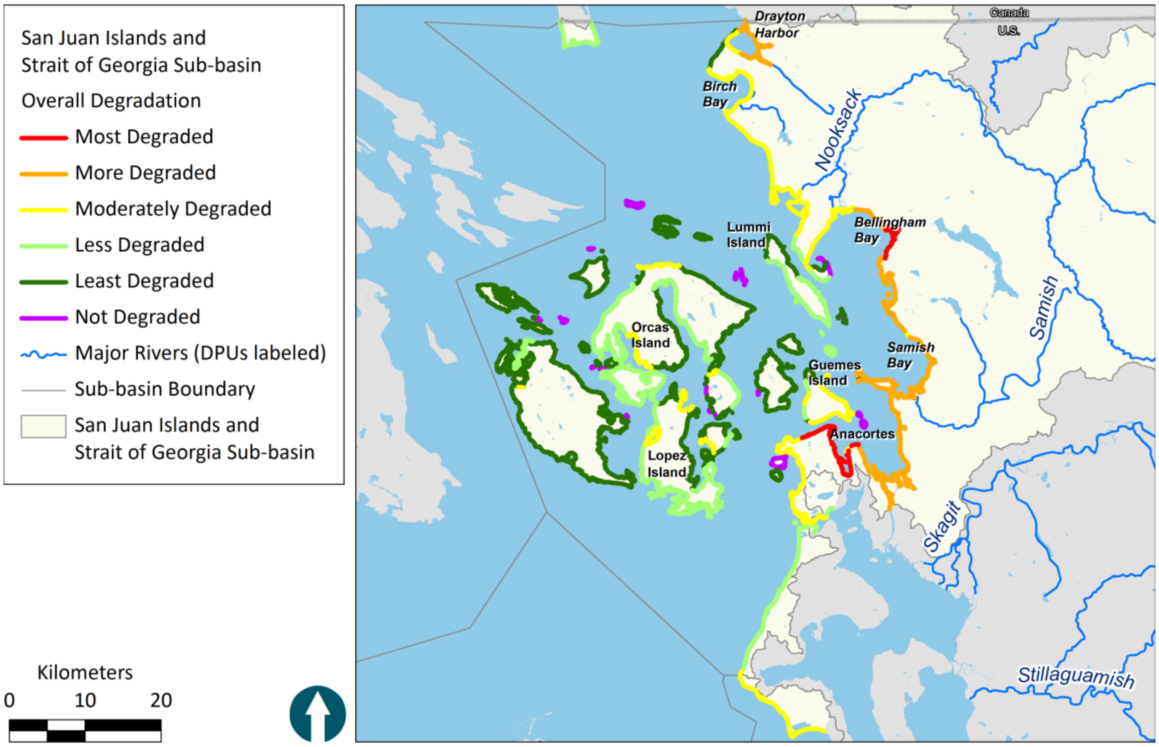


Figure 6-39

Sub-basin Scale Categories of Degradation in the San Juan Islands – Strait of Georgia Sub-basin

6.2.2.4 Hood Canal Sub-basin

In the Hood Canal sub-basin, the interior portion from the Tahuya River on the north shoreline at the Great Bend and extending all the way through the head of Hood Canal at the Union River to just south of the Hamma Hamma DPU was almost entirely classified as More Degraded or Most Degraded (Figure 6-40). The conditions trended from more degraded in the southern and eastern portions of the sub-basin to less degraded in the northern and western portions of the sub-basin. Much of the sub-basin north of the Dosewallips DPU was in the Less Degraded or Least Degraded categories.

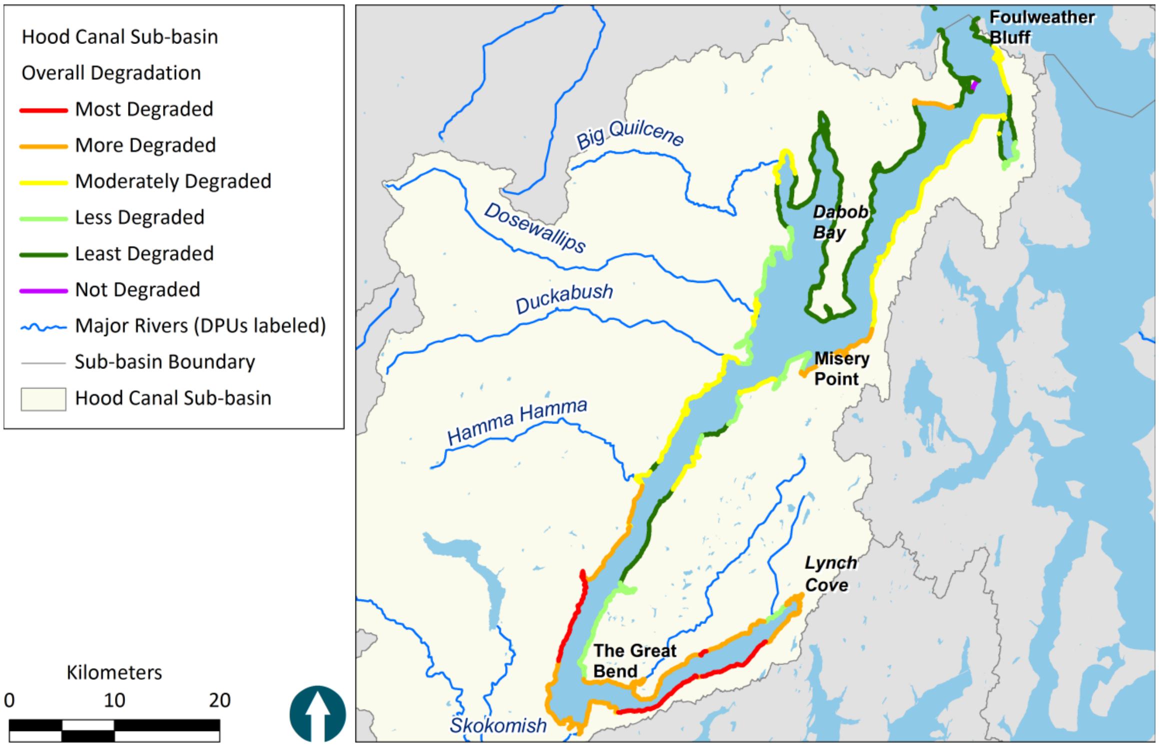


Figure 6-40

Sub-basin Scale Categories of Degradation in the Hood Canal Sub-basin

6.2.2.5 Whidbey Sub-basin

The three DPUs in the Whidbey sub-basin combined to cause nearly the entire extent of the mainland in the sub-basin to be in the More Degraded or Most Degraded categories (Figure 6-41). The process units on Camano Island and Whidbey Island bordering Skagit Bay and extending to Penn Cove on Whidbey Island were in the More Degraded category. The remaining process units in the southern portion of the islands and along the west side of Whidbey Island were largely Moderately Degraded or Less Degraded.

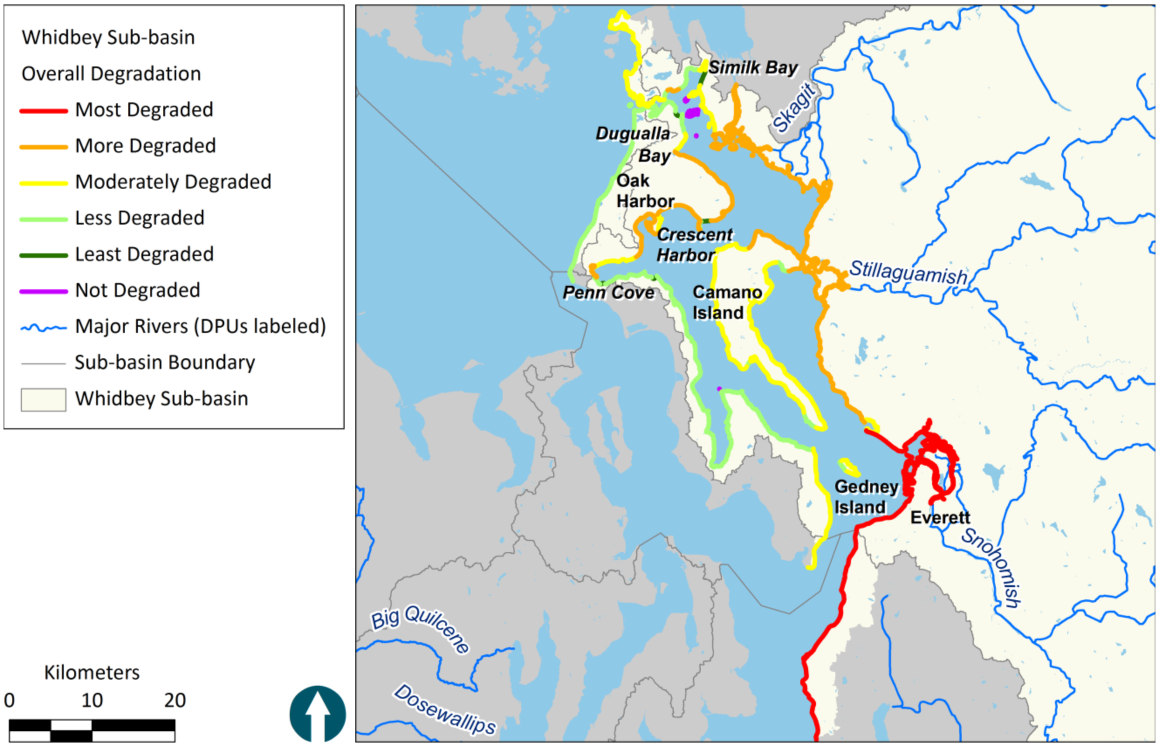


Figure 6-41

Sub-basin Scale Categories of Degradation in the Whidbey Sub-basin

6.2.2.6 North Central Puget Sound

In the North Central Puget Sound sub-basin, much of the western portion of Whidbey Island was moderately degraded (Figure 6-42). Process units classified in the More Degraded categories occurred in Cultus Bay on Whidbey Island and in Port Townsend Bay along the western portion of Indian Island. Marrowstone Island and the shoreline south to Port Ludlow were generally in the Less Degraded and Least Degraded categories.

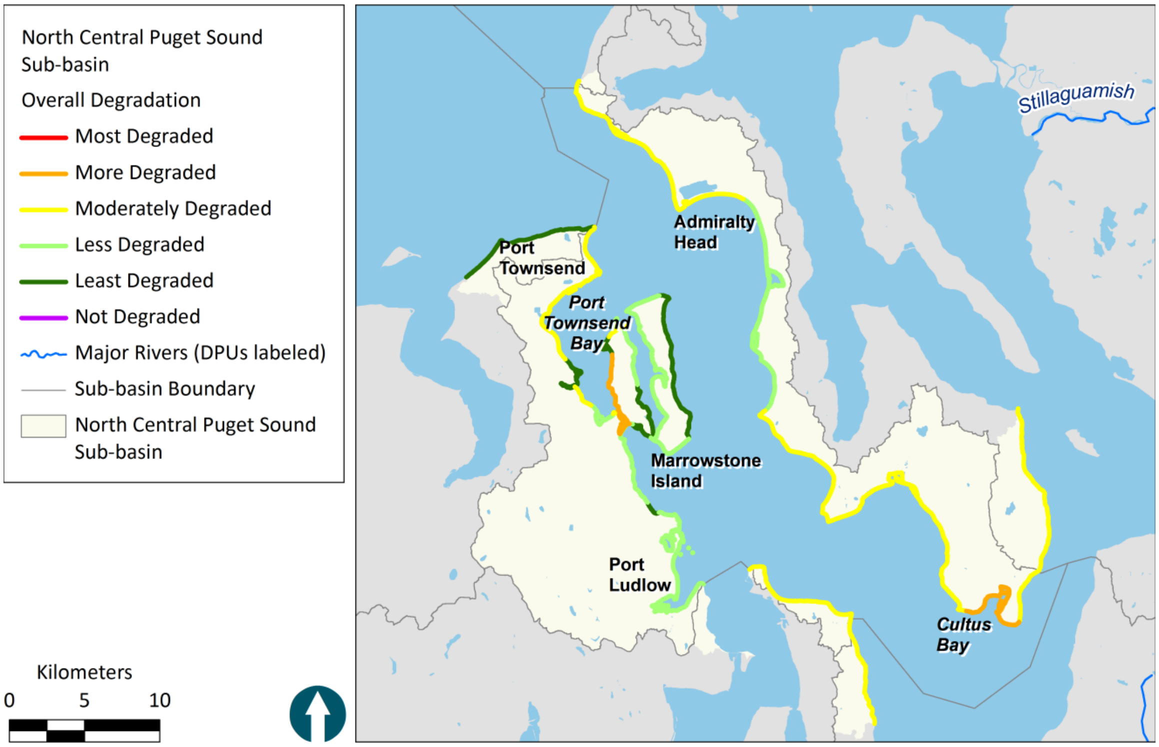


Figure 6-42

Sub-basin Scale Categories of Degradation in the North Central Puget Sound Sub-basin

6.2.2.7 South Central Puget Sound Sub-basin

In the South Central Puget Sound sub-basin, almost the entire eastern shoreline was classified as Most Degraded (Figure 6-43). The exceptions were two process units near Three Tree Point and Point Defiance that were in the More Degraded category, as well as the shoreline between Commencement Bay and Dumas Bay, which was Moderately Degraded. The Kitsap Peninsula shoreline from Southworth through Sinclair and Dyes Inlet was almost continuously More Degraded or Most Degraded. Parts or all of the smaller inlets were also More Degraded or Most Degraded, including Quartermaster Harbor, Eagle Harbor, Port Madison Bay, and Liberty Bay. The Least Degraded and Less Degraded process units in the sub-basin were located along the western side of the Tacoma Narrows, the eastern portion of Vashon Island, along Blake Island, in Blakely Harbor, and along a small area north of Kingston.

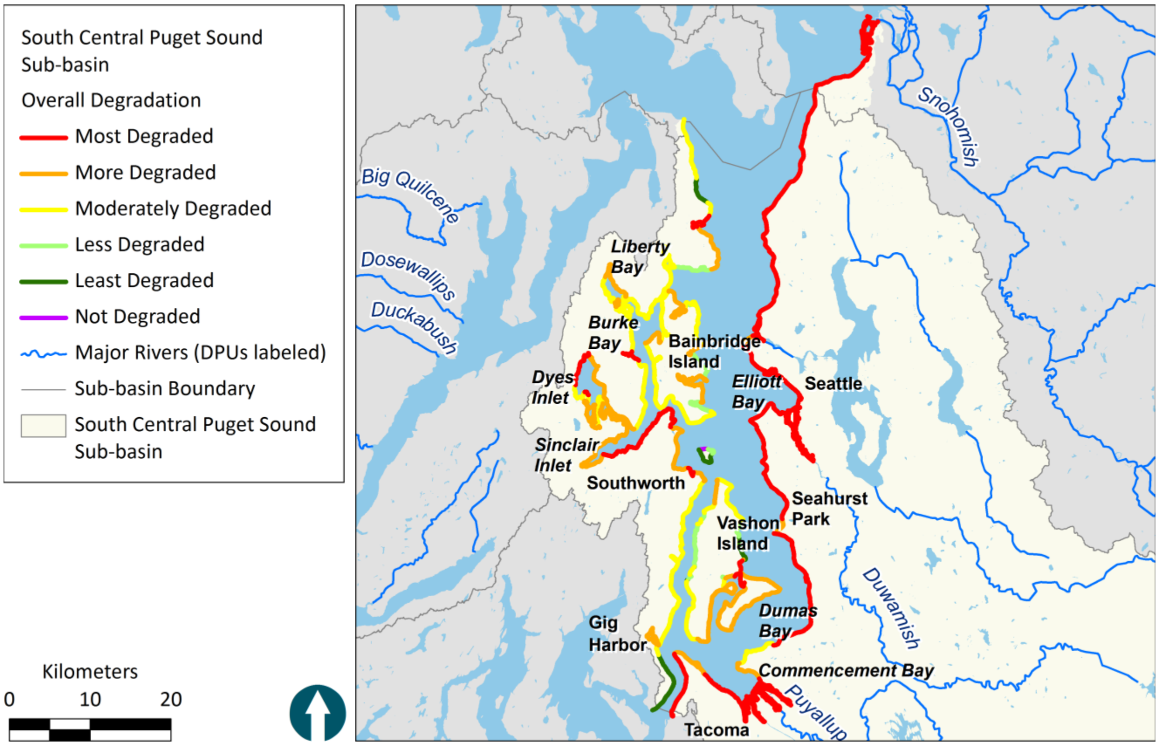


Figure 6-43

Sub-basin Scale Categories of Degradation in the South Central Puget Sound Sub-basin

6.2.2.8 South Puget Sound Sub-basin

In the South Puget Sound sub-basin, the eastern process units between Tacoma and the SPU north of the Nisqually DPU were classified as Most Degraded (Figure 6-44). Other than these areas and the southern portion of Budd Inlet in Olympia, the Most Degraded process units were scattered throughout the sub-basin. Process units between the head of Carr Inlet and Hale Passage, including much of Fox Island, were nearly continuously More Degraded or Most Degraded. The process units along the shorelines of Case Inlet, Carr Inlet, Henderson Inlet, Budd Inlet, and Eld Inlet were largely Moderately Degraded or More Degraded. In contrast, the heads of Totten Inlet and Oakland Bay were primarily Less Degraded or Least Degraded. The larger islands, including Hartstene, Squaxin, Anderson, McNeil, and Ketron Island, were in the Less Degraded or Least Degraded categories.

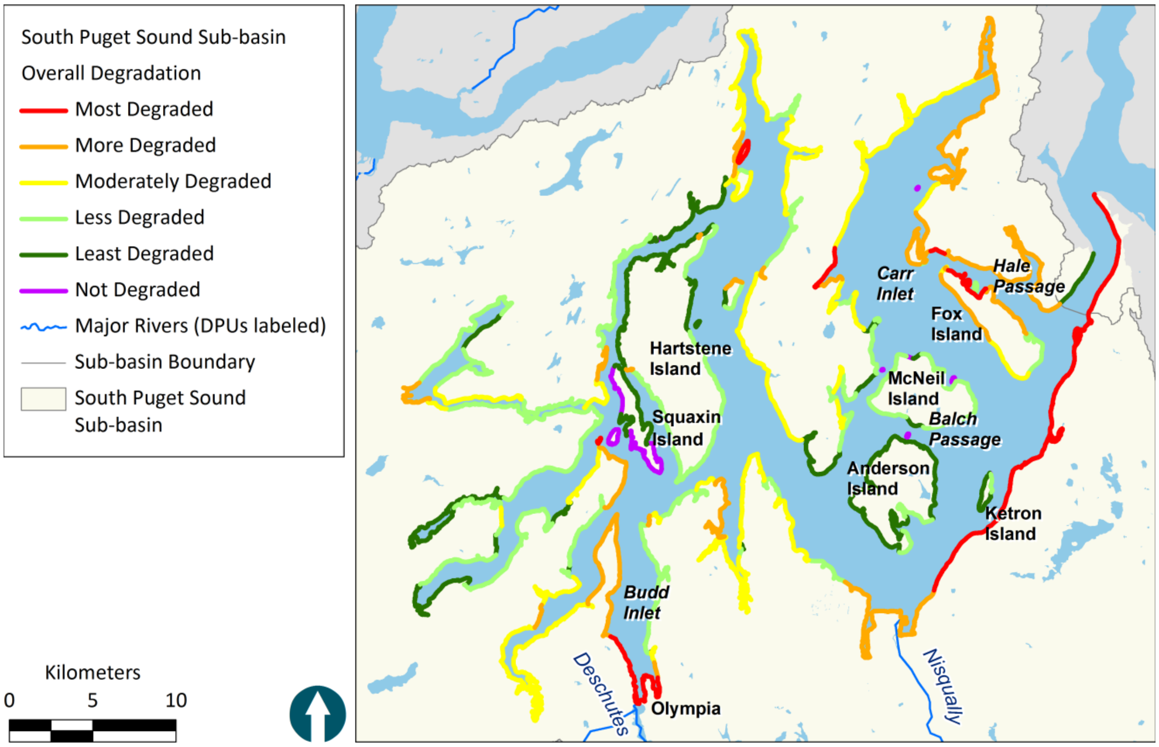


Figure 6-44

Sub-basin Scale Categories of Degradation in the South Puget Sound Sub-basin

6.3 Landscape Scale Nearshore Processes Degradation

Data were analyzed to identify contiguous stretches of minimally degraded shoreline in order to identify long stretches of shoreline to consider targeting for protection and/or restoration of adjacent areas. Rather than looking at the process unit distribution of stressors, the GIS database was queried to determine the longest reaches of shoreline in Puget Sound with none of the stressors used in the Framework, As a result, a shoreline reach with no stressors and spanning 2 process units, would be identified, even if the 2 process units are not entirely absent of stressors. The longest 10 reaches in each of the 7 sub-basins are mapped in Figure 6-45 and their lengths summarized in Table 6-2. Among the longest 10 reaches with no stressors in each sub-basin, the highest average shoreline lengths were in the San Juan Islands – Strait of Georgia and Strait of Juan de Fuca sub-basins (13.7 km and 12.8 km, respectively). In the remaining sub-basins, the average length among the longest 10 reaches with no stressors was 5.3 km or less. The South Central Puget Sound sub-basin had the shortest average (2.9 km) among the longest 10 reaches with no stressors. The longest reach with no stressors in the entire study area was a 38.2 km reach in the Strait of Juan de Fuca sub-basin.

Figure 6-45

Ten Longest Reaches of Shoreline in Each Sub-basin with No Stressors

Table 6-2
Summary Statistics on the Longest 10 Shoreline Reaches Without Stressors in Sub-basins and Puget Sound

Basin/Sub-basin	Average (km)	Range (km)
Strait of Juan de Fuca	12.8	4.7 – 38.2
San Juan Islands – Strait of Georgia	13.7	10.1 – 18.7
Hood Canal	4.2	3.2 – 5.1
Whidbey	4.3	3.7 – 5.2
North Central Puget Sound	4.8	3.6 – 6.9
South Central Puget Sound	2.9	1.7 – 5.3
South Puget Sound	5.3	3.0 – 21.8
Puget Sound Basin	**18.6**	**12.6 – 38.2**

Looking only at shoreline reaches without shoreline armoring, the longest 10 reaches were identified within each sub-basin and Sound-wide. Since shoreline armoring is only a subset of the degradation stressors analyzed above, the resulting lengths in this analysis are longer. The longest 10 reaches without shoreline armoring in each of the 7 sub-basins are mapped in Figure 6-46 and their lengths summarized in Table 6-3. Among the longest 10 reaches with no shoreline armoring in each sub-basin, the highest average shoreline lengths were in the San Juan Islands – Strait of Georgia, Whidbey, and Strait of Juan de Fuca sub-basins (27.1 km, 18.7 km, and 17.2 km, respectively). In the remaining sub-basins, the average length among the longest 10 reaches with no shoreline armoring was 8.7 km or less. The South Central Puget Sound sub-basin had the shortest average (3.6 km) among the longest 10 reaches with no shoreline armoring. The longest reach with no stressors in the entire study area was a 49.2 km reach in the San Juan Islands – Strait of Georgia sub-basin.

Figure 6-46

Ten Longest Reaches of Shoreline in Each Sub-basin with No Shoreline Armoring

Table 6-3
Summary Statistics on the Longest 10 Shoreline Reaches Without Shoreline Armoring in Sub-basins and Puget Sound

Basin/Sub-basin	Average (km)	Range (km)
Strait of Juan de Fuca	17.2	7.3 – 41.9
San Juan Islands – Strait of Georgia	27.1	18.7 – 49.2
Hood Canal	7.1	4.6 – 10.4
Whidbey	18.7	7.1 – 46.6
North Central Puget Sound	7.2	4.8 – 13.5
South Central Puget Sound	3.6	2.3 – 6.1
South Puget Sound	8.7	5.1 – 22.7
Puget Sound Basin	**34.5**	**27.0 – 49.2**

Looking at the distribution of shoreforms, the average distances between shoreforms currently and historically were compared to investigate the spatial distribution of uncommon shoreline types. For shoreforms in embayment systems (i.e., barrier estuaries, barrier lagoons, and closed lagoons/marshes) and deltas, the average distance between natural shoreforms of the same type is longer today than it was historically (Figure 6-47). Historically, closed lagoons/marshes averaged one every 18 km, while currently they average one per 39 km. Barrier lagoons occurred every 20 km historically, while currently they occur every 28 km. Barrier estuaries historically occurred (on average) one per 18 km; now there is one per 22 km. Deltas occurred every 280 km historically and occur every 305 km currently. This change in deltas is due to the transition of delta shoreforms to artificial in the Deschutes, Duwamish, and Puyallup DPUs. These results highlight the decrease in shoreform heterogeneity, the increase in habitat fragmentation, and the vulnerability of delta and embayment systems.

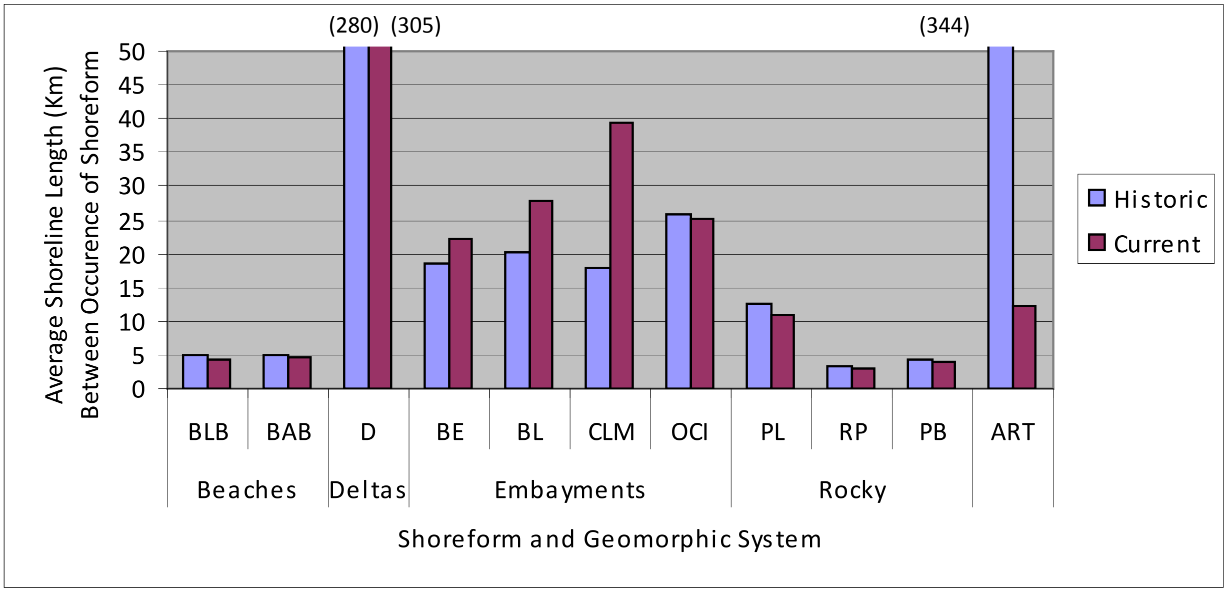


Figure 6-47

Historic and Current Average Distances between Each Shoreform Type

7 DISCUSSION

This Strategic Needs Assessment evaluates the implications of the extensive anthropogenic alterations on the processes that create and sustain the nearshore ecosystems of Puget Sound. This report documents the linkages between nearshore processes, which are the focus of the PSNERP restoration strategy, and the anthropogenic alterations (stressors) acting upon them. The subsequent analyses characterize the degree of degradation to 11 nearshore ecosystem processes. This information on degradation of nearshore processes, as well as the distributions of stressors presented in this report and in the Change Analysis (Simenstad et al. 2011), was used to prepare the problem statement (Section 7.1) and identify recommended restoration and protection priorities (Sections 7.2 and 7.3, respectively).

7.1 Problem Statement for Puget Sound

The pervasiveness of human alterations throughout the Puget Sound study area is clear. The analyses presented in this Strategic Needs Assessment indicate that only very small portions of the Puget Sound shoreline length and watershed area have not encountered any degradation to nearshore processes. This section summarizes the problems identified in the Puget Sound General Investigation study area reflects the findings of the Change Analysis and Strategic Needs Assessment. These problems are further described in Fresh et al. (2011) *Degradation of Nearshore Ecosystems in Puget Sound: Challenges for Restoration*. Six major changes to the physical characteristics of the nearshore ecosystems of Puget Sound were identified. These changes can be grouped into two broad categories: 1) major physical changes to the nearshore ecosystems of Puget Sound; and 2) major types of cumulative impacts.

Four of the six major findings are grouped in the first category of major physical changes to the nearshore ecosystems of Puget Sound:

- There has been a dramatic loss of large river delta habitat, due primarily to barriers that alter tidal hydrology. Much of the remaining large river delta habitat has been altered by shoreline armoring and other changes (see Section 7.1.1)
- Many coastal embayments (i.e., open coastal inlets, barrier estuaries, barrier lagoons, and closed lagoons/marshes) have been eliminated or disconnected from Puget Sound by the placement of fill, tidal barriers, and other stressors (see Section 7.1.2)

- Modifications to beaches and bluffs have disconnected sediment inputs and altered sediment transport and accretion along long sections of the Puget Sound shoreline (see Section 7.1.3)
- Tidal wetlands have been extensively lost throughout Puget Sound; in particular, oligohaline and freshwater tidal wetlands have been almost completely eliminated (see Section 7.1.4)

Two of the six major findings are grouped in the second category of major cumulative impacts:

- The shoreline of Puget Sound has become much shorter and simpler and significantly more artificial (see Section 7.1.5)
- Large portions of Puget Sound have been altered by multiple types of changes that may cumulatively combine to severely degrade nearshore processes (see Section 7.1.6)

The physical change observations supporting these findings and the implications of these findings are provided in the following sections.

7.1.1 Large River Delta Impacts

7.1.1.1 Physical Changes

The 16 largest deltas of Puget Sound (DPUs) have all been heavily modified. Many of the deltas have been markedly altered by multiple stressors that limit the size of river estuaries and degrade nearshore processes. While the change in area from historic to current conditions is impossible to measure accurately, available data based on changes in tidal wetland area indicate an approximately 55 percent decrease (234 km^2 lost out of 422 km^2 historically) in the overall size of DPUs around Puget Sound. A total of 63 percent of DPU nearshore areas (i.e., within 200 m of shoreline) have been developed. The two primary anthropogenic stressors in large deltas are tidal barriers, of which there are 320 km in DPUs, and armoring, which occurs along 174 km of shoreline.

Although all large deltas have been affected, the magnitude of changes varies between systems. In terms of nearshore process degradation, 11 of the 16 DPUs were categorized as highly degraded for three or more of the nearshore ecosystem processes. The exceptions were the Dungeness, Elwha, Big Quilcene, Hamma Hamma, and Nooksack DPUs. The most degraded DPUs were the Duwamish, Puyallup, Snohomish, Deschutes, and Nisqually. In the Duwamish, Puyallup, and Deschutes DPUs, the alterations have been so complete that the historic delta shorelines are considered artificial shoreforms bearing no resemblance to their historic condition. Watershed changes can also affect deltas in ways that are not directly quantifiable. For instance, water diversion can alter the equilibrium between sediment transport to deltas and sediment transport within them.

7.1.1.2 Implications

Wetland loss in the large deltas is of considerable importance and described in detail in Section 7.1.4. However, other changes to the large deltas are also of significance. One important change is that there is less habitat in the deltas for plants and animals. In particular, diking and filling of deltas have eliminated most channels that cut through the deltas and have thus restricted fish and wildlife to smaller areas than they used historically. For example, in the Puyallup and Duwamish river deltas, there is only one channel that salmon can use to migrate upstream or downstream. As a result, they are funneled into a smaller amount of habitat, which limits the number of refuge areas and options the fish have to avoid predators or stressful environmental conditions.

Loss of delta habitat has likely affected the amount and quality of habitat for 30 or more species of shorebirds. In addition to shorebirds, migratory birds use tidal deltas during their migrations, and predatory birds, such as peregrine falcons and great blue herons, forage in these areas. The loss of delta habitat reduces the amount of space available for feeding, roosting, or reproduction.

Other changes to the large river deltas include changes to the estuarine salinity structure resulting from changes to the tidal prism, as well as changes to river flows from dams. This type of changes alters the location of plants and animals that are sensitive to the salinity regime, most notably the tidal wetland plants that are distributed based on salinity.

7.1.2 Coastal Embayment Loss or Disconnection

7.1.2.1 Physical Changes

There has been a significant loss of embayment shoreforms in Puget Sound. Overall, there are currently 35% fewer coastal embayments than there were historically and accordingly the distance between embayments has increased. Historically, embayments on the Puget Sound shoreline (open coastal inlets, barrier estuaries, and barrier lagoons) extended along 1,100 km of the shoreline; currently, they occur along only 600 km. By count, 16 of 173 historical open coastal inlets, 61 of 240 historical barrier estuaries, and 80 of 222 historical barrier lagoons have been lost. Embayments separated from the Puget Sound shoreline (closed lagoons/marshes) historically comprised an additional 2.6 km of shoreline; currently, they account for only 1.6 km of the shoreline. These closed lagoons/marshes were historically, and remain currently, the rarest shoreform by length.

By count, 138 closed lagoons/marshes have been lost out of the 249 that were historically present. Historically, the average distance between closed lagoons/marshes was 18 km of shoreline. Currently, the average distance between closed lagoons/marshes is 39 km of shoreline. The average length of each closed lagoon/marsh has decreased approximately 50 percent from historic times. Most remaining embayments have also been altered to some degree, especially by armoring, tidal barriers, fill, railroads, and conversion to artificial shoreform. In 100 SPUs, 100 percent of the embayment shorelines are impacted by a combination of tidal barriers, fill, railroads, and conversion to artificial shoreforms.

7.1.2.2 Implications

Recent evidence from the Whidbey sub-basin has demonstrated that the loss of embayments (“pocket estuaries”) has resulted in the loss of rearing habitat for one life history type of Chinook salmon in Puget Sound (Beamer et al. 2003). The loss of embayments has reduced the resilience of Chinook salmon populations and likely contributed to the 1999 listing by the federal government of Puget Sound Chinook salmon as threatened (Fresh 2006). Studies have demonstrated that wild Chinook salmon fry accumulate in pocket estuary habitat because these habitats offer a faster growing environment than adjacent nearshore or offshore areas due to their relative warmth, high detritus retention, and lower rates of predation as compared with adjacent nearshore or offshore waters. Not all pocket estuaries are equally important to Chinook salmon populations; the most important pocket estuaries are those that are closest (within 20 km) to the large deltas (Fresh 2006). Other implications include impacts to nutrient inputs, water quality, primary production, and biodiversity loss.

7.1.3 Disconnection of Beaches and Bluffs

7.1.3.1 Physical Changes

As with all natural shoreforms, there is less beach and bluff shoreline than there was historically, although the magnitude of changes was less pronounced than for other shoreforms. Historically, 38.5 percent of the Puget Sound shoreline was composed of more than 1,600 km of bluff-backed beach; it was and is the predominant shoreform type. Bluff-backed beaches are the shoreform considered to include most of the coastal bluffs actively contributing sediment to the aquatic portion of the nearshore and thereby "feeding" the beach sediment input, transport, and accretion processes. Comparison of historic and current conditions showed that the length of bluff-backed beach decreased by 128 km, an 8 percent loss. Among the remaining bluff-backed beaches, stressors are acting to disconnect the sediment sources from the beach. Important stressors associated with Puget Sound's beaches and bluffs include shore-parallel structures such as armoring, roads, railroads, and fill, as well as shore-perpendicular structures such as jetties and breakwaters. Among the 735 SPUs with bluff-backed beaches, 223 have a combination of armoring, fill, railroads, roads, or artificial shoreforms along 50 percent or more of the bluff-backed beaches, including 70 SPUs with those structures along 100 percent of the bluff-backed beach shorelines (calculation based on bluff-backed beaches in the supply areas of drift cells—defined as the divergent zone and transport zone portions of drift cells). Overall, 33 percent of the length of bluff-backed beach shorelines have armoring.

Historically, barrier beaches were the fourth dominant shoreform type accounting for 10 percent (500 km) of the shoreline. There has been a loss of 60 km (12 percent) of this important shoreform type, which forms the spits, tombolos, and other depositional features that make the Puget Sound shoreline unique. Barrier beaches often provide the protective berm that supports coastal embayment shoreforms, such as barrier estuaries and barrier lagoons. Overall, 27 percent of the barrier beach shorelines have been armored.

The distribution of armoring along beaches and bluffs varies considerably between sub-basins, with the most armoring occurring in the South Central Puget Sound sub-basin and the least occurring in the three northernmost sub-basins: Juan de Fuca, San Juan Islands – Strait of Georgia, and North Central Puget Sound.

7.1.3.2 Implications

Several nearshore processes occur along beaches and bluffs, the most influential of which is sediment and wood supply, transport, and deposition. Coastal bluff erosion supplies sediment to the beach, which is reworked and transported to adjacent and/or down-drift shores by waves. The coastal geomorphic processes that drive beach and bluff characteristics are inherently dynamic, episodic in nature, and vary considerably at multiple spatial and temporal scales throughout Puget Sound. Fundamentally influential variables include local geology, wave exposure, topography, tidal range, climate and weather (particularly precipitation), management practices, and the quality and quantity of vegetation (Johannessen and MacLennan 2007; Finlayson 2006). The various combinations of these variables contribute to the large range of bluff erosion, from a fraction of an inch to feet in a year.

Although it appears that bluff-backed beaches are less impacted than other shoreforms, the widespread alteration of this ubiquitous shoreform should not be underestimated. Sediment derived from coastal bluffs has been estimated to supply 90 percent of the sediment on Puget Sound beaches (Downing 1983). Results of these analyses show that shoreline armoring occurs along approximately 33 percent of those bluffs. When considering the greater sediment budget of Puget Sound littoral drift cells (sediment sub-systems), this equates to lost sediment input from more than 500 km of bluff-backed beach shore. The volume of sediment derived from those 500 km over decades is no longer available to supply and maintain down-drift shoreforms. This loss of sediment supply will contribute, and likely already has contributed, to decreased resilience and integrity of shoreforms, including barrier beaches and the barriers that protect coastal embayment systems. Recent research has also highlighted the necessity of intact sediment sources for shores to adapt (or transgress) in response to sea level rise (Pethick 2001). As research has not been conducted on sediment and wood budgets within littoral drift cells in Puget Sound, the magnitude of this impact remains poorly documented.

The growing emphasis on understanding the processes that drive ecosystem structure and function has recently brought coastal geomorphic processes into the ecological limelight. The conceptual framework behind this is that with degradation of coastal geomorphic processes come changes in the physical characteristics of beaches (or nearshore ecosystem structures) that in turn affect nearshore habitat functions.

Due to the spatial and temporal scale in which these processes take place, degraded sediment processes have the potential to adversely impact nearshore ecosystems (from shoreforms to individual habitats) far beyond the limits of the altered shoreforms.

For example, the construction of a bulkhead along an eroding bluff will reduce the rate of bluff recession but will also decrease sediment input as well as alter sediment transport rates. Sediment deposition (accretion) can also be degraded as a result of shore armoring, particularly along barrier beaches. As wave energy reflects off the armoring rather than dissipates along the beach, fine sediment that would naturally deposit on the upper beach is carried down-drift or offshore. This can lead to altered sediment composition (beach coarsening), beach narrowing, and the degradation or loss of nearshore habitats.

How the beach responds to degraded sediment and wood depositional processes can be exacerbated during high water/storm events when waves would naturally deposit material higher on the beach, sometimes via a mechanism referred to as overwash. Overwash aids in the migration and maintenance of barriers, as the sediment and LWD deposited during storms is of higher elevation, and the LWD can aid in the structural development of the shoreform. However, without ample sediment and wood supply to be transported and deposited, overwash processes can also degrade and shoreform resilience can decline. Therefore, the implications of armoring of bluffs and beaches include degraded sediment processes (supply, transport, and deposition), and decreased maintenance of associated nearshore habitats and shoreform resilience.

The implications of changing sediment processes on EFG&S are less understood. Clearly, one result of changes to sediment processes is the amount of beach available for recreation. Erosion control structures often make accessing the beach more difficult, and where the beach has eroded (waterward of the structure), there can be limited beach area for people to walk. As previously stated, more than 500 km of bluff-backed beach has been lost; additional loss has also resulted from marinas, jetties, breakwaters, and some armoring that eliminates beach area. Many of these alterations have also contributed to the decline of the aesthetic value of beaches.

Armoring and the associated impacts to nearshore processes have been connected with the degradation of numerous habitats and associated impacts to various species of fish and wildlife that use the nearshore. Peterson et al. (2006) documented altered characteristics of invertebrate populations along armored beaches and Sobocinski (2003) found that armoring affected abundance and density of insects, amphipods, and isopods. These are small invertebrates that live on beaches and are often important sources of food for fish and birds. Similarly, Dugan and Hubbard (2006) and Dugan et al. (2003, 2008) found that taxa richness and abundance of amphipods and insects was less on armored beaches than unarmored beaches in a study conducted near Santa Barbara, California.

Armoring can also affect reproduction of several species of forage fish, which are small, pelagic fish that are important components of food webs. Two species of forage fish, surf smelt and sand lance, spawn on fine sand along the upper beach (Penttila 2007). Armoring can eliminate this habitat if it is placed over or in front of a spawning area or if it is placed up beach from the spawning area. Armoring can also eliminate the spawning area by coarsening the sediment due to wave refraction. Another mechanism by which armoring can affect forage fish spawning is by increasing the interstitial sediment temperature. Rice (2006) studied the effects of armoring on interstitial sediment temperature and embryo development of surf smelt. He found that armoring dramatically increased sediment temperatures. He also observed that surf smelt embryo survival on the altered beach was half that on the unaltered beach. Rice did not measure any changes in sediment and attributed much of the biological effect to loss of shoreline vegetation that often accompanies armoring.

Changes to forage fish populations are also critical to many other fish and wildlife species in Puget Sound. One bird species of note that appears to be closely linked to forage fish is the surf scoter. This species is closely associated with nearshore habitats, including eelgrass habitats that are especially important during molting. Changes in surf scoter populations seem to be closely linked to biomass of spawning herring (Anderson et al. 2009) with changes in herring spawning biomass increasing the abundance of the scoters.

7.1.4 Loss of Estuarine Wetlands

7.1.4.1 Physical Changes

There has been extensive loss of estuarine wetlands in the nearshore ecosystems of Puget Sound. While a portion of the observed loss can be attributed to transitions to freshwater wetland types caused by various changes to the estuary, much of the loss accurately indicates removal of wetlands. Historically, there were 517 km^2 of wetlands in the large river deltas and coastal embayments of Puget Sound. Currently, there are only 217 km^2 of wetlands, a decline of 58 percent. Of the four wetland classes examined, tidal freshwater and oligohaline transitional wetland have incurred the greatest losses. These two wetland classes, which are positioned higher in the estuary (lower salinity areas) than the other two classes (estuarine mixing and euryhaline unvegetated), have together lost 93 percent of their historic area. Of the 64 km^2 of oligohaline marsh that existed historically, only 1.5 km^2 remains.

The loss of wetlands in all sub-basins and all large deltas is similar, although it was especially dramatic in the Duwamish and Puyallup where there is almost no wetland remaining of any type. In the Whidbey sub-basin where the largest extent of oligohaline and tidal freshwater wetlands occurred historically, losses of 99% of the oligohaline wetlands and 90% of the tidal freshwater wetlands have been documented. Much of these losses have occurred in the three large deltas found in this sub-basin.

7.1.4.2 Implications

Wetlands are considered one of the most important habitat types in any ecosystem because they provide a wide variety of functions, including food production, nutrient production, filtration of contaminants, areas of reproduction, edge effect, and feeding habitat. One important function of wetlands is that they support rearing of juvenile salmon. Recent evidence from throughout the Pacific Northwest has demonstrated that the loss of delta estuaries has affected viability of Chinook salmon populations and has contributed to the depressed condition of Puget Sound Chinook salmon and their listing as threatened. These studies have demonstrated that particular life history types use delta habitat for extended periods and depend on this habitat for initial, early growth (Fresh 2006). There is a strong relationship between juvenile salmon size and their survival (Duffy et al. 2005); therefore, high estuarine growth rates are critical to the survival of this life history type and its contribution to population resilience. Bottom et al. (2005) found that as delta wetlands in the Salmon River, Oregon, were restored, the number of fish that reared in these habitats increased, the number of adult returns of estuarine dependent life history types increased, the diversity of life history types increased dramatically, and the distribution of spawners changed. Ultimately, the resilience of this population, or its ability to withstand other ecosystem stresses, has increased as the wetlands were restored.

7.1.5 Shortening and Simplification of Shoreline

7.1.5.1 Physical Changes

The shoreline of Puget Sound has become shorter over the last 150 years and its historical character has become simpler. Overall, there has been about a 4 percent decline in the number of distinct, natural segments of shoreline. This calculation is based on differences in numbers of historical and current shoreforms and should be considered a conservative estimate of the differences because of the shoreform mapping rules used in the impairment analysis. To explain by example, a single historical shoreform section, such as a bluff-backed beach, that is bisected by construction of an artificial shoreform, such as can occur through construction of a large marina, will result in two bluff-backed beach shoreforms in the current condition. This is an increase in the number of bluff-backed beaches, despite the decrease in bluff-backed beach shoreline length. There was also a decline in length of all natural shoreforms. Total shoreline length of all shoreforms combined, including deltas, declined by approximately 15 percent (loss of 694 km) across Puget Sound from historical to current conditions. More than 1,000 km of natural shoreline were lost and 368 km of artificial shoreline were added over the period of analysis. There were 337 natural shoreforms that were converted to artificial shoreforms and 54 transitions involving a change of one natural shoreform type to another natural type (see Table 2-5).

The most significant declines in numbers of natural shoreform segments were for the embayment shoreforms, which include open coastal inlets, barrier estuaries, barrier lagoons, and closed lagoons/marshes. Nearly 400 of these embayment shoreforms have been lost or transitioned to an artificial shoreform. Among the embayments occurring on the Puget Sound shoreline (open coastal inlets, barrier estuaries, and barrier lagoons), approximately 45 percent (more than 440 km) of the historic shoreline length has been lost. Embayments separated from the Puget Sound shoreline (closed lagoons/marshes), have lost approximately 48 percent (60 km) of the historic length. Delta shoreforms have also experienced significant declines in shoreline length as more than 47 percent (more than 275 km) of historic shoreline length has been lost. In many cases, these changes to all of these shoreforms are due to fill, tidal barriers, or roads that, in addition to removing natural shoreform features, tend to straighten and simplify the shoreline.

An especially dramatic change in the character of the Puget Sound shoreline has been the increase in the number and amount of artificial shoreform. The length of shoreline classified as artificial was negligible historically but now represents 9 percent of the shoreline of Puget Sound. There were 337 historical natural shoreforms that entirely or partially became artificial. While only 13 artificial shoreforms existed historically, the total number of current, continuous artificial shoreforms is 275. Of the 812 SPUs, 195 SPUs currently have artificial shoreforms. Twelve of the 16 deltas have artificial shoreforms, including the Deschutes, Duwamish, and Puyallup deltas, where the shorelines have been extensively modified by stressors and are no longer recognizable as natural delta shoreforms.

There is a strong association between fill placed in the nearshore and the artificial shoreform, with fill occurring along 62 percent of the length of artificial shoreforms. There are approximately 39 km^2 of fill in Puget Sound, which represents approximately 2 percent of the nearshore zone. While this is a large amount of fill, it is also considered a significant underestimate due to the limitations of the fill datasets used.

Changes in shoreforms varied considerably between sub-basins. The greatest extent of shoreline loss in barrier estuaries occurred in the North Central Puget Sound, San Juan Islands – Strait of Georgia, and Whidbey sub-basins (88, 64, and 62 percent, respectively). Barrier lagoon shorelines decreased by more than 50 percent in the South Central Puget Sound, Whidbey, San Juan Islands – Strait of Georgia, and North Central Puget Sound sub-basins. The loss of closed lagoon/marsh shoreline was also highest (89 percent decrease) in the South Central Puget Sound sub-basin. Overall, the proportional total length of the rocky shoreforms (pocket beaches, rocky platform, and plunging rocky shoreline) decreased the least.

7.1.5.2 Implications

Some of the changes in shoreline length and character that we have documented are clearly due to natural processes such as erosion, waves, and floods. However, the great majority of the changes identified, such as the increase in artificial shoreforms and placement of fill in the nearshore, are due to anthropogenic influences. The implications of simplifying and shortening the shoreline of Puget Sound are profound.

One significant implication is that the simplification of the shoreline has altered the fundamental way that nearshore ecosystems function because how an ecosystem functions depends on the spatial arrangement of its parts (Turner 1989; Forman and Godron 1986; Saunders et al. 1991; Fahrig and Merriam 1994). As the size and position of its parts relative to each other are altered, ecosystem processes, structures, and functions will change (Turner 1989). There are almost certainly space threshold levels at which ecosystems functions begin to change rapidly. While these types of relationships have not yet been documented in nearshore ecosystems, it is likely they occur there, given that they have been documented elsewhere (Trombulak and Frissell 2000). For example, many studies have shown how the configuration of wetland habitats affects fish community composition, species richness, and food web structure (Peterson and Turner 1994; West and Zedler 2000; Visintainer et al. 2006). In the case of the nearshore, the fundamental change has been that the nearshore has lost complexity. Thus, a simple change in how the nearshore parts are arranged has impacted several nearshore processes, including how sediment moves around, where it is deposited, how much sediment is deposited in a place, and how detritus and nutrients are cycled.

Second, the loss of several particular types of shoreforms is important. For example, the decrease in the number of embayments is important because embayments support juvenile salmon rearing during early spring and unique shorebird and waterfowl communities (Beamer et al. 2005; Kagley et al. 2007; Fresh 2006). The loss of embayments results in less rearing area for salmon and altered bird communities using shorelines in these areas.

Another important implication of changes to shoreform and loss of shoreline length is that the amount of space in Puget Sound has been reduced for nearshore ecosystems to function and for fish and wildlife to reproduce, feed, and grow. Space is a valuable commodity in ecosystems and the rate, magnitude, and effectives of many ecosystem processes depend on how much space they have to operate in. Juvenile salmon, which are closely associated with nearshore ecosystems during their migration from Puget Sound, now have less space to feed and grow. This can restrict the amount of food they have available and provide less space in which to evade predators; both impacts will reduce their survival. Greene and Beechie (2004) and Greene et al. (2005) have found evidence that the carrying capacity of some nearshore habitats is being exceeded due to habitat loss (i.e., density-dependent processes are occurring). The loss of suitable habitats also affects other resource groups such as eelgrass, Olympia oysters, and forage fish.

7.1.6 Multiple Stressors Causing Cumulative Effects In Large Portions of Puget Sound

7.1.6.1 Physical Changes

Many shoreline segments have been altered, and many segments have also experienced multiple types of changes. Of the 828 process units, 89 percent have one or more stressors occurring along the shoreline, including all 16 deltas, accounting for slightly more than 40 percent of the Puget Sound shoreline. While armoring is clearly the dominant stressor along the nearshore and occurs in nearly 78 percent of process units, covering 27 percent of the length of the Puget Sound shoreline, there are eight additional Shoreline Alteration (Tier 2) stressors that occur in nearshore ecosystems. Although none of the shoreline units in Puget Sound contained all nine types of stressors, 65 percent of the process units had multiple types of stressors, suggesting a high potential for cumulative impacts. As would be expected, the greatest number of shoreline alterations was associated with the largest process units, while the least number of alterations was associated with the smallest process units.

There was also a high co-occurrence of other stressors with armoring. For example, 72 percent of active railroads and 71 percent of marinas also had armored shorelines. The two most commonly co-occurring stressors were nearshore roads and armoring, which cooccurred in 379 (46 percent) of all process units. A total of 692 process units (84 percent) were altered by the combination of tidal barriers, armoring, and nearshore roads. In addition, there was a high co-occurrence of nearshore fill with marinas, and tidal barriers were highly correlated with deltas. Cumulative impacts varied with sub-basin in Puget Sound. For example, overwater structures in the San Juan Islands – Strait of Georgia sub-basin typically occurred alone or with armoring only, whereas in most other sub-basins, overwater structures more often occurred with both armoring and fill.

7.1.6.2 Implications

An important implication of the results of the spatial distribution of problems along the nearshore is that cumulative impacts must be an important consideration. Cumulative impacts refer to the combined, incremental effects of human activity on the environment. Such changes are usually small-scale and can occur through persistent additions or losses of the same materials or resources, and through the compounding effects of two or more stressors. While a small-scale alteration may be insignificant by itself, cumulative impacts accumulate over time, from one or more sources. While we have yet to document how cumulative impacts are manifested in nearshore ecosystems, it is clear from studies of other ecosystems that they occur in the nearshore. For example, in forest ecosystems, Reeves et al. (1993) found that at timber harvest levels in excess of 25 percent, impacts to salmonids were dramatically more severe. Similarly, Coats and Miller (1981) found that more substantial sediment impacts in streams occurred at a timber harvest level greater than 30 percent. Studies of urban streams suggest that 10 percent impervious surface is a threshold above which ecosystem impacts rapidly increase (May 1996).

7.2 Strategic Needs Assessment Priority Recommendations for Restoration

Based on the findings of the Strategic Needs Assessment and Change Analysis, including the problem statement described above, the strategies for process-based restoration can be further advanced. Restoration approaches and considerations put forth in *Guidance for Protection and Restoration of the Nearshore Ecosystems of Puget Sound* (Fresh et al. 2004), *Guiding Restoration Principles* (Goetz et al. 2004), and *Principles for Strategic Protection and Restoration* (Greiner 2010) will be applied to develop comprehensive restoration alternatives.

The following four restoration priorities are recommended (in no particular order). These are intentionally presented as general recommendations with the idea that subsequent work by PSNERP will be conducted to generate more specific projects and locations based on the recommendations. It is appropriate to keep the recommendations general at this stage because the Strategic Needs Assessment at the scale of process units is fairly broad for identifying specific projects and during the development of the comprehensive alternatives, closer consideration of conditions within process units will be necessary to more fully understand the distribution of stressors within process units. For the purposes of this discussion, the term "restoration" is used in a broad sense that encompasses the restoration, rehabilitation, and substitution actions that address process restoration to various degrees as described in Fresh et al. 2004.

- <u>Restore the connectivity and size of large river deltas.</u> The 16 large river deltas distributed throughout Puget Sound are vital contributors to the overall health of Puget Sound ecosystems. These delta areas support nearshore processes in different ways than shoreline areas and their contributions extend far beyond their delineated boundaries. As described previously, many of the large river deltas have been altered by multiple stressors that greatly impact nearshore processes. Reconnecting the historic delta extent and re-establishing tidal wetlands will significantly enhance several nearshore processes and influence conditions far beyond their delineated extents. These ecological benefits could be accomplished through restoration actions to remove tidal barriers and other stressors that function like tidal barriers by constraining the river and reducing the river's access to its floodplain. In addition, restoration actions to address stressors such as roads and railroads that bisect the river deltas and limit tidal flow and other associated nearshore processes would be particularly beneficial in large river deltas. In the most degraded deltas where full restoration is infeasible due to existing development and land uses, opportunities to partially or incrementally restore processes should be generated. While restoration of any of the 16 large river deltas would provide major ecological benefits, the Deschutes, Snohomish, Skokomish, Skagit, and Nisqually River deltas provide notable opportunities for particularly large-scale restoration.

- Restore sediment input, sediment transport, and sediment accretion processes. The nearshore processes of sediment input, transport, and accretion provide vital support for many of the unique and important characteristics of Puget Sound. There is a widespread need for the restoration of this type of sediment movement throughout Puget Sound. The benefits of restoring these processes extend far beyond the site of restoration (Johannessen and MacLennan 2007), and the shoreline improvements will also benefit several other processes. Special priority should be given to those shoreline segments with historically active sediment sources that have been disconnected from the aquatic portion of the nearshore and therefore no longer deliver sediment to the nearshore system. Disconnected historic sediment sources located in divergence zones, otherwise near the updrift end of a drift cell, or updrift of one or more barrier beaches protecting embayment shoreforms would be most beneficial. While restoration of sediment processes is appropriate in all sub-basins, three sub-basins that have highly degraded sediment processes that would particularly benefit from sediment processes restoration are the South Central Puget Sound, Hood Canal, and Whidbey sub-basins.
- Restore embayments to increase distribution, shoreline complexity, and length. Embayments are significant landscape features contributing to the complexity and heterogeneity of the Puget Sound shoreline. The size, shape, and configuration of shoreforms included in the embayment geomorphic system are exceptionally broad by definition. As described previously, embayments range from the relatively small closed lagoons/marshes and barrier lagoons to the stream and river mouths of all tributary systems smaller than the 16 large rivers delineated as deltas. As such, embayments contribute significantly to nearshore processes and provide important shallow water and tidal wetland habitats. Restoration of embayments is needed at sites where they have been eliminated due to fill and other stressors. Recovering lost embayments will be necessary to restore the historic frequency of embayments at a landscape scale. Historically, barrier estuaries, barrier lagoons, and closed lagoons/marshes occurred an average of one per every 6 km of shoreline; currently, this frequency has been reduced to one per every 9 km of shoreline. Restoration of embayments is also needed to recover the historic footprint (size and shape) and associated functions of embayments. Many of the remaining embayments have been reduced in area, shoreline length, and function through stressors such as fill,

armoring, stream crossings, roads, and railroads. While restoration of embayments is particularly important for all sub-basins, the South Puget Sound, South Central Puget Sound, Hood Canal, and Whidbey sub-basins have especially high losses of embayment shoreforms.

- <u>Enhance landscape heterogeneity and ecological connectivity.</u> Restoration of habitat diversity and ecological connectivity along shorelines can improve multiple nearshore processes and address landscape principles that, when applied, contribute to more successful ecosystem restoration. In this recommendation, ecological connectivity refers to the natural, uninterrupted shoreform sequences along the shoreline, including the sequence of bluff-backed beaches to barrier beaches and then embayment shoreforms. Ecological connectivity also refers to the natural connectivity and transition between watershed areas, adjacent uplands (riparian), and aquatic nearshore ecosystems. Actions to address restoration priorities 1 through 3 would also address this fourth restoration priority. An important aspect of addressing this restoration priority will be to complete restoration where feasible among the 337 artificial shoreform areas extending across 378 km of shoreline. These artificial shoreforms represent a transition of natural shorelines to a much more degraded condition that contributes minimally to natural nearshore processes. While this is a particularly broad recommendation, it is important because application can be adapted to the general conditions of an area or sub-basin of interest. In the South Central Puget Sound and South Puget Sound sub-basins, where the eastern shoreline of Puget Sound is among the most degraded, opportunities should be generated to increase the length of shoreline or create “stepping stones of healthy patches” (Greiner 2010). In degraded sub-basins, such as the Strait of Juan de Fuca and San Juan Islands – Strait of Georgia sub-basins, these principles should be applied by restoring shorelines to extend the areas of relatively intact nearshore processes and by addressing the smaller concentrations of degradation that occur within fairly intact stretches.

7.3 Strategic Needs Assessment Priority Recommendations for Protection

Like the restoration priorities, the priority recommendations for protection are general recommendations that are expected to be further refined with specificity added in subsequent steps of the progress toward comprehensive alternatives. An important consideration to keep in mind when considering these broad protection recommendations (and the preceding restoration recommendations) is that when taking a closer look at specific areas, the strategies needed will likely include a combination of protection of those features that are less degraded and restoration of those features that are more degraded. Conserving less degraded shoreforms is consistent with the Greiner (2010) principles, and protection of degraded shoreforms may be necessary to complete restoration actions.

A natural starting point for protection strategies is to conserve those processes and shoreforms identified in the restoration priorities that are relatively intact (i.e., conserve healthy deltas, intact sediment movement processes, and embayments). Successful ecosystem restoration will require stopping the loss of relatively less impacted areas through protection actions and addressing restoration priorities. Three protection priorities that merit highlighting include:

- <u>Conserve relatively intact large river delta areas.</u> An important aspect of ecosystem restoration will be to prevent degradation of those large river deltas or portions of large river deltas that are relatively intact. The most intact large river deltas to conserve include the Elwha, Dungeness, Dosewallips, Duckabush, Hamma Hamma, Big Quilcene, and Nooksack Rivers. Relatively less impacted portions of other large river deltas also require protection.
- <u>Conserve intact or minimally degraded sediment input, sediment transport, and sediment accretion processes.</u> With the extensive placement of armoring and other stressors affecting how well bluffs feed sediment to beaches, protection of intact or minimally degraded bluff-backed beaches is critical. These shoreforms, particularly those positioned in divergence zones or near the updrift end of drift cells, provide the sediment inputs that drive the sediment transport and sediment accretion processes over extended stretches of shoreline far beyond the sediment input areas. A closer look at bluff-backed beaches will be necessary during subsequent steps in order to correctly identify those portions of the bluff-backed beaches that input sediments.

- Conserve relatively intact embayment shoreforms. Embayment shoreforms range in size from river deltas slightly smaller than the 16 delineated DPUs to small barrier lagoons, closed lagoons/marshes, and all intermediate sizes of inlets and coves, which are classified as some combination of barrier estuaries and open coastal inlets. As described previously, these shoreforms support nearshore processes, unique habitat conditions such as pocket estuaries, and a wide diversity of biological resources, included numerous VECs. There are several relatively intact embayments in the South Puget Sound, Hood Canal, and San Juan Islands – Strait of Georgia Juan de Fuca sub-basins that appear to merit protection. In addition, as mentioned above, the process unit scale of analysis is too broad to be able to identify relatively intact embayments situated in the midst of more degraded conditions. Therefore, closer consideration is needed of some of the relatively more degraded stretches of shoreline that contain somewhat intact embayments whose protection would be consistent with the principle of providing stepping stones of healthy shoreline segments. Protection of these embayments would commonly also entail protection of the barrier beaches (spits) that protect the embayments. The protection of barrier beaches requires also addressing the sediment sources providing sediment and wood to the area.

8 RISK AND UNCERTAINTY OF ANALYSIS

Four components contributing to uncertainty of analysis should be acknowledged. First, the analysis is based on the best available datasets. To allow for a consistent analysis throughout the study area, it was decided that only those datasets that are available consistently across the study area would be used. Also, when comparing current and historic datasets, there is an unknown degree of inherent inaccuracy because of historic limitations on mapping; for example, the historic rate and quantity of sediment, wood, and nutrient input is unknown. That said, the historic datasets used in the analysis are remarkably detailed and a tribute to those who conducted the historic mapping. Among the datasets used, some are more comprehensive than others and this can affect the accuracy of the process evaluation framework outputs. For some datasets, such as fill, the limitations of the dataset are known and these limitations are factored into the analysis. However, there is the potential for inaccuracies among the datasets that are not recognized. Many datasets were compiled from a variety of sources. While the datasets have been reviewed for quality control (presumably by the author) and again during their incorporation into the geospatial database, these reviews have not been comprehensive; therefore, the potential for inaccuracies must be acknowledged. There are also physical attributes that would have been used if an adequate dataset was available. It is assumed that the extensive geospatial database that has been compiled is sufficiently comprehensive that the degradation that is caused by stressors not included in the analysis is covered by other stressors that satisfactorily depict the magnitude and location of impacts to nearshore processes.

Second, the process evaluation framework developed for the Strategic Needs Assessment and the analyses developed in the Change Analysis may not be as accurate as intended. The methods used in these analyses have been fully explained in order to be transparent about the steps and assumptions, as well as to allow for critical review by users in order to identify any shortcomings. The scientific foundation for the approaches and the linkages between nearshore processes and stressors is based largely on empirical data in the scientific literature. The process evaluation framework, by necessity, is based on best professional judgment in terms of applying ecological knowledge into an assessment tool that relies on existing data.

Third, the variable scale of the process unit analysis and the somewhat coarse scale of analysis may skew the findings. The process unit scale at which the Strategic Needs Assessment and Change Analysis were conducted is a variable scale ranging from a few meters to several hundred kilometers. As a result, two features of the same size will have more or less impact or weight in the analysis depending on how large a process unit they occur in. Another aspect of the scale of analysis that causes uncertainty is that the process unit scale may be too broad and, therefore, certain "outlier" areas (such as a highly degraded section within a larger intact reach, or an intact section within a highly degraded reach) will not be picked up in the analysis. This could unintentionally make an area look better or worse than it actually is. While this uncertainty is real, it is expected to be satisfactorily addressed in subsequent steps that more closely examine the shoreline.

Lastly, the decision not to include biological or chemical parameters has the potential to limit the accuracy and utility of the Strategic Needs Assessment and Change Analysis. While there is expected to be some correlation between physical degradation and biological/chemical characteristics in terms of their spatial distributions, subsequent steps in the development of comprehensive alternatives will be informed to some degree by information on chemical contamination and biological resources.

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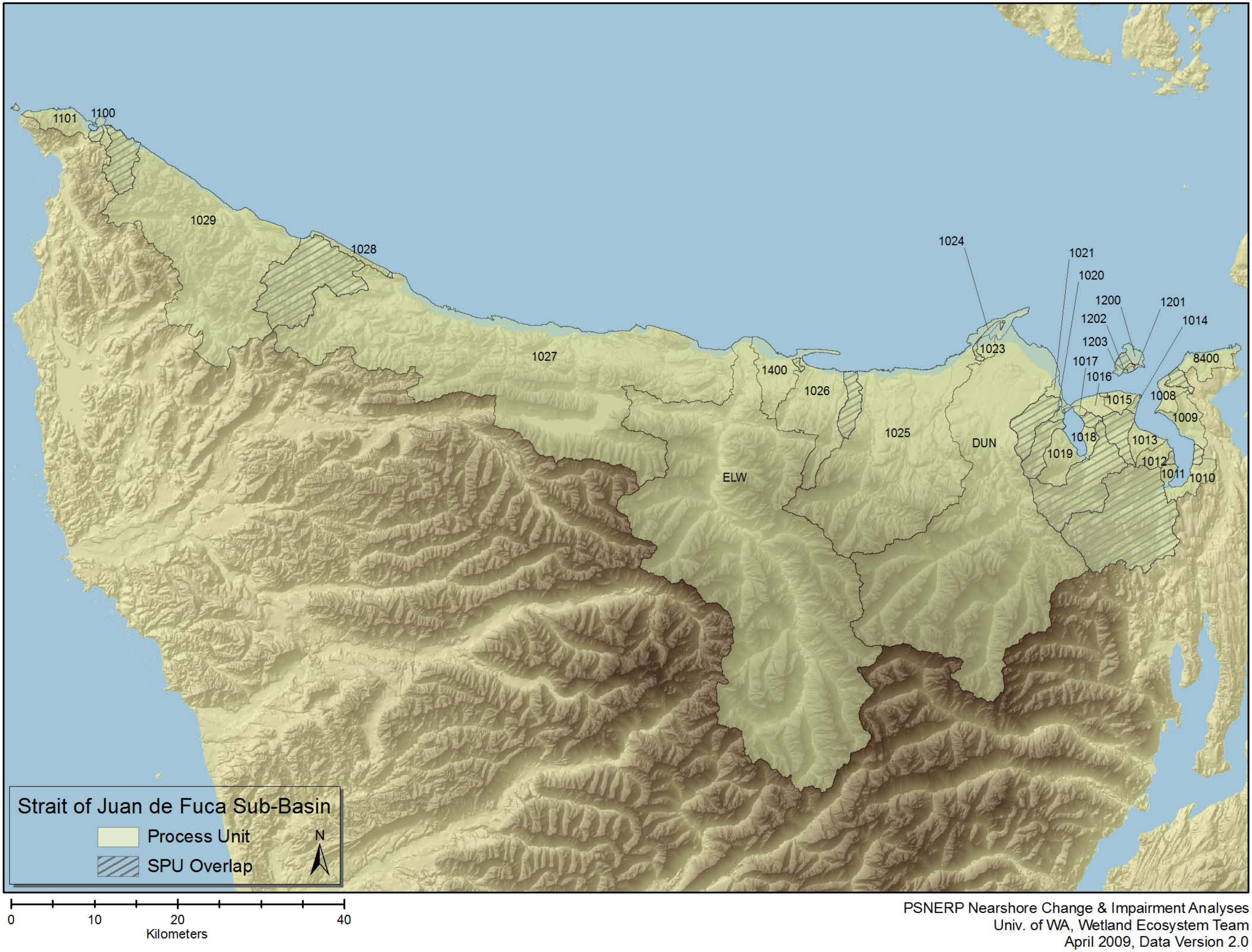
APPENDIX A
MAPS OF SHORELINE PROCESS UNITS AND DELTA PROCESS UNITS

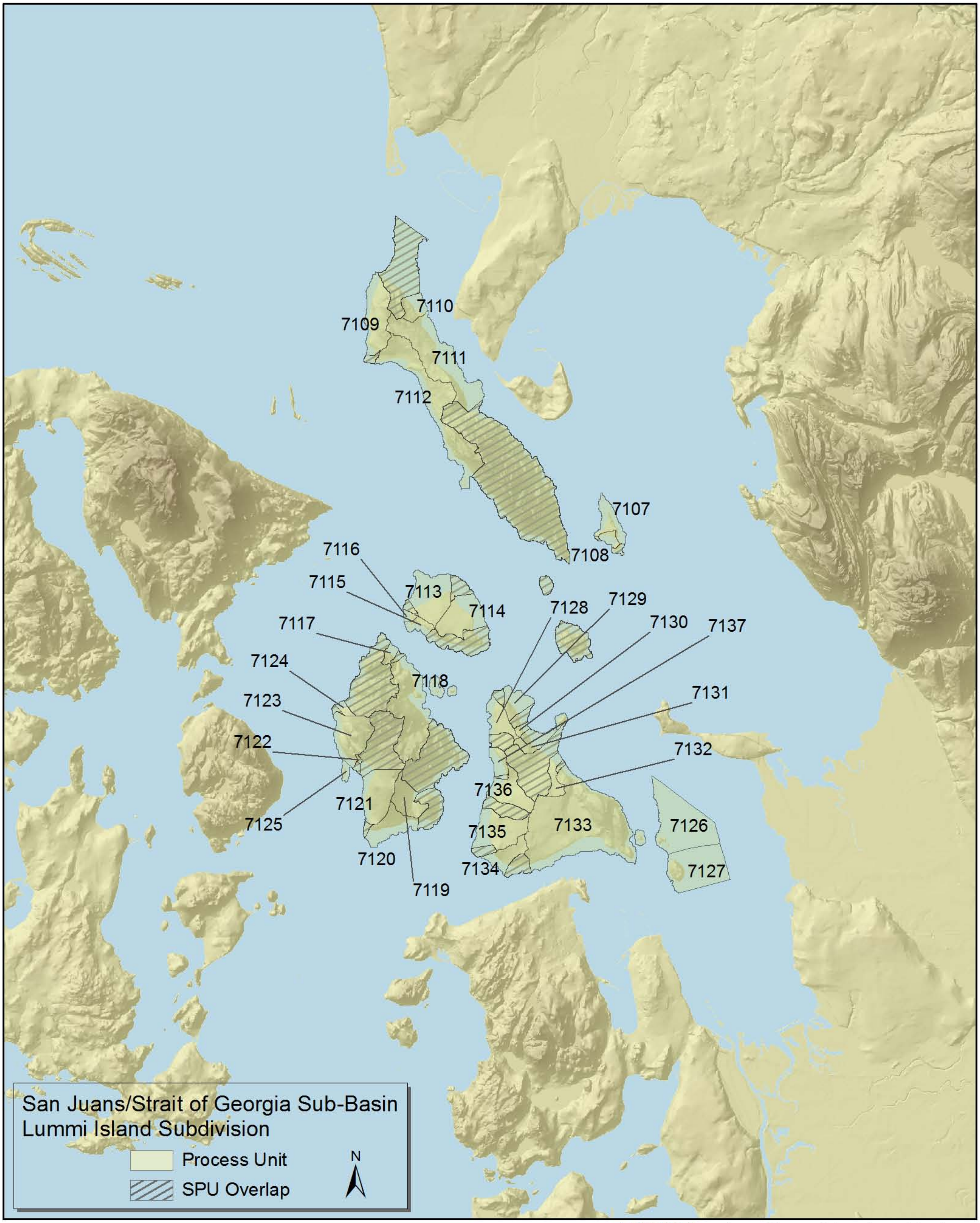
Maps prepared by the University of Washington Wetland Ecosystem Team,

April 2009, Data Version 2.0



PSNERP Nearshore Change & Impairment Analyses
Univ. of WA, Wetland Ecosystem Team
April 2009, Data Version 2.0
USGS 10-m DEM

PSNERP Nearshore Change & Impairment Analyses
Univ. of WA, Wetland Ecosystem Team
April 2009, Data Version 2.0
USGS 10-m DEM



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Univ. of WA, Wetland Ecosystem Team
April 2009, Data Version 2.0
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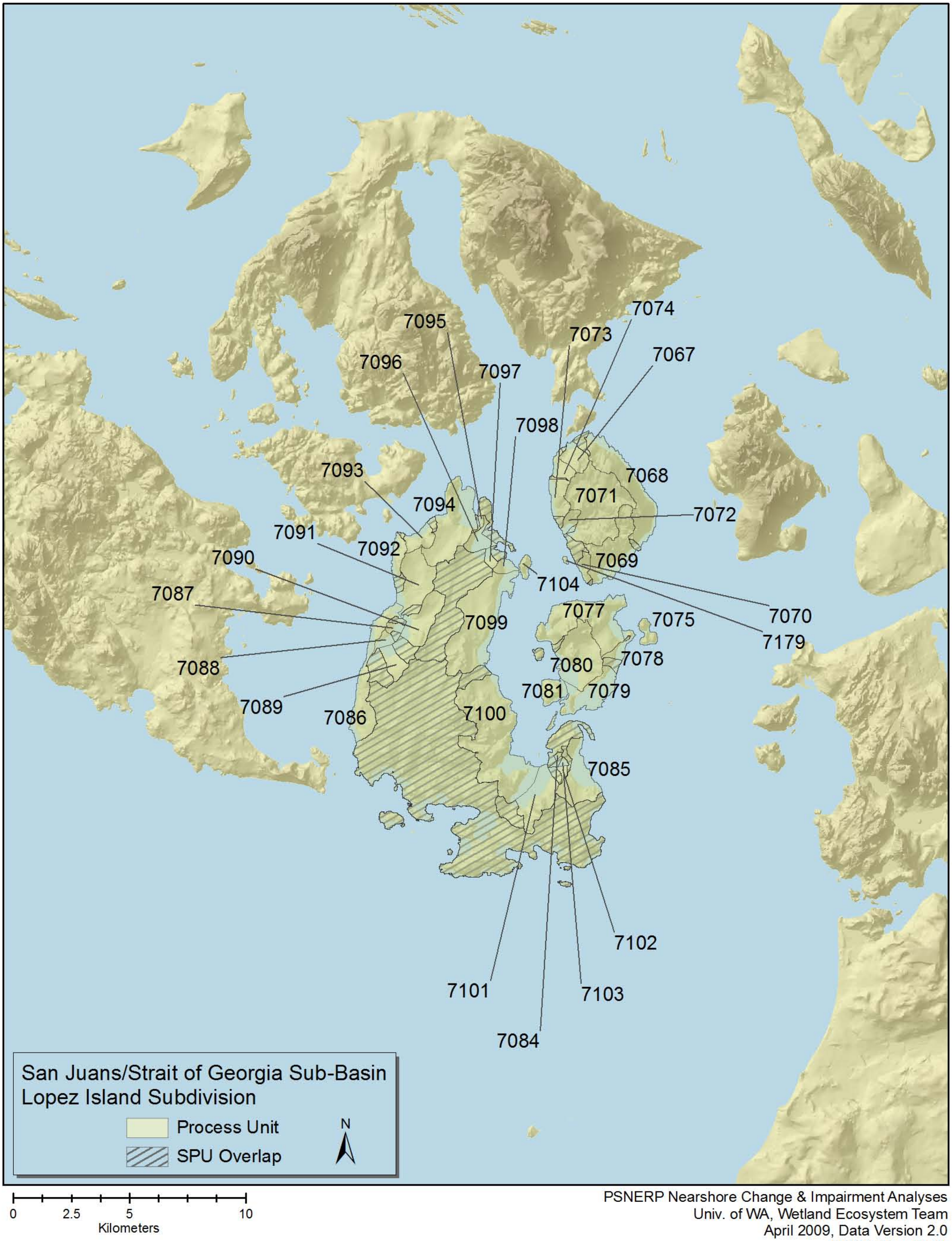
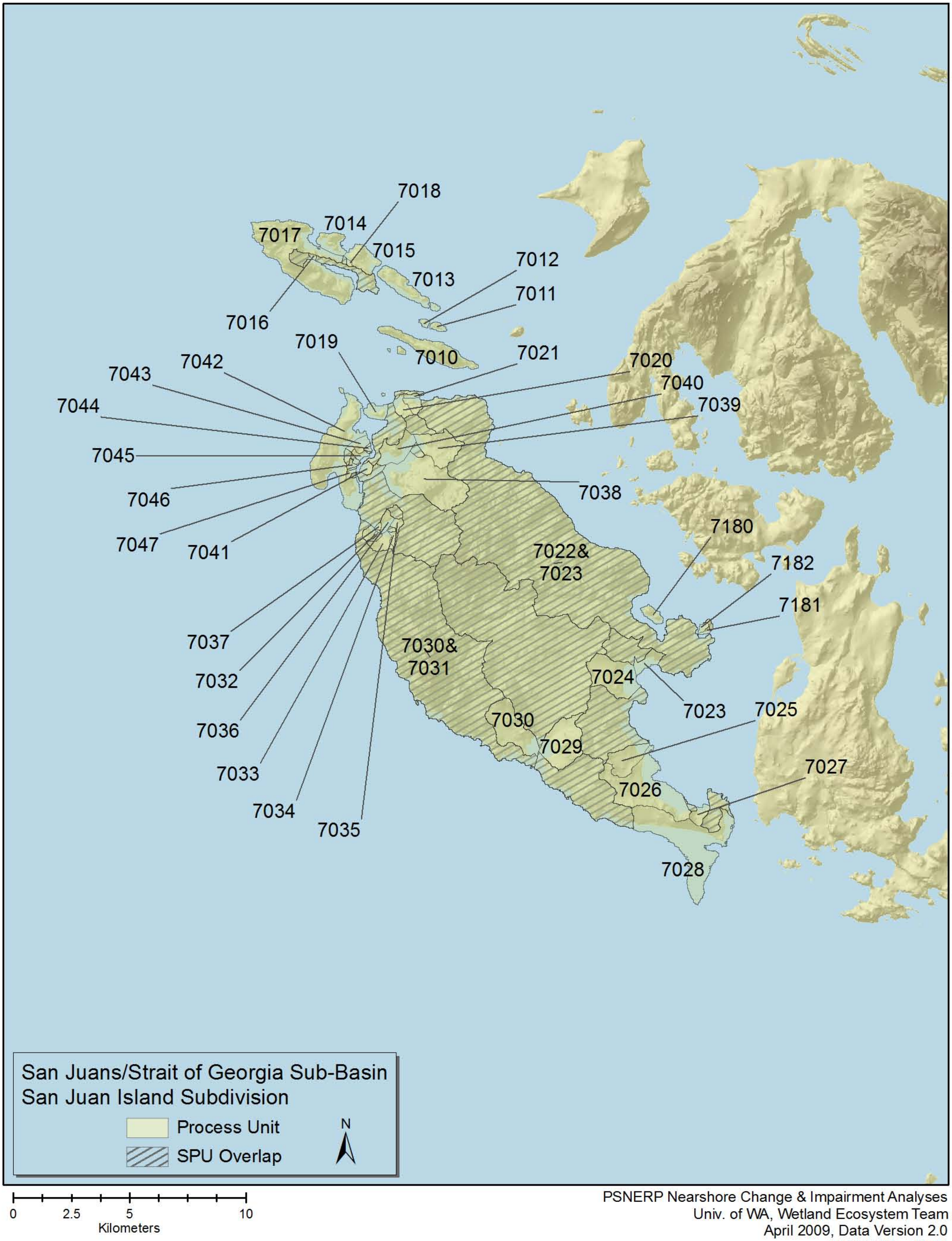


San Juans/Strait of Georgia Sub-Basin
Lopez Island Subdivision

PSNERP Nearshore Change & Impairment Analyses
Univ. of WA, Wetland Ecosystem Team
April 2009, Data Version 2.0
USGS 10-m DEM

San Juans/Strait of Georgia Sub-Basin
Orcas Island Subdivision

PSNERP Nearshore Change & Impairment Analyses
Univ. of WA, Wetland Ecosystem Team
April 2009, Data Version 2.0
USGS 10-m DEM



San Juans/Strait of Georgia Sub-Basin
San Juan Island Subdivision

PSNERP Nearshore Change & Impairment Analyses
Univ. of WA, Wetland Ecosystem Team
April 2009, Data Version 2.0
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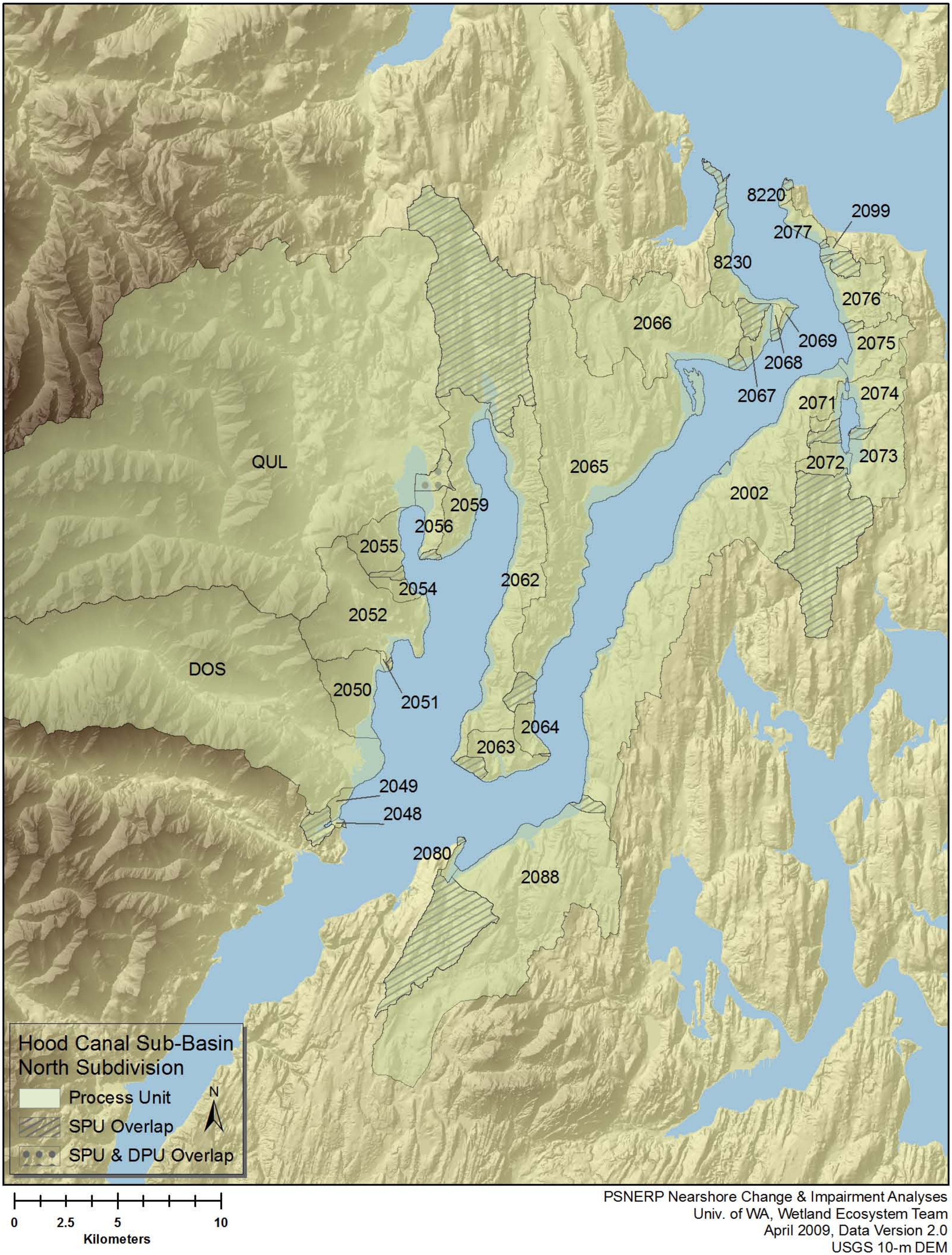

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Univ. of WA, Wetland Ecosystem Team
April 2009, Data Version 2.0
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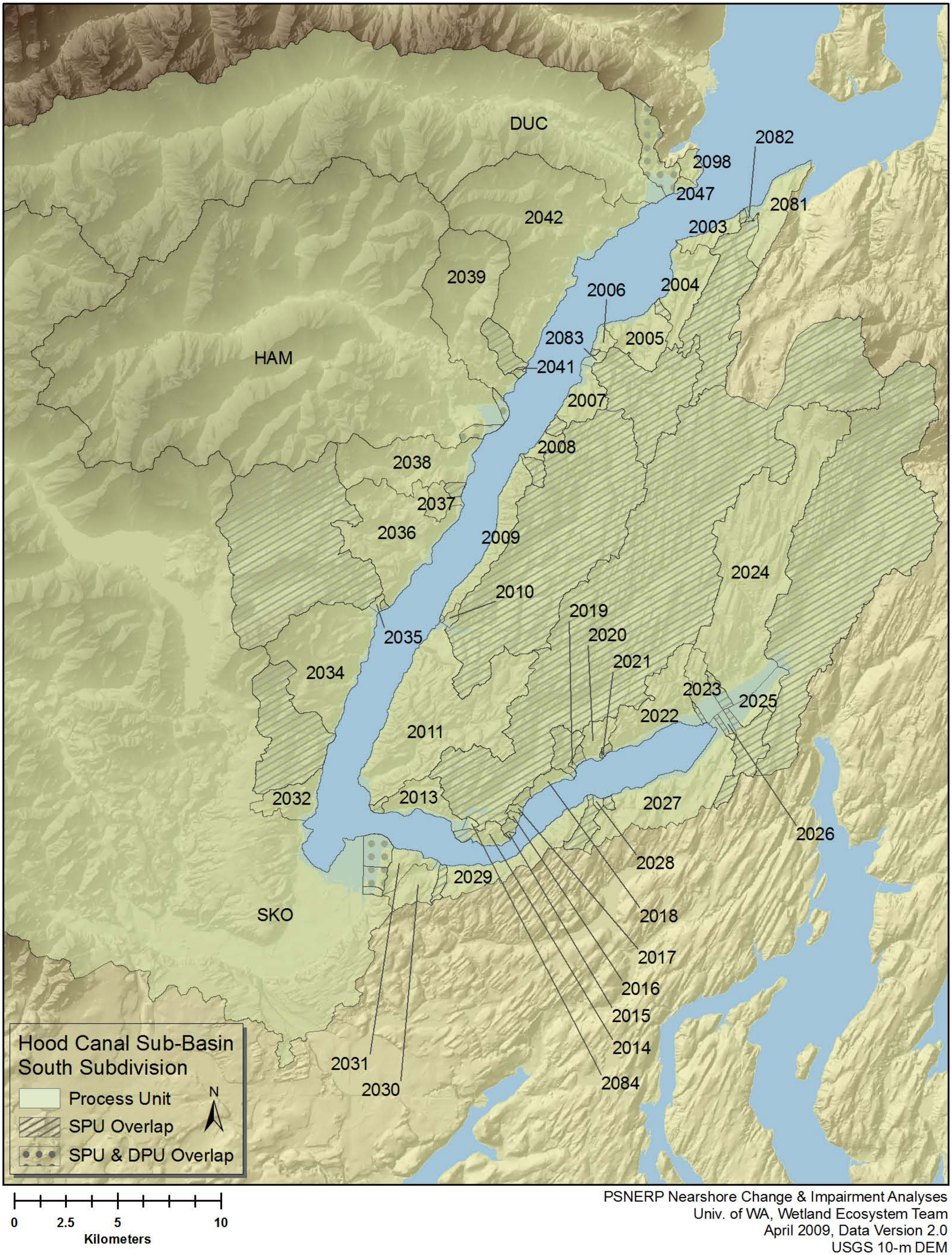

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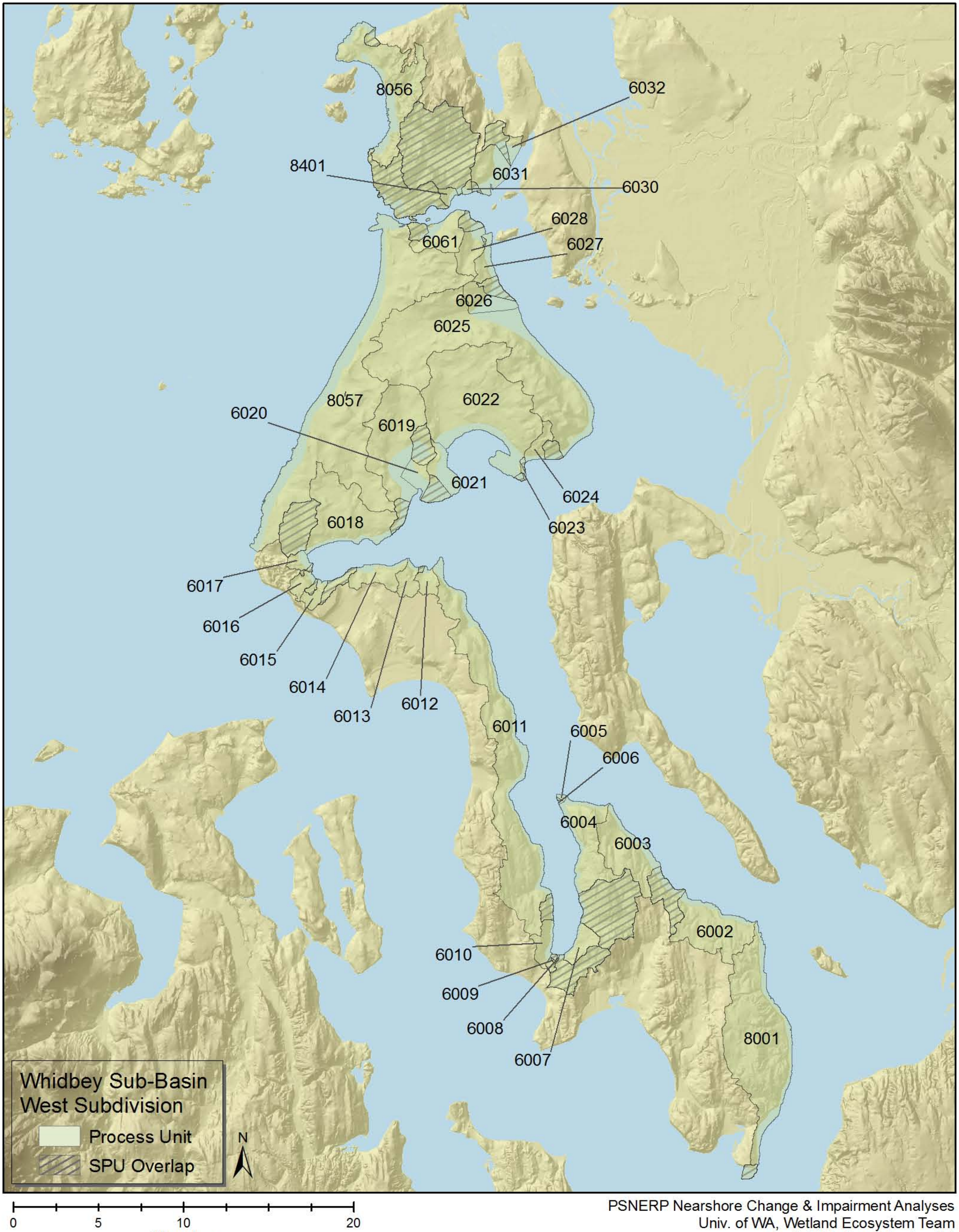

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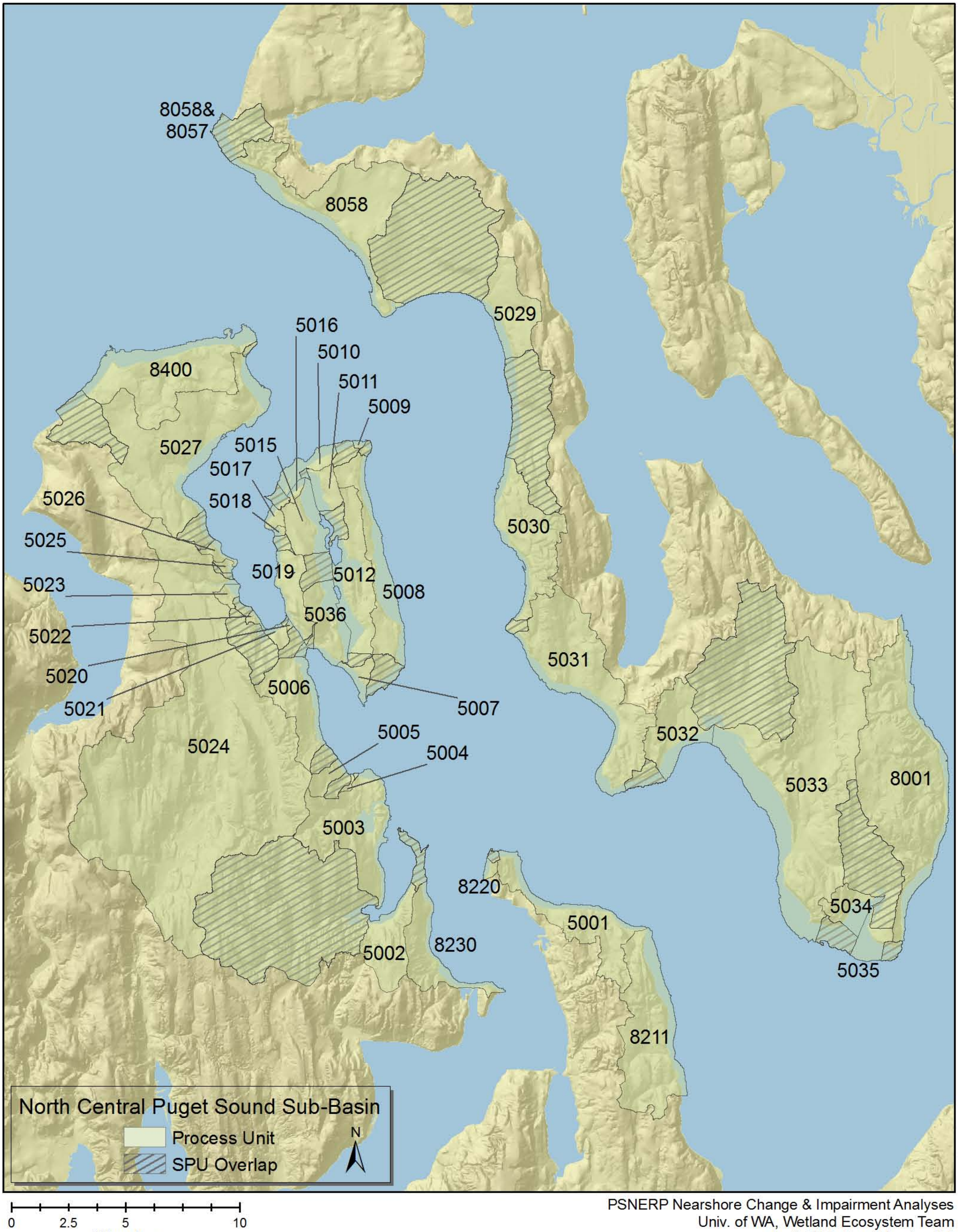
April 2009, Data Version 2.0
USGS 10-m DEM



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Univ. of WA, Wetland Ecosystem Team
April 2009, Data Version 2.0
USGS 10-m DEM

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Univ. of WA, Wetland Ecosystem Team
April 2009, Data Version 2.0
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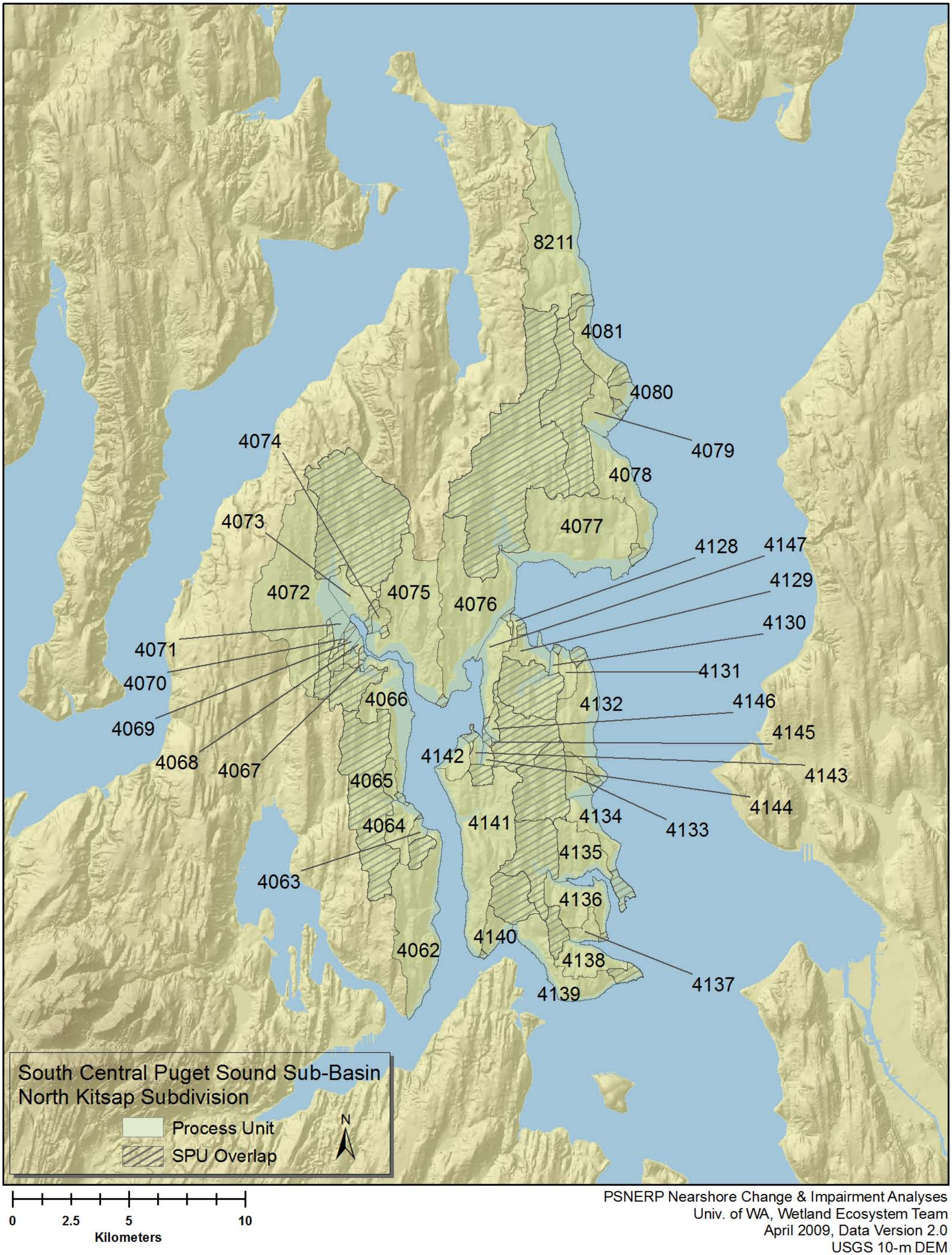

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Univ. of WA, Wetland Ecosystem Team
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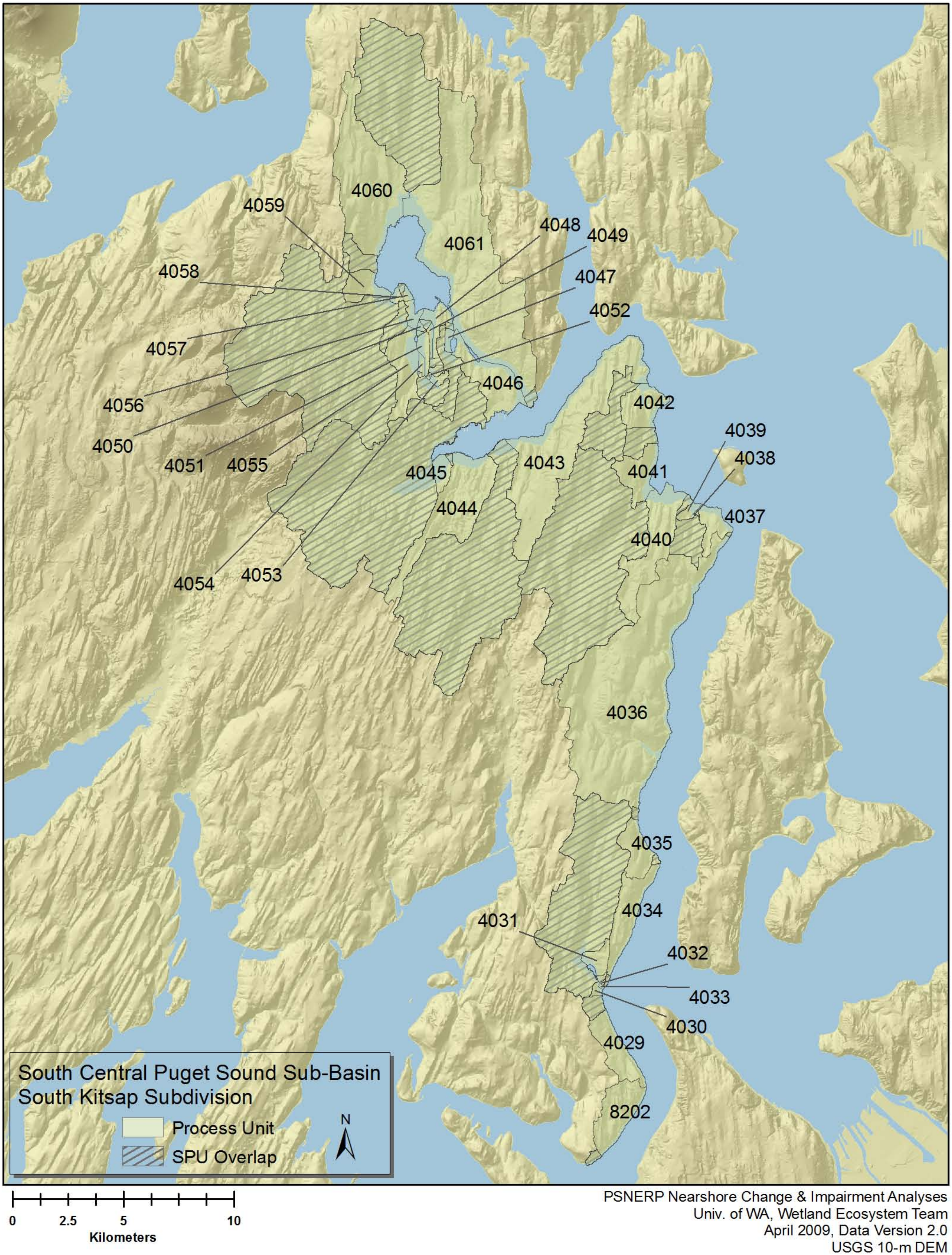

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Univ. of WA, Wetland Ecosystem Team
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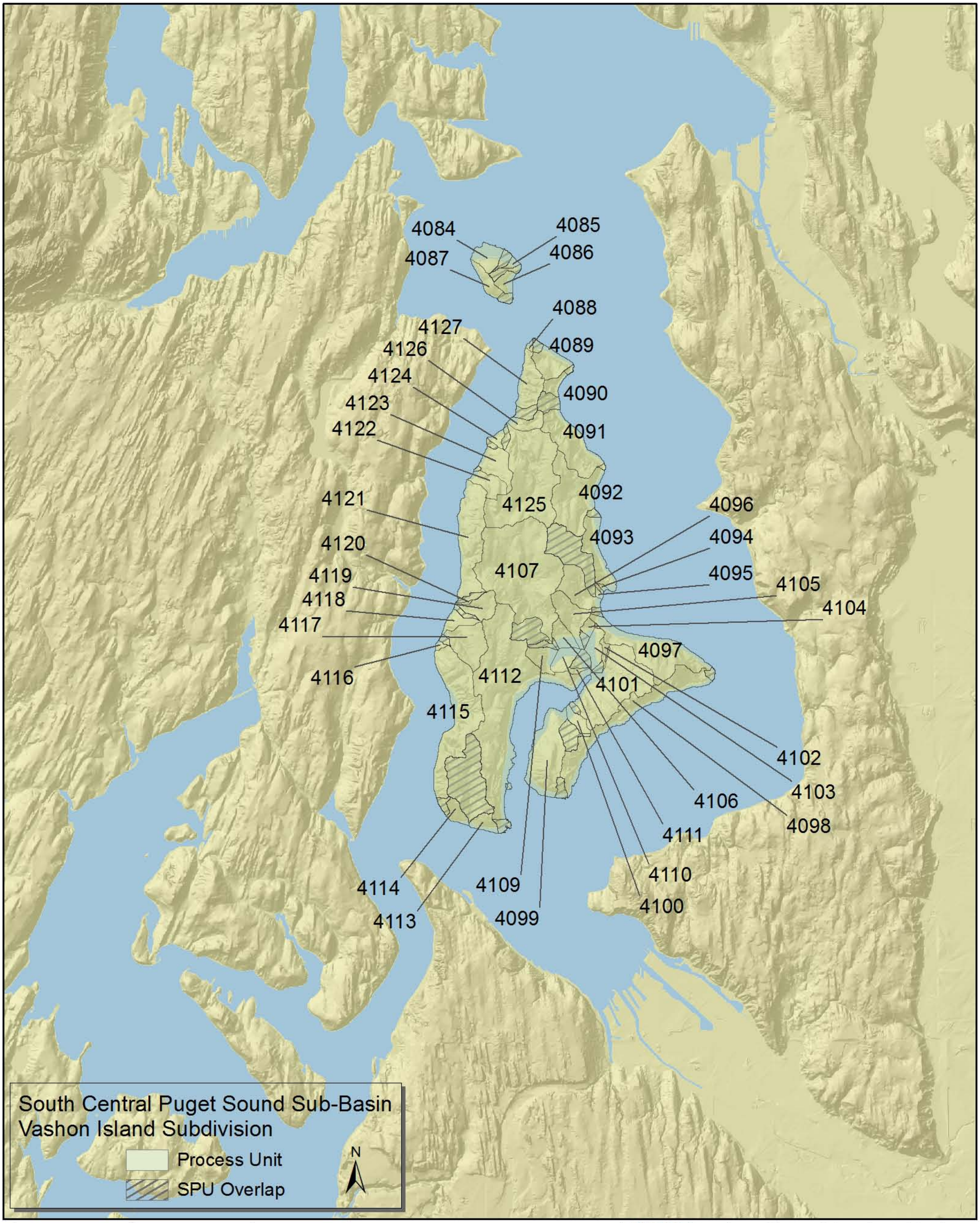
South Central Puget Sound Sub-Basin
Vashon Island Subdivision

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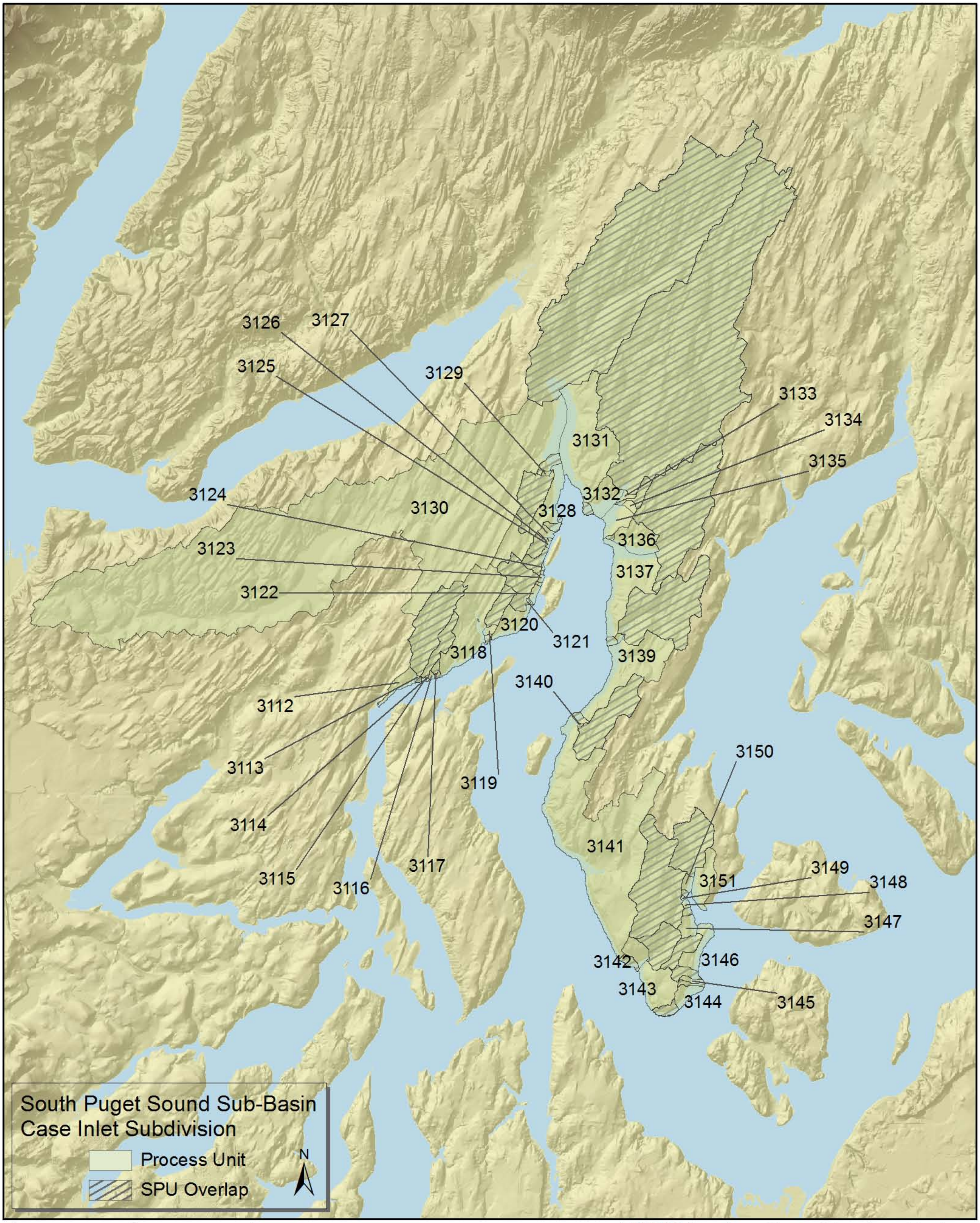

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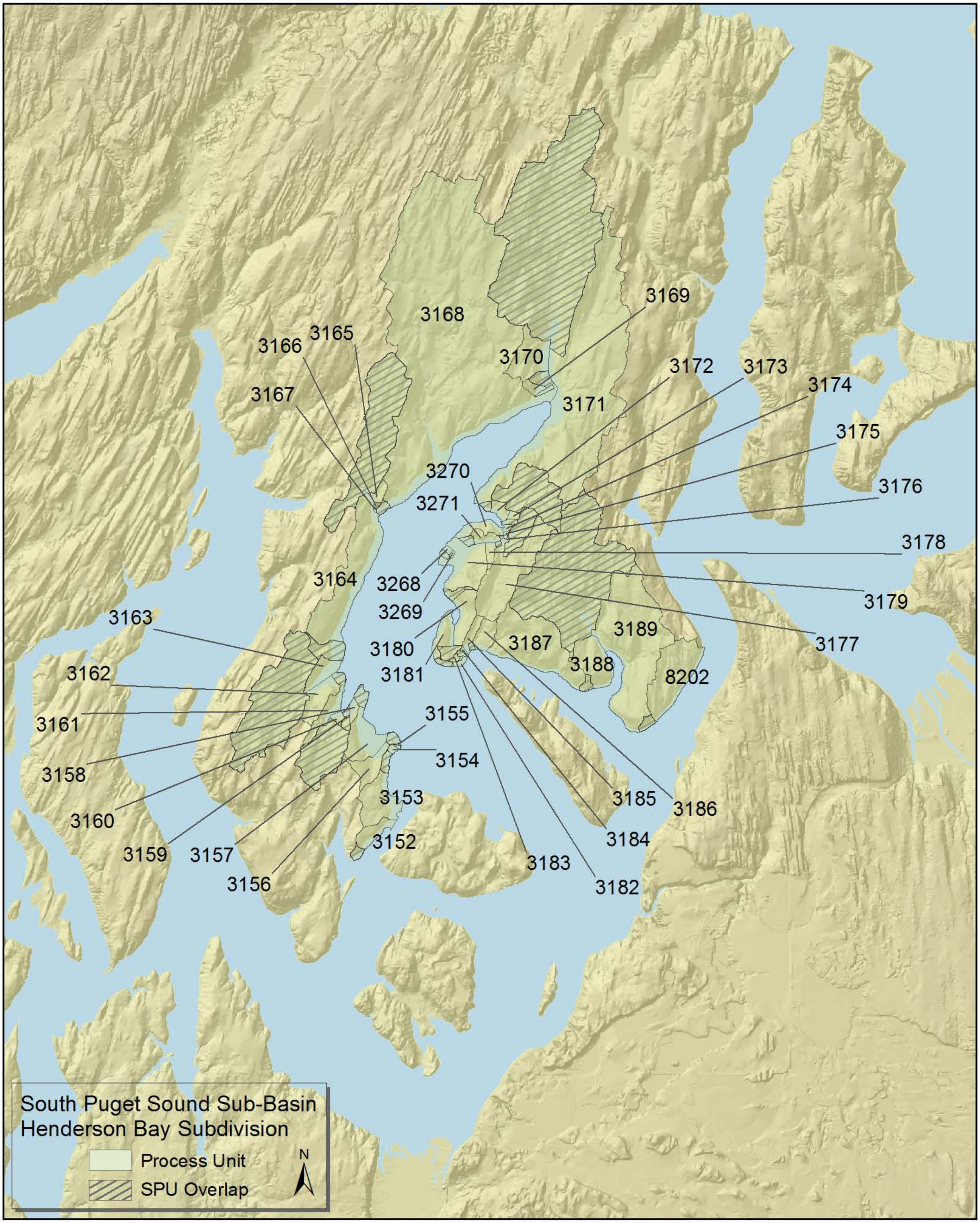

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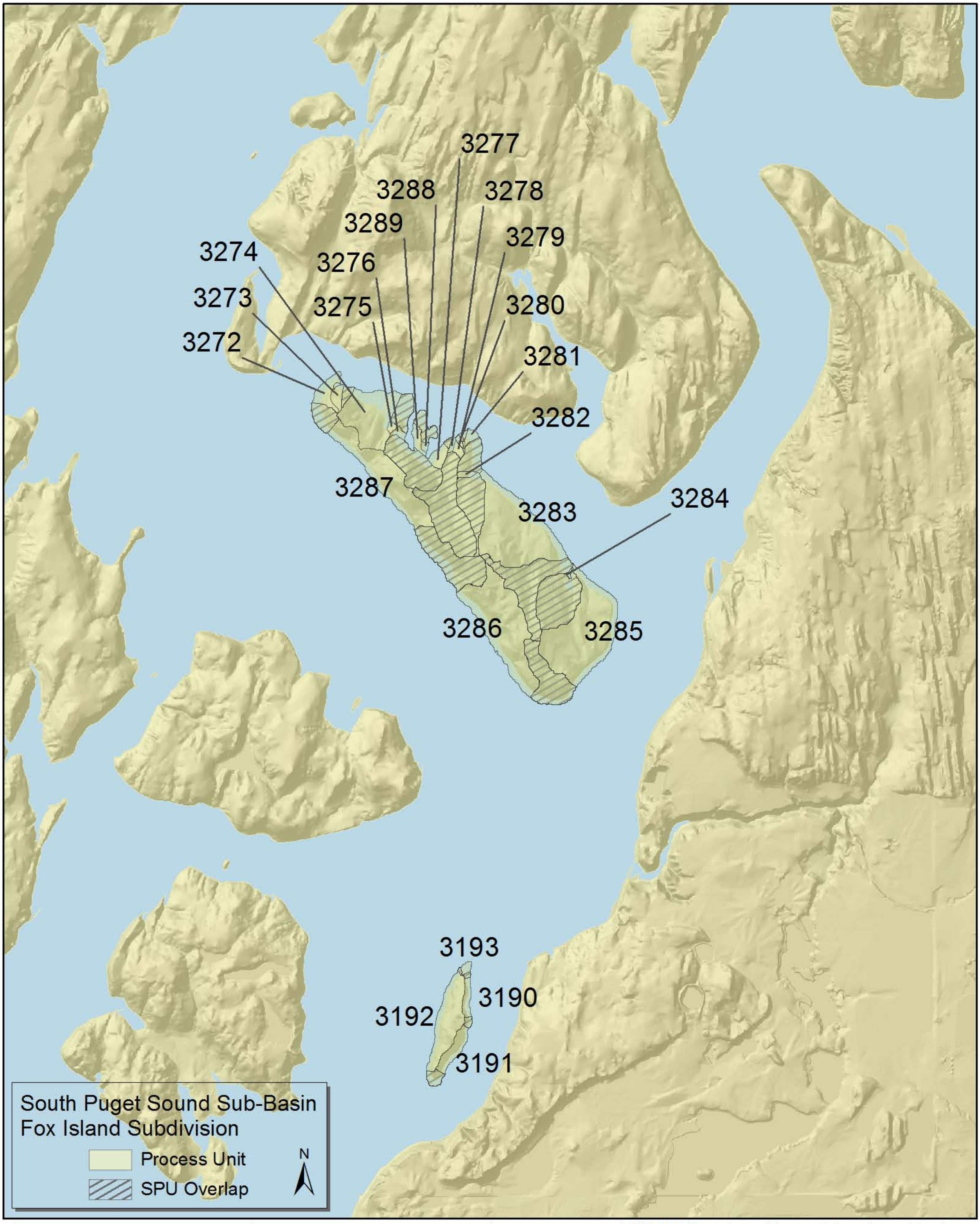

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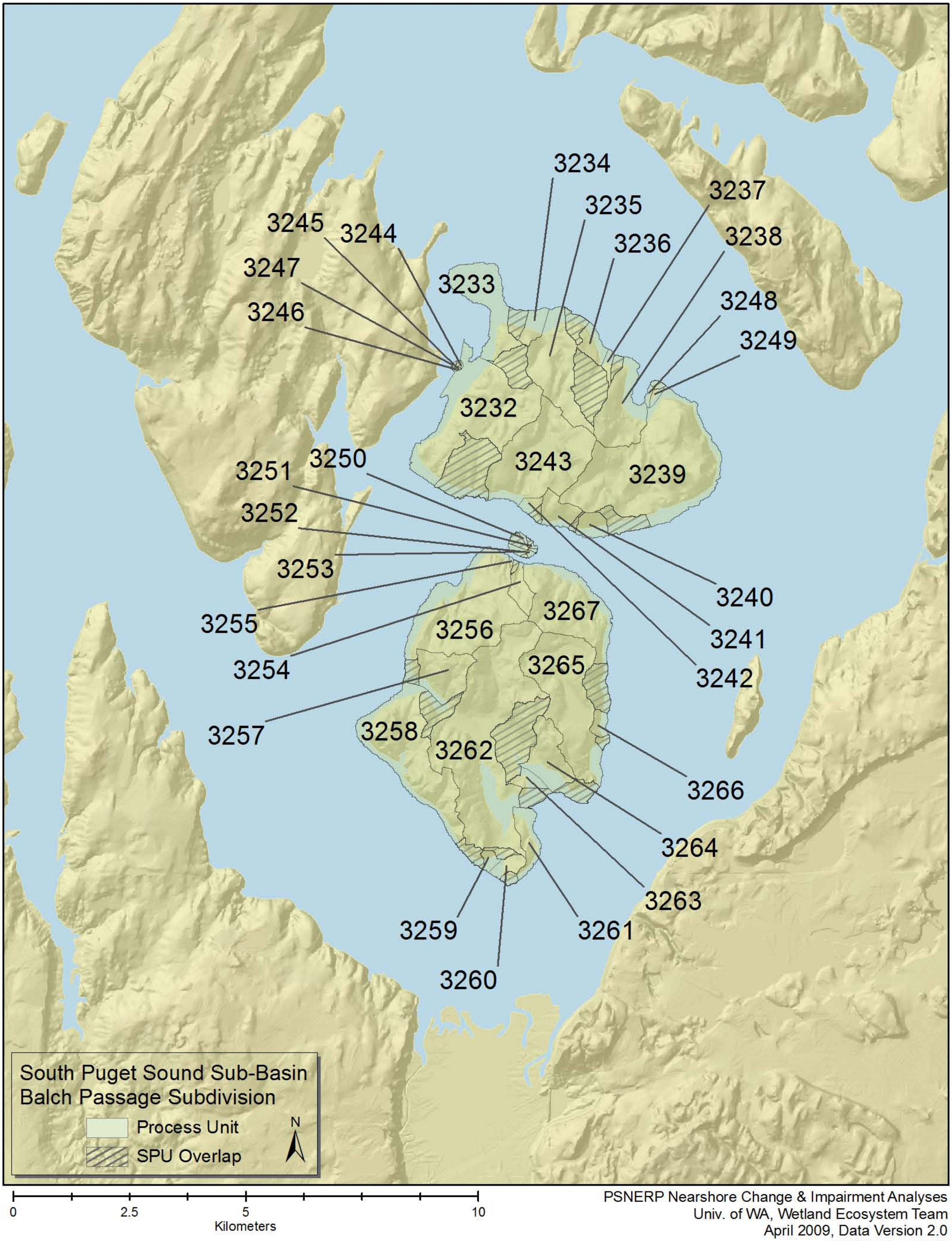

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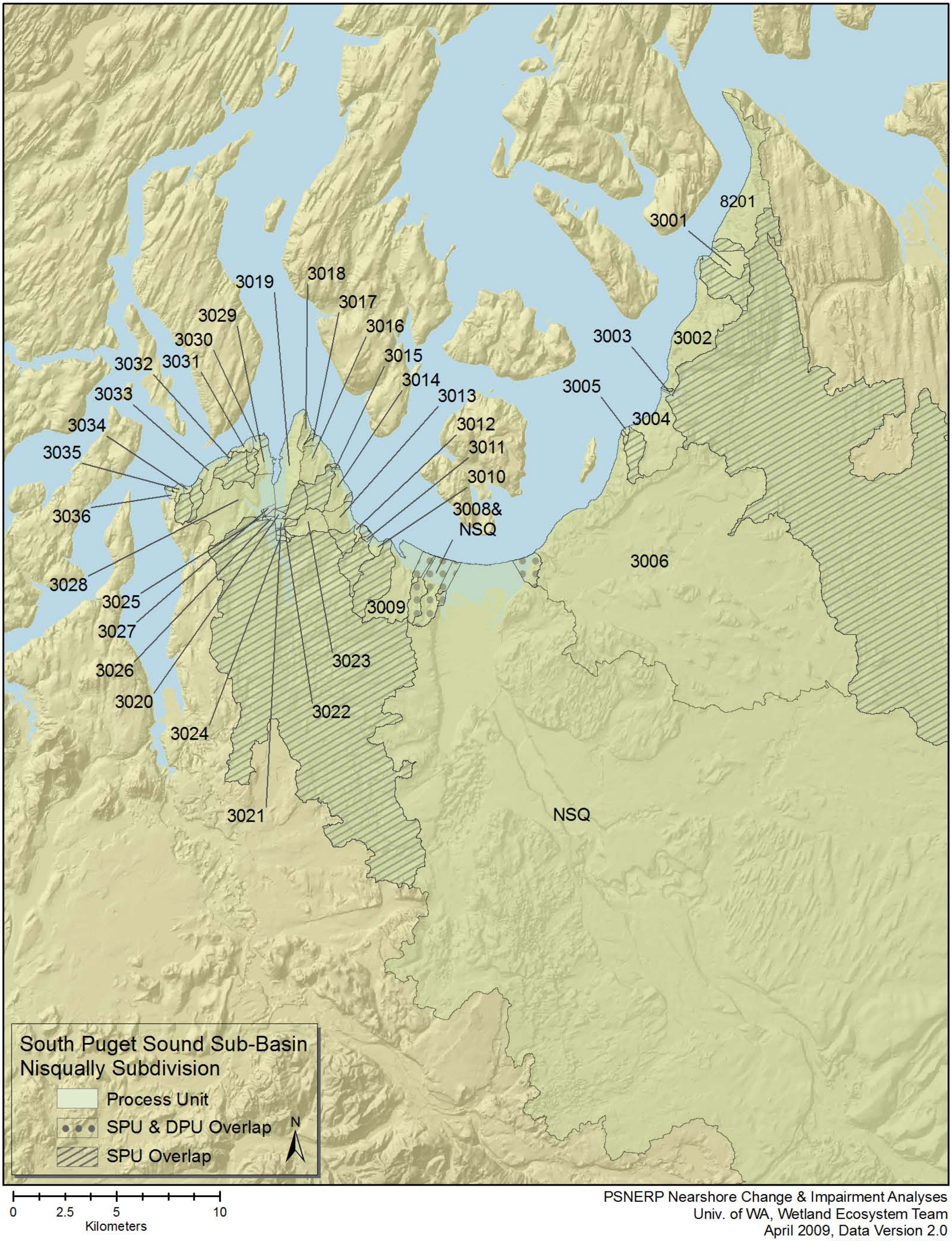

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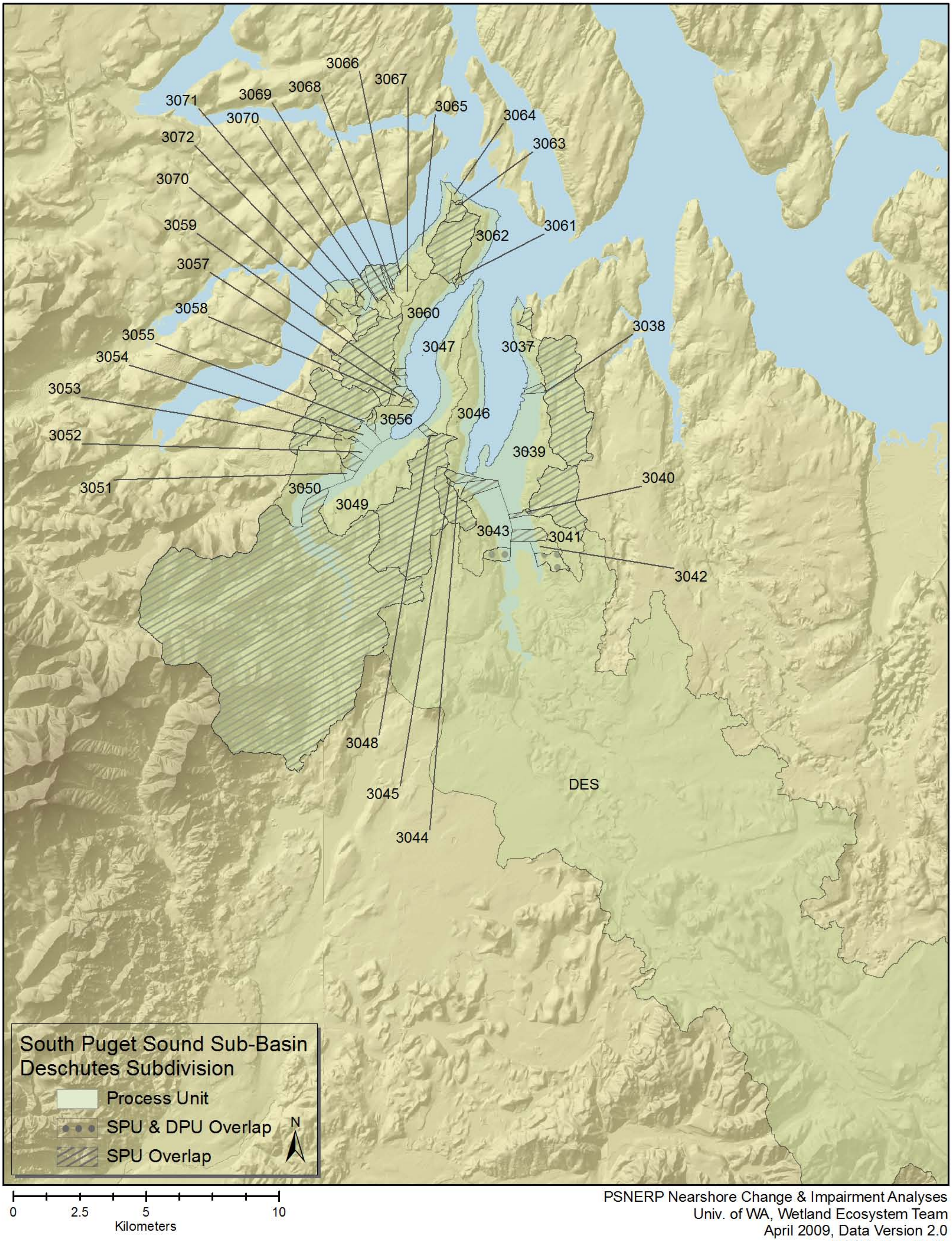

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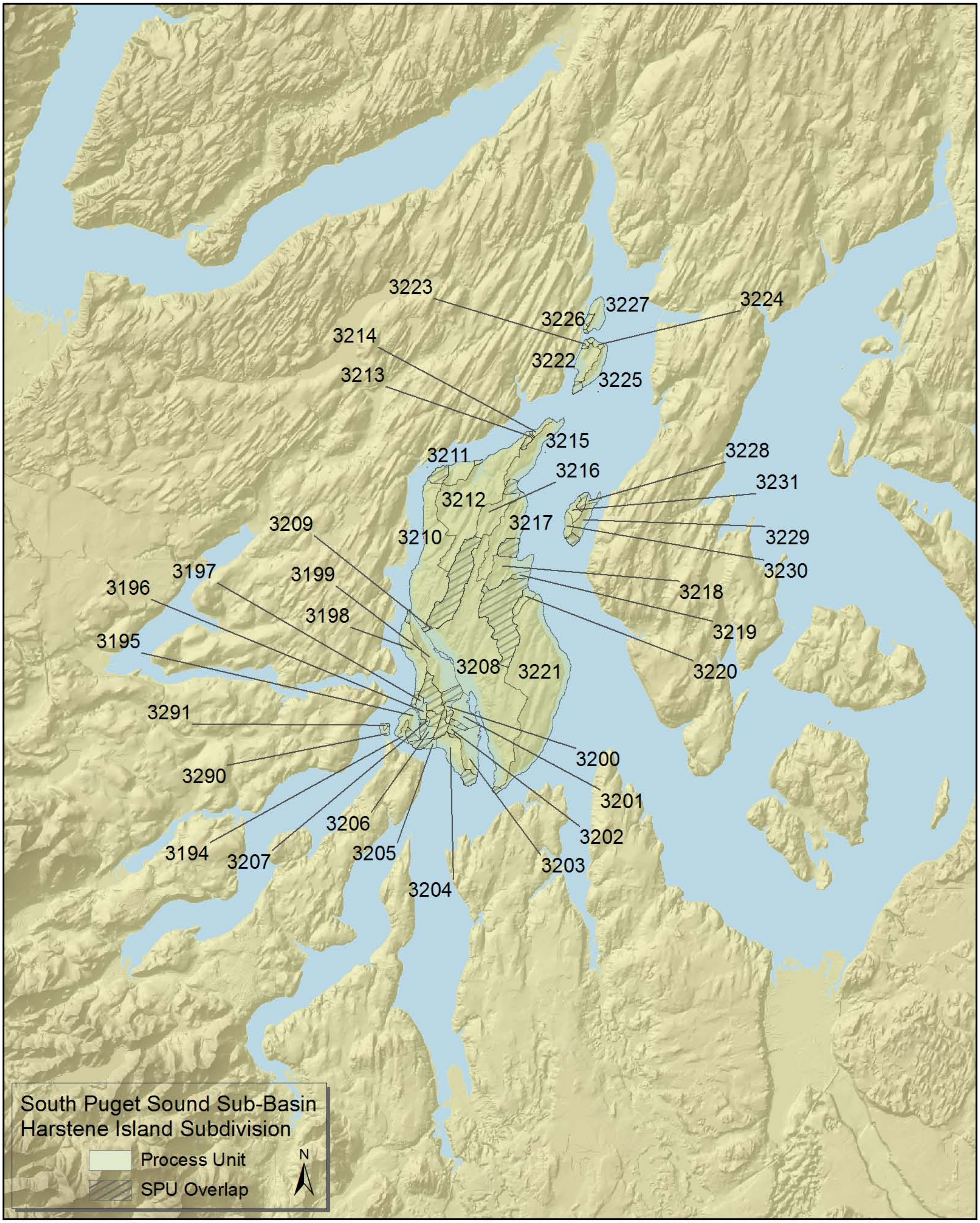

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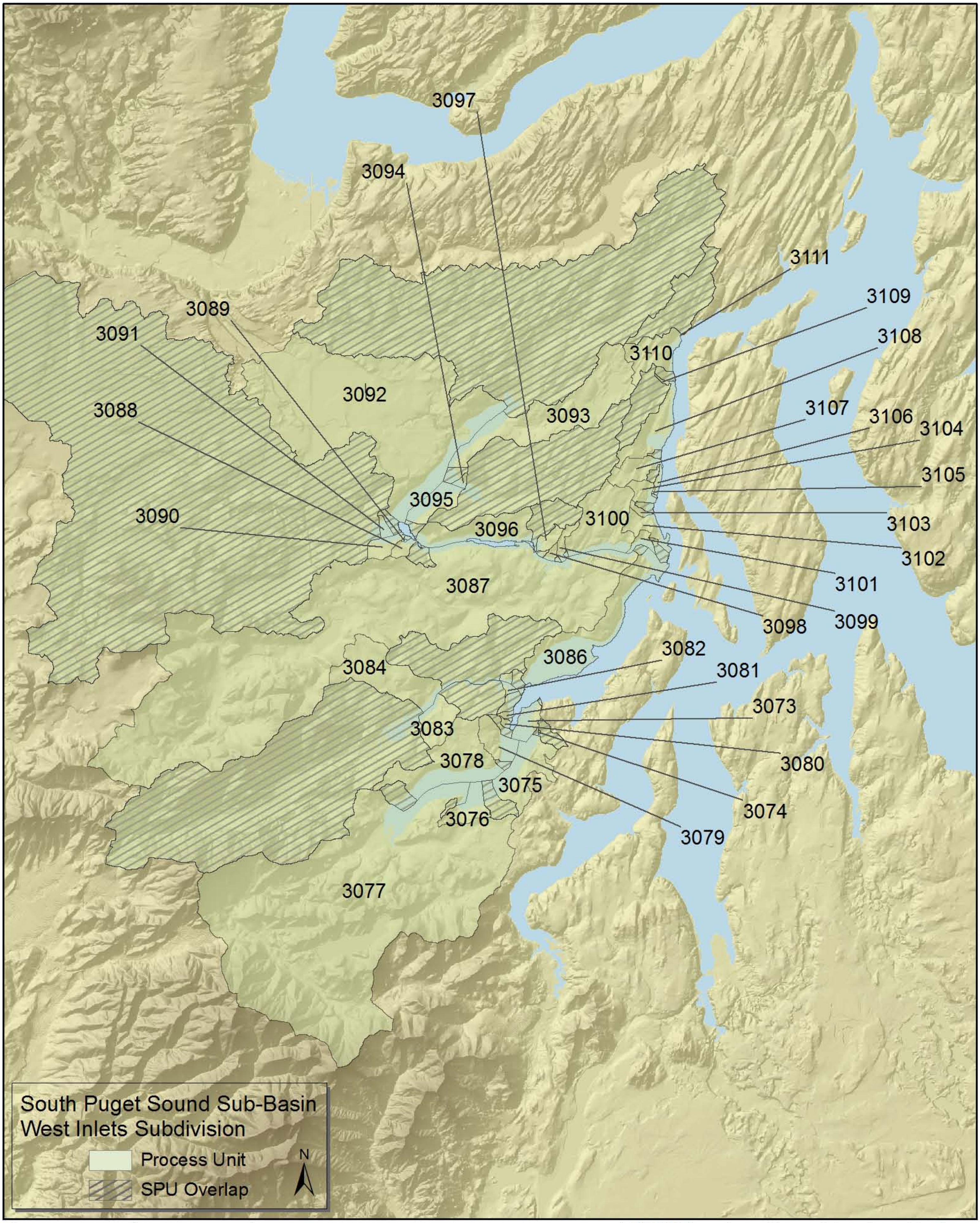

PSNERP Nearshore Change & Impairment Analyses
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April 2009, Data Version 2.0
USGS 10-m DEM

APPENDIX B

EXAMPLES OF PROCESS DEGRADATION OF SHOREFORMS FROM PRIMARY STRESSORS

Examples of Representative Process Degradation of Various Shoreforms Resulting from Primary Stressors

Nearshore process	Stressor	Shoreform type	Resulting process degradation
Sediment Supply	Shoreline Armoring	D, BLB	Shoreline Armoring halts or slows erosion of bluff backed beaches and river banks, thereby substantially reducing or eliminating Sediment Supply.
	Nearshore Fill	D, BLB	Nearshore Fill that is located waterward of an eroding bluff or along river banks typically prevents erosion, thereby reducing Sediment Supply.
	Nearshore Roads and Railroads	BLB, D	The occurrence of a road prism or rail causeway degrades this process similarly to Nearshore Fill combined with Shoreline Armoring. In both cases, the cross-shore connectivity is effectively blocked, which eliminates Sediment Supply from both eroding channel banks and bluff backed beaches from entering the nearshore system.
Sediment Transport	Shoreline Armoring	BAB, BLB	Wave energy can reflect rather than dissipate along Armored shores, resulting in altered Sediment Transport rates.
	Tidal Barriers	Deltas and Embayments	Tidal Barriers can prevent the transport and deposition of mostly fine sediment in tidally-dominated systems.
	Jetties and Breakwaters	BAB, BLB	The altered wave regime resulting from large cross-shore structures like Jetties and Breakwaters, can reduce and in many cases impede littoral drift (alongshore Sediment Transport).
	Nearshore Fill	BLB, BAB	Nearshore Fill areas typically infringe on the intertidal and impede or alter littoral Sediment Transport.
		D	Nearshore Fill areas prevent inundation of wetlands and alter flow in existing channels, both of which alter Sediment Transport.
		OCI, BE, BL,	Fill in embayments can preclude tidal inundation (tidal prism) within embayments which alters the tidal flow in which sediment are transported.
	Marinas	BLB, BAB, D	Marinas are often associated with dense Overwater Structures and dredge areas, both of which are known to alter Sediment Transport. A dredged navigation channel can often be below the depth of closure, thereby creating a sediment sink.
	Dams	D	Dams impound sediment that would otherwise be transported downstream.
Erosion/Accretion of Sediment	Shoreline Armoring	Deltas and Embayments	Shoreline Armoring alters natural wave dissipation and resulting deposition of fine sediments. It is also typically placed over the supratidal and upper intertidal where marsh accretion takes place and emergent vegetation develops.
	Tidal Barriers	Deltas and Embayments	Tidal Barriers reduce tidal prisms/inundated areas resulting in altered vegetation regimes and marsh plain subsidence due to lack of sediment deposition.
	Nearshore Fill	BAB, Deltas and Embayments	Nearshore Fill areas prevent natural inundation and the associated deposition of fine sediment.
	Nearshore Roads and Railroads	BAB, Deltas and Embayments	The occurrence of a road prism or rail causeway in the backshore or across and embayment or tidal wetland can alter or degrade the Erosion/Accretion of Sediment (similarly to fill and armoring) by reducing the dissipative function of the upper beach and altering tidal prism, thus impacting marsh development.
	Marinas	BAB, Deltas and Embayments	Marinas often encompass numerous features that can impact the Accretion of Sediment, including: a dredged navigation channel, Jetties and Breakwaters, Nearshore Fill and Shoreline Armoring as well as boat wakes. Each of these stressors alters sediment accretion and the ability for marshes to develop and be maintained.
	Wetland Loss	Deltas and Embayments	Wetland vegetation aids in the accretion of fine sediment, so this process typically degraded as a result of Wetland Loss.

Nearshore process	Stressor	Shoreform type	Resulting process degradation
Tidal Flow	Tidal Barriers	Deltas and Embayments	Tidal Barriers impede tidal flow leading to reduced tidal prism, lost channel networks and associated tidal wetlands.
	Nearshore Fill	Deltas and Embayments	Nearshore Fill alters Tidal Flow similarly to Tidal Barriers, by preventing (tidal) inundation, which can result in reduced tidal prism and flushing.
	Nearshore Roads and Railroads	Deltas and Embayments	Railroad causeways, often associated with fill areas, commonly alter or constrain Tidal Flow when they extend across Puget Sound rivers and embayments.
	Wetland Loss	Deltas and Embayments	Wetland Loss typically occurs as a result of the placement of fill, which alters elevations resulting in impeded tidal flow.
Distributary Channel Migration	Shoreline Armoring	Deltas	Shoreline Armoring precludes the avulsion and migration of distributary channels.
	Tidal Barriers	Deltas	The altered inundation regime resulting from Tidal Barriers can prevent or constrain natural Distributary Channel Migration.
	Nearshore Fill	Deltas	Nearshore Fill, which is typically associated with Shoreline Armoring, alters and constrains flooding, which can cause enhanced or reduced Distributary Channel Migration.
Tide Channel Formation and Maintenance	Tidal Barriers	Deltas and Embayments	Tidal Barriers typically reduce tidal prism and tidal flushing, both of which alter the hydrology that drives Channel Formation and Maintenance.
	Nearshore Fill	Deltas and Embayments	Nearshore Fill alters Tide Channel Formation and Maintenance by reducing tidal prism, thus the hydraulic head that scours and maintains tidal channels.
	Wetland Loss	Deltas and Embayments	Tide Channel Formation and Maintenance is degraded from Wetland Loss as a result of reduced tidal prism and hydraulic head which together can decrease inlet stability.
Freshwater Input	Impervious Surfaces	All Shoretypes	Impervious surfaces alter Freshwater Input by increasing surface water runoff and reducing infiltration and groundwater recharge, all of which results in more dynamic hydrography.
	Dams	Deltas and Embayments	Dams impact Freshwater Input by controlling (reducing) the volume and timing of water release downstream of the dam or impoundment area.
Detritus Input and Export	Shoreline Armoring	All Shoretypes	Shoreline Armoring degrades Detritus Input and Export by impairing cross-shore connectivity and precluding access to the upper beach within which LWD and beach wrack deposit.
	Tidal Barriers	Deltas and Embayments	Tidal Barriers preclude the Input and Export of Detritus by impeding the transport of detritus in and out of deltas and embayments.
	Nearshore Fill	All Shoretypes	Similar to Shoreline Armoring, Nearshore Fill reduces Detritus Input and Export by degrading cross-shore connectivity and precluding access to the upper beach within which LWD and beach wrack deposit.
	Nearshore Roads and Railroads	All Shoretypes	Similar to Shoreline Armoring, Roads and Railroads reduce Detritus Input and Export by degrading cross-shore connectivity and eliminating access to the upper beach within which LWD and beach wrack deposit.
	Wetland Loss	Deltas and Embayments	Detritus Input and Export is degraded as a result of Wetland Loss as wetlands often function as sinks or depositional areas for detritus.
	Dams	Deltas	Along with sediment and water, dams also impound detritus and typically control high water events during which abundant detritus would otherwise be recruited (input) and exported from the fluvial to the marine environment.

Nearshore process	Stressor	Shoreform type	Resulting process degradation
Exchange of Aquatic Organisms	Shoreline Armoring	All Shoretypes	Shoreline Armoring impacts the Exchange of Aquatic Organisms by fragmenting and or eliminating alongshore and cross-shore connectivity of shoreline habitats.
	Tidal Barriers	Deltas and Embayments	Tidal Barriers impact the Exchange of Aquatic Organisms by precluding access to estuarine and embayment habitats.
	Jetties and Breakwaters	All Shoretypes (excluding CLMs)	Jetties and Breakwaters degrade the Exchange of Aquatic Organisms by impacting the alongshore connectivity of shallow water habitats, and eliminating cross-shore connectivity.
	Nearshore Fill	All Shoretypes	Nearshore Fill degrades the Exchange of Aquatic Organisms by precluding access to upper intertidal habitats, as well as reducing the alongshore connectivity of shallow water habitats (migratory pathways) and cross-shore connectivity.
	Nearshore Roads and Railroads	All Shoretypes	Similar process degradation of the Exchange of Aquatic Organisms occurs as a result of Nearshore Roads and Railroads as Nearshore Fill and Shoreline Armoring with degraded cross-shore and alongshore habitat connectivity and eliminated upper beach habitats where causeways infringe on the beach.
	Overwater Structures	All Shoretypes	The Exchange of Aquatic Organisms is degraded as a result of the shade produced by Overwater Structures, which is known to alter juvenile salmonid migration pathways into deeper water where they are more vulnerable to predation.
	Marinas	All Shoretypes	Similar to the impacts created by Overwater Structures, the exchange of aquatic organisms is degraded by the shading from docks and moored vessels, as well as other impacts including additional deepwater created from dredged navigation channels and the occurrence of other stressors such as Shoreline Armoring, Nearshore Fill, Impervious Surfaces and Jetties and Breakwaters.
	Stream Crossings	Deltas and Embayments	Stream Crossings degrade the Exchange of Aquatic Organisms by precluding or reducing access to upstream habitats.
	Dams	Deltas	Dams degrade the Exchange of Aquatic Organisms by precluding or reducing (such as with fish ladder access to upstream habitats.
	Historic Drainage Area	Deltas	Altered Historic Drainage areas impact the Exchange of Aquatic Organisms by precluding access to those river-miles that have been fragmented from the watershed.
Physical Disturbance	Shoreline Armoring	Beaches (BLB, BAB) and Pocket Beaches	Shoreline Armoring reduces Physical Disturbance by preventing wave energy dissipation and often increasing wave reflection, which leads to other changes in beach characteristics (e.g. sediment composition).
	Jetties and Breakwaters	Beaches (BLB, BAB) and Pocket Beaches	Jetties and Breakwaters impede Physical Disturbance by protecting shores from wave energy that would otherwise be exposed thus altering the natural wave regime and sediment transport landward of structures.
	Nearshore Fill	Beaches (BLB, BAB) and Pocket Beaches	Nearshore Fill precludes Physical Disturbance similarly to Shoreline Armoring, by preventing or altering wave dissipation.
	Nearshore Roads and Railroads	Beaches (BLB, BAB) and Pocket Beaches	Similar to Nearshore Fill and Shoreline Armoring, Nearshore Roads and Railways prevent wave dissipation along the upper beach and causes increased wave energy reflection from a hard structure.
	Marinas	Beaches (BLB, BAB) and Pocket Beaches	Marinas degrade Physical Disturbance typically as a result of several co-located stressors including: Nearshore Fill, Shoreline Armoring, Jetties and Breakwaters, and the presence of many pilings and Overwater Structures that attenuate wave energy, cumulatively altering the natural wave regime. In addition boat wake and propeller chop can further alter natural level of physical disturbance from historic conditions.
	Wetland Loss	Deltas	Wetlands and submerged aquatic vegetation aid in the attenuation of wave energy, thus when Wetland Loss occurs and those functions are lost, and altered Physical Disturbance is the result.

Nearshore process	Stressor	Shoreform type	Resulting process degradation
Solar Radiation	Overwater Structures	All Shoretypes	Overwater Structures shade the water column which results in decreased Solar Radiation and reduced photosynthesis/primary production.
	Marinas	All Shoretypes	Marinas typically encompass numerous Overwater Structures including piers, docks, and moored boats; each of which contributes shade that decreases Solar Radiation.
	Impervious Surface	All Shoretypes	Impervious surfaces preclude the process of Solar Radiation, which in turn reduces photosynthesis/primary production.

Notes:
*All shoretypes excluding plunging rocky shorelines (PL)
** All shoretypes excluding plunging rocky shorelines (PL) and rocky platforms (RP)

APPENDIX C
EXPANDED NEARSHORE ECOSYSTEM PROCESS EVALUATION FRAMEWORK

Expanded Nearshore Ecosystem Process Evaluation Framework

Nearshore Process	Primary Stressors	Secondary Stressors	Areas to Investigate	Stressor Information to Evaluate Process Impacts in DPUs	Stressor Information to Evaluate Process Impacts in SPUs	Other Filters Considered by SNAT
Sediment Input	Armoring, Dams, Railroads, Roads, Fill, Historic Drainage Area, ARTIFICIAL shoreforms	Land cover, Marinas, Impervious surfaces, Breakwaters/ Jetties, Dams	Entire DPUs In SPUs: DZs, TZs, BLBs,	Percent of total DPU area above lowermost dam in DPU Percent of shoreline with one or more: 1. Fill 2. Armoring 3. Railroads 4. Roads 5. ARTIFICIAL shoreform Is current drainage area smaller than historic drainage area? (Y/N)	Percent of BLB shorelines in DZ and TZ with one or more: 1. Fill 2. Armoring 3. Railroads 4. Roads 5. ARTIFICIAL shoreform	DPU: Percent of shoreline with two or more of the same four stressors DPU: Sum of percentages of impoundment area of each dam SPU: Percent of BLB shorelines in DZ with one or more: 1. Armoring 2. Railroads 3. Roads SPU: Percent of BLB shorelines in TZ with one or more: 1. Armoring 2. Railroads 3. Roads SPU: Percent of BLB shorelines in DZ with two or more stressors SPU: Percent of BLB shorelines in TZ with two or more stressors SPU: Percent of BLB shorelines in DZ and TZ with two or more stressors SPU: rule for dams into embayments
Sediment Transport	Breakwaters/Jetties, Armoring, Marinas, Fill, Tidal barriers, Dams, ARTIFICIAL shoreforms	Impervious surface, Overwater structures, Railroads, Roads, Tidal wetland loss	Entire DPUs In SPUs: BABs and BLBs Embayment shores (BE, BL, OCI)	Percent of shoreline with one or more: 1. Tidal barriers 2. Fill 3. Armoring 4. Marinas 5. ARTIFICIAL shoreform Percent of total DPU area above lowermost dam in DPU	Percent of BLB and BAB shorelines with one or more: Fill 1. Armoring 2. downdrift of marina and/or breakwater/jetty in transport zone 3. ARTIFICIAL shoreform For Embayment Shores (OCI, BE, BL): Percent of OCI, BE, BL shorelines with one or more: 1. Tidal barriers 2. Fill 3. Armoring 4. ARTIFICIAL shoreform	DPU: Percent of shoreline with two or more of the same five stressors SPU: Percent of BLB and BAB shorelines with two or more of the same four stressors SPU: Percent of OCI, BE, BL shorelines with two or more of the same four stressors SPU: limit dataset to jetties and/or calculate percent of shoreline downdrift of most updrift structure SPU: include RR/roads DPU/SPU: rule to filter out smaller marinas

Nearshore Process	Primary Stressors	Secondary Stressors	Areas to Investigate	Stressor Information to Evaluate Process Impacts in DPUs	Stressor Information to Evaluate Process Impacts in SPUs	Other Filters Considered by SNAT
Erosion and Accretion of Sediment	Armoring, Railroads, Roads, Marinas, Breakwaters/Jetties, Fill, Tidal Barriers, ARTIFICIAL shoreforms	Land Cover, Overwater structures, Breakwaters/Jetties	Entire DPUs In SPUs: BABs Embayment shores (BE, BL, OCI, CLM)	Percent of shoreline with one or more: 1. Tidal barriers 2. Fill 3. Armoring 4. Railroads 5. Roads 6. Marinas 7. ARTIFICIAL shoreform	Percent of BAB shorelines with one or more: 1. Fill 2. Armoring 3. Railroads 4. Roads 5. Marinas 6. Breakwaters/jetties 7. ARTIFICIAL shoreform Percent of embayment shorelines with one or more: Tidal barriers 1. Fill 2. Armoring 3. Railroads 4. Roads 5. Marinas 6. Breakwaters/jetties 7. ARTIFICIAL shoreform	DPU: Percent of shoreline with two or more of the same five stressors SPU: Percent of BLB and BAB shorelines with two or more of the same four stressors SPU: Percent of OCI, BE, BL shorelines with two or more of the same four stressors DPU/SPU: rule to filter out smaller marinas SPU: % of shoreline downdrift of most updrift structure
Tidal Flow	Tidal barriers, Tidal Barrier Impoundment Area, Fill, Railroads, Roads Breakwaters/Jetties, ARTIFICIAL shoreforms	Marinas, Armoring, Roads	Entire DPUs In SPUs: Embayment shores (BE, BL, OCI)	Percent of shoreline with one or more: 1. Tidal barriers 2. Fill 3. Railroads 4. Roads 5. ARTIFICIAL shoreform Percent of historic wetland area that has been impacted by tidal barrier or fill (impacted area / historic area)	Percent of BE, BL, OCI shoreline with one or more: 1. Tidal barriers 2. Fill 3. Railroads 4. ARTIFICIAL shoreform Percent of historic wetland area (excluding Euryhaline Unvegetated wetlands) that has been impacted by tidal barrier or fill (impacted area / historic area)	DPU/SPU: rule to include roads

Nearshore Process	Primary Stressors	Secondary Stressors	Areas to Investigate	Stressor Information to Evaluate Process Impacts in DPUs	Stressor Information to Evaluate Process Impacts in SPUs	Other Filters Considered by SNAT
Distributary Channel Migration	Tidal barriers, Fill, Armoring, ARTIFICIAL shoreforms	Impervious surfaces, Stream crossings, Land Cover, Railroads, dams	Entire DPUs	Percent of shoreline with one or more: 1. Tidal barriers 2. Fill 3. Armoring 4. ARTIFICIAL shoreform Number of dams per km2 of watershed area	N/A	DPU: rule to include dams
Tidal Channel Formation and Maintenance	Tidal barriers, Fill	Railroads, Roads, Armoring, Marinas	Entire DPUs In SPUs: Embayment shores (BL, BE)	Percent of historic wetland area that has been impacted by tidal barrier or fill (impacted area / historic area)	Percent of historic wetland area (excluding Euryhaline Unvegetated wetlands) that has been impacted by tidal barrier or fill (impacted area / historic area)	
Freshwater Input	Dams, changes to historic drainage area, Impervious surface	Stream crossings, Fill, Tidal barriers, Roads, Land cover, armoring, Railroads	Entire DPUs Entire SPUs	Percent of total DPU watershed area above lowermost dam in DPU Is current drainage area smaller than historic drainage area? (Y/N) Percent of Adjacent Upland Area with 30% or more impervious surfaces	Percent of Watershed Area with 10 percent or more impervious surfaces Percent of total SPU watershed area above lowermost dam in SPU	SPU: rule to include consideration of groundwater seepage
Detritus Import and Export	Armoring, Fill, Roads, Railroads, Tidal barriers, ARTIFICIAL shoreforms, wetland area loss	Breakwaters and Jetties, overwater structures, stream crossings, land cover, Dams	Entire DPUs Entire SPUs	Percent of shoreline with one or more: 1. Tidal barriers 2. Fill 3. Armoring 4. ARTIFICIAL shoreform Percent loss of wetland area calculated as (current – historic)/ historic	Percent of shoreline with one or more: Tidal barriers 1. Fill 2. Railroads 3. Roads 4. Armoring 5. ARTIFICIAL shoreform Percent loss of wetland area calculated as (current – historic)/ historic	DPU/SPU: include Land cover DPU/SPUs: stream crossings

Nearshore Process	Primary Stressors	Secondary Stressors	Areas to Investigate	Stressor Information to Evaluate Process Impacts in DPUs	Stressor Information to Evaluate Process Impacts in SPUs	Other Filters Considered by SNAT
Exchange of Aquatic Organisms	Tidal barriers, Breakwaters/Jetties, Stream crossings, Dams, Fill, Armoring, Roads, Railroads, Overwater structures, ARTIFICIAL shoreforms		Entire DPUs Entire SPUs	Percent of shoreline with one or more: 1. Tidal barriers 2. Fill 3. Railroads 4. Roads 5. Armoring 6. OWS, including marinas 7. Breakwaters/Jetties 8. ARTIFICIAL shoreform Number of stream crossings and dams per km2 of watershed area	Percent of shoreline with one or more: 1. Tidal barriers 2. Fill 3. Railroads 4. Roads 5. Armoring 6. OWS, including marinas 7. Breakwaters/Jetties 8. ARTIFICIAL shoreform Number of stream crossings and dams per km2 of watershed area	DPU/SPU: rule related to OWS size and/or percent of aquatic area
Physical Disturbance	Armoring, Breakwaters/Jetties, Marinas, Roads, Railroads, Fill , ARTIFICIAL shoreforms	Overwater structures, Tidal barriers, Dams	In SPUs: BLB, BAB, and PB	N/A	Percent of BLB, BAB, and PB shorelines in SPU with one or more: 1. Fill 2. Armoring 3. Railroads 4. Roads 5. Marinas 6. Breakwaters/Jetties 7. ARTIFICIAL shoreform	SPU: Percent of BLB and BAB shorelines with two or more of the same four stressors
Solar Incidence	Overwater structures, Impervious surfaces	Roads, Railroads, Armoring, Land cover, Marinas	Entire DPUs Entire SPUs	Percent of aquatic area with OWS	Percent of aquatic area with OWS	DPU/SPU: Area of OWS Percent of Adjacent Upland Area with 30% or more impervious surfaces

Notes:
(Underline denotes the primary indicator used in the evaluation of process degradation)

APPENDIX D
MAPS OF DEGRADATION OF INDIVIDUAL NEARSHORE PROCESSES

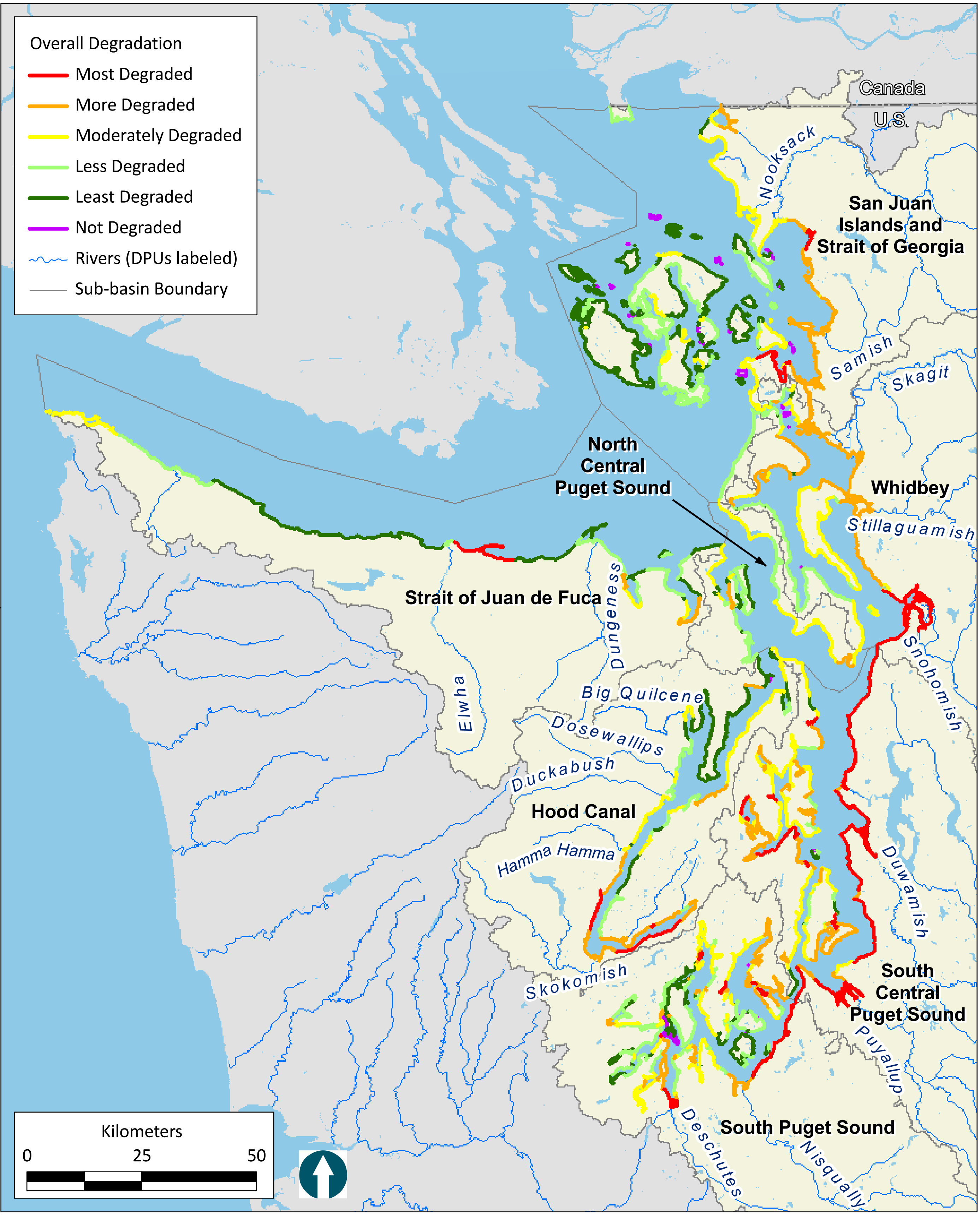

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Figure D-1
Overall Process Degradation by Process Unit
Nearshore Process Evaluation Framework Results

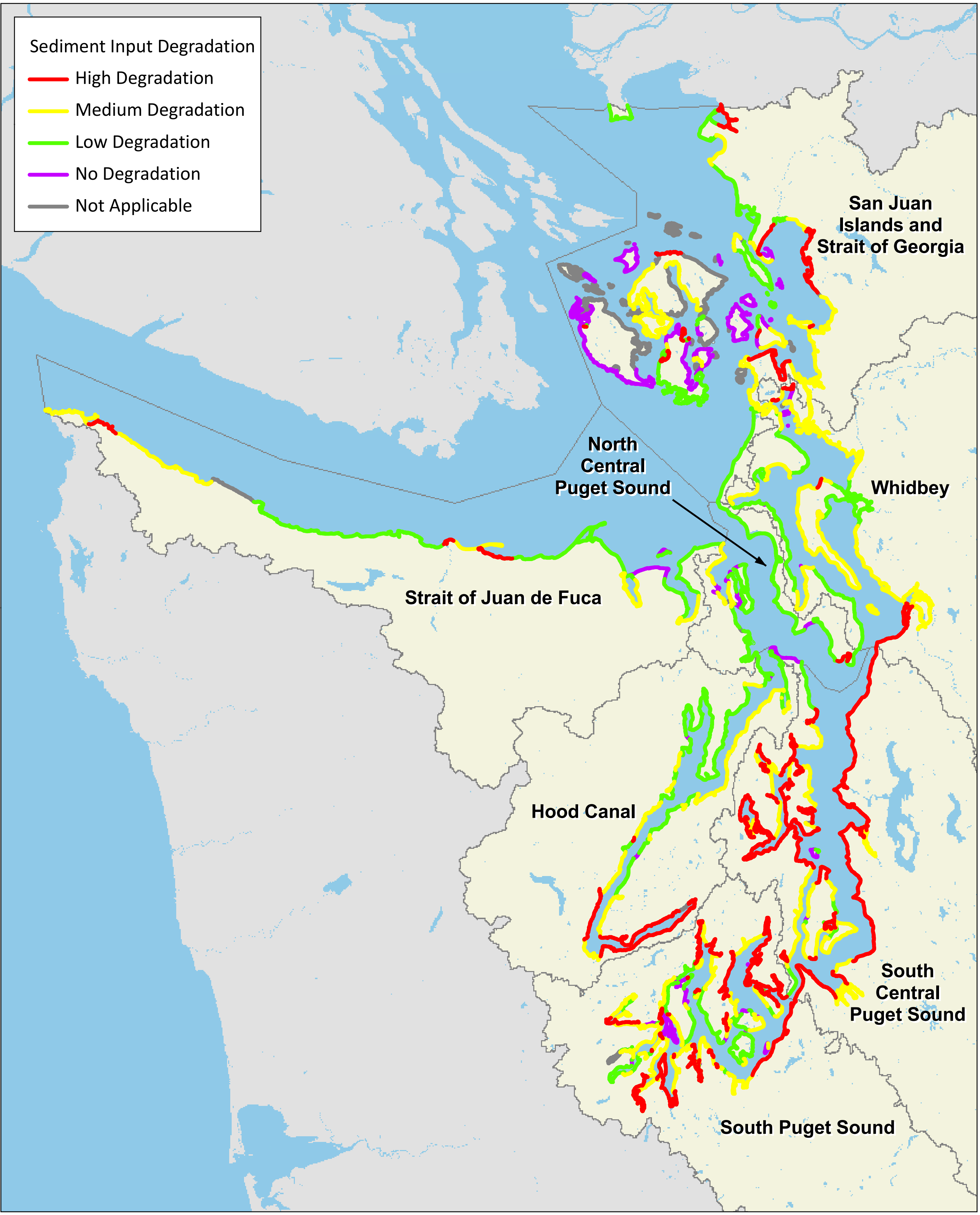

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Figure D-2
Sediment Input
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

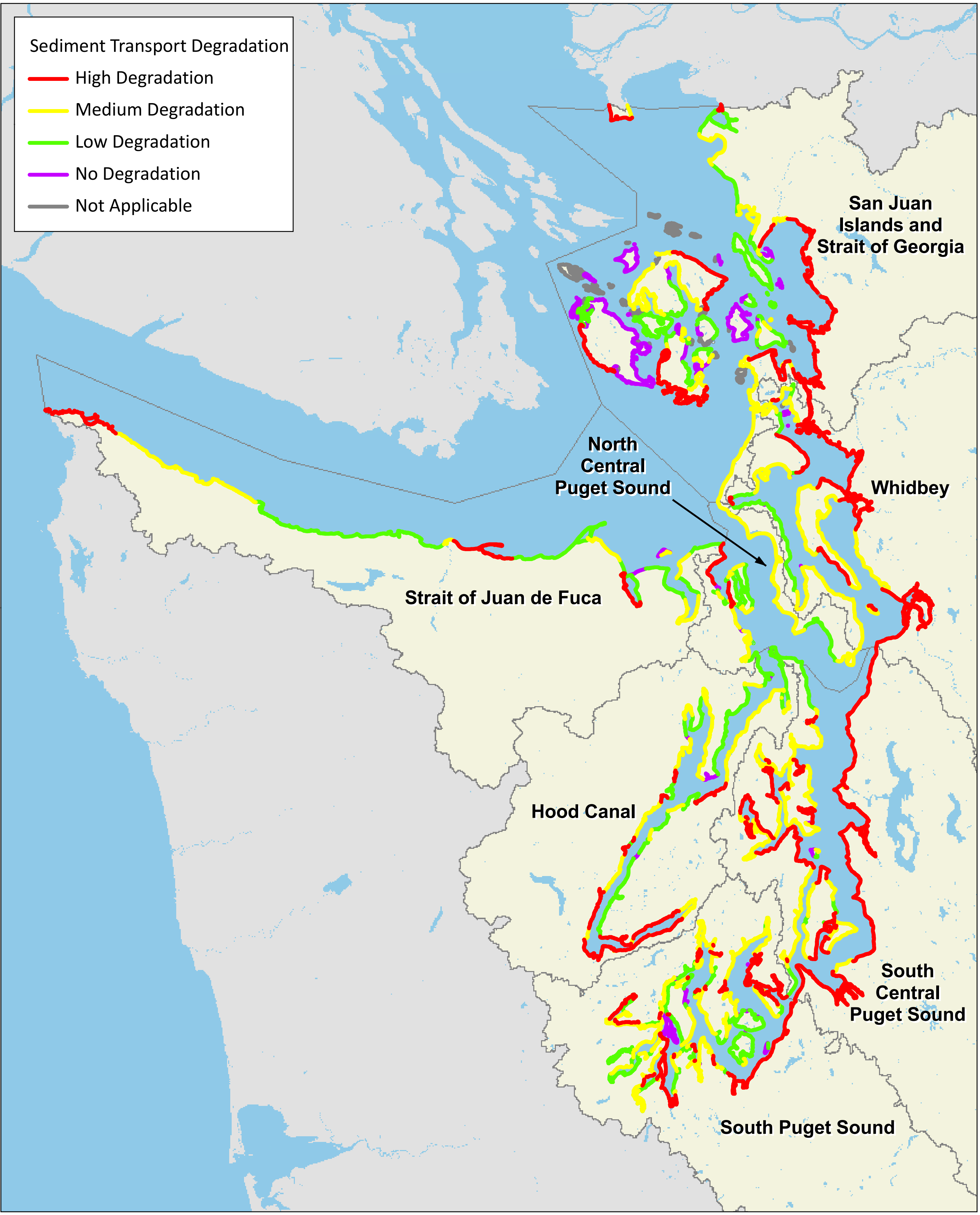

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Figure D-3

Sediment Transport
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

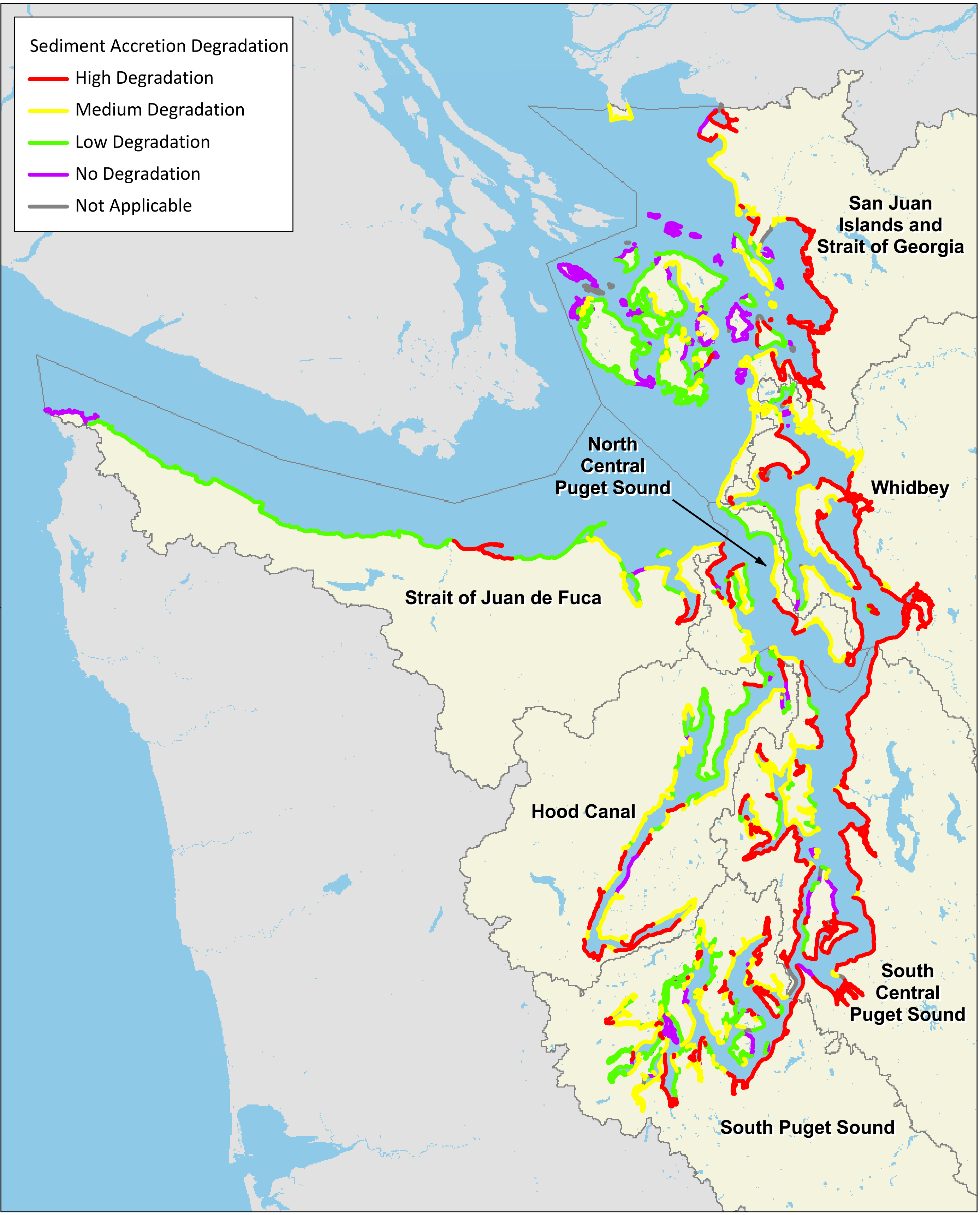

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Figure D-4
Sediment Erosion and Accretion
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

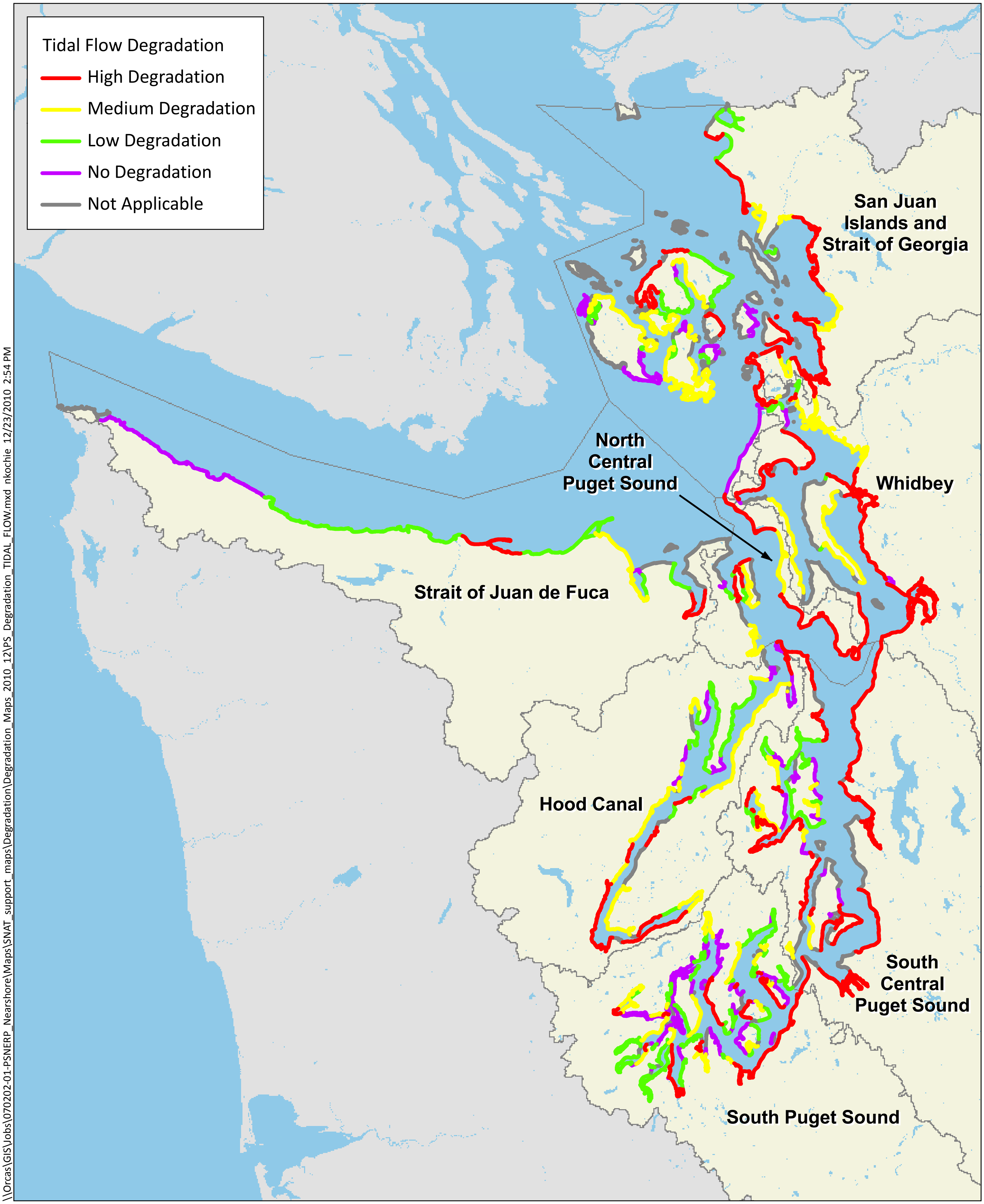

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Figure D-5
Tidal Flow
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

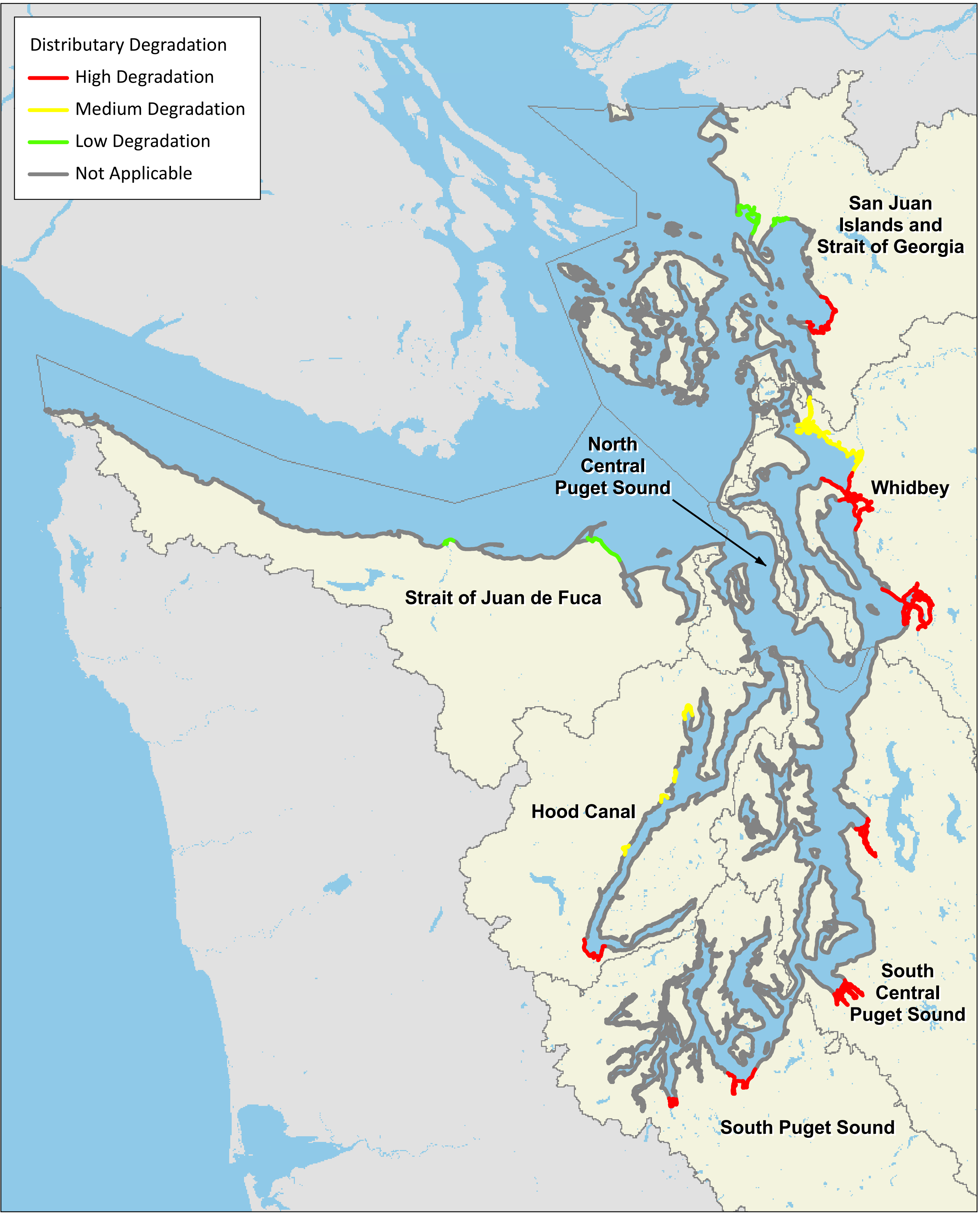

Figure D-6
Distributary Channel Migration
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

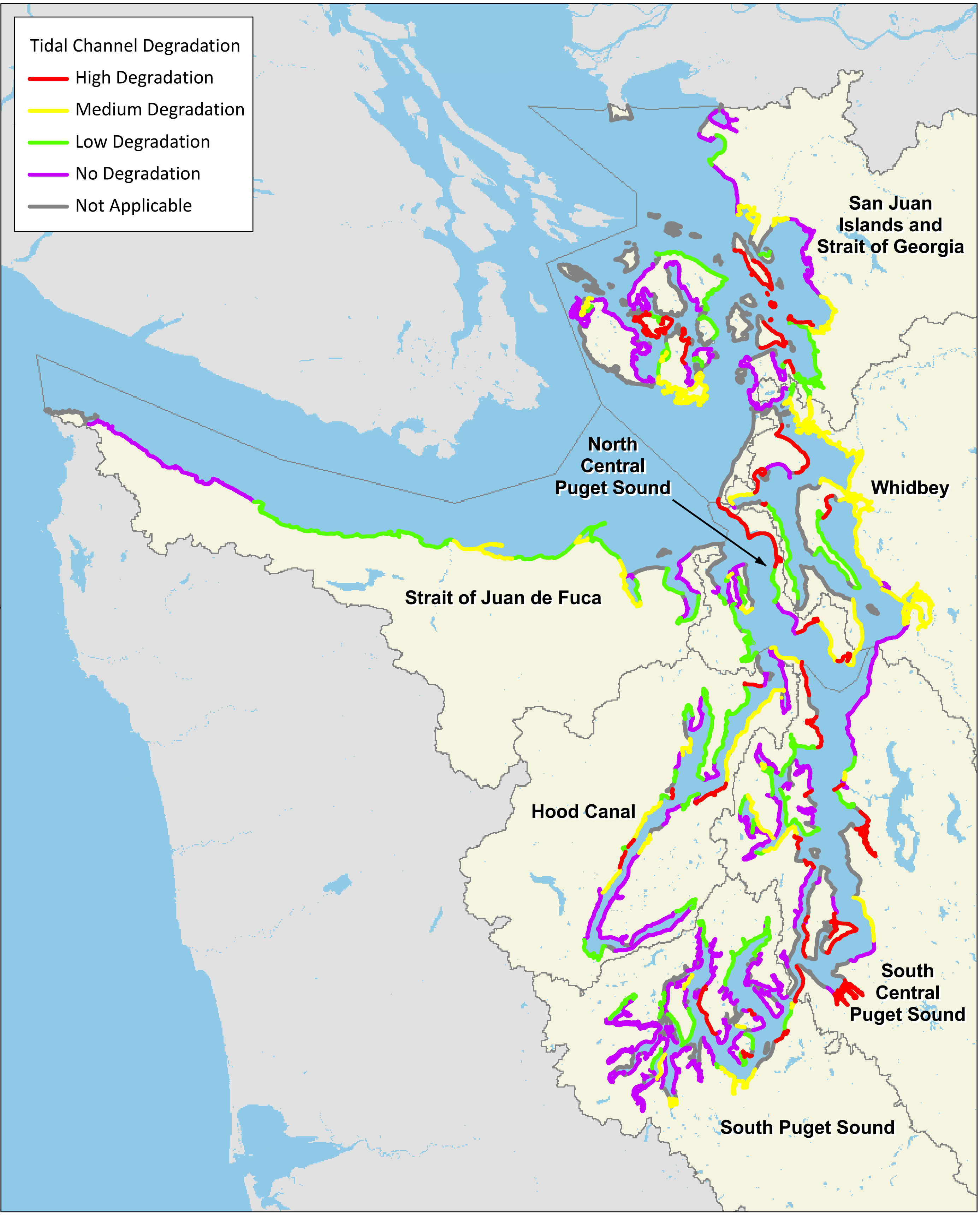

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Figure D-7
Tidal Channel Formation and Maintenance
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

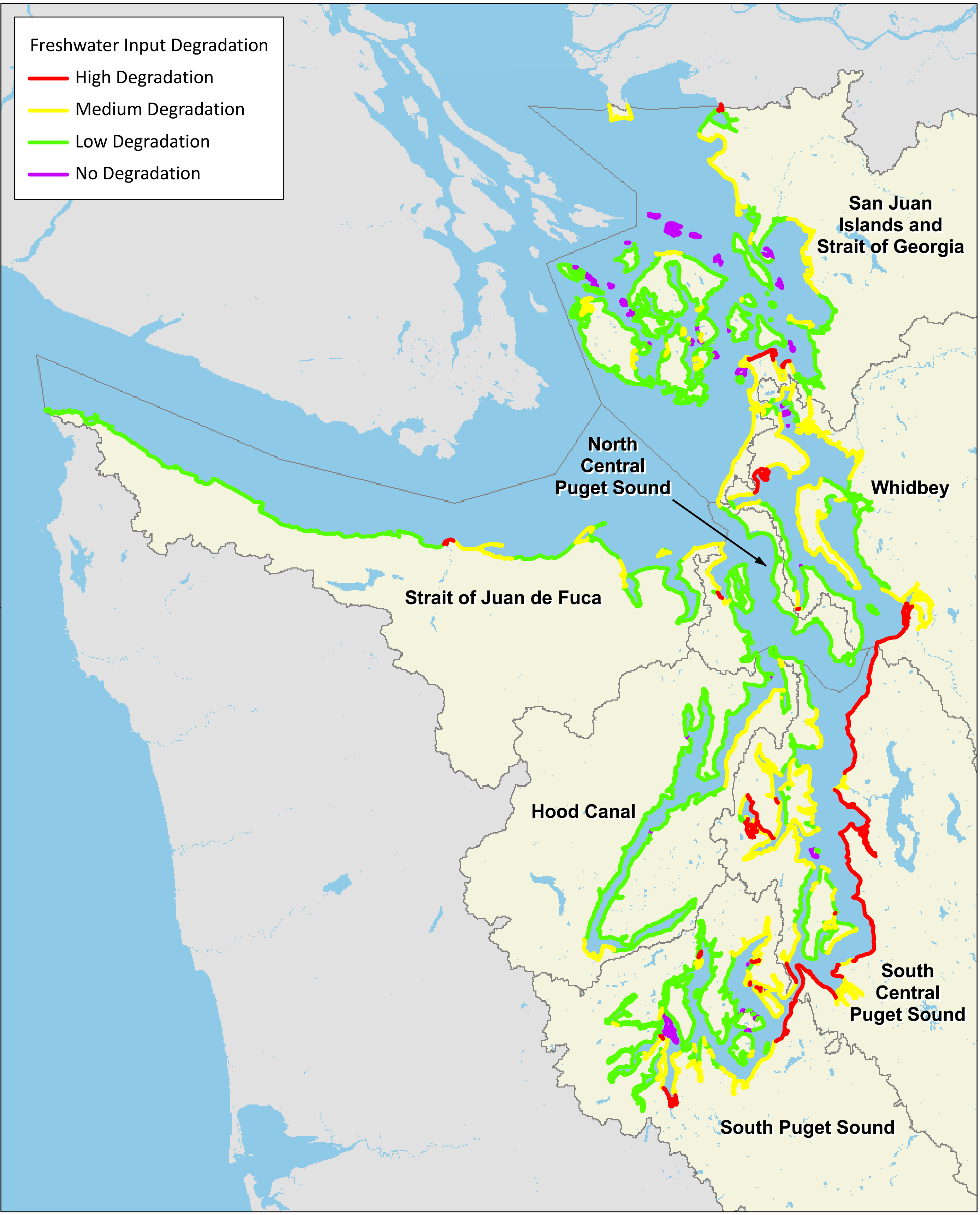

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Figure D-8
Freshwater Input
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

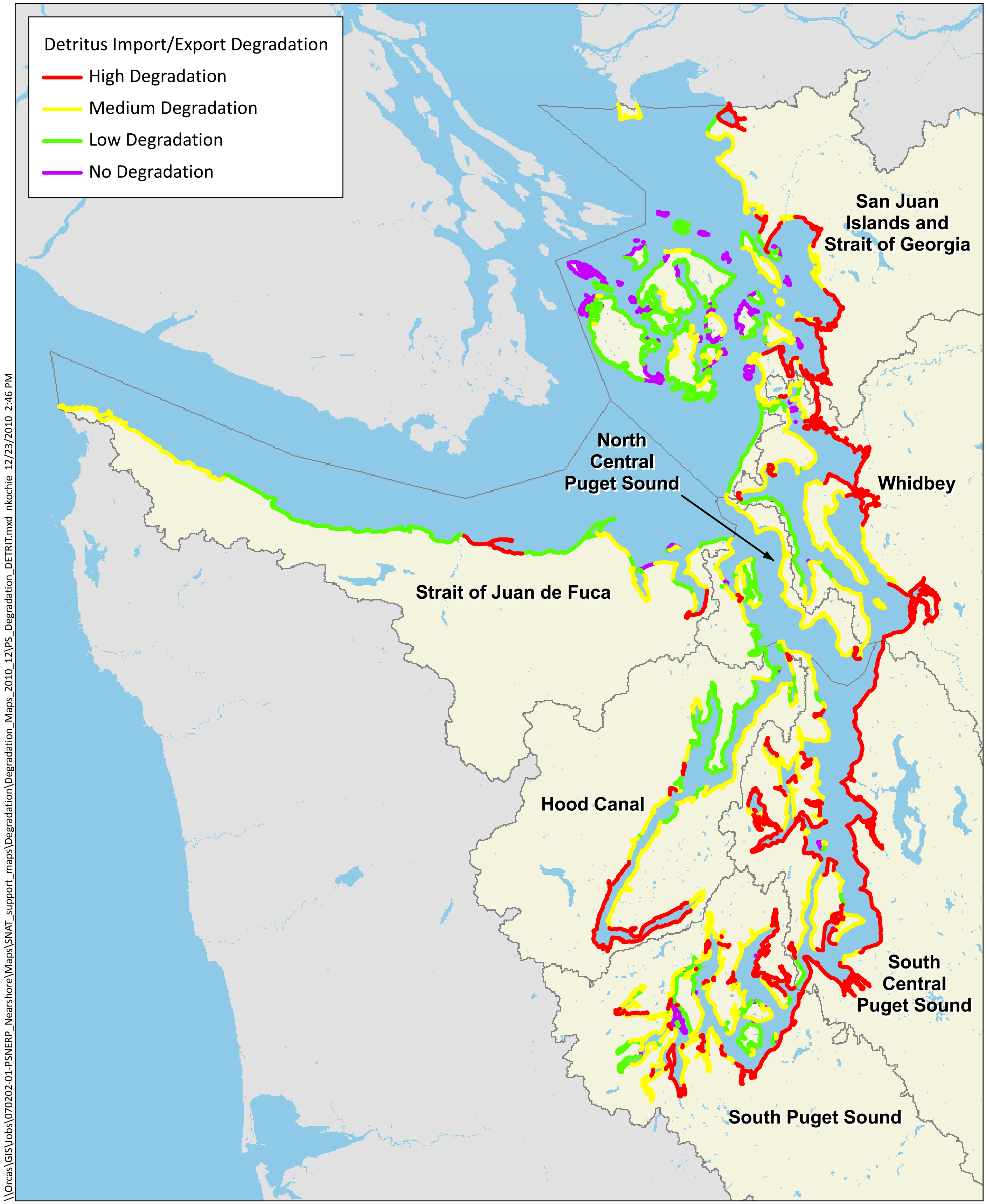

Figure D-9

Detritus Import and Export
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

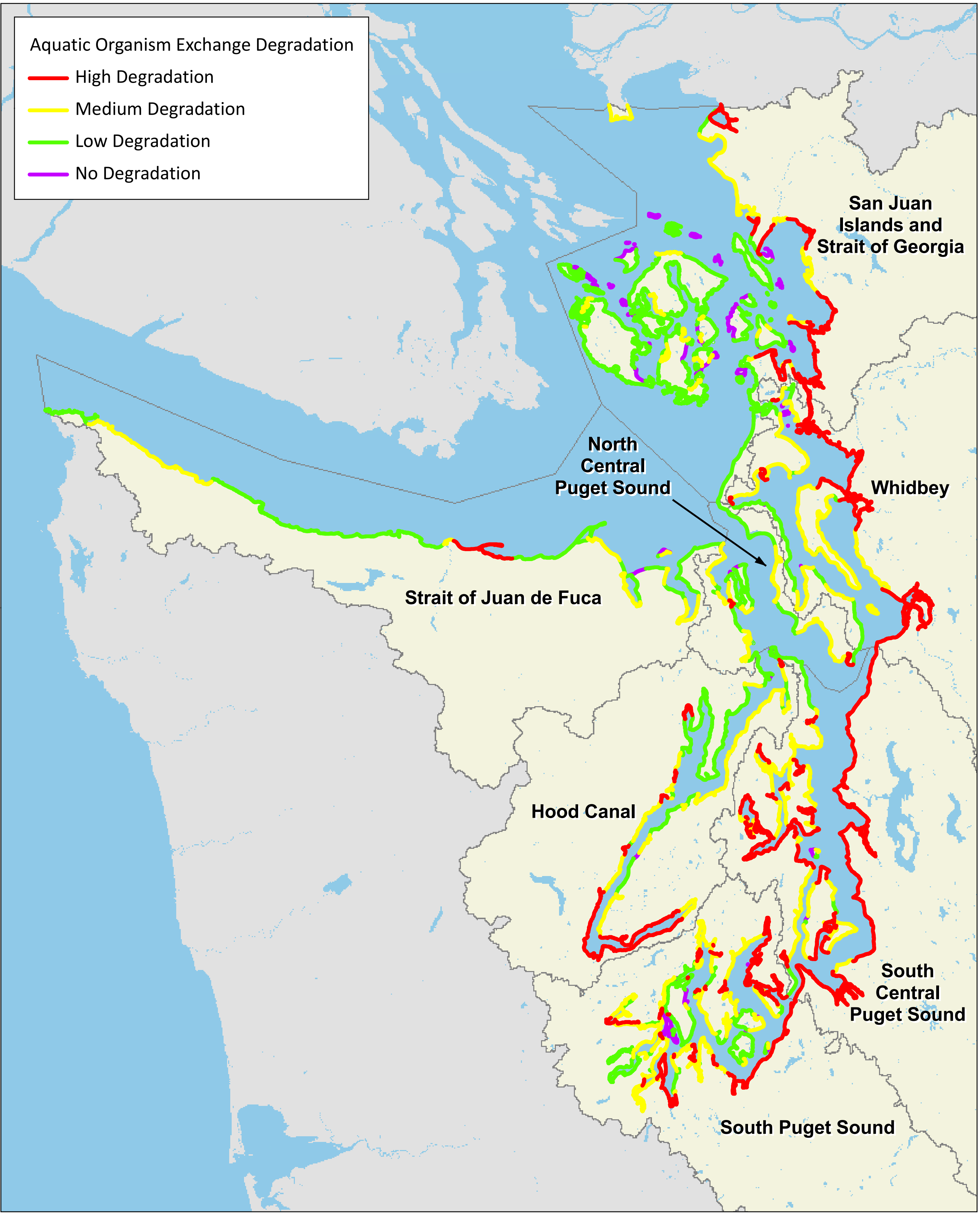

Figure D-10

Exchange of Aquatic Organisms Degradation by Process Unit

Nearshore Process Evaluation Framework Results

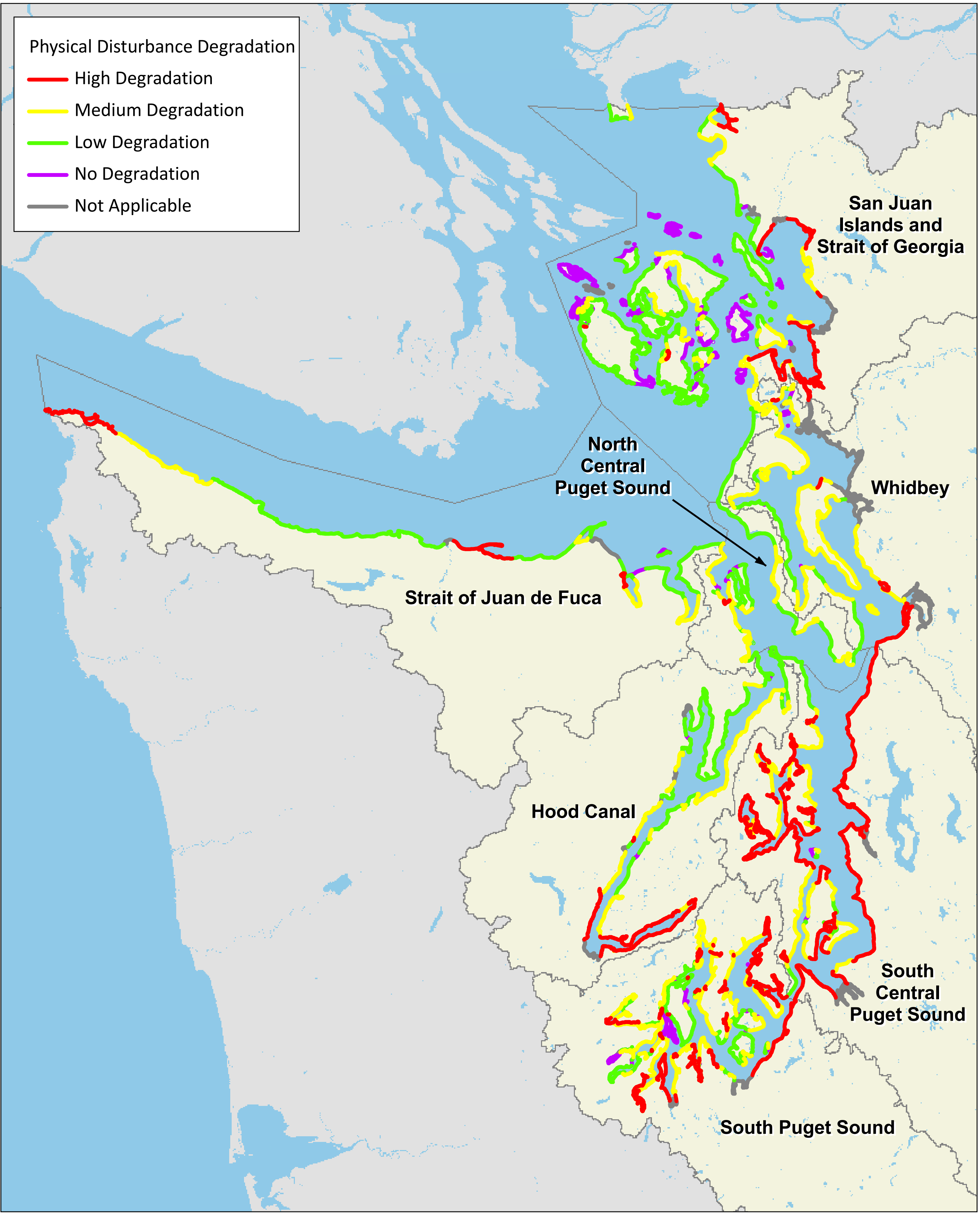

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Figure D-11
Physical Disturbance
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

\\Orcas\GIS\Jobs\070202-01-PSNERP_Nearshore\Maps\SNAT_support_maps\Degradation\Degradation_Maps_2010_12\PS_Degradation_SOLAR.mxd nkochie 12/23/2010 2:54 PM

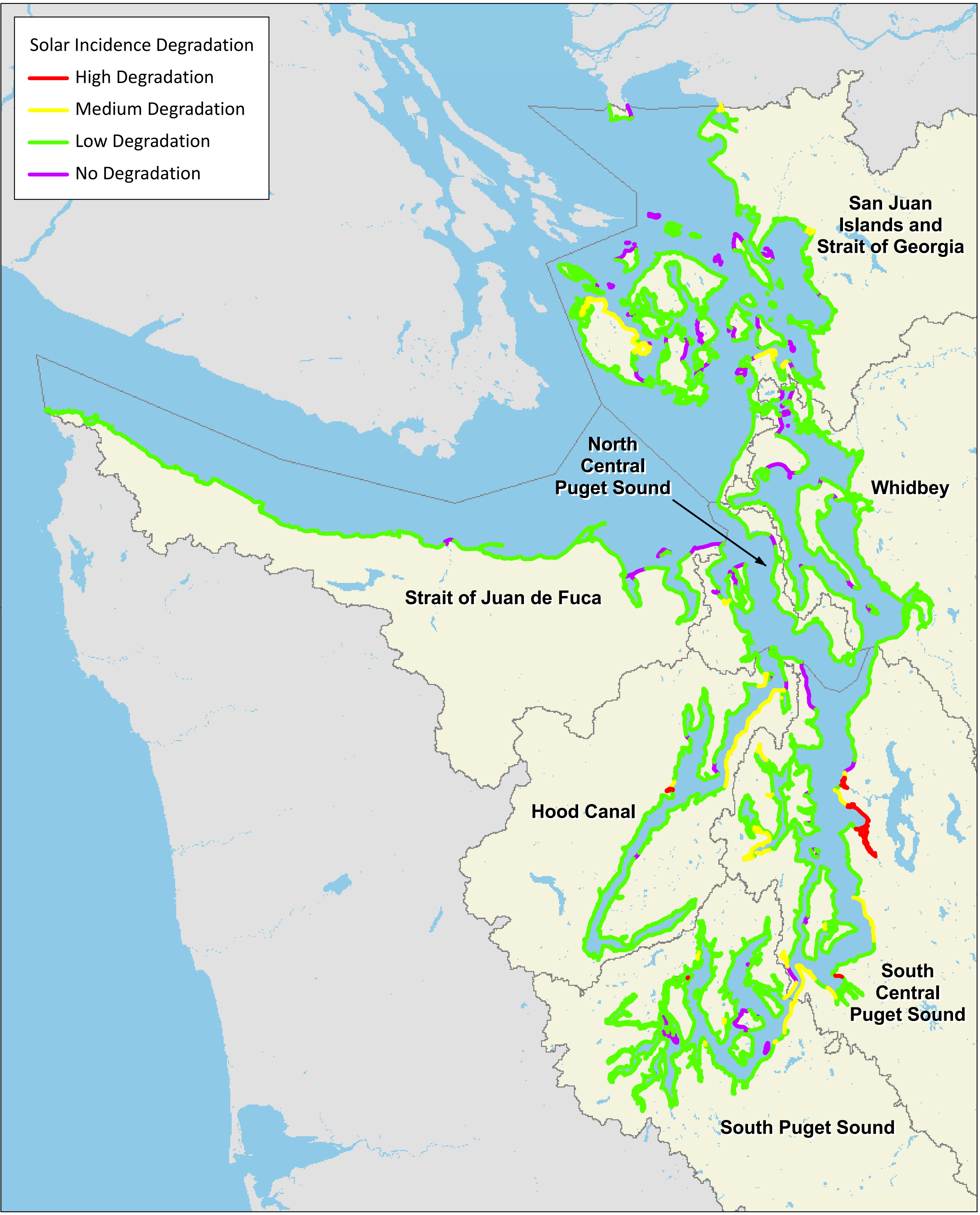


Figure D-12
Solar Incidence
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

APPENDIX E

TABLE OF DEGRADATION CATEGORIES ASSIGNED TO EACH PROCESS UNIT

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
Deschutes DPU	SP	9.0	466.3	H	H	H	H	H	M	H	H	H	N/A	L		Deschutes DPU	Most
Dosewallips DPU	HC	4.7	306.8	L	H	M	M	M	L	L	H	H	N/A	L		Dosewallips DPU	Mod.
Duckabush DPU	HC	3.9	204.0	L	H	M	M	M	L	L	H	H	N/A	L		Duckabush DPU	Mod.
Dungeness DPU	JF	11.6	563.7	L	M	M	M	L	L	L	M	M	N/A	L		Dungeness DPU	Less
Duwamish DPU	SC	32.5	1,257.0	M	H	H	H	H	H	H	H	H	N/A	H		Duwamish DPU	Most
Elwha DPU	JF	4.1	837.9	H	M	L	L	L	L	H	L	M	N/A	N		Elwha DPU	Less
Hamma Hamma DPU	HC	5.1	222.0	L	H	M	M	M	L	L	M	H	N/A	L		Hamma Hamma DPU	Mod.
Nooksack DPU	SJ	40.5	2,083.8	L	M	M	M	L	M	L	M	M	N/A	L		Nooksack DPU	Mod.
Nisqually DPU	SP	20.2	2,159.6	M	H	H	H	H	M	M	H	H	N/A	L		Nisqually DPU	More
Puyallup DPU	SC	45.7	2,535.2	M	H	H	H	H	H	M	H	H	N/A	L		Puyallup DPU	Most
Quilcene DPU	HC	8.1	295.2	L	M	M	M	M	L	L	M	H	N/A	L		Quilcene DPU	Mod.
Samish DPU	SJ	29.0	402.6	M	H	H	M	H	M	L	H	H	N/A	L		Samish DPU	More
Skagit DPU	WH	96.2	7,300.6	M	H	M	M	M	M	M	H	H	N/A	L		Skagit DPU	More
Skokomish DPU	HC	13.7	653.5	M	H	H	H	H	L	M	H	H	N/A	L		Skokomish DPU	More
Snohomish DPU	WH	95.3	4,747.7	M	H	H	H	H	M	M	H	H	N/A	L		Snohomish DPU	Most
Stillaguamish DPU	WH	65.5	1,875.5	L	H	H	H	H	M	L	H	H	N/A	L		Stillaguamish DPU	More
SPU 1008	JF	7.2	13.3	L	M	M	N/A	N/A	N	L	M	L	L	L		SPU 1008	Less
SPU 1009	JF	9.4	19.4	L	L	M	N/A	N/A	N	L	M	L	L	L		SPU 1009	Least
SPU 1010	JF	12.4	132.5	M	M	H	H	N/A	L	L	H	M	M	L		SPU 1010	More
SPU 1011	JF	9.5	122.0	L	M	H	H	N/A	N	L	M	M	M	L		SPU 1011	Mod.
SPU 1012	JF	3.4	9.9	L	L	M	N/A	N/A	N/A	L	L	L	L	L		SPU 1012	Least
SPU 1013	JF	7.1	25.2	L	L	L	L	N/A	L	L	L	L	L	L		SPU 1013	Less
SPU 1014	JF	4.6	16.8	N	L	M	L	N/A	L	L	M	M	L	L		SPU 1014	Less
SPU 1015	JF	6.0	7.6	N	L	M	N/A	N/A	N/A	L	M	L	L	L		SPU 1015	Less
SPU 1016	JF	6.2	8.3	N	N	N	N/A	N/A	N/A	L	N	N	N	N		SPU 1016	Least
SPU 1017	JF	5.3	4.9	L	L	L	N	N/A	N	L	L	L	L	N		SPU 1017	Least
SPU 1018	JF	8.8	67.7	M	L	L	L	N/A	L	L	M	L	M	L		SPU 1018	Less

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 1019	JF	10.8	96.1	M	H	M	M	N/A	M	L	M	M	M	L		SPU 1019	Mod.
SPU 1020	JF	7.2	38.2	M	H	M	M	N/A	M	M	M	M	H	L		SPU 1020	More
SPU 1021	JF	6.5	24.9	L	L	L	M	N/A	M	M	L	L	L	L		SPU 1021	Less
SPU 1023	JF	5.0	6.5	L	L	L	L	N/A	M	M	L	L	M	L		SPU 1023	Less
SPU 1024	JF	9.0	2.9	N/A	L	L	L	N/A	L	M	L	L	N	L		SPU 1024	Least
SPU 1025	JF	36.2	338.0	L	L	L	L	N/A	L	L	L	L	L	L		SPU 1025	Least
SPU 1026	JF	11.0	84.3	H	H	H	H	N/A	M	M	H	H	H	L		SPU 1026	Most
SPU 1027	JF	59.4	594.2	L	L	L	L	N/A	L	L	L	L	L	L		SPU 1027	Least
SPU 1028	JF	16.6	88.0	N/A	N	L	N	N/A	N	L	L	L	L	L		SPU 1028	Least
SPU 1029	JF	39.0	379.5	M	M	L	N	N/A	N	L	M	M	M	L		SPU 1029	Less
SPU 1100	JF	8.8	27.3	H	H	L	N	N/A	N	L	M	M	H	L		SPU 1100	Mod.
SPU 1101	JF	31.4	21.2	M	H	N	N/A	N/A	N/A	L	M	L	H	L		SPU 1101	Mod.
SPU 1200	JF	3.2	6.2	N	N	L	N/A	N/A	N/A	L	N	N	N	N		SPU 1200	Least
SPU 1201	JF	3.1	1.2	L	M	M	N/A	N/A	N/A	M	M	M	L	L		SPU 1201	Less
SPU 1202	JF	1.9	1.1	L	N	L	N/A	N/A	N/A	M	L	L	L	N		SPU 1202	Least
SPU 1203	JF	1.6	3.3	N	N	N	N/A	N/A	N/A	M	N	N	N	N		SPU 1203	Least
SPU 1400	JF	18.7	34.8	M	H	H	H	N/A	M	M	H	H	H	L		SPU 1400	Most
SPU 2002	HC	29.8	66.1	M	M	M	M	N/A	M	M	M	M	M	M		SPU 2002	Mod.
SPU 2003	HC	3.9	2.3	L	M	H	H	N/A	N	L	M	L	L	L		SPU 2003	Mod.
SPU 2004	HC	3.8	7.4	L	L	M	L	N/A	N	L	L	L	L	L		SPU 2004	Less
SPU 2005	HC	3.5	6.2	L	L	L	N/A	N/A	N/A	L	L	L	L	L		SPU 2005	Least
SPU 2006	HC	1.6	1.0	L	M	M	N/A	N/A	N/A	N	M	L	M	L		SPU 2006	Less
SPU 2007	HC	5.2	20.8	L	L	H	H	N/A	M	L	M	M	L	L		SPU 2007	Mod.
SPU 2008	HC	2.8	3.0	N	N	N	N/A	N/A	N	L	M	N	N	N		SPU 2008	Least
SPU 2009	HC	9.6	7.5	L	L	N	N/A	N/A	N	L	M	L	L	L		SPU 2009	Least
SPU 2010	HC	3.9	59.1	L	L	M	M	N/A	N	L	M	M	L	L		SPU 2010	Less
SPU 2011	HC	15.6	93.1	M	L	M	M	N/A	N	L	M	M	M	L		SPU 2011	Less
SPU 2013	HC	9.1	131.5	H	H	M	M	N/A	N	L	H	H	H	L		SPU 2013	More
SPU 2014	HC	2.7	1.9	H	H	H	N/A	N/A	N/A	L	H	H	H	L		SPU 2014	More
SPU 2015	HC	0.9	0.5	M	M	H	H	N/A	N	L	M	M	M	L		SPU 2015	Mod.
SPU 2016	HC	1.1	0.7	H	M	M	N/A	N/A	N/A	L	H	H	H	L		SPU 2016	More
SPU 2017	HC	1.1	0.8	H	H	H	N/A	N/A	N/A	L	H	H	H	L		SPU 2017	More
SPU 2018	HC	3.3	4.1	H	H	H	H	N/A	N	L	H	H	H	L		SPU 2018	More

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 2019	HC	1.1	2.9	H	H	H	N/A	N/A	N	L	H	H	H	L		SPU 2019	More
SPU 2020	HC	1.7	2.7	H	H	H	H	N/A	N	L	H	H	H	L		SPU 2020	More
SPU 2021	HC	0.8	0.2	H	H	H	H	N/A	N/A	L	H	H	H	L		SPU 2021	Most
SPU 2022	HC	5.5	10.7	H	H	M	L	N/A	N	L	H	H	H	L		SPU 2022	More
SPU 2023	HC	2.3	4.4	H	H	M	M	N/A	N	L	H	H	H	L		SPU 2023	More
SPU 2024	HC	10.4	116.9	N/A	M	M	M	N/A	L	L	M	M	M	L		SPU 2024	Less
SPU 2025	HC	10.4	81.2	H	M	M	M	N/A	N	L	M	M	H	L		SPU 2025	More
SPU 2026	HC	1.0	5.8	H	H	M	N/A	N/A	N	L	H	H	H	L		SPU 2026	More
SPU 2027	HC	7.4	16.4	H	H	H	H	N/A	N	L	H	H	H	L		SPU 2027	Most
SPU 2028	HC	1.3	2.4	H	M	M	H	N/A	N	L	H	H	H	L		SPU 2028	More
SPU 2029	HC	9.1	10.8	H	H	H	H	N/A	N	L	H	H	H	L		SPU 2029	Most
SPU 2030	HC	0.9	4.2	H	M	M	N/A	N/A	N/A	L	M	H	M	L		SPU 2030	Mod.
SPU 2031	HC	5.4	5.6	H	H	M	N/A	N/A	N/A	M	H	H	H	L		SPU 2031	More
SPU 2032	HC	4.9	19.4	H	M	M	H	N/A	N	L	H	H	H	L		SPU 2032	More
SPU 2034	HC	10.7	82.2	H	H	H	H	N/A	N	L	H	H	H	L		SPU 2034	Most
SPU 2035	HC	2.5	47.4	M	H	H	H	N/A	N	L	H	H	M	L		SPU 2035	More
SPU 2036	HC	6.7	18.9	M	M	M	M	N/A	M	L	H	M	M	L		SPU 2036	More
SPU 2037	HC	1.3	2.5	M	M	H	H	N/A	N	L	M	M	M	L		SPU 2037	Mod.
SPU 2038	HC	3.8	15.5	M	M	H	H	N/A	H	L	M	M	M	L		SPU 2038	More
SPU 2039	HC	2.4	21.3	L	L	L	M	N/A	H	L	L	L	L	L		SPU 2039	Least
SPU 2041	HC	1.0	2.9	H	H	M	N/A	N/A	N/A	L	M	M	H	L		SPU 2041	Mod.
SPU 2042	HC	13.4	47.3	M	M	M	M	N/A	M	L	M	M	M	L		SPU 2042	Mod.
SPU 2047	HC	3.7	5.1	L	L	M	N/A	N/A	N/A	L	M	M	L	L		SPU 2047	Less
SPU 2048	HC	3.1	2.1	L	L	M	N	N/A	N/A	L	L	M	L	H		SPU 2048	Less
SPU 2049	HC	4.0	2.8	M	L	M	N	N/A	N/A	L	L	M	M	M		SPU 2049	Less
SPU 2050	HC	4.5	9.0	M	M	L	N	N/A	N	L	M	M	M	L		SPU 2050	Less
SPU 2051	HC	1.7	0.4	N/A	L	M	N	N/A	N	L	L	L	M	L		SPU 2051	Less
SPU 2052	HC	8.8	21.0	L	M	M	L	N/A	M	L	L	L	L	L		SPU 2052	Less
SPU 2054	HC	1.9	2.2	N	N	N	N/A	N/A	N/A	N	L	L	N	N		SPU 2054	Least
SPU 2055	HC	3.7	6.3	L	L	L	N/A	N/A	N/A	L	L	L	L	L		SPU 2055	Least
SPU 2056	HC	5.6	5.4	L	L	L	L	N/A	N	L	L	L	L	L		SPU 2056	Least
SPU 2059	HC	17.9	51.4	L	L	L	N	N/A	N	L	L	L	L	L		SPU 2059	Least
SPU 2062	HC	30.7	66.7	L	M	L	L	N/A	L	L	L	L	L	L		SPU 2062	Least

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 2063	HC	8.1	6.7	L	N	L	N	N/A	N	L	L	L	L	L		SPU 2063	Least
SPU 2064	HC	4.3	4.5	L	L	L	N	N/A	N	L	L	L	L	N		SPU 2064	Least
SPU 2065	HC	28.4	68.1	L	L	L	L	N/A	L	L	L	L	L	L		SPU 2065	Least
SPU 2066	HC	4.7	28.9	M	M	H	M	N/A	H	L	M	M	M	L		SPU 2066	More
SPU 2067	HC	6.6	4.5	L	L	L	N	N/A	N	L	L	L	L	M		SPU 2067	Least
SPU 2068	HC	3.8	2.8	L	L	N	N	N/A	N/A	L	L	L	L	L		SPU 2068	Least
SPU 2069	HC	1.6	0.6	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 2069	None
SPU 2071	HC	3.1	2.5	L	L	N/A	N/A	N/A	N/A	L	L	M	L	L		SPU 2071	Least
SPU 2072	HC	4.2	24.7	L	L	N	N	N/A	N	L	L	L	L	L		SPU 2072	Least
SPU 2073	HC	4.9	30.5	M	M	L	N	N/A	N	L	M	M	M	L		SPU 2073	Less
SPU 2074	HC	3.2	6.7	L	L	N	N	N/A	N	L	L	L	L	L		SPU 2074	Least
SPU 2075	HC	3.0	6.4	L	L	N	N	N/A	N	L	L	L	L	N		SPU 2075	Least
SPU 2076	HC	7.1	9.6	L	L	H	H	N/A	N	L	M	M	L	L		SPU 2076	Mod.
SPU 2077	HC	4.9	2.2	L	L	L	N	N/A	N	L	L	L	L	L		SPU 2077	Least
SPU 2080	HC	3.8	15.7	M	L	L	N	N/A	N	L	M	M	M	L		SPU 2080	Less
SPU 2081	HC	8.2	21.6	L	L	L	L	N/A	L	L	L	L	L	L		SPU 2081	Less
SPU 2082	HC	3.1	16.0	M	L	M	L	N/A	L	L	M	M	M	L		SPU 2082	Less
SPU 2083	HC	1.4	16.8	M	M	H	H	N/A	M	L	M	M	M	L		SPU 2083	Mod.
SPU 2084	HC	5.0	127.1	H	H	M	M	N/A	N	L	H	H	H	L		SPU 2084	More
SPU 2088	HC	11.4	73.1	M	H	M	M	N/A	H	L	M	M	M	L		SPU 2088	More
SPU 2098	HC	2.6	1.4	L	L	L	M	N/A	H	L	L	L	L	L		SPU 2098	Less
SPU 2099	HC	3.6	2.4	L	L	H	H	N/A	N	M	H	H	L	L		SPU 2099	Mod.
SPU 2100	HC	1.5	1.5	H	M	N/A	N/A	N/A	N/A	L	H	H	H	L		SPU 2100	More
SPU 3001	SP	4.2	6.0	H	M	H	H	N/A	M	H	H	H	H	M		SPU 3001	Most
SPU 3002	SP	10.2	11.6	H	H	H	H	N/A	L	H	H	H	H	M		SPU 3002	Most
SPU 3003	SP	3.0	242.9	H	M	H	H	N/A	H	H	H	H	H	L		SPU 3003	Most
SPU 3004	SP	5.9	249.9	H	H	H	H	N/A	H	H	H	H	H	L		SPU 3004	Most
SPU 3005	SP	0.7	2.0	H	H	H	H	N/A	N/A	M	H	H	H	M		SPU 3005	Most
SPU 3006	SP	9.3	129.1	H	H	H	H	N/A	N/A	M	H	H	H	L		SPU 3006	Most
SPU 3007	SP	1.0	0.9	M	L	N	N/A	N/A	N/A	M	L	L	L	L		SPU 3007	Less
SPU 3008	SP	1.7	4.7	M	M	L	L	N/A	M	M	M	M	M	L		SPU 3008	Mod.
SPU 3009	SP	3.9	11.2	L	L	M	M	N/A	M	M	M	M	L	L		SPU 3009	Less
SPU 3010	SP	2.6	6.6	M	M	L	L	N/A	L	L	M	M	M	L		SPU 3010	Less

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 3011	SP	1.6	2.5	H	M	L	L	N/A	L	L	M	M	H	L		SPU 3011	Mod.
SPU 3012	SP	0.9	1.4	M	M	M	N	N/A	N	L	H	H	M	L		SPU 3012	Mod.
SPU 3013	SP	2.0	2.7	M	H	M	N	N/A	N	L	H	H	H	L		SPU 3013	Mod.
SPU 3014	SP	3.3	3.4	H	M	L	N	N/A	N	M	M	M	H	L		SPU 3014	Mod.
SPU 3015	SP	1.4	2.0	M	L	L	N	N/A	N	L	L	L	M	N		SPU 3015	Less
SPU 3016	SP	3.2	2.3	M	M	L	N	N/A	N	L	M	M	M	L		SPU 3016	Less
SPU 3017	SP	0.6	0.4	M	M	H	N	N/A	N	M	M	M	M	M		SPU 3017	Mod.
SPU 3018	SP	1.5	0.7	M	M	M	N	N/A	N	M	M	M	M	L		SPU 3018	Mod.
SPU 3019	SP	5.4	3.9	M	M	H	N/A	N/A	N/A	L	M	M	M	L		SPU 3019	Mod.
SPU 3020	SP	1.3	1.5	M	M	M	N	N/A	N/A	L	M	M	H	L		SPU 3020	Mod.
SPU 3021	SP	1.2	1.5	H	M	L	N	N/A	N/A	L	M	M	H	L		SPU 3021	Mod.
SPU 3022	SP	0.4	0.3	M	L	N	N	N/A	N/A	L	L	L	M	L		SPU 3022	Least
SPU 3023	SP	0.9	2.1	N	N	N	N	N/A	N/A	M	N	L	N	L		SPU 3023	Least
SPU 3024	SP	17.0	105.5	L	M	M	M	N/A	N	M	M	M	L	L		SPU 3024	Less
SPU 3025	SP	16.9	105.2	H	M	M	M	N/A	N	M	M	M	H	L		SPU 3025	Mod.
SPU 3026	SP	0.3	0.2	M	H	N/A	N/A	N/A	N/A	N	H	H	H	N		SPU 3026	Mod.
SPU 3027	SP	0.2	0.3	L	M	N/A	N/A	N/A	N/A	N	M	M	M	L		SPU 3027	Less
SPU 3028	SP	5.5	7.3	H	L	H	H	N/A	N/A	L	H	H	H	L		SPU 3028	More
SPU 3029	SP	1.8	1.2	H	H	M	N/A	N/A	N/A	M	H	H	H	L		SPU 3029	More
SPU 3030	SP	0.9	1.0	H	H	M	L	N/A	N/A	L	H	H	H	L		SPU 3030	More
SPU 3031	SP	2.0	1.0	M	M	M	L	N/A	N/A	L	M	M	M	L		SPU 3031	Mod.
SPU 3032	SP	3.3	2.1	M	L	N	N	N/A	N/A	L	L	L	M	L		SPU 3032	Least
SPU 3033	SP	6.0	3.9	M	L	L	L	N/A	N	L	M	M	M	L		SPU 3033	Less
SPU 3034	SP	1.6	1.9	M	M	L	N	N/A	N/A	M	M	M	M	N		SPU 3034	Less
SPU 3035	SP	1.6	1.3	M	M	M	L	N/A	N	M	M	M	H	L		SPU 3035	Mod.
SPU 3036	SP	0.7	0.5	H	H	H	N	N/A	N/A	M	H	H	H	L		SPU 3036	More
SPU 3037	SP	4.4	2.3	M	M	M	N	N/A	N	M	M	M	M	L		SPU 3037	Less
SPU 3038	SP	3.1	6.8	N	N	N	N	N/A	N	L	M	L	N	L		SPU 3038	Least
SPU 3039	SP	8.4	14.0	M	L	L	L	N/A	N	M	M	L	M	L		SPU 3039	Less
SPU 3040	SP	1.4	3.6	N	N	L	L	N/A	N/A	M	N	N	N	N		SPU 3040	Least
SPU 3041	SP	2.0	6.4	H	M	L	L	N/A	N/A	M	M	M	M	L		SPU 3041	Mod.
SPU 3042	SP	1.4	1.7	H	H	N/A	N/A	N/A	N/A	H	H	H	H	L		SPU 3042	More
SPU 3043	SP	3.5	5.1	H	H	H	H	N/A	N/A	H	H	H	H	L		SPU 3043	Most

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 3044	SP	1.0	2.5	H	H	M	N	N/A	N/A	M	H	H	H	L		SPU 3044	More
SPU 3045	SP	0.6	2.2	M	M	M	N	N/A	N/A	M	M	M	M	L		SPU 3045	Mod.
SPU 3046	SP	7.7	5.1	H	H	H	H	N/A	N	M	H	H	H	L		SPU 3046	More
SPU 3047	SP	6.5	4.1	H	H	M	L	N/A	M	M	H	H	H	L		SPU 3047	More
SPU 3048	SP	1.0	9.1	M	M	N	N	N/A	N/A	M	M	M	H	L		SPU 3048	Less
SPU 3049	SP	25.3	76.8	M	L	M	L	N/A	N	L	M	M	M	L		SPU 3049	Mod.
SPU 3050	SP	22.7	65.6	H	M	M	L	N/A	N	L	M	M	H	L		SPU 3050	Mod.
SPU 3051	SP	0.9	0.5	H	H	N/A	N/A	N/A	N/A	L	H	H	H	L		SPU 3051	More
SPU 3052	SP	1.1	0.8	H	H	N/A	N/A	N/A	N/A	L	H	H	H	L		SPU 3052	More
SPU 3053	SP	0.3	0.5	H	H	N/A	N/A	N/A	N/A	L	H	H	H	L		SPU 3053	Mod.
SPU 3054	SP	2.9	5.6	H	M	M	N	N/A	N	L	M	M	H	L		SPU 3054	Mod.
SPU 3055	SP	2.8	5.2	H	M	L	L	N/A	N	L	M	M	H	L		SPU 3055	Mod.
SPU 3056	SP	2.0	1.4	M	H	N	N/A	N/A	N/A	L	M	M	M	L		SPU 3056	Mod.
SPU 3057	SP	0.8	0.3	M	M	M	L	N/A	N	L	M	M	M	N		SPU 3057	Mod.
SPU 3058	SP	1.7	5.4	M	M	L	L	N/A	N	L	M	L	M	L		SPU 3058	Less
SPU 3059	SP	1.5	5.2	L	L	N	N	N/A	N/A	L	L	L	L	N		SPU 3059	Least
SPU 3060	SP	5.9	6.1	M	M	L	L	N/A	L	L	M	M	M	L		SPU 3060	Less
SPU 3061	SP	2.1	3.0	M	L	L	N	N/A	N	L	L	L	M	L		SPU 3061	Less
SPU 3062	SP	4.4	2.7	M	H	M	M	N/A	N	M	M	M	M	L		SPU 3062	More
SPU 3063	SP	0.2	0.5	M	L	N	N	N/A	N/A	H	L	L	M	N		SPU 3063	Less
SPU 3064	SP	0.9	0.3	H	H	H	N/A	N/A	N/A	H	H	H	H	L		SPU 3064	More
SPU 3065	SP	4.4	2.3	M	M	L	N	N/A	N	M	M	M	M	L		SPU 3065	Mod.
SPU 3066	SP	0.5	0.3	H	M	L	N	N/A	N/A	L	M	M	H	L		SPU 3066	Mod.
SPU 3067	SP	0.7	1.1	L	L	N	N	N/A	N	L	L	L	L	L		SPU 3067	Least
SPU 3068	SP	0.4	0.2	L	L	L	N	N/A	N	M	L	L	L	L		SPU 3068	Least
SPU 3069	SP	0.8	1.3	L	L	N	N	N/A	N	M	L	L	L	N		SPU 3069	Least
SPU 3070	SP	2.2	2.8	L	L	L	L	N/A	N	L	L	L	L	L		SPU 3070	Least
SPU 3071	SP	2.4	1.5	M	M	L	N	N/A	N	M	M	M	M	L		SPU 3071	Less
SPU 3072	SP	1.6	1.3	M	M	L	N/A	N/A	N/A	L	M	M	M	L		SPU 3072	Less
SPU 3073	SP	1.6	1.4	L	L	M	H	N/A	N	L	M	L	L	L		SPU 3073	Less
SPU 3074	SP	1.2	0.8	N	N	N	N	N/A	N/A	L	N	L	N	L		SPU 3074	Least
SPU 3075	SP	4.8	6.1	L	L	M	M	N/A	N	L	M	L	L	L		SPU 3075	Less
SPU 3076	SP	2.2	3.4	M	L	L	N	N/A	N/A	L	M	L	M	L		SPU 3076	Less

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 3077	SP	9.4	82.5	L	L	L	L	N/A	N	L	L	L	L	L		SPU 3077	Least
SPU 3078	SP	5.9	8.8	L	M	L	L	N/A	N/A	L	L	L	L	L		SPU 3078	Less
SPU 3079	SP	1.8	2.4	N	L	N	N/A	N/A	N/A	L	N	L	N	L		SPU 3079	Least
SPU 3080	SP	0.8	0.5	L	L	H	N/A	N/A	N/A	L	M	L	L	L		SPU 3080	Less
SPU 3081	SP	1.2	0.7	M	M	H	N/A	N/A	N/A	L	M	M	M	L		SPU 3081	Mod.
SPU 3082	SP	5.8	3.9	M	L	L	L	N/A	N/A	L	L	L	M	L		SPU 3082	Less
SPU 3083	SP	12.8	61.7	N/A	L	L	L	N/A	N	L	L	L	N	L		SPU 3083	Least
SPU 3084	SP	12.1	74.4	N/A	L	L	L	N/A	N	L	L	L	N/A	L		SPU 3084	Least
SPU 3085	SP	4.8	12.3	L	L	L	L	N/A	N	L	M	L	L	L		SPU 3085	Least
SPU 3086	SP	10.6	9.3	M	M	M	M	N/A	N	L	M	M	M	L		SPU 3086	Less
SPU 3087	SP	12.6	85.3	M	M	M	N	N/A	N	L	M	M	M	L		SPU 3087	Less
SPU 3088	SP	1.3	1.2	M	M	N/A	N/A	N/A	N/A	M	M	M	M	L		SPU 3088	Mod.
SPU 3089	SP	0.2	0.1	N	N	N/A	N/A	N/A	N/A	N	N	N	N	N		SPU 3089	None
SPU 3090	SP	4.9	161.0	H	M	H	H	N/A	N	L	H	H	H	L		SPU 3090	More
SPU 3091	SP	3.7	160.7	H	L	H	H	N/A	N	L	H	H	H	L		SPU 3091	More
SPU 3092	SP	10.9	117.9	M	H	M	M	N/A	L	L	M	M	M	L		SPU 3092	Less
SPU 3093	SP	6.5	87.5	L	L	L	L	N/A	N	L	L	L	L	L		SPU 3093	Least
SPU 3094	SP	5.3	20.3	N	L	M	M	N/A	N	L	M	M	N	L		SPU 3094	Less
SPU 3095	SP	7.5	21.9	M	M	M	M	N/A	N	L	M	M	M	L		SPU 3095	Less
SPU 3096	SP	6.6	7.3	H	H	M	N	N/A	N	L	H	H	H	L		SPU 3096	Mod.
SPU 3097	SP	1.5	3.2	M	M	L	N	N/A	N	L	M	M	M	L		SPU 3097	Less
SPU 3098	SP	1.0	0.4	M	M	N/A	N/A	N/A	N/A	L	M	M	M	L		SPU 3098	Less
SPU 3099	SP	0.8	0.6	M	M	N/A	N/A	N/A	N/A	L	M	M	M	L		SPU 3099	Less
SPU 3100	SP	4.0	6.1	N	L	M	M	N/A	N	L	M	L	L	L		SPU 3100	Less
SPU 3101	SP	1.6	0.9	L	L	H	H	N/A	N/A	L	L	L	L	L		SPU 3101	Mod.
SPU 3102	SP	2.0	1.8	H	M	L	N	N/A	N/A	L	M	M	M	L		SPU 3102	Mod.
SPU 3103	SP	0.6	0.5	H	H	N	N	N/A	N/A	M	H	H	H	L		SPU 3103	Mod.
SPU 3104	SP	1.1	1.1	H	H	M	M	N/A	L	M	H	H	H	L		SPU 3104	More
SPU 3105	SP	0.4	0.1	H	L	L	L	N/A	L	L	M	M	H	L		SPU 3105	Mod.
SPU 3106	SP	2.3	0.5	H	M	M	L	N/A	L	M	H	H	H	L		SPU 3106	More
SPU 3107	SP	2.1	2.1	M	L	M	L	N/A	N	L	M	M	L	L		SPU 3107	Less
SPU 3108	SP	6.4	6.5	M	M	L	L	N/A	L	L	M	M	M	L		SPU 3108	Less
SPU 3109	SP	1.6	3.6	M	L	L	N	N/A	N/A	L	L	L	M	L		SPU 3109	Least

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 3110	SP	3.1	8.8	M	M	L	N	N/A	N/A	L	M	M	M	L		SPU 3110	Less
SPU 3111	SP	0.9	5.5	N/A	N	L	N	N/A	N/A	L	L	L	M	L		SPU 3111	Least
SPU 3112	SP	2.6	4.9	M	M	L	N	N/A	N/A	L	M	M	M	L		SPU 3112	Less
SPU 3113	SP	0.9	4.2	N	N	N	N	N/A	N/A	L	N	L	N	L		SPU 3113	Least
SPU 3114	SP	0.6	1.2	N	N	N	N	N/A	N/A	L	N	N	N	N		SPU 3114	Least
SPU 3115	SP	0.5	1.2	N	N	N	N	N/A	N/A	L	N	N	N	N		SPU 3115	Least
SPU 3116	SP	0.5	0.2	N	N	N	N	N/A	N/A	N	N	N	N	N		SPU 3116	None
SPU 3117	SP	0.5	0.2	N	N	N	N	N/A	N/A	L	N	N	N	N		SPU 3117	Least
SPU 3118	SP	5.9	6.8	L	L	L	N	N/A	N/A	L	L	L	L	L		SPU 3118	Least
SPU 3119	SP	0.9	1.2	N	N	N	N	N/A	N/A	L	N	N	N	N		SPU 3119	Least
SPU 3120	SP	4.4	3.4	L	L	L	L	N/A	N	L	M	L	L	L		SPU 3120	Least
SPU 3121	SP	2.1	2.2	N/A	L	L	N	N/A	N/A	L	L	L	N	L		SPU 3121	Least
SPU 3122	SP	0.9	0.3	H	M	M	N/A	N/A	N/A	M	M	M	M	L		SPU 3122	Mod.
SPU 3123	SP	0.7	0.1	H	H	M	N/A	N/A	N/A	L	H	H	H	L		SPU 3123	More
SPU 3124	SP	1.3	0.6	H	H	H	N	N/A	N	L	H	H	H	M		SPU 3124	More
SPU 3125	SP	1.2	0.6	N/A	H	H	N	N/A	N	L	H	H	H	M		SPU 3125	More
SPU 3126	SP	0.9	0.6	N/A	H	H	N	N/A	N/A	L	H	H	H	L		SPU 3126	Mod.
SPU 3127	SP	1.4	1.0	H	H	M	N	N/A	N/A	L	H	H	H	L		SPU 3127	More
SPU 3128	SP	6.0	6.0	H	M	L	L	N/A	N	L	M	M	M	L		SPU 3128	Mod.
SPU 3129	SP	2.5	2.8	H	M	M	M	N/A	N	L	M	M	L	L		SPU 3129	Mod.
SPU 3130	SP	6.1	128.2	H	M	L	M	N/A	N	L	M	M	M	L		SPU 3130	Mod.
SPU 3131	SP	8.3	49.3	M	M	M	M	N/A	L	L	M	M	M	L		SPU 3131	Mod.
SPU 3132	SP	4.7	51.4	H	M	L	N	N/A	N	L	M	M	M	L		SPU 3132	Less
SPU 3133	SP	2.6	50.6	M	L	L	N	N/A	N	L	L	L	M	L		SPU 3133	Less
SPU 3134	SP	0.3	0.7	H	H	N/A	N/A	N/A	N/A	L	H	H	H	L		SPU 3134	Mod.
SPU 3135	SP	2.7	1.2	H	M	M	N	N/A	N	L	M	M	M	L		SPU 3135	Mod.
SPU 3136	SP	3.6	13.2	H	H	L	N	N/A	N	L	H	H	H	L		SPU 3136	Mod.
SPU 3137	SP	7.8	16.0	M	M	L	N	N/A	N	L	M	M	M	L		SPU 3137	Mod.
SPU 3138	SP	3.3	8.0	M	L	L	N	N/A	N	L	L	L	M	L		SPU 3138	Less
SPU 3139	SP	7.7	13.0	M	L	L	N	N/A	N	L	M	L	M	L		SPU 3139	Less
SPU 3140	SP	1.4	4.0	M	H	H	H	N/A	H	L	H	H	H	L		SPU 3140	More
SPU 3141	SP	13.3	24.8	L	M	M	H	N/A	H	L	M	M	M	L		SPU 3141	Mod.
SPU 3142	SP	2.5	3.0	L	L	M	L	N/A	N	L	L	L	L	L		SPU 3142	Least

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 3143	SP	5.1	4.5	L	L	M	L	N/A	N	L	L	L	L	L		SPU 3143	Least
SPU 3144	SP	2.3	1.2	N	L	L	N	N/A	N	L	M	L	L	L		SPU 3144	Least
SPU 3145	SP	0.7	0.9	N	N	N	N	N/A	N	L	N	N	N	N		SPU 3145	Least
SPU 3146	SP	4.4	2.6	M	M	M	L	N/A	N	L	M	M	M	L		SPU 3146	Less
SPU 3147	SP	2.5	1.7	H	M	M	L	N/A	N/A	L	M	M	H	L		SPU 3147	Mod.
SPU 3148	SP	2.3	7.5	H	M	L	L	N/A	N	L	M	M	H	L		SPU 3148	Less
SPU 3149	SP	1.9	7.4	M	M	L	L	N/A	N	L	M	M	H	M		SPU 3149	Less
SPU 3150	SP	2.0	3.7	H	M	L	N	N/A	N/A	L	M	M	H	L		SPU 3150	Mod.
SPU 3151	SP	3.8	5.1	M	L	L	N	N/A	N/A	L	M	M	M	L		SPU 3151	Less
SPU 3152	SP	2.4	1.2	L	L	L	N/A	N/A	N/A	L	L	L	L	L		SPU 3152	Least
SPU 3153	SP	3.2	2.9	M	M	L	N/A	N/A	N/A	L	M	M	M	L		SPU 3153	Less
SPU 3154	SP	1.4	0.4	L	L	N	N/A	N/A	N/A	L	L	L	L	L		SPU 3154	Least
SPU 3155	SP	0.5	0.3	M	M	N	N/A	N/A	N/A	L	M	M	M	N		SPU 3155	Less
SPU 3156	SP	1.5	1.5	L	L	L	N	N/A	N	L	L	L	L	L		SPU 3156	Least
SPU 3157	SP	2.8	2.6	M	M	H	N	N/A	N	L	M	M	M	L		SPU 3157	Mod.
SPU 3158	SP	1.2	0.8	N	L	M	H	N/A	N/A	N	N	N	N	N		SPU 3158	Less
SPU 3159	SP	0.3	0.3	H	M	N	N/A	N/A	N/A	L	M	M	M	N		SPU 3159	Less
SPU 3160	SP	2.1	4.0	M	M	M	N	N/A	N	L	M	M	M	L		SPU 3160	Less
SPU 3161	SP	4.2	5.1	H	M	M	N	N/A	N	L	M	M	M	L		SPU 3161	Mod.
SPU 3162	SP	2.4	11.8	H	H	H	L	N/A	N/A	L	H	H	H	L		SPU 3162	More
SPU 3163	SP	3.1	12.2	H	H	H	M	N/A	N	L	H	H	H	L		SPU 3163	Most
SPU 3164	SP	9.7	17.5	H	M	M	M	N/A	L	L	M	M	M	L		SPU 3164	Mod.
SPU 3165	SP	1.5	9.5	M	M	H	M	N/A	N	M	M	M	M	L		SPU 3165	Mod.
SPU 3166	SP	0.4	0.1	H	M	N	N	N/A	N	N	M	M	H	L		SPU 3166	Less
SPU 3167	SP	1.0	0.3	L	L	N	N	N/A	N	L	L	L	L	L		SPU 3167	Least
SPU 3168	SP	15.3	53.8	M	M	M	L	N/A	L	M	M	M	M	L		SPU 3168	Mod.
SPU 3169	SP	2.0	0.9	H	M	H	N/A	N/A	L	M	H	H	H	L		SPU 3169	More
SPU 3170	SP	6.3	32.2	H	L	H	N	N/A	N	M	H	H	H	L		SPU 3170	More
SPU 3171	SP	15.9	56.2	H	M	H	L	N/A	L	M	H	H	H	L		SPU 3171	More
SPU 3172	SP	3.5	5.0	H	H	H	M	N/A	N	M	H	H	H	L		SPU 3172	More
SPU 3173	SP	2.4	4.7	H	H	H	M	N/A	N	M	H	H	H	L		SPU 3173	More
SPU 3174	SP	0.5	0.2	H	H	N/A	N/A	N/A	N/A	M	H	H	H	L		SPU 3174	More
SPU 3175	SP	0.3	0.1	H	H	N/A	N/A	N/A	N	H	H	H	H	L		SPU 3175	More

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 3176	SP	2.0	1.4	H	H	H	L	N/A	N	M	H	H	H	L		SPU 3176	More
SPU 3177	SP	3.1	6.8	H	H	H	L	N/A	N	M	H	H	H	L		SPU 3177	More
SPU 3178	SP	0.6	0.4	H	H	N/A	N/A	N/A	N/A	M	H	H	H	L		SPU 3178	More
SPU 3179	SP	3.1	3.3	H	H	M	M	N/A	N	L	H	H	H	L		SPU 3179	Mod.
SPU 3180	SP	3.6	2.2	H	H	H	L	N/A	N/A	M	H	H	H	L		SPU 3180	More
SPU 3181	SP	5.3	1.7	H	H	M	L	N/A	N	M	H	H	M	L		SPU 3181	More
SPU 3182	SP	1.5	0.3	M	M	L	N	N/A	N/A	M	M	M	M	L		SPU 3182	Less
SPU 3183	SP	0.7	0.2	H	H	L	N	N/A	N/A	H	H	H	H	L		SPU 3183	More
SPU 3184	SP	0.4	0.1	H	H	N/A	N/A	N/A	N/A	H	H	H	H	L		SPU 3184	More
SPU 3185	SP	0.5	0.6	H	H	H	N/A	N/A	N/A	M	H	H	H	L		SPU 3185	More
SPU 3186	SP	0.9	1.0	H	H	M	H	N/A	N	M	H	H	H	L		SPU 3186	Most
SPU 3187	SP	5.4	7.0	H	H	M	N	N/A	N	M	H	H	H	L		SPU 3187	More
SPU 3188	SP	6.9	19.6	H	H	M	L	N/A	N	M	H	H	H	L		SPU 3188	More
SPU 3189	SP	10.0	29.3	H	H	M	L	N/A	N	M	H	H	H	L		SPU 3189	More
SPU 3190	SP	1.2	0.2	M	L	N	N/A	N/A	N/A	L	M	M	M	N		SPU 3190	Less
SPU 3191	SP	1.8	0.4	N	N	N	N/A	N/A	N/A	L	N	N	N	N		SPU 3191	Least
SPU 3192	SP	2.7	0.9	N	N	L	N	N/A	N/A	L	L	L	L	N		SPU 3192	Least
SPU 3193	SP	0.2	0.1	N	N	N	N	N/A	N/A	N	N	N	N	N		SPU 3193	None
SPU 3194	SP	0.7	0.4	N/A	N	N	N	N/A	N/A	N	N	N	N	N		SPU 3194	None
SPU 3195	SP	2.2	0.9	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3195	None
SPU 3196	SP	2.4	1.4	N	N	N	N	N/A	N	N	N	N	N	L		SPU 3196	Least
SPU 3197	SP	2.5	1.3	N	N	N	N	N/A	N	N	N	N	N	L		SPU 3197	Least
SPU 3198	SP	4.0	1.7	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3198	None
SPU 3199	SP	4.5	2.9	N	N	N	N	N/A	N/A	N	N	N	N	L		SPU 3199	Least
SPU 3200	SP	1.4	0.7	N	N	N	N	N/A	N	N	N	N	N	L		SPU 3200	Least
SPU 3201	SP	1.7	1.3	N	N	N	N	N/A	N/A	N	N	L	N	L		SPU 3201	Least
SPU 3202	SP	0.8	0.4	N	N	N	N	N/A	N/A	N	N	L	N	L		SPU 3202	Least
SPU 3203	SP	3.3	1.7	N	N	N	N	N/A	N/A	N	N	N	N	N		SPU 3203	None
SPU 3204	SP	4.2	1.8	N	N	N	N	N/A	N	N	N	N	N	N		SPU 3204	None
SPU 3205	SP	1.2	0.8	N	N	N	N	N/A	N	N	L	N	N	N		SPU 3205	None
SPU 3206	SP	1.4	0.8	N	N	N	N	N/A	N	N	N	N	N	N		SPU 3206	None
SPU 3207	SP	1.2	0.5	N	N	N	N	N/A	N	N	L	N	N	N		SPU 3207	None
SPU 3208	SP	10.1	17.0	M	L	L	L	N/A	L	L	L	L	L	L		SPU 3208	Less

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 3209	SP	0.6	3.0	H	H	M	L	N/A	L	L	H	H	H	N		SPU 3209	More
SPU 3210	SP	9.4	6.4	L	L	L	N	N/A	N	L	L	L	L	L		SPU 3210	Least
SPU 3211	SP	2.8	1.3	L	L	L	N	N/A	N/A	L	L	L	L	L		SPU 3211	Least
SPU 3212	SP	6.9	7.5	N	M	L	N	N/A	N	L	M	L	L	L		SPU 3212	Least
SPU 3213	SP	0.4	0.2	H	H	H	N	N/A	N	L	H	H	H	H		SPU 3213	More
SPU 3214	SP	1.1	0.2	L	L	M	N/A	N/A	N/A	L	L	L	L	L		SPU 3214	Least
SPU 3215	SP	4.5	2.3	L	L	M	L	N/A	M	L	L	L	L	L		SPU 3215	Less
SPU 3216	SP	1.0	1.8	N	N	N/A	N/A	N/A	N/A	L	N	L	N	L		SPU 3216	Least
SPU 3217	SP	3.3	3.0	N	N	N	N	N/A	N	L	L	N	N	L		SPU 3217	Least
SPU 3218	SP	2.5	2.2	N	N	N	N/A	N/A	N/A	L	N	N	N	L		SPU 3218	Least
SPU 3219	SP	0.8	4.1	M	L	N/A	N/A	N/A	N/A	L	M	M	M	L		SPU 3219	Less
SPU 3220	SP	1.0	4.4	M	L	M	M	N/A	N	L	M	M	M	L		SPU 3220	Less
SPU 3221	SP	10.3	11.6	L	M	M	M	N/A	L	L	M	L	L	L		SPU 3221	Less
SPU 3222	SP	2.5	1.1	M	M	M	L	N/A	N/A	M	M	M	M	L		SPU 3222	Mod.
SPU 3223	SP	0.6	0.1	N	M	M	N/A	N/A	N/A	M	M	M	M	L		SPU 3223	Less
SPU 3224	SP	0.7	0.2	M	M	N	N	N/A	N	M	M	M	M	L		SPU 3224	Less
SPU 3225	SP	2.3	0.8	M	M	L	N	N/A	N	M	M	M	M	L		SPU 3225	Mod.
SPU 3226	SP	0.9	0.2	H	H	H	N	N/A	N	H	H	H	H	L		SPU 3226	Most
SPU 3227	SP	2.8	0.9	H	H	H	N	N/A	N	H	H	H	H	L		SPU 3227	Most
SPU 3228	SP	0.6	0.4	H	H	M	N	N/A	N/A	L	H	H	H	L		SPU 3228	More
SPU 3229	SP	2.1	0.8	M	M	M	N/A	N/A	N	L	M	M	M	L		SPU 3229	Less
SPU 3230	SP	2.4	0.5	L	L	L	N	N/A	N	L	L	L	L	L		SPU 3230	Least
SPU 3231	SP	1.1	0.5	H	H	M	N	N/A	N/A	L	H	H	H	L		SPU 3231	More
SPU 3232	SP	4.6	5.3	L	L	L	H	N/A	N/A	L	L	L	L	N		SPU 3232	Less
SPU 3233	SP	1.4	2.1	N	L	L	H	N/A	N/A	N	L	L	L	N		SPU 3233	Less
SPU 3234	SP	0.8	0.5	N	N	N/A	N/A	N/A	N	N	N	N	N	N		SPU 3234	None
SPU 3235	SP	1.0	2.0	N	N	N	N	N/A	N	L	N	L	N	N		SPU 3235	Least
SPU 3236	SP	1.5	1.4	L	L	H	M	N/A	H	N	L	L	L	L		SPU 3236	Less
SPU 3237	SP	0.6	1.0	N	L	H	M	N/A	H	L	L	L	L	L		SPU 3237	Less
SPU 3238	SP	1.9	1.5	M	L	M	M	N/A	N	N	M	M	M	L		SPU 3238	Less
SPU 3239	SP	5.8	6.0	M	L	L	L	N/A	N	L	M	M	M	L		SPU 3239	Less
SPU 3240	SP	1.7	0.7	M	L	N/A	N/A	N/A	N/A	N	M	M	M	L		SPU 3240	Less
SPU 3241	SP	1.1	0.6	L	L	N/A	N/A	N/A	N/A	N	M	L	L	N		SPU 3241	Least

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 3242	SP	0.6	0.2	L	N	N/A	N/A	N/A	N/A	N	L	L	L	N		SPU 3242	Least
SPU 3243	SP	1.9	4.3	L	L	M	H	N/A	M	L	M	L	L	N		SPU 3243	Less
SPU 3244	SP	0.1	0.0	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3244	None
SPU 3245	SP	0.1	0.0	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3245	None
SPU 3246	SP	0.1	0.0	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3246	None
SPU 3247	SP	0.2	0.0	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3247	None
SPU 3248	SP	0.5	0.1	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3248	None
SPU 3249	SP	0.4	0.1	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3249	None
SPU 3250	SP	0.2	0.1	N	N	N/A	N/A	N/A	N/A	N	N	N	N	N		SPU 3250	None
SPU 3251	SP	0.2	0.0	N	N	N/A	N/A	N/A	N/A	N	N	N	N	N		SPU 3251	None
SPU 3252	SP	0.2	0.0	N	N	N/A	N/A	N/A	N/A	N	N	N	N	N		SPU 3252	None
SPU 3253	SP	0.3	0.2	N	N	N/A	N/A	N/A	N/A	N	N	N	N	N		SPU 3253	None
SPU 3254	SP	0.3	0.4	N	N	N/A	N/A	N/A	N/A	L	N	N	N	N		SPU 3254	Least
SPU 3255	SP	0.2	0.0	N	N	N/A	N/A	N/A	N/A	L	N	N	N	N		SPU 3255	Least
SPU 3256	SP	5.1	3.7	L	L	L	N	N/A	N	L	L	L	L	L		SPU 3256	Least
SPU 3257	SP	2.4	1.6	L	L	L	N	N/A	N/A	L	L	L	L	L		SPU 3257	Least
SPU 3258	SP	7.8	3.7	L	L	L	N	N/A	N	L	L	L	L	L		SPU 3258	Least
SPU 3259	SP	1.3	0.4	L	L	L	N	N/A	N	L	L	L	L	L		SPU 3259	Least
SPU 3260	SP	1.0	0.4	N	N	N	N	N/A	N	L	L	L	N	L		SPU 3260	Least
SPU 3261	SP	2.0	0.6	M	M	M	L	N/A	L	L	M	M	M	L		SPU 3261	Less
SPU 3262	SP	4.5	6.3	L	L	L	M	N/A	L	L	L	L	L	L		SPU 3262	Least
SPU 3263	SP	3.3	1.6	N	L	L	M	N/A	H	L	L	L	N	L		SPU 3263	Least
SPU 3264	SP	4.7	2.4	L	L	L	M	N/A	H	L	L	L	M	L		SPU 3264	Less
SPU 3265	SP	2.1	3.5	L	L	N	N/A	N/A	N/A	M	L	L	L	L		SPU 3265	Least
SPU 3266	SP	1.9	0.7	L	L	N	N/A	N/A	N/A	L	L	L	L	L		SPU 3266	Least
SPU 3267	SP	4.8	2.8	L	L	N	L	N/A	L	L	L	L	L	L		SPU 3267	Least
SPU 3268	SP	0.2	0.2	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3268	None
SPU 3269	SP	0.3	0.2	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3269	None
SPU 3270	SP	2.4	1.0	H	H	M	N/A	N/A	N/A	M	H	H	H	L		SPU 3270	More
SPU 3271	SP	1.6	0.7	H	H	M	N/A	N/A	N/A	H	H	H	H	L		SPU 3271	More
SPU 3272	SP	1.4	0.5	M	M	M	N	N/A	N/A	L	M	M	M	L		SPU 3272	Mod.
SPU 3273	SP	0.5	0.2	H	H	N	N	N/A	N/A	M	H	H	H	L		SPU 3273	More
SPU 3274	SP	2.1	1.1	H	H	H	H	N/A	N/A	H	H	H	H	L		SPU 3274	Most

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 3275	SP	0.7	0.3	H	H	N/A	N/A	N/A	N/A	M	H	H	H	L		SPU 3275	More
SPU 3276	SP	2.0	1.0	H	H	H	M	N/A	N	M	H	H	H	L		SPU 3276	Most
SPU 3277	SP	1.8	0.9	H	H	H	M	N/A	N	M	H	H	H	L		SPU 3277	Most
SPU 3278	SP	0.4	1.3	M	H	H	N	N/A	N/A	M	H	H	M	L		SPU 3278	Mod.
SPU 3279	SP	0.4	1.3	H	H	M	N	N/A	N	M	H	H	H	N		SPU 3279	More
SPU 3280	SP	0.2	0.1	H	H	H	N	N/A	N	M	H	H	H	N		SPU 3280	More
SPU 3281	SP	0.8	0.3	H	H	L	N	N/A	N	M	H	H	H	L		SPU 3281	More
SPU 3282	SP	1.1	0.9	H	H	M	N	N/A	N	M	H	H	H	L		SPU 3282	More
SPU 3283	SP	3.1	3.6	H	H	H	N	N/A	N/A	M	H	H	H	L		SPU 3283	More
SPU 3284	SP	1.5	1.9	H	M	L	N	N/A	N	M	M	M	H	L		SPU 3284	Less
SPU 3285	SP	5.6	3.7	M	L	L	N	N/A	N	M	L	L	M	L		SPU 3285	Less
SPU 3286	SP	5.3	3.5	L	M	H	H	N/A	N	M	M	M	M	L		SPU 3286	Mod.
SPU 3287	SP	5.0	2.4	M	M	H	H	N/A	N	M	M	M	M	L		SPU 3287	More
SPU 3288	SP	0.6	0.2	L	M	H	N/A	N/A	N/A	N	M	M	M	L		SPU 3288	Less
SPU 3289	SP	1.0	0.3	L	M	H	N/A	N/A	N/A	N	M	M	M	L		SPU 3289	Less
SPU 3290	SP	0.6	0.1	H	H	H	N/A	N/A	N/A	L	H	H	H	L		SPU 3290	Most
SPU 3291	SP	0.3	0.1	H	H	H	N/A	N/A	N/A	L	H	H	H	L		SPU 3291	More
SPU 4002	SC	4.5	11.8	H	H	H	H	N/A	L	H	H	H	H	N		SPU 4002	Most
SPU 4003	SC	3.2	0.9	H	H	H	H	N/A	M	M	H	H	H	M		SPU 4003	Most
SPU 4004	SC	5.6	1,561.7	H	H	H	H	N/A	N	M	H	H	H	H		SPU 4004	Most
SPU 4005	SC	2.5	1,562.0	H	M	H	H	N/A	N	M	H	H	H	H		SPU 4005	Most
SPU 4006	SC	2.5	2.4	H	H	M	N/A	N/A	H	M	H	H	H	L		SPU 4006	More
SPU 4007	SC	9.8	10.2	H	H	H	H	N/A	L	H	H	H	H	M		SPU 4007	Most
SPU 4008	SC	5.0	3.7	H	M	H	H	N/A	N	H	H	H	H	H		SPU 4008	Most
SPU 4009	SC	3.4	3.4	H	H	H	H	N/A	N/A	H	H	H	H	H		SPU 4009	Most
SPU 4010	SC	4.1	2.5	H	H	H	H	N/A	H	H	H	H	H	H		SPU 4010	Most
SPU 4013	SC	22.5	34.4	H	H	H	N/A	N/A	N/A	H	H	H	H	L		SPU 4013	Most
SPU 4014	SC	2.9	2.0	H	H	M	N/A	N/A	N/A	H	H	H	H	L		SPU 4014	More
SPU 4015	SC	13.8	61.6	H	H	H	H	N/A	M	H	H	H	H	M		SPU 4015	Most
SPU 4016	SC	7.8	31.9	H	H	H	H	N/A	N	H	H	H	H	L		SPU 4016	Most
SPU 4017	SC	0.7	0.4	N	M	H	H	N/A	N	M	M	L	L	L		SPU 4017	Less
SPU 4018	SC	3.8	4.8	M	M	H	N/A	N/A	N/A	M	M	M	M	L		SPU 4018	Mod.
SPU 4019	SC	1.6	1.7	L	M	H	N/A	N/A	N/A	H	M	M	M	L		SPU 4019	Mod.

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 4020	SC	1.9	2.2	M	M	M	N/A	N/A	N/A	H	M	M	M	L		SPU 4020	Mod.
SPU 4021	SC	2.0	0.6	H	H	M	N/A	N/A	N/A	H	H	H	H	L		SPU 4021	More
SPU 4022	SC	1.7	0.9	H	H	N/A	N/A	N/A	N/A	H	H	H	H	H		SPU 4022	More
SPU 4023	SC	2.1	1.6	H	H	N/A	N/A	N/A	N/A	M	H	H	H	L		SPU 4023	More
SPU 4024	SC	3.0	2.9	H	H	H	H	N/A	N	H	H	H	H	M		SPU 4024	Most
SPU 4025	SC	4.3	12.4	H	H	H	H	N/A	N/A	H	H	H	H	L		SPU 4025	Most
SPU 4026	SC	7.1	10.7	H	H	N	N/A	N/A	N/A	H	H	H	H	M		SPU 4026	More
SPU 4029	SC	4.8	4.2	L	L	N/A	N/A	N/A	N/A	H	L	L	L	N		SPU 4029	Least
SPU 4030	SC	5.5	23.3	M	M	H	M	N/A	N	M	H	H	M	M		SPU 4030	Mod.
SPU 4031	SC	5.7	23.5	H	M	H	M	N/A	N	M	H	H	H	M		SPU 4031	More
SPU 4032	SC	0.5	0.2	H	H	H	N/A	N/A	N/A	M	H	H	H	M		SPU 4032	More
SPU 4033	SC	0.9	0.1	M	M	L	N/A	N/A	N/A	M	M	M	M	L		SPU 4033	Less
SPU 4034	SC	6.7	4.4	M	M	H	N/A	N/A	N/A	M	M	M	M	L		SPU 4034	Mod.
SPU 4035	SC	2.9	2.9	M	M	H	N/A	N/A	N/A	M	M	M	M	L		SPU 4035	Mod.
SPU 4036	SC	17.5	40.0	M	M	H	H	N/A	N	L	M	M	M	L		SPU 4036	Mod.
SPU 4037	SC	2.3	1.9	H	H	M	N/A	N/A	H	M	H	H	H	L		SPU 4037	More
SPU 4038	SC	0.8	2.4	H	H	H	H	N/A	H	M	H	H	H	L		SPU 4038	Most
SPU 4039	SC	1.6	3.1	H	H	H	H	N/A	H	M	H	H	H	L		SPU 4039	Most
SPU 4040	SC	2.3	42.3	H	H	H	N	N/A	N/A	M	H	H	H	L		SPU 4040	More
SPU 4041	SC	3.6	39.6	H	H	H	N	N/A	N/A	M	H	H	H	L		SPU 4041	More
SPU 4042	SC	4.5	9.5	H	H	H	M	N/A	H	M	M	M	H	L		SPU 4042	More
SPU 4043	SC	13.9	55.8	H	H	H	H	N/A	M	M	H	H	H	L		SPU 4043	Most
SPU 4044	SC	3.8	41.8	H	H	H	H	N/A	L	M	H	H	H	M		SPU 4044	Most
SPU 4045	SC	11.5	46.1	H	M	H	H	N/A	N	M	H	H	H	L		SPU 4045	More
SPU 4046	SC	20.2	52.2	H	M	H	H	N/A	N	M	H	H	H	M		SPU 4046	More
SPU 4047	SC	3.8	2.7	H	M	M	L	N/A	N	H	H	H	H	L		SPU 4047	More
SPU 4048	SC	4.8	1.6	M	M	M	M	N/A	L	M	M	M	M	L		SPU 4048	Mod.
SPU 4049	SC	2.5	0.6	M	M	M	M	N/A	N	H	M	M	M	L		SPU 4049	Mod.
SPU 4050	SC	0.5	0.3	N/A	H	H	H	N/A	N	M	H	H	H	L		SPU 4050	More
SPU 4051	SC	2.3	0.8	M	H	H	H	N/A	N/A	M	H	M	M	L		SPU 4051	More
SPU 4052	SC	1.2	0.3	L	M	M	M	N/A	N	H	M	M	L	N		SPU 4052	Less
SPU 4053	SC	3.5	1.9	M	M	M	M	N/A	N	H	M	M	M	L		SPU 4053	Mod.
SPU 4054	SC	3.7	1.6	H	H	M	N	N/A	N	H	H	H	H	L		SPU 4054	More

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 4055	SC	4.2	5.4	H	H	M	L	N/A	N	H	H	H	H	L		SPU 4055	More
SPU 4056	SC	2.3	1.9	M	M	M	L	N/A	N	H	M	M	M	L		SPU 4056	Mod.
SPU 4057	SC	0.8	0.3	H	H	H	H	N/A	N	M	H	H	H	L		SPU 4057	Most
SPU 4058	SC	2.6	44.2	H	M	L	L	N/A	N	L	M	M	H	L		SPU 4058	Mod.
SPU 4059	SC	3.9	47.3	H	M	L	L	N/A	N	L	M	M	H	L		SPU 4059	Mod.
SPU 4060	SC	5.9	37.0	H	H	H	H	N/A	L	M	H	H	H	L		SPU 4060	Most
SPU 4061	SC	14.9	54.3	H	H	M	M	N/A	M	H	H	H	H	L		SPU 4061	More
SPU 4062	SC	9.8	12.2	M	M	L	N	N/A	N	M	M	M	M	L		SPU 4062	Mod.
SPU 4063	SC	1.2	1.7	H	H	L	N	N/A	N	H	H	M	H	L		SPU 4063	Mod.
SPU 4064	SC	3.5	15.2	H	H	H	H	N/A	N	M	H	H	H	L		SPU 4064	Most
SPU 4065	SC	2.3	13.8	M	H	H	H	N/A	N	M	H	H	H	M		SPU 4065	Most
SPU 4066	SC	12.4	9.4	M	H	M	M	N/A	L	M	M	M	M	L		SPU 4066	Mod.
SPU 4067	SC	3.9	3.3	H	M	M	M	N/A	N	M	M	M	H	L		SPU 4067	Mod.
SPU 4068	SC	2.8	0.7	H	M	M	M	N/A	M	M	M	M	H	L		SPU 4068	More
SPU 4069	SC	2.3	1.1	H	M	M	M	N/A	M	M	M	M	M	L		SPU 4069	Mod.
SPU 4070	SC	0.9	0.9	H	M	L	L	N/A	N/A	M	M	M	H	L		SPU 4070	Mod.
SPU 4071	SC	2.5	3.1	M	M	L	L	N/A	N/A	M	M	M	M	L		SPU 4071	Mod.
SPU 4072	SC	6.9	37.9	M	M	M	L	N/A	N	M	M	M	M	L		SPU 4072	Mod.
SPU 4073	SC	6.3	21.6	H	M	H	L	N/A	N	M	H	H	H	M		SPU 4073	More
SPU 4074	SC	1.4	1.2	H	H	M	N	N/A	N/A	M	H	H	H	L		SPU 4074	More
SPU 4075	SC	7.0	13.4	M	M	M	N	N/A	N	M	M	M	M	L		SPU 4075	Mod.
SPU 4076	SC	16.5	42.1	H	M	M	L	N/A	L	L	M	M	H	L		SPU 4076	Mod.
SPU 4077	SC	16.2	43.0	M	M	M	L	N/A	L	L	M	M	M	L		SPU 4077	Less
SPU 4078	SC	10.3	15.7	M	M	H	H	N/A	H	M	M	M	M	L		SPU 4078	More
SPU 4079	SC	6.3	12.4	H	H	H	H	N/A	H	M	H	H	H	L		SPU 4079	Most
SPU 4080	SC	2.5	1.9	H	M	L	N/A	N/A	N/A	M	M	M	M	L		SPU 4080	Mod.
SPU 4081	SC	4.7	4.3	L	L	L	N/A	N/A	N/A	L	L	L	L	N		SPU 4081	Least
SPU 4082	SC	0.5	0.6	N	N	N/A	N/A	N/A	N/A	L	N	N	N	N		SPU 4082	Least
SPU 4084	SC	1.6	1.3	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 4084	None
SPU 4085	SC	1.6	0.8	L	M	M	N/A	N/A	N/A	L	M	M	M	L		SPU 4085	Less
SPU 4086	SC	2.1	1.1	N	L	M	N/A	N/A	N/A	N	L	L	L	N		SPU 4086	Least
SPU 4087	SC	2.6	0.9	N	N	N	N/A	N/A	N/A	N	N	N	N	L		SPU 4087	Least
SPU 4088	SC	0.6	0.3	M	H	N/A	N/A	N/A	N/A	L	H	H	H	N		SPU 4088	Mod.

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 4089	SC	2.2	1.7	H	H	L	N/A	N/A	N/A	M	H	H	H	L		SPU 4089	Mod.
SPU 4090	SC	2.1	1.2	H	H	M	N/A	N/A	N/A	L	H	H	H	L		SPU 4090	Mod.
SPU 4091	SC	4.0	4.0	M	M	N	N/A	N/A	N/A	L	M	M	M	L		SPU 4091	Mod.
SPU 4092	SC	2.6	4.5	M	M	N	N/A	N/A	N/A	M	M	M	M	L		SPU 4092	Less
SPU 4093	SC	4.2	2.1	L	L	N	N	N/A	N	L	L	L	L	L		SPU 4093	Least
SPU 4094	SC	0.3	0.1	H	H	N/A	N/A	N/A	N/A	H	H	H	H	N		SPU 4094	More
SPU 4095	SC	0.5	2.9	H	H	H	H	N/A	H	M	H	H	H	L		SPU 4095	Most
SPU 4096	SC	1.0	4.7	H	H	H	H	N/A	H	M	H	H	H	L		SPU 4096	Most
SPU 4097	SC	6.5	5.0	M	M	H	H	N/A	H	L	M	M	M	L		SPU 4097	More
SPU 4098	SC	9.5	5.4	M	M	H	H	N/A	H	M	M	M	M	L		SPU 4098	More
SPU 4099	SC	5.7	5.4	M	H	H	N/A	N/A	N/A	L	H	H	H	L		SPU 4099	More
SPU 4100	SC	0.9	1.5	L	M	H	N/A	N/A	N/A	L	M	M	M	L		SPU 4100	Mod.
SPU 4101	SC	3.7	6.3	L	M	H	H	N/A	H	L	M	M	L	L		SPU 4101	More
SPU 4102	SC	0.8	0.4	M	H	H	H	N/A	H	M	H	H	M	N		SPU 4102	Most
SPU 4103	SC	1.9	1.0	H	H	H	N/A	N/A	H	M	H	H	H	L		SPU 4103	Most
SPU 4104	SC	1.0	0.5	H	H	H	N/A	N/A	H	M	H	H	H	L		SPU 4104	Most
SPU 4105	SC	0.6	1.9	H	H	N/A	N/A	N/A	N/A	M	H	H	H	L		SPU 4105	More
SPU 4106	SC	0.9	0.9	H	H	N/A	N/A	N/A	N/A	M	H	H	H	L		SPU 4106	More
SPU 4107	SC	0.8	12.7	L	L	H	N	N/A	N/A	L	M	M	L	L		SPU 4107	Less
SPU 4108	SC	0.9	1.5	N	N	H	N	N/A	N/A	L	M	M	N	L		SPU 4108	Less
SPU 4109	SC	1.3	1.2	H	H	N/A	N/A	N/A	N/A	M	H	H	H	M		SPU 4109	Mod.
SPU 4110	SC	1.8	1.3	H	H	H	N/A	N/A	N/A	M	H	H	H	L		SPU 4110	More
SPU 4111	SC	0.7	0.6	H	H	H	N/A	N/A	N/A	L	H	H	H	L		SPU 4111	More
SPU 4112	SC	9.6	13.8	M	H	H	H	N/A	N/A	L	H	H	H	L		SPU 4112	More
SPU 4113	SC	1.8	5.0	H	H	H	N/A	N/A	N/A	L	H	H	H	L		SPU 4113	More
SPU 4114	SC	2.0	4.9	M	M	H	N/A	N/A	N/A	L	M	M	M	L		SPU 4114	Mod.
SPU 4115	SC	7.7	6.4	M	M	L	M	N/A	H	L	M	M	M	L		SPU 4115	Mod.
SPU 4116	SC	0.7	0.3	L	L	N/A	N/A	N/A	N/A	L	L	L	L	N		SPU 4116	Least
SPU 4117	SC	0.7	2.3	L	L	H	H	N/A	N	L	M	L	L	N		SPU 4117	Less
SPU 4118	SC	1.2	0.9	N	L	H	H	N/A	H	L	M	N	N	N		SPU 4118	Mod.
SPU 4119	SC	0.3	1.3	N	N	N/A	N/A	N/A	N/A	L	N	N	N	N		SPU 4119	Least
SPU 4120	SC	0.3	0.3	L	M	N/A	N/A	N/A	N/A	L	M	L	L	N		SPU 4120	Less
SPU 4121	SC	5.6	4.6	M	M	N	N/A	N/A	N/A	L	M	M	M	L		SPU 4121	Less

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 4122	SC	0.9	1.1	M	M	N	N/A	N/A	N/A	L	M	M	M	L		SPU 4122	Mod.
SPU 4123	SC	1.6	1.6	M	M	L	N/A	N/A	N/A	M	M	M	M	L		SPU 4123	Less
SPU 4124	SC	1.2	0.6	M	M	L	N/A	N/A	N/A	M	M	M	M	L		SPU 4124	Mod.
SPU 4125	SC	0.5	8.7	H	H	L	N	N/A	N	L	H	H	H	L		SPU 4125	Mod.
SPU 4126	SC	1.0	1.2	H	H	N	N	N/A	N	L	H	H	H	L		SPU 4126	Mod.
SPU 4127	SC	3.0	2.2	H	H	N/A	N/A	N/A	N/A	L	H	H	H	L		SPU 4127	More
SPU 4128	SC	1.3	0.8	H	H	M	N/A	N/A	N/A	L	H	H	H	L		SPU 4128	More
SPU 4129	SC	8.2	7.4	H	H	H	L	N/A	N	L	H	H	H	L		SPU 4129	More
SPU 4130	SC	6.7	6.0	M	H	H	L	N/A	N	M	H	H	M	L		SPU 4130	Mod.
SPU 4131	SC	3.3	1.8	M	M	M	N	N/A	N	L	M	M	M	L		SPU 4131	Less
SPU 4132	SC	8.7	6.7	M	M	M	N	N/A	N	M	M	M	M	L		SPU 4132	Mod.
SPU 4133	SC	2.6	8.3	M	M	M	M	N/A	H	M	M	M	M	N		SPU 4133	More
SPU 4134	SC	5.6	9.6	M	M	L	N	N/A	N/A	M	M	M	M	L		SPU 4134	Less
SPU 4135	SC	7.4	10.9	H	H	M	L	N/A	N	M	H	H	H	L		SPU 4135	More
SPU 4136	SC	8.7	10.3	H	H	M	M	N/A	N	M	H	H	H	L		SPU 4136	More
SPU 4137	SC	2.1	2.6	N/A	N	L	N	N/A	N/A	L	M	M	L	N		SPU 4137	Less
SPU 4138	SC	4.7	5.2	M	M	L	N	N/A	N/A	L	M	M	M	L		SPU 4138	Less
SPU 4139	SC	8.5	9.2	H	M	M	L	N/A	L	M	H	H	H	L		SPU 4139	Mod.
SPU 4140	SC	2.4	4.9	H	M	M	L	N/A	L	M	H	H	H	L		SPU 4140	Mod.
SPU 4141	SC	12.5	13.6	H	M	M	L	N/A	L	L	M	M	H	L		SPU 4141	Mod.
SPU 4142	SC	2.2	1.9	H	H	M	N/A	N/A	N	M	H	H	H	L		SPU 4142	More
SPU 4143	SC	1.9	1.6	H	H	L	N	N/A	N	L	H	H	H	L		SPU 4143	More
SPU 4144	SC	1.5	1.4	H	M	L	N	N/A	N	L	M	M	H	L		SPU 4144	Mod.
SPU 4145	SC	1.6	5.7	H	M	L	N	N/A	N/A	M	M	M	H	L		SPU 4145	Mod.
SPU 4146	SC	2.4	6.2	H	M	L	N	N/A	N/A	M	M	M	H	L		SPU 4146	Mod.
SPU 4147	SC	5.1	3.5	M	M	M	N/A	N/A	N/A	M	M	M	M	L		SPU 4147	Mod.
SPU 4148	SC	2.6	10.4	H	H	H	N/A	N/A	N/A	H	H	H	H	M		SPU 4148	Most
SPU 4149	SC	5.2	1.9	H	H	N/A	N/A	N/A	N/A	H	H	H	H	L		SPU 4149	More
SPU 4150	SC	2.6	4.2	H	H	H	H	N/A	H	H	H	H	H	H		SPU 4150	Most
SPU 5001	NC	8.6	9.5	N	L	M	H	N/A	M	L	M	L	L	L		SPU 5001	Mod.
SPU 5002	NC	9.7	43.4	L	L	M	M	N/A	L	L	L	L	L	L		SPU 5002	Less
SPU 5003	NC	19.6	48.8	L	M	M	M	N/A	L	L	L	M	M	L		SPU 5003	Less
SPU 5004	NC	0.7	0.9	N/A	N	L	N/A	N/A	N/A	L	L	L	L	L		SPU 5004	Least

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 5005	NC	1.9	3.0	N/A	N/A	L	N/A	N/A	N/A	L	L	L	L	L		SPU 5005	Least
SPU 5006	NC	6.2	8.4	L	M	M	N/A	N/A	L	L	M	L	M	L		SPU 5006	Less
SPU 5007	NC	3.8	3.5	L	M	M	M	N/A	M	L	M	M	M	L		SPU 5007	Less
SPU 5008	NC	12.2	10.2	L	L	L	N/A	N/A	N/A	L	L	L	L	L		SPU 5008	Least
SPU 5009	NC	1.8	1.3	L	L	L	N/A	N/A	N/A	L	L	L	L	N		SPU 5009	Least
SPU 5010	NC	3.9	3.1	N	M	H	H	N/A	N	L	M	N	N	N		SPU 5010	Less
SPU 5011	NC	4.1	3.3	L	L	M	M	N/A	N	L	L	L	L	L		SPU 5011	Less
SPU 5012	NC	10.4	10.1	L	L	M	M	N/A	L	L	L	L	L	L		SPU 5012	Less
SPU 5015	NC	4.4	5.9	L	L	L	H	N/A	N	L	M	L	L	N		SPU 5015	Less
SPU 5016	NC	1.4	0.9	L	M	H	H	N/A	M	L	M	L	L	N		SPU 5016	Mod.
SPU 5017	NC	3.2	1.2	N	L	L	L	N/A	L	L	L	L	N	L		SPU 5017	Least
SPU 5018	NC	1.1	0.7	N	N	N	N	N/A	N	L	L	N	N	N		SPU 5018	Least
SPU 5019	NC	8.2	5.0	M	H	H	H	N/A	N	L	M	M	M	L		SPU 5019	More
SPU 5020	NC	3.4	1.0	N/A	M	H	H	N/A	N	L	H	H	N	L		SPU 5020	Mod.
SPU 5021	NC	3.0	4.8	N/A	L	M	L	N/A	N	M	M	M	H	M		SPU 5021	Less
SPU 5022	NC	3.6	4.6	M	L	L	L	N/A	L	M	M	M	M	L		SPU 5022	Less
SPU 5023	NC	1.8	1.1	M	M	H	N/A	N/A	N	H	M	M	M	N		SPU 5023	Mod.
SPU 5024	NC	2.8	91.9	N	L	L	N	N/A	N	L	L	L	L	N		SPU 5024	Least
SPU 5025	NC	2.0	0.6	N	N	N	N	N/A	N	M	N	N	N	N		SPU 5025	Least
SPU 5026	NC	3.0	2.1	N	N	N	N/A	N/A	N/A	M	N	L	N	L		SPU 5026	Least
SPU 5027	NC	15.0	25.3	M	H	H	N/A	N/A	N/A	M	M	M	M	L		SPU 5027	Mod.
SPU 5029	NC	15.1	41.6	L	M	L	M	N/A	H	L	M	L	L	N		SPU 5029	Less
SPU 5030	NC	21.1	21.9	L	M	M	M	N/A	L	L	M	M	M	L		SPU 5030	Less
SPU 5031	NC	12.9	21.8	L	M	H	H	N/A	N	L	M	L	L	L		SPU 5031	Mod.
SPU 5032	NC	7.7	29.0	N	L	M	H	N/A	H	L	M	M	M	L		SPU 5032	Mod.
SPU 5033	NC	16.9	65.7	L	L	M	H	N/A	M	L	M	M	L	L		SPU 5033	Mod.
SPU 5034	NC	7.7	14.4	H	M	M	H	N/A	H	L	M	M	M	L		SPU 5034	More
SPU 5035	NC	7.0	12.4	L	M	H	H	N/A	M	L	H	H	M	L		SPU 5035	More
SPU 5036	NC	9.3	7.0	N	L	L	L	N/A	N	L	L	L	L	L		SPU 5036	Least
SPU 6002	WH	7.4	14.8	L	M	M	N/A	N/A	N/A	L	M	M	M	L		SPU 6002	Less
SPU 6003	WH	7.2	12.8	L	M	M	N/A	N/A	N/A	L	L	L	L	L		SPU 6003	Less
SPU 6004	WH	10.3	20.2	M	M	M	N/A	N/A	N/A	L	M	M	M	L		SPU 6004	Less
SPU 6005	WH	0.1	0.2	N	N	N/A	N/A	N/A	N/A	N	N	N	N	N		SPU 6005	None

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 6006	WH	0.1	0.1	N	N	N/A	N/A	N/A	N/A	N	N	N	N	N		SPU 6006	None
SPU 6007	WH	4.8	17.9	M	M	L	N/A	N/A	N/A	L	M	M	M	L		SPU 6007	Less
SPU 6008	WH	0.6	4.8	N	N	N	N/A	N/A	N/A	M	N	N	N	L		SPU 6008	Least
SPU 6009	WH	0.7	0.5	L	N	N/A	N/A	N/A	N/A	H	M	M	M	N		SPU 6009	Less
SPU 6010	WH	4.3	3.7	M	M	N	N/A	N/A	N/A	M	M	M	M	L		SPU 6010	Less
SPU 6011	WH	28.6	36.3	L	L	L	M	N/A	L	L	L	L	L	L		SPU 6011	Less
SPU 6012	WH	1.1	1.8	N	N	N	M	N/A	H	L	N	N	N	N		SPU 6012	Least
SPU 6013	WH	1.3	2.2	L	L	L	N/A	N/A	N/A	L	L	L	L	L		SPU 6013	Less
SPU 6014	WH	5.5	4.8	L	L	L	N/A	N/A	N/A	M	L	L	L	L		SPU 6014	Less
SPU 6015	WH	2.9	2.8	L	L	M	N/A	N/A	N/A	L	L	L	L	L		SPU 6015	Least
SPU 6016	WH	2.2	2.0	L	L	L	N	N/A	N	L	L	L	M	L		SPU 6016	Less
SPU 6017	WH	3.2	6.7	M	H	H	H	N/A	M	L	H	H	M	L		SPU 6017	More
SPU 6018	WH	9.0	21.1	M	L	M	H	N/A	M	M	M	M	M	L		SPU 6018	Mod.
SPU 6019	WH	10.5	19.6	L	M	M	H	N/A	H	H	M	M	L	L		SPU 6019	More
SPU 6020	WH	8.4	6.1	L	M	H	H	N/A	N/A	H	H	H	M	L		SPU 6020	More
SPU 6021	WH	3.7	4.6	M	M	N/A	N/A	N/A	N/A	H	M	M	M	L		SPU 6021	Mod.
SPU 6022	WH	7.6	33.1	M	M	H	H	N/A	N	M	M	M	M	N		SPU 6022	More
SPU 6023	WH	1.3	0.5	L	N	M	N/A	N/A	N/A	M	M	L	M	N		SPU 6023	Less
SPU 6024	WH	2.6	3.0	L	L	M	N/A	N/A	N/A	M	L	L	L	N		SPU 6024	Least
SPU 6025	WH	15.3	48.1	L	H	H	H	N/A	H	M	M	M	M	L		SPU 6025	More
SPU 6026	WH	2.7	4.7	L	L	H	N/A	N/A	H	M	M	M	M	N		SPU 6026	Mod.
SPU 6027	WH	4.3	3.5	M	L	M	N	N/A	N/A	M	M	M	M	N		SPU 6027	Less
SPU 6028	WH	2.9	4.3	L	L	L	N	N/A	N/A	L	L	L	L	L		SPU 6028	Least
SPU 6030	WH	1.5	19.8	H	H	N/A	N/A	N/A	N/A	L	H	H	H	L		SPU 6030	More
SPU 6031	WH	4.0	6.6	M	M	L	N/A	N/A	N	M	M	M	M	N		SPU 6031	Less
SPU 6032	WH	2.1	3.7	H	M	L	N/A	N/A	N	M	M	L	L	L		SPU 6032	Less
SPU 6033	WH	3.6	4.4	H	L	L	L	N/A	L	M	M	L	M	L		SPU 6033	Mod.
SPU 6034	WH	5.5	7.5	N	L	L	L	N/A	L	M	L	L	N	N		SPU 6034	Least
SPU 6035	WH	2.7	2.7	N	M	H	H	N/A	M	L	L	L	L	N		SPU 6035	Mod.
SPU 6036	WH	11.3	14.6	M	M	M	M	N/A	M	L	M	M	M	L		SPU 6036	Mod.
SPU 6037	WH	4.0	5.3	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 6037	None
SPU 6038	WH	4.0	5.3	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 6038	None
SPU 6039	WH	1.2	0.2	N/A	N/A	N/A	N/A	N/A	N/A	N	N	N	N/A	N		SPU 6039	None

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 6041	WH	2.2	8.6	H	H	H	N/A	N/A	N/A	M	H	H	H	N		SPU 6041	More
SPU 6042	WH	22.3	47.9	M	M	M	N/A	N/A	N/A	M	M	M	M	L		SPU 6042	Mod.
SPU 6043	WH	3.4	5.5	M	L	L	L	N/A	L	L	L	L	M	L		SPU 6043	Less
SPU 6044	WH	11.9	16.6	M	H	M	M	N/A	L	M	M	M	M	L		SPU 6044	Mod.
SPU 6045	WH	3.0	3.7	M	H	L	N/A	N/A	N/A	L	M	M	M	N		SPU 6045	Less
SPU 6046	WH	2.8	2.0	M	M	M	N/A	N/A	N/A	L	M	M	M	N		SPU 6046	Less
SPU 6047	WH	25.0	40.2	M	M	H	M	N/A	L	M	M	M	M	L		SPU 6047	Mod.
SPU 6048	WH	5.6	15.8	N	L	H	M	N/A	L	M	M	M	L	L		SPU 6048	Mod.
SPU 6049	WH	8.0	17.8	L	M	M	M	N/A	H	L	M	M	M	L		SPU 6049	Mod.
SPU 6050	WH	3.5	12.1	L	M	M	N/A	N/A	N/A	L	M	L	M	N		SPU 6050	Less
SPU 6051	WH	2.1	13.7	L	M	M	N/A	N/A	N/A	M	L	L	L	L		SPU 6051	Less
SPU 6052	WH	16.1	45.9	M	M	H	H	N/A	M	L	M	M	M	L		SPU 6052	More
SPU 6053	WH	5.6	66.1	M	M	M	N	N/A	N	L	M	M	H	L		SPU 6053	Mod.
SPU 6054	WH	7.9	68.8	M	M	M	N	N/A	N	L	M	M	M	L		SPU 6054	Less
SPU 6056	WH	5.2	11.1	M	M	H	N/A	N/A	N/A	M	H	H	M	L		SPU 6056	Mod.
SPU 6057	WH	0.9	0.4	L	L	L	N/A	N/A	N/A	L	L	L	L	N		SPU 6057	Least
SPU 6058	WH	3.0	1.6	M	M	L	N/A	N/A	N/A	L	M	M	M	N		SPU 6058	Less
SPU 6059	WH	2.7	2.2	M	M	H	N/A	N/A	N/A	L	M	M	M	L		SPU 6059	Mod.
SPU 6060	WH	2.7	1.2	M	H	H	N/A	N/A	N/A	L	M	M	M	L		SPU 6060	Mod.
SPU 6061	WH	8.5	6.6	M	M	M	L	N/A	N/A	L	L	L	M	L		SPU 6061	Less
SPU 6062	WH	3.6	9.3	M	M	L	L	N/A	M	L	M	M	M	N		SPU 6062	Less
SPU 7001	SJ	7.3	1.5	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7001	None
SPU 7002	SJ	30.1	5.4	N/A	N/A	N	N/A	N/A	N/A	N	L	L	N	L		SPU 7002	Least
SPU 7003	SJ	6.9	1.0	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	L		SPU 7003	Least
SPU 7004	SJ	2.0	0.4	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7004	None
SPU 7005	SJ	4.6	0.7	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7005	None
SPU 7006	SJ	1.8	0.2	N/A	N/A	N/A	N/A	N/A	N/A	N	N	N	N/A	N		SPU 7006	None
SPU 7007	SJ	6.9	4.7	N	N	N	N/A	N/A	N/A	L	N	N	N	N		SPU 7007	Least
SPU 7008	SJ	12.6	10.3	N	L	L	N/A	N/A	N/A	L	L	L	L	L		SPU 7008	Least
SPU 7009	SJ	2.5	0.3	N/A	N/A	N/A	N/A	N/A	N/A	N	N	N	N/A	N		SPU 7009	None
SPU 7010	SJ	11.4	2.5	N/A	N/A	N/A	N/A	N/A	N/A	L	L	L	N/A	L		SPU 7010	Least
SPU 7011	SJ	1.7	0.2	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7011	None
SPU 7012	SJ	0.8	0.1	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	L		SPU 7012	Least

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 7013	SJ	7.3	1.6	N	N	N	N/A	N/A	N/A	N	N	N	N	L		SPU 7013	Least
SPU 7014	SJ	5.0	0.9	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	L		SPU 7014	Least
SPU 7015	SJ	8.4	2.2	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7015	Least
SPU 7016	SJ	5.4	1.5	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7016	Least
SPU 7017	SJ	16.5	7.5	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7017	Least
SPU 7018	SJ	0.4	0.1	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7018	Least
SPU 7019	SJ	2.5	0.6	N/A	N/A	N	N/A	N/A	N/A	M	N	L	N	L		SPU 7019	Least
SPU 7020	SJ	7.5	2.4	N/A	L	M	M	N/A	M	M	L	M	M	M		SPU 7020	Less
SPU 7021	SJ	2.1	0.3	N/A	N	L	N/A	N/A	N	M	M	L	L	L		SPU 7021	Least
SPU 7022	SJ	34.1	44.8	N/A	N	L	N	N/A	N	L	L	L	L	M		SPU 7022	Least
SPU 7023	SJ	36.5	46.9	N/A	N	L	L	N/A	N	L	L	L	L	M		SPU 7023	Least
SPU 7024	SJ	8.7	10.8	N/A	N	L	N	N/A	N	M	L	L	L	L		SPU 7024	Least
SPU 7025	SJ	5.7	7.7	N/A	N/A	N	N/A	N/A	N	L	N	N	N	L		SPU 7025	Least
SPU 7026	SJ	4.5	5.3	N	N	N	N	N/A	N	L	N	N	N	N		SPU 7026	Least
SPU 7027	SJ	4.6	1.8	N	N	N	N	N/A	N	L	N	L	N	L		SPU 7027	Least
SPU 7028	SJ	19.7	14.0	N	N	N	N	N/A	N/A	L	N	L	N	L		SPU 7028	Least
SPU 7029	SJ	11.8	38.9	N/A	N/A	L	N/A	N/A	N/A	L	L	L	L	L		SPU 7029	Least
SPU 7030	SJ	22.9	59.2	N/A	N	L	N/A	N/A	N/A	L	L	L	L	L		SPU 7030	Least
SPU 7031	SJ	21.6	26.8	N	H	L	N/A	N/A	N/A	L	L	L	L	L		SPU 7031	Least
SPU 7032	SJ	0.4	0.1	N/A	N/A	L	N/A	N/A	N/A	L	L	L	L	L		SPU 7032	Least
SPU 7033	SJ	0.7	0.7	H	N	N/A	N/A	N/A	N/A	L	M	M	H	L		SPU 7033	Mod.
SPU 7034	SJ	0.4	0.2	L	L	N/A	N/A	N/A	N/A	L	L	L	L	L		SPU 7034	Least
SPU 7035	SJ	1.4	0.5	N	N	L	N	N/A	N	L	L	L	N	L		SPU 7035	Least
SPU 7036	SJ	1.8	0.6	N	N	L	N	N/A	N	L	L	L	N	L		SPU 7036	Least
SPU 7037	SJ	7.3	8.6	N/A	L	L	L	N/A	N	L	L	L	L	L		SPU 7037	Least
SPU 7038	SJ	11.1	14.1	N	L	L	L	N/A	N	L	L	L	L	L		SPU 7038	Least
SPU 7039	SJ	1.9	3.0	N	N	N	N	N/A	N	M	N	L	N	L		SPU 7039	Least
SPU 7040	SJ	4.7	2.5	N/A	N	L	L	N/A	L	M	L	L	L	L		SPU 7040	Least
SPU 7041	SJ	7.3	2.3	N/A	L	M	M	N/A	M	M	L	L	L	M		SPU 7041	Less
SPU 7042	SJ	16.3	5.7	N	N	N	N	N/A	N	L	N	L	N	L		SPU 7042	Least
SPU 7043	SJ	1.5	0.6	N	L	L	N	N/A	N	L	L	L	M	L		SPU 7043	Least
SPU 7044	SJ	0.4	0.1	N	N	N	N/A	N/A	N/A	L	N	N	N	N		SPU 7044	Least
SPU 7045	SJ	0.9	0.3	N	N	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7045	Least

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 7046	SJ	0.9	0.2	N	N	N	N	N/A	N	L	N	N	N	L		SPU 7046	Least
SPU 7047	SJ	0.5	0.2	N	N	N	N	N/A	N	N	N	N	N	N		SPU 7047	None
SPU 7048	SJ	5.2	1.0	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	L		SPU 7048	Least
SPU 7049	SJ	2.7	0.4	N/A	N/A	N	N/A	N/A	N/A	N	N	L	N	L		SPU 7049	Least
SPU 7050	SJ	1.1	0.2	N/A	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7050	None
SPU 7051	SJ	1.6	0.2	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7051	None
SPU 7052	SJ	5.0	1.3	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7052	Least
SPU 7053	SJ	34.5	18.7	M	L	L	L	N/A	L	L	L	L	L	L		SPU 7053	Less
SPU 7054	SJ	39.0	18.7	M	L	L	M	N/A	H	L	L	L	L	L		SPU 7054	Less
SPU 7055	SJ	38.3	28.0	M	M	L	H	N/A	N	L	L	L	L	L		SPU 7055	Less
SPU 7056	SJ	5.1	3.4	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7056	Least
SPU 7057	SJ	7.9	8.0	H	M	L	H	N/A	L	M	M	M	M	L		SPU 7057	Mod.
SPU 7058	SJ	29.7	31.5	N/A	H	L	L	N/A	L	L	L	L	L	L		SPU 7058	Least
SPU 7059	SJ	23.9	24.9	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7059	Least
SPU 7060	SJ	2.7	1.2	N/A	N/A	N	N/A	N/A	N/A	M	N	L	N	L		SPU 7060	Least
SPU 7061	SJ	22.6	42.7	M	M	M	M	N/A	N	L	L	L	M	L		SPU 7061	Less
SPU 7062	SJ	22.1	25.4	N/A	N	N	N	N/A	N/A	L	N	L	N	L		SPU 7062	Least
SPU 7063	SJ	19.2	19.3	N/A	L	L	L	N/A	N/A	L	L	L	L	L		SPU 7063	Least
SPU 7064	SJ	10.6	26.5	M	M	M	L	N/A	N/A	L	M	M	M	L		SPU 7064	Mod.
SPU 7065	SJ	4.4	1.6	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7065	Least
SPU 7066	SJ	1.0	0.4	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7066	Least
SPU 7067	SJ	2.3	1.4	L	L	M	H	N/A	L	L	M	M	M	L		SPU 7067	Mod.
SPU 7068	SJ	8.1	5.1	N/A	L	M	H	N/A	L	L	M	L	L	L		SPU 7068	Less
SPU 7069	SJ	4.6	3.8	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7069	Least
SPU 7070	SJ	2.5	1.1	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7070	None
SPU 7071	SJ	2.1	7.2	N/A	N/A	N	N/A	N/A	N/A	M	N	M	N	N		SPU 7071	Least
SPU 7072	SJ	1.4	0.7	N	N	M	N/A	N/A	N/A	L	L	L	M	N		SPU 7072	Least
SPU 7073	SJ	2.4	1.4	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7073	None
SPU 7074	SJ	1.7	0.8	L	L	N	N/A	N/A	N/A	L	L	L	L	N		SPU 7074	Least
SPU 7075	SJ	3.9	0.6	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	L		SPU 7075	Least
SPU 7077	SJ	11.5	5.7	N	L	L	N	N/A	N	L	L	L	L	L		SPU 7077	Least
SPU 7078	SJ	3.1	1.0	N	M	H	N	N/A	N	L	M	M	M	L		SPU 7078	Less
SPU 7079	SJ	8.0	3.0	N	N	N	N/A	N/A	N/A	L	N	N	N	N		SPU 7079	Least

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 7080	SJ	4.0	4.4	M	M	M	L	N/A	L	M	M	M	M	L		SPU 7080	Mod.
SPU 7081	SJ	3.4	1.0	N/A	N	L	N/A	N/A	N/A	M	L	L	L	L		SPU 7081	Least
SPU 7082	SJ	7.2	2.3	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7082	None
SPU 7083	SJ	5.0	1.4	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7083	Least
SPU 7084	SJ	4.7	1.7	N	N	N	N	N/A	N	L	L	N	N	L		SPU 7084	Least
SPU 7085	SJ	64.5	43.9	L	M	L	M	N/A	M	L	L	L	L	L		SPU 7085	Less
SPU 7086	SJ	64.9	43.1	L	H	L	M	N/A	L	L	L	L	L	L		SPU 7086	Less
SPU 7087	SJ	1.5	0.6	N	H	M	L	N/A	M	M	M	M	M	L		SPU 7087	Mod.
SPU 7088	SJ	4.0	1.7	L	M	M	L	N/A	M	L	M	M	L	L		SPU 7088	Mod.
SPU 7089	SJ	3.3	2.9	H	H	M	L	N/A	L	L	M	M	M	L		SPU 7089	Mod.
SPU 7090	SJ	3.0	3.3	H	H	L	L	N/A	L	L	M	M	H	L		SPU 7090	Mod.
SPU 7091	SJ	2.6	3.5	M	M	L	L	N/A	L	M	M	M	M	L		SPU 7091	Less
SPU 7092	SJ	2.9	1.1	N	L	M	N/A	N/A	N/A	L	L	L	L	N		SPU 7092	Less
SPU 7093	SJ	2.0	1.2	N	L	L	N/A	N/A	N/A	L	L	L	L	L		SPU 7093	Least
SPU 7094	SJ	6.7	5.0	L	L	L	N	N/A	N/A	L	L	L	L	L		SPU 7094	Least
SPU 7095	SJ	4.2	1.1	H	M	L	N	N/A	N/A	M	L	L	M	L		SPU 7095	Less
SPU 7096	SJ	5.4	8.3	H	M	M	M	N/A	H	L	M	M	M	L		SPU 7096	Mod.
SPU 7097	SJ	1.5	7.1	L	L	M	N/A	N/A	H	L	M	M	M	N		SPU 7097	Mod.
SPU 7098	SJ	2.5	0.7	N	L	L	M	N/A	L	L	L	L	N	N		SPU 7098	Least
SPU 7099	SJ	5.4	7.5	N	N	N	N/A	N/A	H	L	M	N	N	N		SPU 7099	Least
SPU 7100	SJ	11.0	11.5	N	L	L	N	N/A	N	L	L	L	L	L		SPU 7100	Least
SPU 7101	SJ	3.8	3.9	N	M	M	M	N/A	M	L	M	M	N	L		SPU 7101	Less
SPU 7102	SJ	1.7	0.6	N	L	M	L	N/A	L	L	M	M	N	L		SPU 7102	Less
SPU 7103	SJ	1.6	0.4	N	N	M	N	N/A	N	L	M	M	N	N		SPU 7103	Least
SPU 7104	SJ	2.7	0.4	N/A	N/A	N	N/A	N/A	N/A	N	N	L	N	L		SPU 7104	Least
SPU 7107	SJ	4.2	1.4	N	N	N	N/A	N/A	N/A	N	N	N	N	L		SPU 7107	Least
SPU 7108	SJ	2.3	0.6	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7108	None
SPU 7109	SJ	5.8	7.1	M	L	N	N/A	N/A	N/A	L	L	L	L	N		SPU 7109	Least
SPU 7110	SJ	2.8	5.1	N/A	L	L	N/A	N/A	N/A	L	L	L	L	N		SPU 7110	Least
SPU 7111	SJ	26.7	21.5	L	L	L	N/A	N/A	N/A	L	L	L	L	L		SPU 7111	Least
SPU 7112	SJ	30.7	22.2	L	L	M	N/A	N/A	H	L	M	L	L	L		SPU 7112	Less
SPU 7113	SJ	2.3	3.6	N	N	N	N/A	N/A	N/A	L	N	N	N	L		SPU 7113	Least
SPU 7114	SJ	6.0	5.0	N	L	L	N/A	N/A	N/A	L	L	L	L	L		SPU 7114	Least

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 7115	SJ	5.1	2.5	N	L	L	N/A	N/A	N/A	L	L	L	L	L		SPU 7115	Least
SPU 7116	SJ	0.7	0.4	N	N	N	N/A	N/A	N/A	M	N	N	N	N		SPU 7116	Least
SPU 7117	SJ	5.1	4.8	N/A	N	N	N/A	N/A	N/A	L	N	N	N	L		SPU 7117	Least
SPU 7118	SJ	12.5	10.0	N	N	N	N	N/A	N/A	L	N	L	N	L		SPU 7118	Least
SPU 7119	SJ	9.4	7.2	N	N	N	N	N/A	N/A	L	L	L	N	L		SPU 7119	Least
SPU 7120	SJ	5.6	3.4	N	N	N	N/A	N/A	N/A	L	L	L	N	L		SPU 7120	Least
SPU 7121	SJ	3.4	6.1	N	N	N	N/A	N/A	N/A	L	N	N	N	N		SPU 7121	Least
SPU 7122	SJ	0.9	3.5	N	N	N	N/A	N/A	N/A	L	N	N	N	N		SPU 7122	Least
SPU 7123	SJ	2.9	2.7	N	N	N	N/A	N/A	N/A	L	N	N	N	L		SPU 7123	Least
SPU 7124	SJ	4.8	4.6	N	N	N	N/A	N/A	N/A	L	N	N	N	L		SPU 7124	Least
SPU 7125	SJ	1.2	0.2	N/A	N/A	N/A	N/A	N/A	N/A	N	N	N	N/A	N		SPU 7125	None
SPU 7126	SJ	2.1	5.0	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7126	None
SPU 7127	SJ	2.6	3.9	N/A	N/A	N/A	N/A	N/A	N/A	N	N	N	N/A	N		SPU 7127	None
SPU 7128	SJ	2.3	2.0	L	N	N/A	N/A	N/A	N/A	L	L	L	L	N		SPU 7128	Least
SPU 7129	SJ	1.7	1.7	N	L	N/A	N/A	N/A	N/A	L	L	L	L	L		SPU 7129	Least
SPU 7130	SJ	1.3	1.0	N	L	N/A	N/A	N/A	N/A	L	L	L	L	L		SPU 7130	Least
SPU 7131	SJ	2.7	4.7	N	M	H	H	N/A	H	L	M	L	L	L		SPU 7131	Mod.
SPU 7132	SJ	1.2	4.3	N	M	H	H	N/A	H	L	M	M	M	N		SPU 7132	Mod.
SPU 7133	SJ	13.1	12.9	M	L	L	H	N/A	H	L	M	L	M	L		SPU 7133	Mod.
SPU 7134	SJ	2.1	2.2	N	N	N	N/A	N/A	N/A	L	N	N	N	N		SPU 7134	Least
SPU 7135	SJ	2.4	3.9	N	L	H	N/A	N/A	N/A	L	L	L	L	L		SPU 7135	Less
SPU 7136	SJ	1.6	2.8	H	M	M	N/A	N/A	N/A	L	M	M	M	L		SPU 7136	Mod.
SPU 7137	SJ	2.0	1.3	L	L	H	N/A	N/A	N/A	L	L	L	L	N		SPU 7137	Less
SPU 7138	SJ	10.4	16.6	L	H	M	N/A	N/A	N/A	M	M	M	L	L		SPU 7138	Less
SPU 7139	SJ	3.6	10.6	L	M	M	N/A	N/A	N/A	M	M	M	M	N		SPU 7139	Less
SPU 7140	SJ	6.4	6.8	H	H	N/A	N/A	N/A	N/A	H	H	H	H	M		SPU 7140	More
SPU 7141	SJ	16.9	142.0	H	L	H	L	N/A	N	L	H	H	H	L		SPU 7141	More
SPU 7142	SJ	20.2	146.5	L	L	H	L	N/A	N	L	H	H	M	L		SPU 7142	Mod.
SPU 7143	SJ	7.6	8.9	L	L	N	N/A	N/A	N/A	L	L	L	L	L		SPU 7143	Least
SPU 7144	SJ	6.5	13.8	L	M	H	H	N/A	N	M	M	M	M	L		SPU 7144	Mod.
SPU 7145	SJ	10.1	66.8	M	M	M	L	N/A	L	M	M	M	M	L		SPU 7145	Mod.
SPU 7146	SJ	22.8	34.2	L	L	M	H	N/A	N	M	M	M	L	L		SPU 7146	Mod.
SPU 7150	SJ	2.3	2.4	L	L	M	N/A	N/A	N/A	M	L	L	L	L		SPU 7150	Less

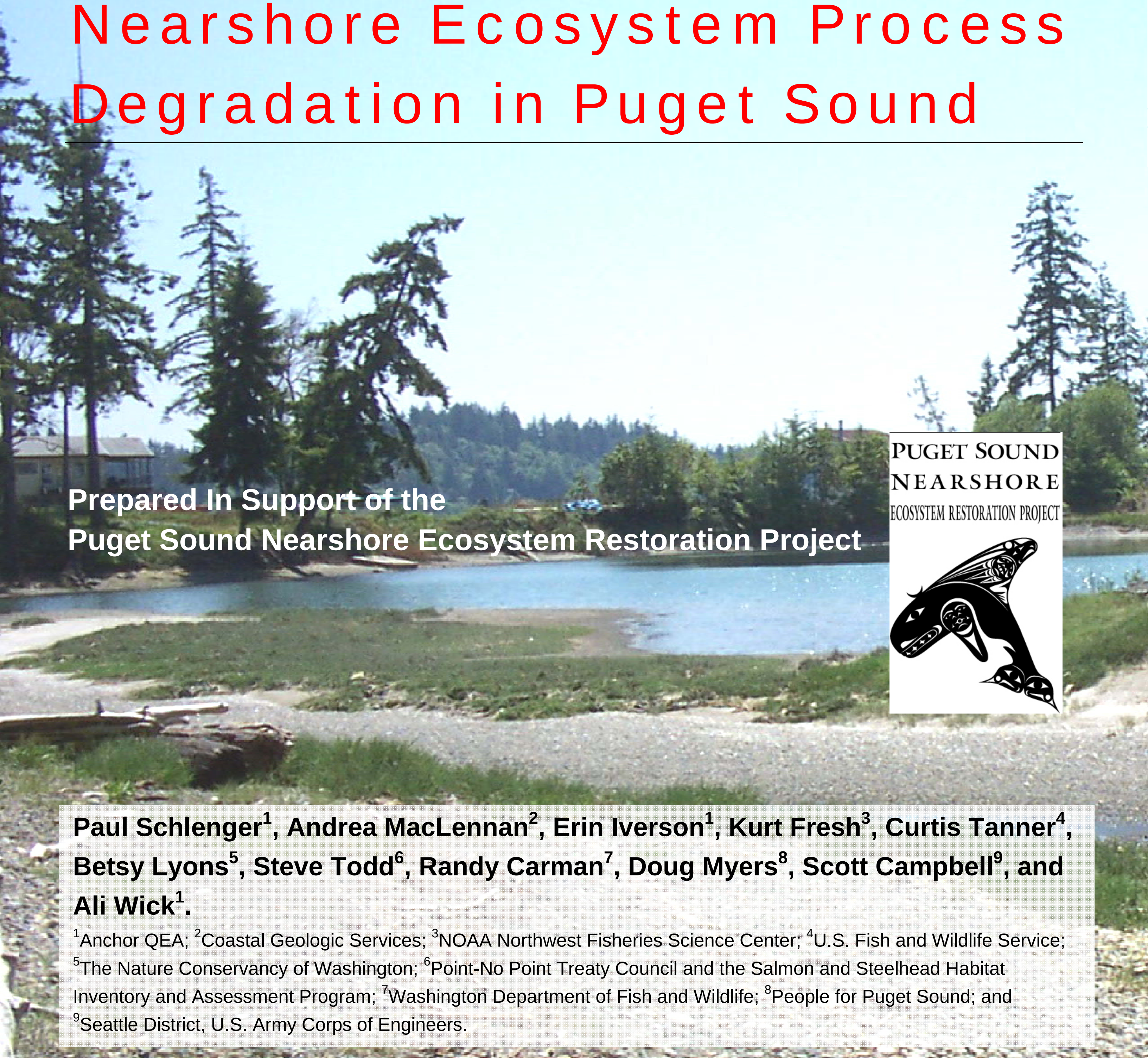
Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 7151	SJ	7.1	7.6	M	L	L	N/A	N/A	N/A	L	L	L	L	L		SPU 7151	Less
SPU 7152	SJ	4.6	4.1	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7152	None
SPU 7153	SJ	1.4	0.7	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7153	None
SPU 7154	SJ	3.2	2.7	N	N	N	L	N/A	L	N	L	N	N	N		SPU 7154	Least
SPU 7155	SJ	2.4	3.1	H	M	M	N/A	N/A	N/A	L	H	H	H	L		SPU 7155	Mod.
SPU 7156	SJ	5.9	18.7	H	H	N/A	N/A	N/A	N/A	L	H	H	H	L		SPU 7156	Mod.
SPU 7157	SJ	11.6	80.1	M	H	H	H	N/A	N	M	H	H	H	L		SPU 7157	More
SPU 7158	SJ	6.1	174.2	H	H	H	H	N/A	N	M	H	H	H	M		SPU 7158	Most
SPU 7159	SJ	4.8	172.9	H	H	H	H	N/A	N	M	H	H	H	L		SPU 7159	Most
SPU 7160	SJ	1.2	17.1	H	H	H	H	N/A	N	M	H	H	H	L		SPU 7160	Most
SPU 7161	SJ	25.8	52.4	H	H	H	H	N/A	N	M	M	M	M	L		SPU 7161	More
SPU 7162	SJ	1.2	1.8	N/A	N/A	H	N/A	N/A	N/A	L	H	H	H	N		SPU 7162	Mod.
SPU 7163	SJ	7.8	8.2	M	H	H	H	N/A	H	M	M	M	M	L		SPU 7163	More
SPU 7164	SJ	2.6	1.2	L	L	N	N/A	N/A	N/A	L	L	L	L	N		SPU 7164	Least
SPU 7165	SJ	58.6	203.4	M	H	H	H	N/A	L	L	H	H	H	L		SPU 7165	More
SPU 7166	SJ	3.0	10.8	M	M	H	H	N/A	H	M	M	M	M	N		SPU 7166	More
SPU 7167	SJ	1.1	4.1	H	H	H	H	N/A	H	H	H	H	H	L		SPU 7167	Most
SPU 7168	SJ	4.0	3.9	H	M	M	L	N/A	L	H	M	M	M	M		SPU 7168	Mod.
SPU 7169	SJ	13.2	23.4	H	H	H	M	N/A	N	M	H	H	H	L		SPU 7169	Most
SPU 7170	SJ	2.6	4.9	H	H	H	H	N/A	N	H	H	H	H	M		SPU 7170	Most
SPU 7171	SJ	9.5	8.8	H	H	M	H	N/A	N/A	H	H	H	H	M		SPU 7171	Most
SPU 7172	SJ	3.3	3.0	H	H	L	N/A	N/A	N/A	H	M	M	H	N		SPU 7172	Mod.
SPU 7174	SJ	1.0	0.3	H	H	N	N/A	N/A	N/A	M	H	H	H	L		SPU 7174	Mod.
SPU 7175	SJ	9.8	15.8	L	L	H	N/A	N/A	N/A	L	H	H	L	N		SPU 7175	Mod.
SPU 7176	SJ	0.9	3.5	N	M	H	H	N/A	N/A	L	N	N	N	N		SPU 7176	Less
SPU 7177	SJ	0.5	0.4	N	N	N/A	N/A	N/A	N/A	M	N	N	N	N		SPU 7177	Least
SPU 7179	SJ	0.8	0.1	N/A	N/A	N/A	N/A	N/A	N/A	N	N	N	N/A	N		SPU 7179	None
SPU 7180	SJ	2.6	0.5	N/A	N/A	L	N/A	N/A	N/A	L	N	L	L	L		SPU 7180	Least
SPU 7181	SJ	1.2	0.2	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7181	None
SPU 7182	SJ	1.4	0.2	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7182	None
SPU 8001	WH/NC	16.5	30.7	L	M	H	H	N/A	M	L	M	L	L	L		SPU 8001	Mod.
SPU 8055	WH/SC	60.4	135.7	H	H	H	H	N/A	N	H	H	H	H	L		SPU 8055	Most
SPU 8056	WH/SJ	31.8	24.7	M	M	M	H	N/A	N	M	M	L	M	L		SPU 8056	Mod.

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 8057	NC/SJ	27.7	63.3	L	M	M	N	N/A	N/A	M	L	L	L	L		SPU 8057	Less
SPU 8058	NC/SJ	20.0	45.3	L	M	L	H	N/A	H	L	M	L	L	L		SPU 8058	Mod.
SPU 8201	SC/SP	9.1	8.3	H	H	H	H	N/A	H	H	H	H	H	M		SPU 8201	Most
SPU 8202	SC/SP	4.5	4.7	L	L	N/A	N/A	N/A	N/A	M	L	L	L	M		SPU 8202	Least
SPU 8211	SC/NC	7.8	16.0	L	L	H	H	N/A	H	L	M	L	L	N		SPU 8211	Mod.
SPU 8220	HC/NC	1.9	0.6	N	N	N	N	N/A	N	L	L	N	N	N		SPU 8220	Least
SPU 8230	HC/NC	8.2	7.0	L	L	L	N/A	N/A	N/A	L	L	L	L	L		SPU 8230	Least
SPU 8400	JF/NC	10.8	21.4	L	L	M	N/A	N/A	N/A	M	L	L	L	N		SPU 8400	Least
SPU 8401	WH/SJ	16.0	28.3	M	M	L	M	N/A	N	L	L	L	M	L		SPU 8401	Less

ADDENDUM
STRATEGIC NEEDS ASSESSMENT: ANALYSIS OF PROJECTED FUTURE NEARSHORE ECOSYSTEM PROCESS DEGRADATION IN PUGET SOUND

Addendum to Technical Report 2011-02

Addendum to Strategic Needs Assessment: Analysis of Projected Future Nearshore Ecosystem Process Degradation in Puget Sound



Prepared In Support of the
Puget Sound Nearshore Ecosystem Restoration Project

PUGET SOUND
NEARSHORE
ECOSYSTEM RESTORATION PROJECT

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PUGET SOUND
NEARSHORE
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LIST OF ACRONYMS AND ABBREVIATIONS

Corps	U.S. Army Corps of Engineers
DPU	delta process unit
EFG&S	ecosystem functions, goods, and services
km	kilometer
km^2	square kilometer
m	meter
m^2	square meter
PSNERP	Puget Sound Nearshore Ecosystem Restoration Project
SPU	shoreline process unit

LEGENDS

DPU Abbreviation Legend

DPU Code	River	Sub-basin
NKS	Nooksack	San Juan Islands – Strait of Georgia
SAM	Samish	San Juan Islands – Strait of Georgia
SKG	Skagit	Whidbey
STL	Stillaguamish	Whidbey
SNH	Snohomish	Whidbey
DUW	Duwamish/Green/White/Cedar/ Black/Lake Washington/Sammamish Rivers	South Central Puget Sound
PUY	Puyallup	South Central Puget Sound
NSQ	Nisqually	South Puget Sound
DES	Deschutes	South Puget Sound
ELW	Elwha	Strait of Juan de Fuca
DUN	Dungeness	Strait of Juan de Fuca
QUL	Big Quilcene	Hood Canal
DOS	Dosewallips	Hood Canal
DUC	Duckabush	Hood Canal
HAM	Hamma Hamma	Hood Canal
SKO	Skokomish	Hood Canal

Sub-basin Abbreviation Legend

Sub-basin Abbreviation	Sub-basin Name
JF	Strait of Juan de Fuca
SJ	San Juan Islands – Strait of Georgia
HC	Hood Canal
NC	North Central Puget Sound
WH	Whidbey
SC	South Central Puget Sound
SP	South Puget Sound

Shipman (2008) Geomorphic Shoreforms Abbreviation Legend

Shoreform Abbreviation	Shoreform
BAB	Barrier Beach
BLB	Bluff-backed Beach
BE	Barrier Estuary
BL	Barrier Lagoon
CLM	Closed Lagoon/Marsh
OCI	Open Coastal Inlet
PB	Pocket Beach
PL	Plunging Rocky Shoreline
RP	Rocky Platform
D	Delta

1 INTRODUCTION

This Addendum to the Strategic Needs Assessment reports on the projected future degradation of nearshore processes in the Puget Sound study area. The analysis results will provide the future-without-project conditions that will be used in the U.S. Army Corps of Engineers' (Corps') Puget Sound Nearshore General Investigation. The analysis applies the Process Evaluation Framework (the Framework) methods reported in the main text of the Strategic Needs Assessment Report. The Framework estimates the degradation of 11 nearshore processes that are integral to the creation and maintenance of the shoreforms and energy regimes that characterize Puget Sound's shorelines. The Framework estimates the degradation of each process individually, as well as the combined overall degradation of all 11 nearshore processes. Degradation is estimated at the process unit scale based on the occurrence and distribution of physical stressors.

This Addendum describes the future conditions information used in the degradation analysis and the results of the analysis. In addition, the limitations and uncertainties of the analysis are discussed.

2 FUTURE CONDITIONS FORECAST USED IN THE ANALYSIS

The future conditions that were analyzed are based on the future development projections prepared for the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) by Oregon State University and reported in Bolte and Vache (2010). The process degradation analysis reported here used the forecast outputs prepared to represent the year 2060. Bolte and Vache (2010) developed a computer modeling program named ENVISION to forecast land development patterns associated with human population growth. Bolte and Vache (2010) ran the model using three scenarios of land use based on a series of assumptions that they had developed in collaboration with the PSNERP Nearshore Science Team. The "Status Quo" scenario was used in this analysis of process degradation in the future. The "Status Quo" scenario assumes a continuation of current land development trends and, for Corps' planning purposes, represents the most likely future scenario.

The future forecasts reported by Bolte and Vache (2010) were used to inform future distributions of three stressors used in the Framework: shoreline armoring, marinas, and tidal wetlands. Bolte and Vache (2010) provided data for shoreline armoring and marinas; however, tidal wetland losses needed to be inferred from the future land cover data. Tidal wetlands were assumed to be lost in areas that are currently undeveloped, but are projected to be converted to developed land by the year 2060. The rationale for this scenario is based on the observations that the regulatory environment of Washington is not fully effective in preventing wetland loss due to development and that the effectiveness of compensatory mitigation is highly uncertain. Although compensatory mitigation would be required for lost wetlands, the habitat functions of a restored wetland do not immediately match the functions of a natural wetland and sometimes never achieve comparable function (Johnson et al. 2002; Kihslinger 2002). The implication of this assumption for tidal wetland loss is that the analysis may overestimate future tidal wetland losses.

No future projections were available for the 10 other stressors used in the Framework: tidal barriers, overwater structures (other than marinas), breakwaters/jetties, nearshore fill, roads, railroads, transition to artificial shoreforms, impervious surfaces, dams, and stream-crossings. For these stressors, current conditions were assumed to persist unchanged into the future. While these datasets would have been informative to include in this analysis, there is reason to speculate that there may not be major changes associated with the stressors that will not be picked up in the model by the datasets for which there are data. For example, stressors such as nearshore fill, transition to artificial shorelines, and tidal barriers can be expected to be constructed at a much slower rate than historically due to increased regulatory scrutiny. In addition, those stressors are also more likely to occur in areas where at least one of the other stressors already occurs and, therefore, the area would already be degraded per the Framework.

3 RESULTS

The process degradation results presented in this section include percentages of shoreline length and watershed area throughout the Puget Sound study area as well as in each of the seven sub-basins. The percentage calculations were based on the sum of the individual shoreline process unit (SPU) or delta process unit (DPU) values. These sums are greater than the actual shoreline length or watershed area in the analysis area because SPUs overlap with each other and with DPUs[1]. In addition, two DPUs, the Stillaguamish and Samish River deltas, overlap each other. The portions of overlap are included twice in the calculation (i.e., once for each process unit in which the overlap area occurs). Given the potential for differences in the conditions of the process units in which the overlap areas occur, the overlap areas may be assigned to two different categories of degradation. In maps showing degradation, the areas of overlap are displayed in the colors depicting the higher of the two degradation categories assigned to the overlap area.

3.1 Degradation Results of Individual Nearshore Processes

3.1.1 Puget Sound Basin

3.1.1.1 Shoreline Process Unit Results for Individual Nearshore Processes

The future degradation analysis was able to predict changes in degradation among 9 of the 11 nearshore processes. The Framework metrics for estimating degradation of the other two processes, distributary channels and freshwater input, did not include any of the stressors for which future changes were projected; therefore, it was not possible to forecast future changes of those two processes. Maps depicting the Framework results for degradation of each of the 11 nearshore ecosystem processes are presented in Appendix A to this Addendum. The degradation categories assigned to each process unit is presented in tabular format in Appendix B. As described in the methods section of the Strategic Needs Assessment document, the degradation category assignments were based on relative degradation compared to all other process units, rather than on absolute thresholds of degradation. Degradation categories were assigned based on natural breaks, which do not necessarily result in equal numbers of process units in each degradation category.

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[1] The overlap among process used is described in more detail in Section 2.4 of the main Strategic Needs Assessment document and in Anchor QEA (2009).

The largest amount of change between current conditions and future conditions is detected for the tidal flow process. This is the case for the number of process units, shoreline length, and watershed area. Most of the forecasted change to tidal flow will be in the future degradation of SPUs that are currently not degraded. The percentages of the Puget Sound SPUs, shoreline length, and watershed area that are currently Not Degraded but are predicted to incur future degradation are19 percent, 27 percent, and 53 percent, respectively.

Based on this analysis of future conditions, the percentage of the 812 SPUs assigned to each degradation category, by nearshore process, is presented in Figure 3-1. Generally, the assignment of SPUs to the High, Medium, and Low Degradation categories using natural breaks resulted in nearly equal numbers of SPUs in each category. However, this is not the case for two nearshore processes: freshwater input and solar incidence. Freshwater input and solar incidence are both projected to have much larger percentages of SPUs in the Low Degradation category compared to the Medium Degradation or High Degradation category.

The percentage of total shoreline length in SPUs within each degradation category (Figure 3-2) is projected to be similar to the distribution based on SPU counts (see Figure 3-1). In contrast, the percentage of total SPU watershed area assigned to each degradation category based on future stressor distributions (Figure 3-3) is markedly different from the distribution based on the percentage of SPUs by count (see Figure 3-1). Most notably, a much larger percentage of the total watershed area in SPUs in the PSNERP General Investigation study area will be in the High Degradation category compared to the percentage of SPUs by count assigned to the High Degradation category. For example, for the sediment input process, nearly 50 percent of the SPU watershed area is projected to be in the High Degradation category, but only 33 percent of the SPUs (by count) are assigned to the High Degradation category. This indicates that SPUs of larger watershed areas will be more degraded than SPUs that are smaller in watershed area.

Six nearshore processes are projected to be highly degraded among 28 percent or more of the SPUs, including all three sediment-related processes, as well as detritus import and export, exchange of aquatic organisms, and physical disturbance. Similar percentages of shoreline length will be contained in those SPUs; however, a much larger percentage of the watershed area—48 percent or more in five of the six processes—is projected to be contained in the High Degradation category for those processes.

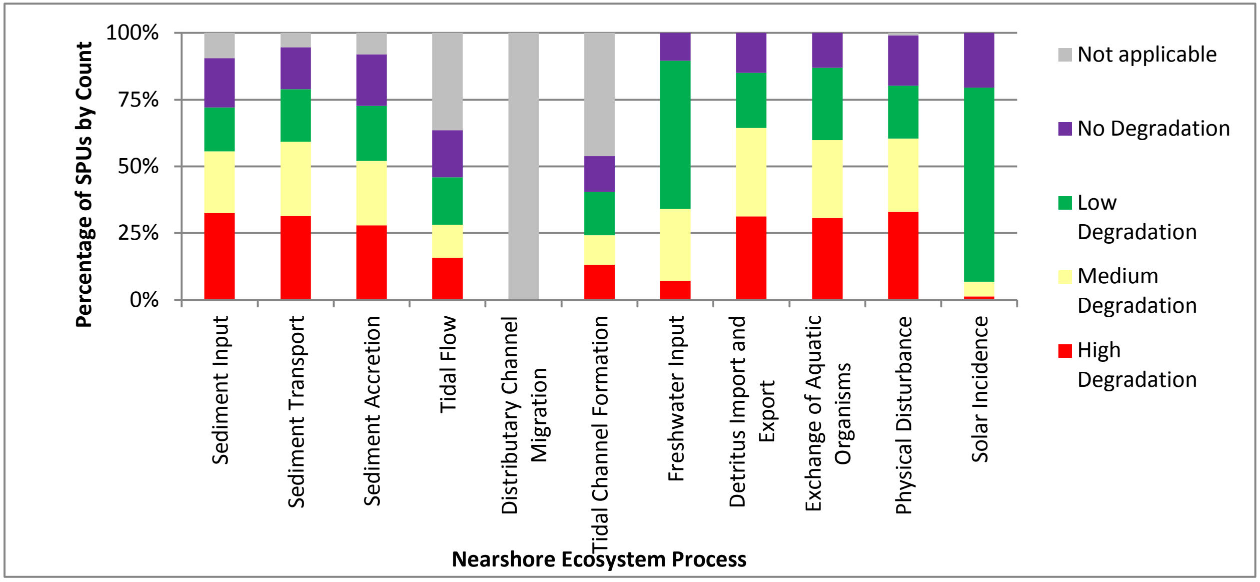


Figure 3-1

Future Sound-wide Nearshore Process Degradation by Percentage of SPUs

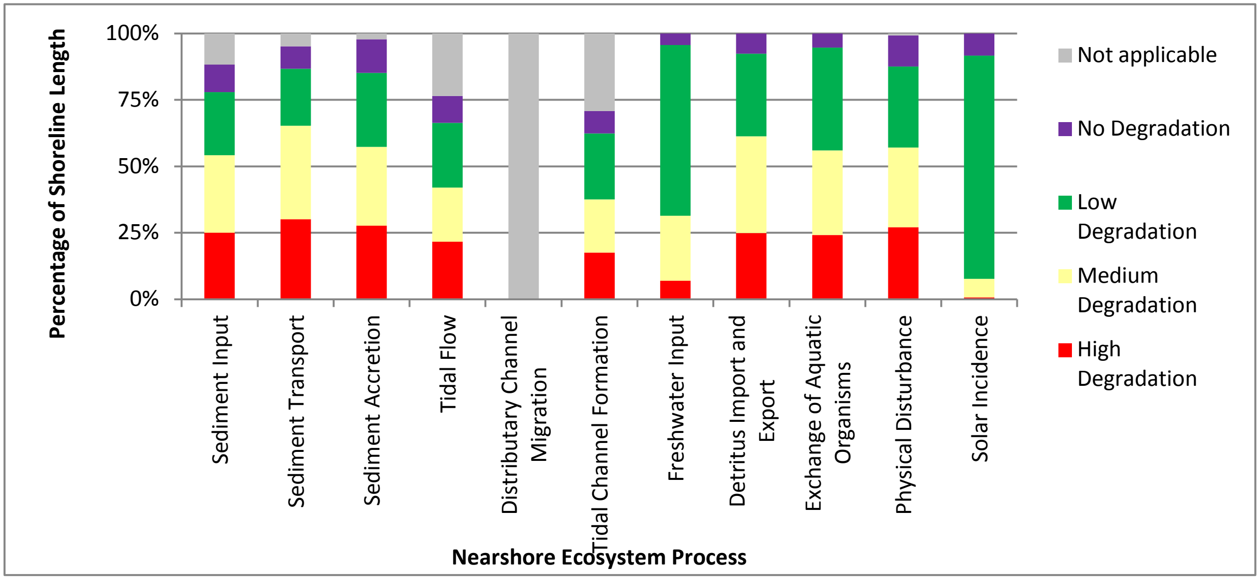


Figure 3-2

Future Sound-wide Nearshore Process Degradation by Percentage of Total SPU Shoreline Length

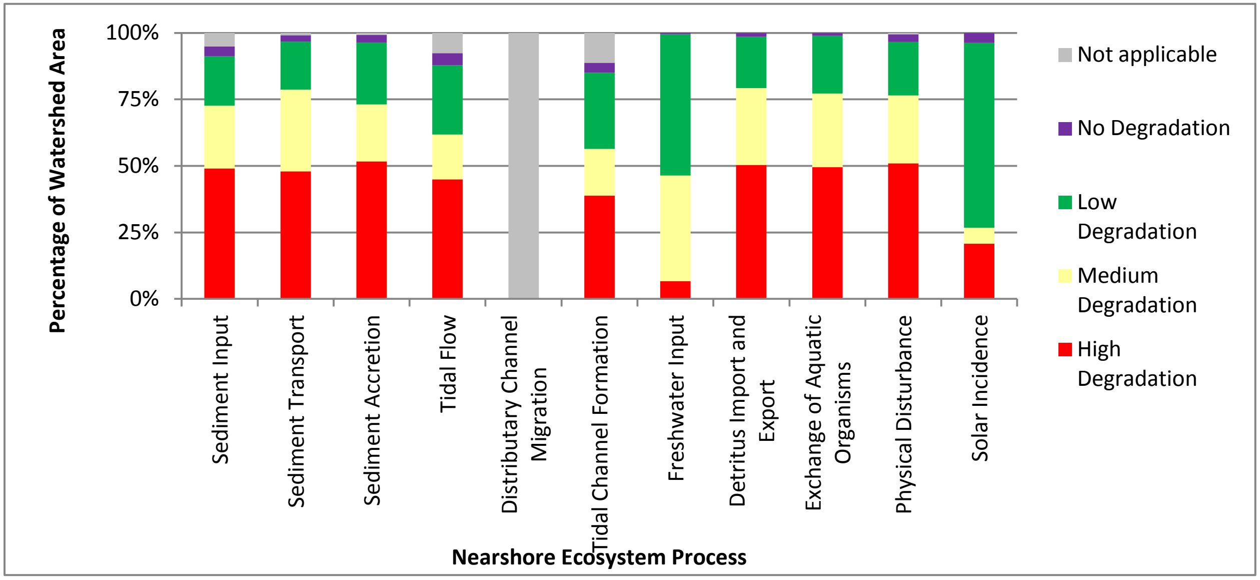


Figure 3-3

Future Sound-wide Nearshore Process Degradation by Percentage of Total SPU Watershed Area

3.1.1.2 Delta Process Unit Results for Individual Nearshore Processes

Fifty percent or more of the DPUs (i.e., 8 or more of the 16 DPUs) are projected to be assigned to the High Degradation category for five of the nearshore processes: sediment transport, sediment accretion, distributary channel migration, detritus import and export, and exchange of aquatic organisms (Figure 3-4). The five most degraded nearshore ecosystem processes in DPUs are those impacted primarily by shoreline alterations, including tidal barriers and armoring. Seven of the nearshore processes had more than 75 percent of the DPU shoreline length in the High Degradation or Medium Degradation Category. For watershed area, 9 of the processes are projected to be in the High Degradation or Medium Degradation category for more than 75 percent of the total DPU watershed areas. For sediment input and tidal channel formation, notably higher percentages of DPU shoreline length and watershed area in the High Degradation and Medium Degradation categories combined were reported compared to the percentage of SPUs assigned to those categories as disproportionately higher than the percentage of DPUs by count (Figures 3-5 and 3-6). This indicates that the larger DPUs tended to be more degraded than smaller DPUs. The degradation categories assigned to each nearshore process for each DPU based on future stressor distributions is presented in Table 3-1.

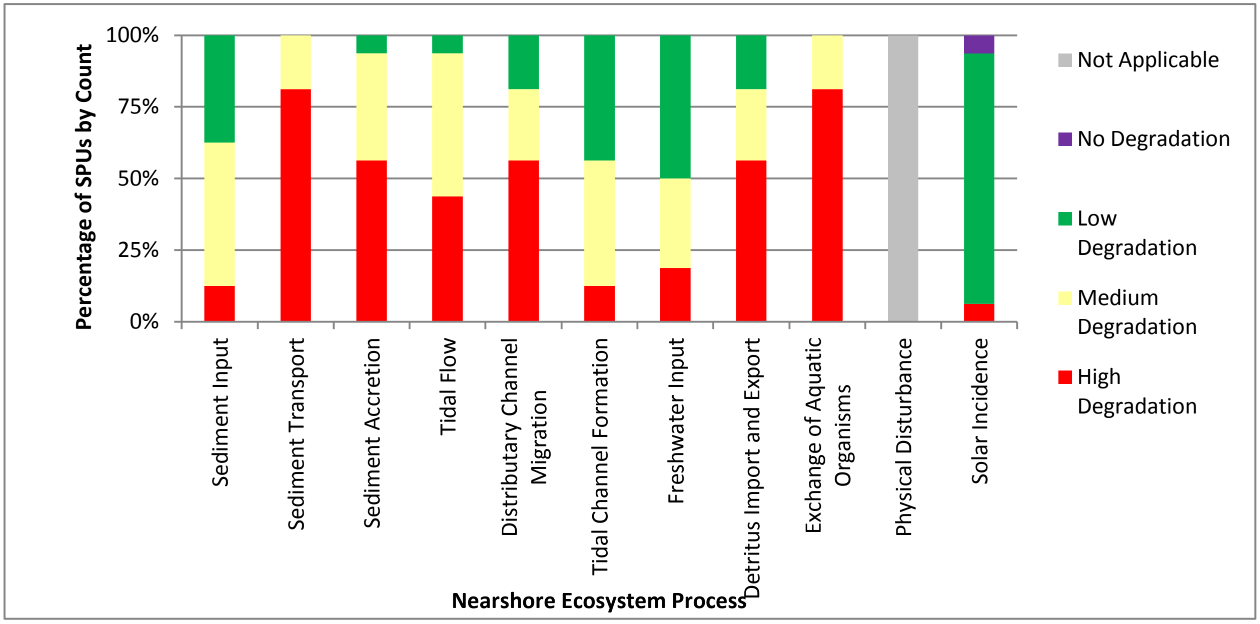


Figure 3-4

Future Sound-wide Nearshore Process Degradation by Percentage of DPUs

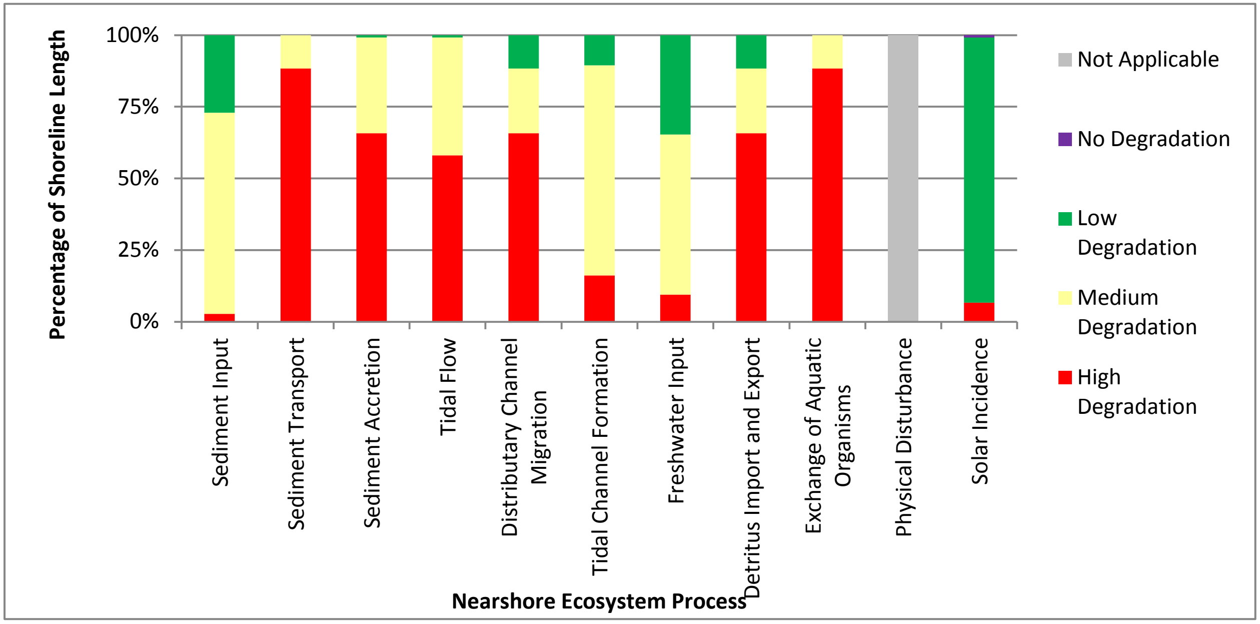


Figure 3-5

Future Sound-wide Nearshore Process Degradation by Percentage of Total DPU Shoreline Length

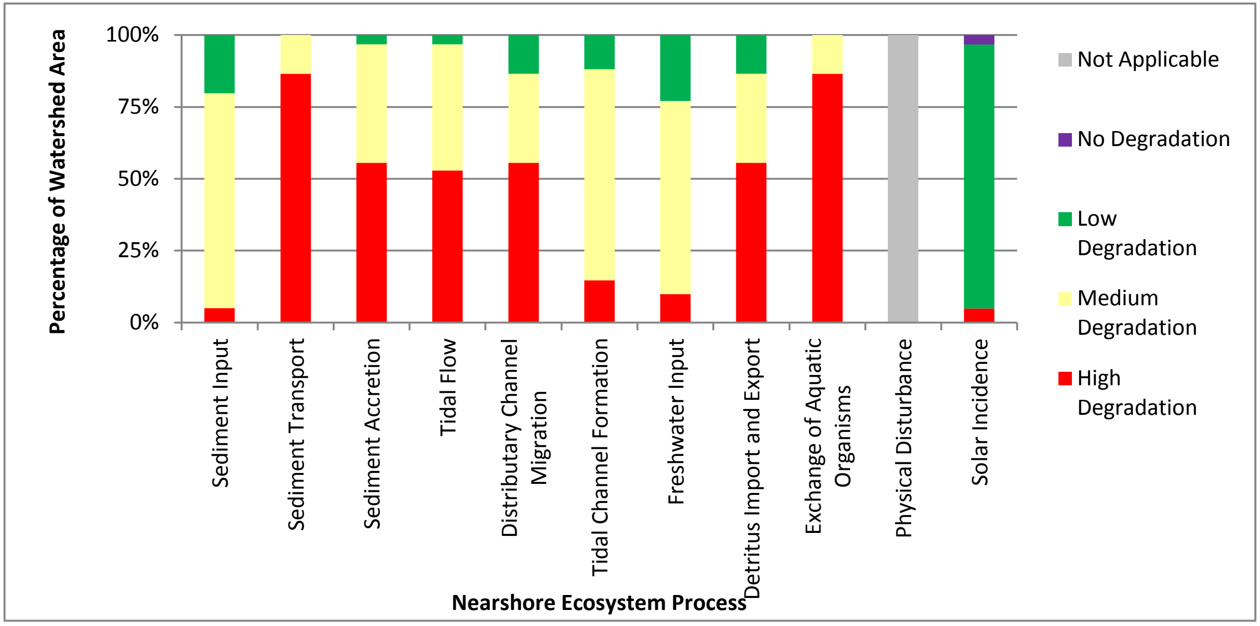


Figure 3-6

Future Sound-wide Nearshore Process Degradation by Percentage of Total DPU Watershed Area

Table 3-1
Process Degradation Categories of DPUs Based on Future Stressor Distributions

DPU	Sub-basin	Shoreline Length (km)	Watershed Area (km2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence
Nooksack	SJ	41	2,084	L	M	M	M	L	M	L	M	M	NA	L
Samish	SJ	29	403	M	H	H	M	H	M	L	H	H	NA	L
Skagit	WH	96	7,301	M	H	M	M	M	M	M	H	H	NA	L
Stillaguamish	WH	65	1,876	L	H	H	H	H	M	L	H	H	NA	L
Snohomish	WH	95	4,748	M	H	H	H	H	M	M	H	H	NA	L
Duwamish	SC	32	1,257	M	H	H	H	H	H	H	H	H	NA	H
Puyallup	SC	46	2,535	M	H	H	H	H	H	M	H	H	NA	L
Nisqually	SP	20	2,160	M	H	H	H	H	M	M	H	H	NA	L
Deschutes	SP	9	466	H	H	H	H	H	M	H	H	H	NA	L
Elwha	JF	4	838	H	M	L	L	L	L	H	L	M	NA	N
Dungeness	JF	12	564	L	M	M	M	L	L	L	M	M	NA	L
Quilcene	HC	8	295	M	H	H	M	H	L	L	H	H	NA	L
Dosewallips	HC	5	307	L	H	M	M	M	L	L	H	H	NA	L
Duckabush	HC	4	204	L	H	M	M	M	L	L	H	H	NA	L
Hamma Hamma	HC	5	222	L	H	M	M	M	L	L	H	H	NA	L
Skokomish	HC	14	654	M	H	H	H	H	L	M	H	H	NA	L

3.1.2 Sub-basin Summaries of the Future Degradation of the Individual Nearshore Processes

3.1.2.1 Strait of Juan de Fuca Sub-basin

The Strait of Juan de Fuca sub-basin is projected to remain among the least degraded sub-basins in Puget Sound. Detritus import and export will be the most widely degraded process in the sub-basin. It is projected to be the only process in which more than 50 percent of the SPU shoreline length and SPU count will be categorized as having High or Medium

Degradation (Figure 3-7). Sediment transport and physical disturbance is projected to have the largest percentage of the shoreline length in the High Degradation category (24 and 21 percent, respectively). There are no SPUs categorized as having High Degradation for only two processes: solar incidence and freshwater input. No SPUs are projected to have a high degree of freshwater input degradation. Tidal flow will have the smallest percentage (less than 25 percent) of SPUs in the High and Medium Degradation categories combined (Figures 3-8 and 3-9). Seven of the 11 nearshore processes are projected to have no degradation in 10 percent or more of the SPUs, although these appear to be smaller SPUs because they tended to comprise a smaller portion of the shoreline length and watershed area.

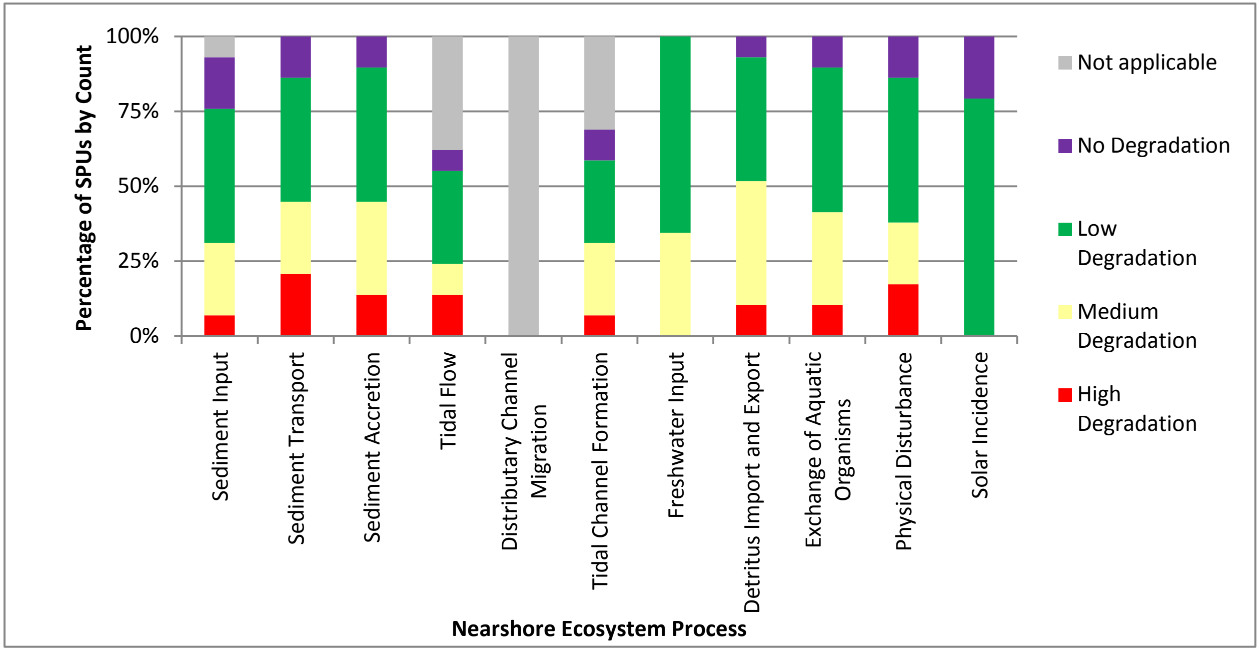


Figure 3-7

Future Degradation of Nearshore Processes in Strait of Juan de Fuca Sub-basin by Percent of SPU Count

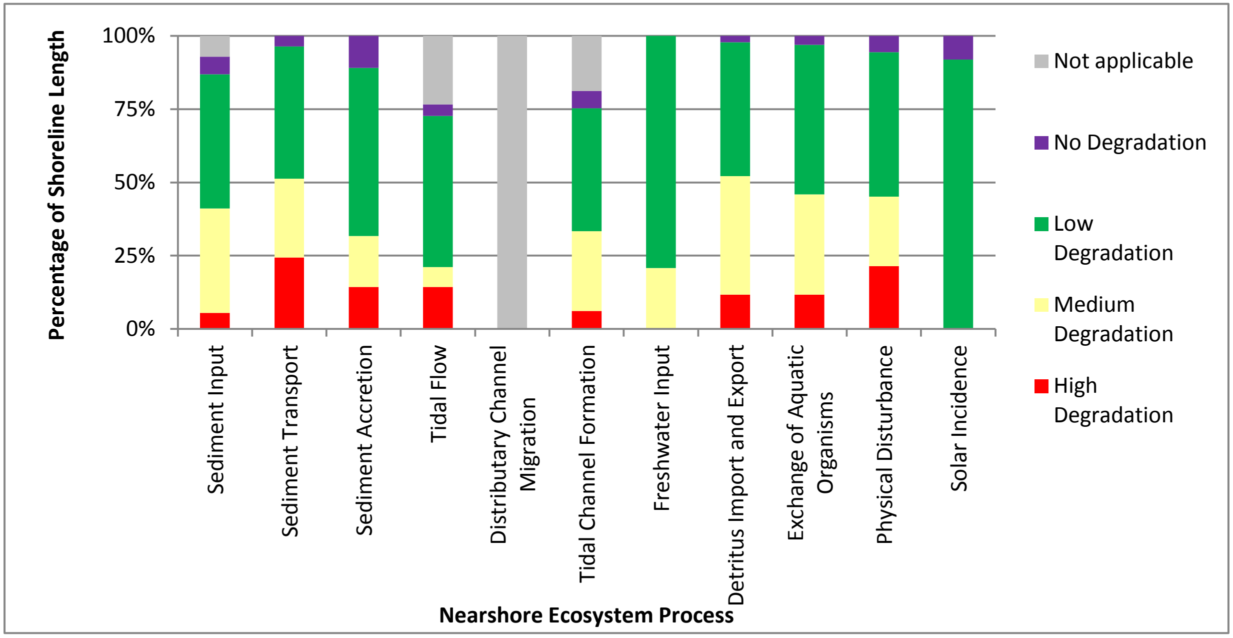


Figure 3-8

Future Nearshore Process Degradation in Strait of Juan de Fuca Sub-basin by Percent of Total SPU Shoreline Length

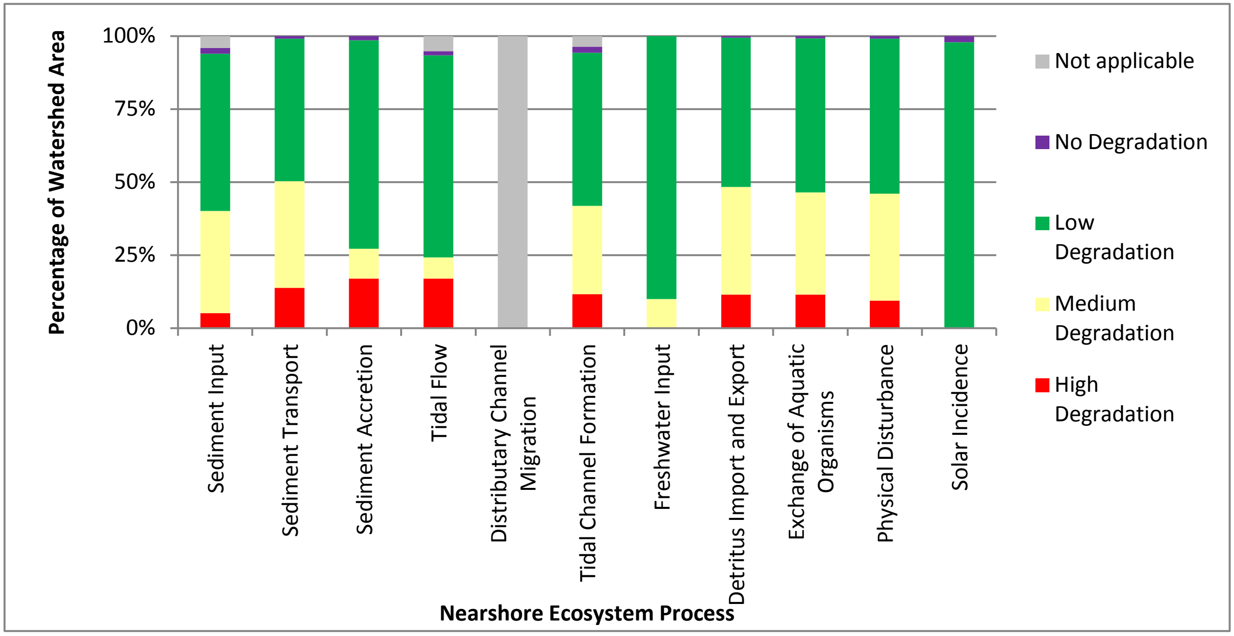


Figure 3-9

Future Nearshore Process Degradation in Strait of Juan de Fuca Sub-basin by Percent of Total SPU Watershed Area

3.1.2.2 San Juan Islands – Strait of Georgia Sub-basin

The San Juan Islands – Strait of Georgia sub-basin is projected to remain among the least degraded sub-basins in Puget Sound. There are several processes classified as Not Applicable for several SPUs in the sub-basin because the Framework metrics focused on conditions in a subset of shoreforms that are not present in the SPUs (Figure 3-10). Specifically, several SPUs do not have bluff-backed beaches or embayments (e.g., barrier estuaries and barrier lagoons) in which to evaluate conditions. Six nearshore processes are projected to be classified as having High or Medium Degradation along more than 25 percent of the sub-basin shoreline length, including all three sediment processes, tidal flow, detritus import and export, and physical disturbance. A larger percentage of the total watershed area is projected to be in the High Degradation category compared to the percent count or percent shoreline length. This indicates that the larger SPUs, based on area, will be more degraded than smaller SPUs (Figures 3-11 and 3-12).

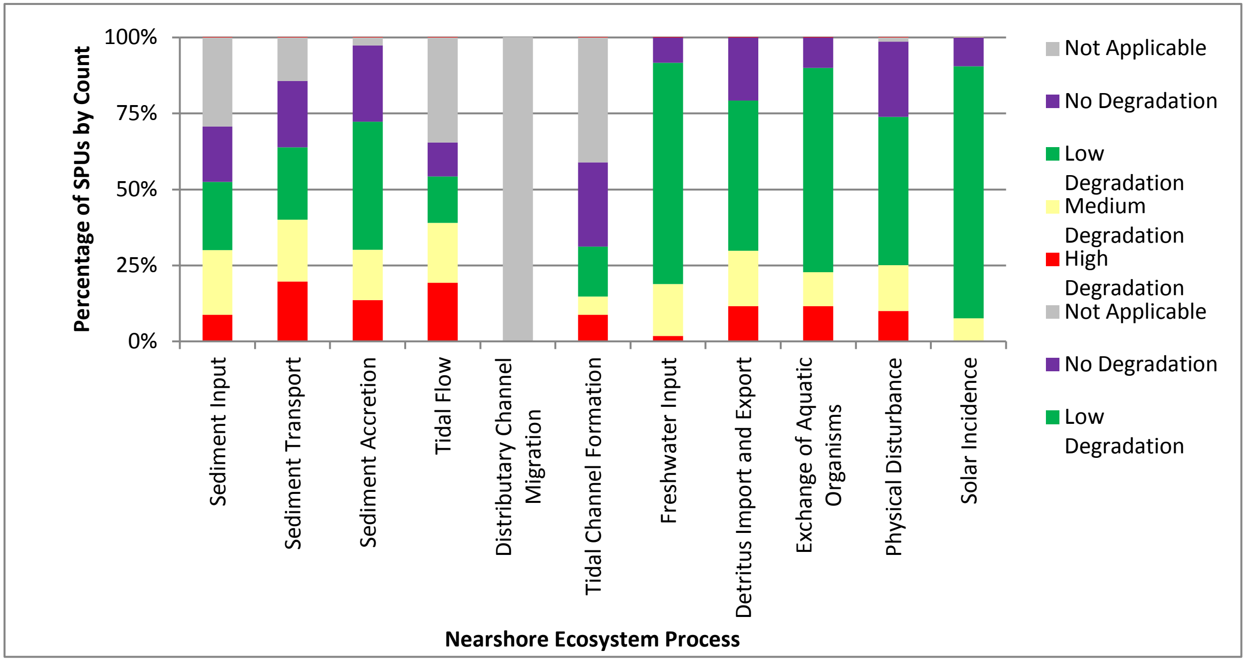


Figure 3-10
Future Nearshore Process Degradation in San Juan Islands – Strait of Georgia Sub-basin by Percent of SPU Count

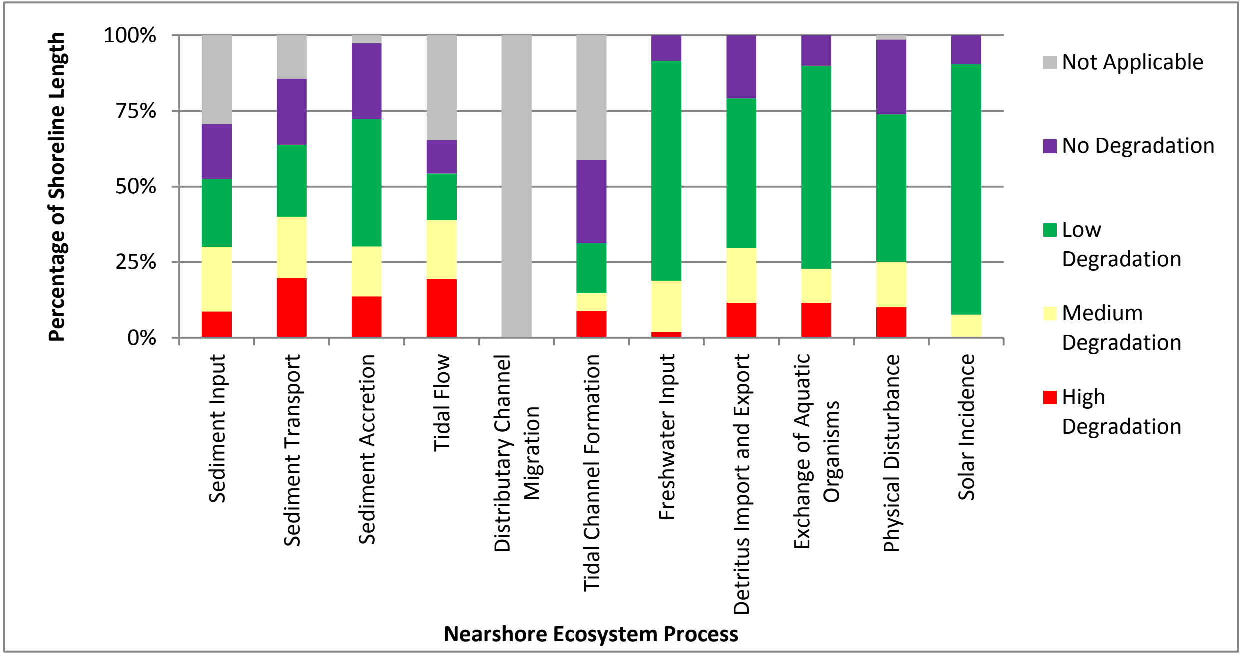


Figure 3-11

Future Nearshore Process Degradation in San Juan Islands – Strait of Georgia Sub-basin by Percent of Total SPU Shoreline Length

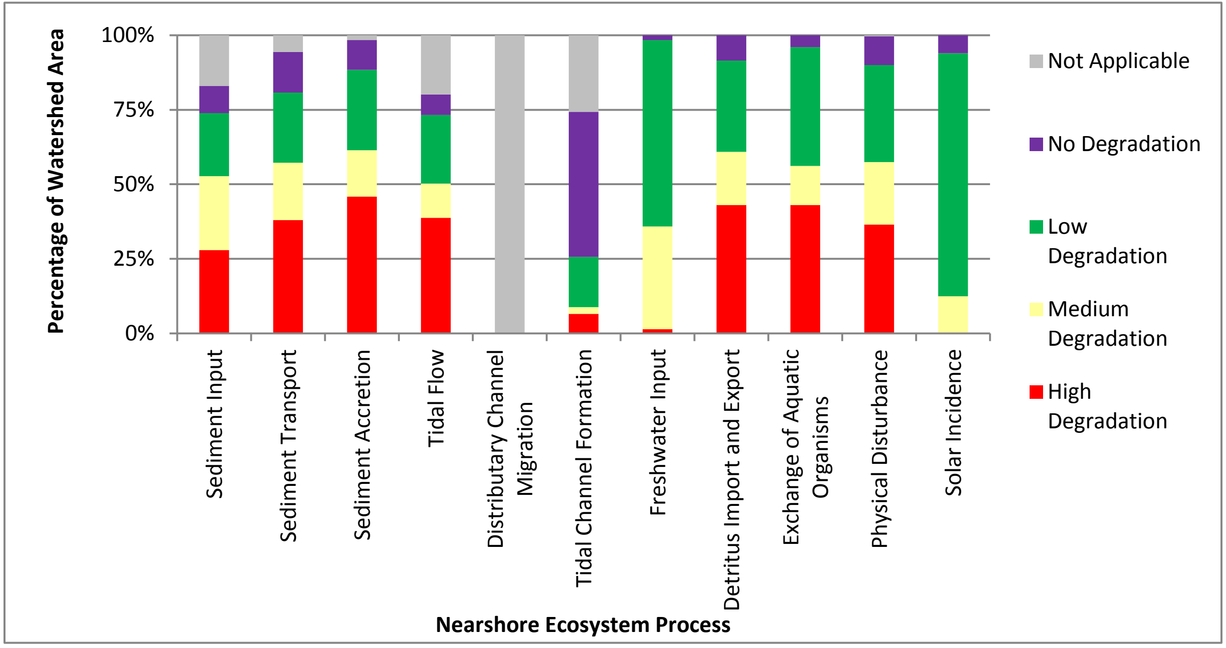


Figure 3-12

Future Nearshore Process Degradation in San Juan Islands – Strait of Georgia Sub-basin by Percent of Total SPU Watershed Area

3.1.2.3 Hood Canal Sub-basin

The Hood Canal sub-basin is projected to have several nearshore processes that have been widely degraded. Future degradation in the sub-basin is projected to occur as small increases in degradation among nearly all of the processes. The most pronounced changes are predicted for the tidal channel formation process as SPUs currently not degraded will incur low levels of degradation. Future degradation among six nearshore processes is predicted to be categorized as High Degradation in 30 percent or more of the SPUs in the sub-basin, which corresponds to 20 to 26 percent of the total SPU shoreline length in the sub-basin. Five nearshore processes are projected to be categorized as having High Degradation or Medium Degradation along more than 50 percent of the SPU shoreline length and watershed area. The processes in this category are sediment transport, sediment accretion, detritus import and export, exchange of aquatic organisms, and physical disturbance (Figures 3-13, 3-14, and 3-15). The least degraded processes in the sub-basin are forecast to be solar incidence and freshwater input.

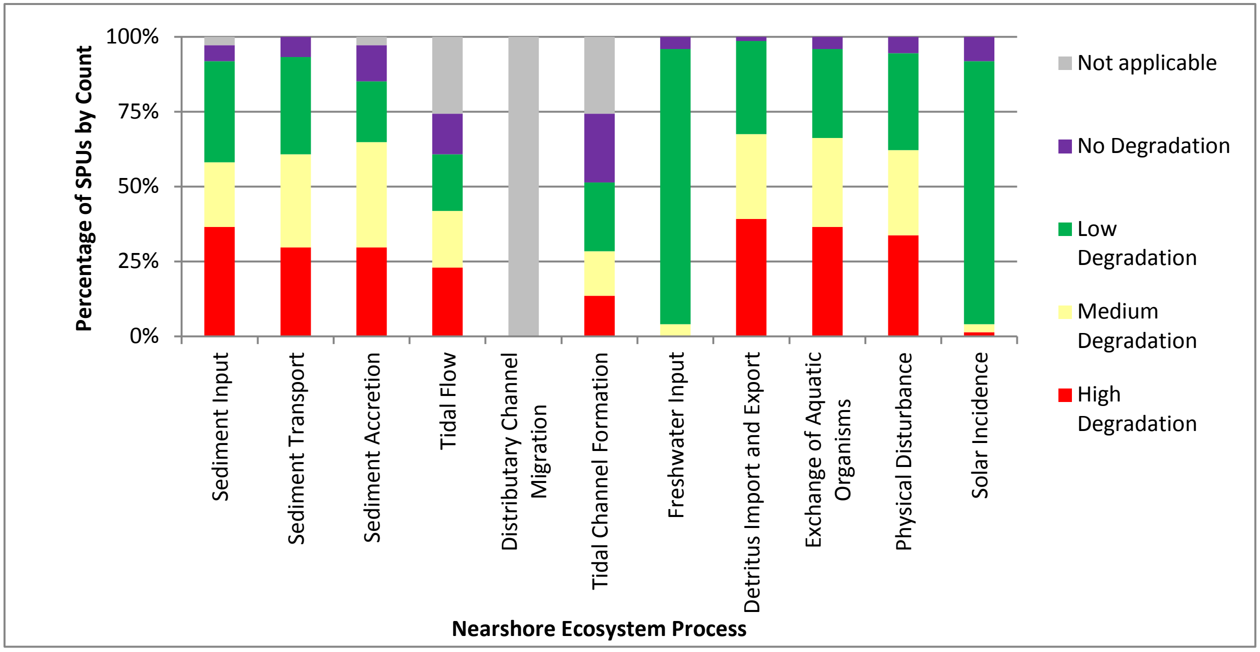


Figure 3-13

Future Nearshore Process Degradation in Hood Canal Sub-basin by Percent of SPU Count

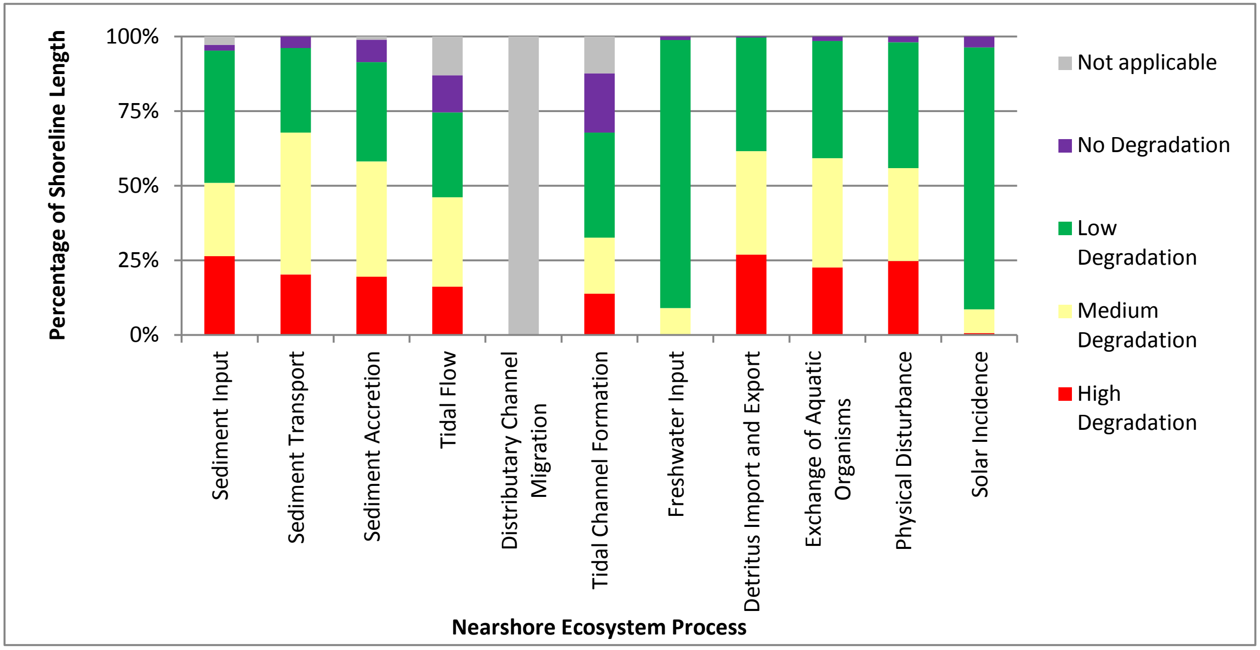


Figure 3-14
Future Nearshore Process Degradation in Hood Canal Sub-basin by Percent of Total SPU Shoreline Length

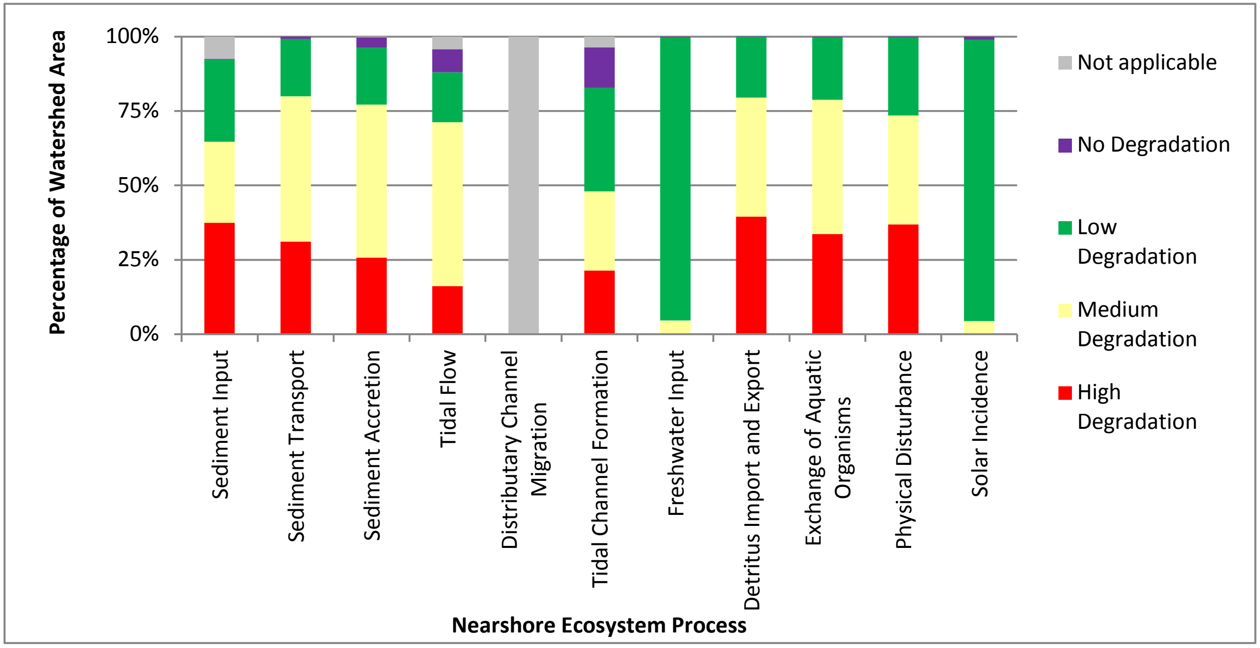


Figure 3-15
Future Nearshore Process Degradation in Hood Canal Sub-basin by Percent of Total SPU Watershed Area

3.1.2.4 Whidbey Sub-basin

The Whidbey sub-basin is projected to have widespread High and Medium Degradation of several nearshore processes across large portions of the sub-basin. Six nearshore processes in the Whidbey sub-basin will have incurred High or Medium Degradation along 70 percent or more of the shoreline length and watershed area in the sub-basin (Figures 3-16, 3-17, and 3-18). The processes in this group include all three sediment processes, detritus import and export, exchange of aquatic organisms, and physical disturbance. Sediment accretion and tidal flow is projected to be the only nearshore process for which the High Degradation category is assigned to more than 25 percent of the shoreline length or watershed area.

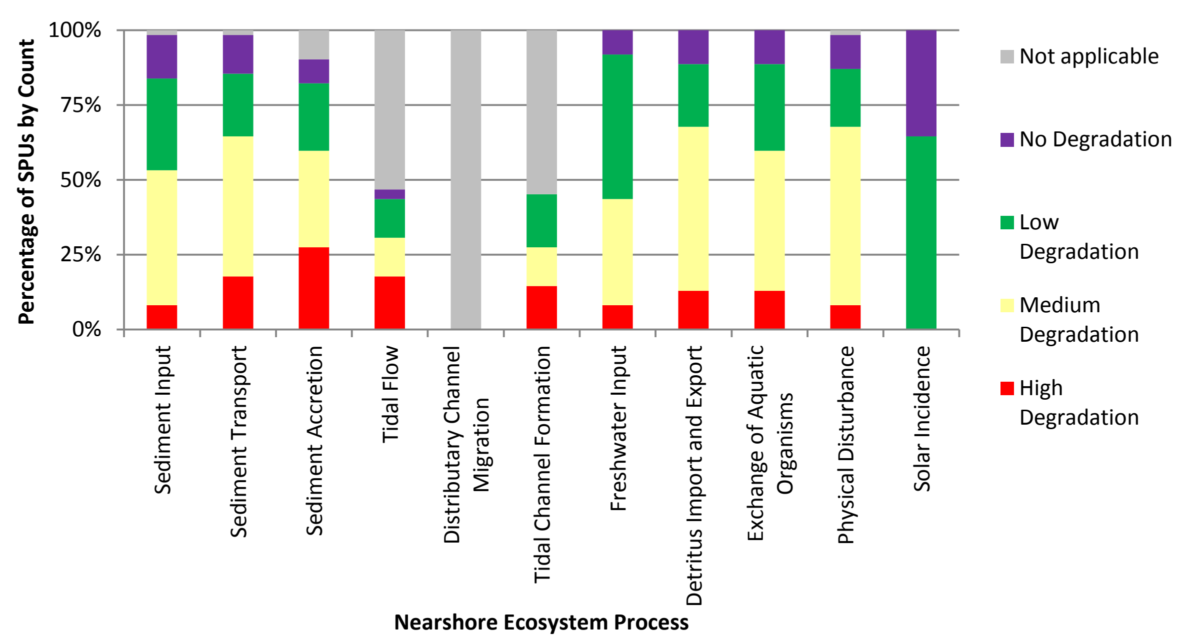


Figure 3-16
Future Nearshore Process Degradation in Whidbey Sub-basin by Percent of SPU Count

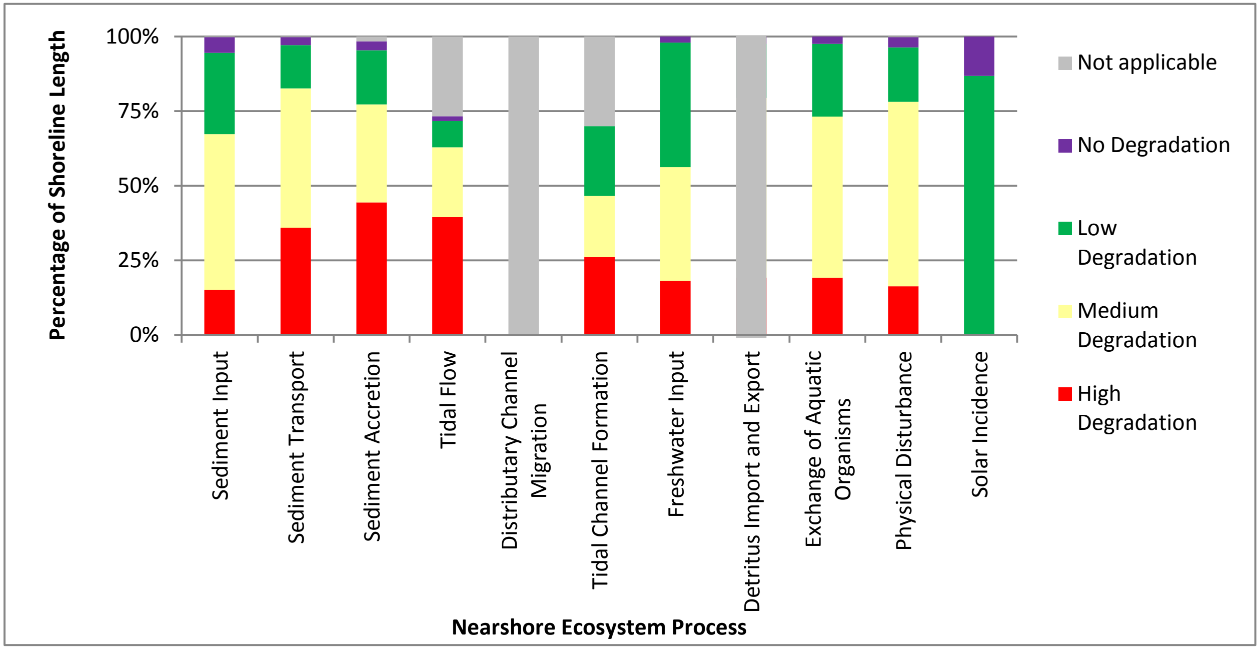


Figure 3-17
Future Nearshore Process Degradation in Whidbey Sub-basin by Percent of Total SPU Shoreline Length

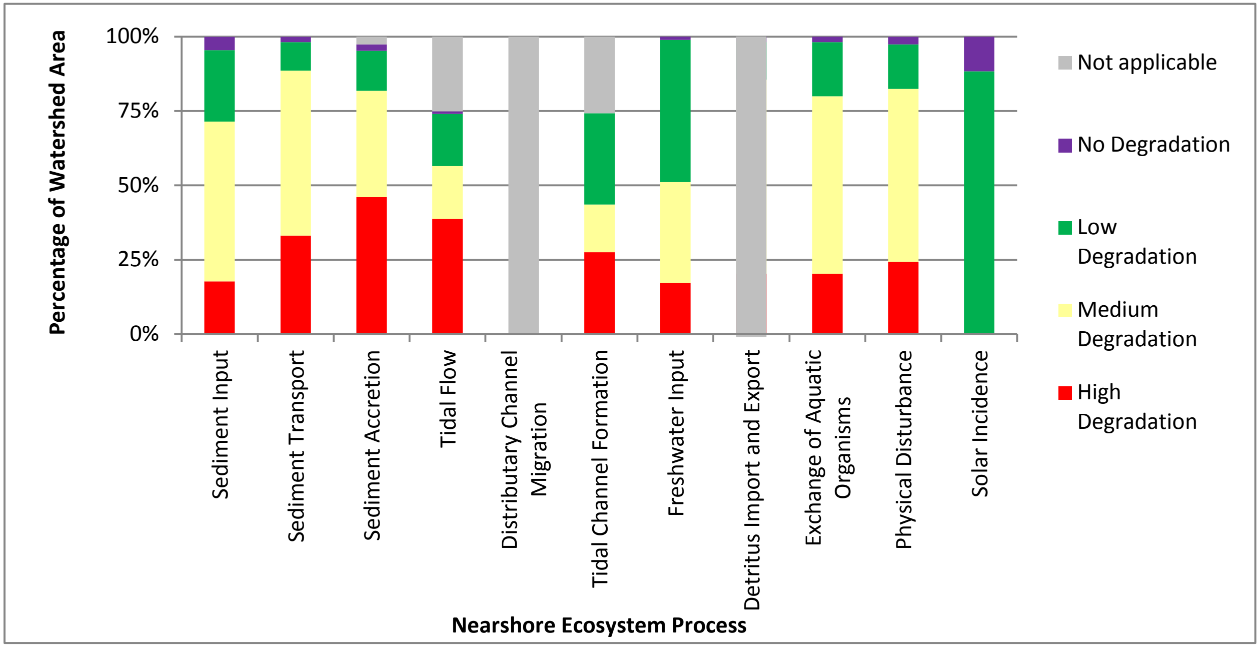


Figure 3-18
Future Nearshore Process Degradation in Whidbey Sub-basin by Percent of Total SPU Watershed Area

3.1.2.5 North Central Puget Sound Sub-basin

The North Central Puget Sound sub-basin is projected to be one of the less degraded sub-basins in Puget Sound. Only four nearshore processes in the sub-basin (sediment transport, sediment accretion, tidal flow, and detritus import and export) are projected to have High or Medium Degradation along more than 50 percent of the shoreline length and watershed area in the sub-basin (Figures 3-19, 3-20, and 3-21). Further, sediment accretion, tidal flow, and tidal channel formation are the only nearshore processes for which more than 10 percent of the shoreline length and watershed area of the sub-basin is projected to be classified in the High Degradation category. The least degraded processes will be solar incidence, sediment input, and freshwater input.

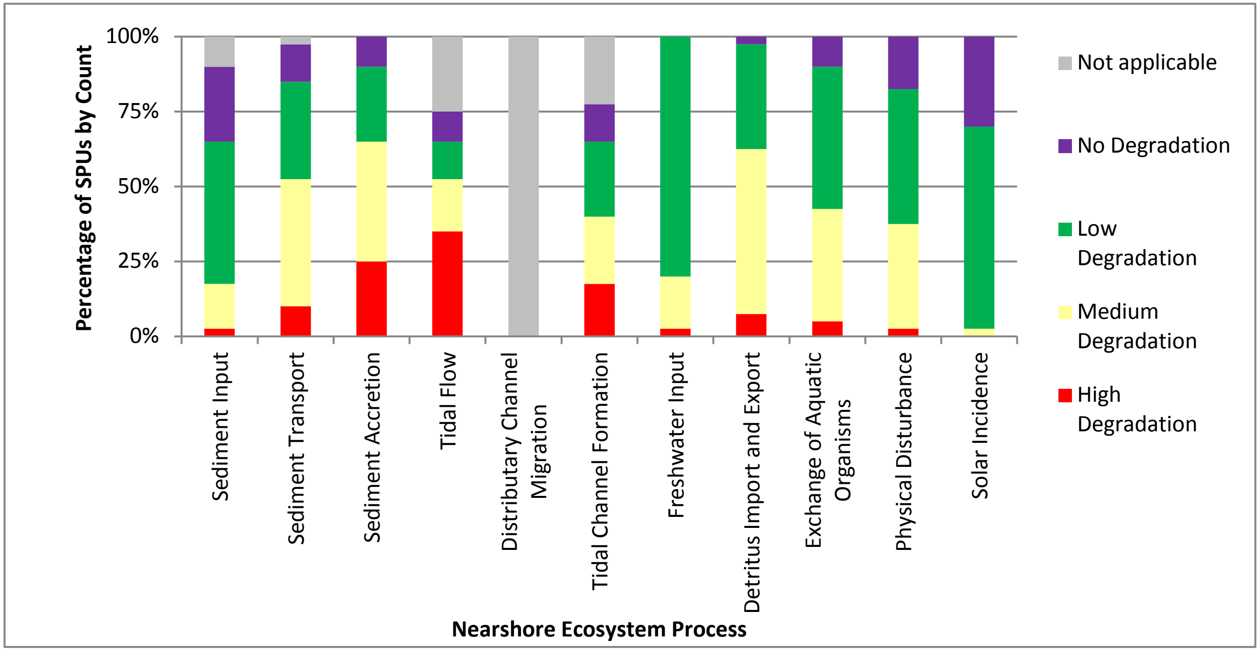


Figure 3-19
Future Nearshore Process Degradation in North Central Puget Sound Sub-basin by Percent of SPU Count

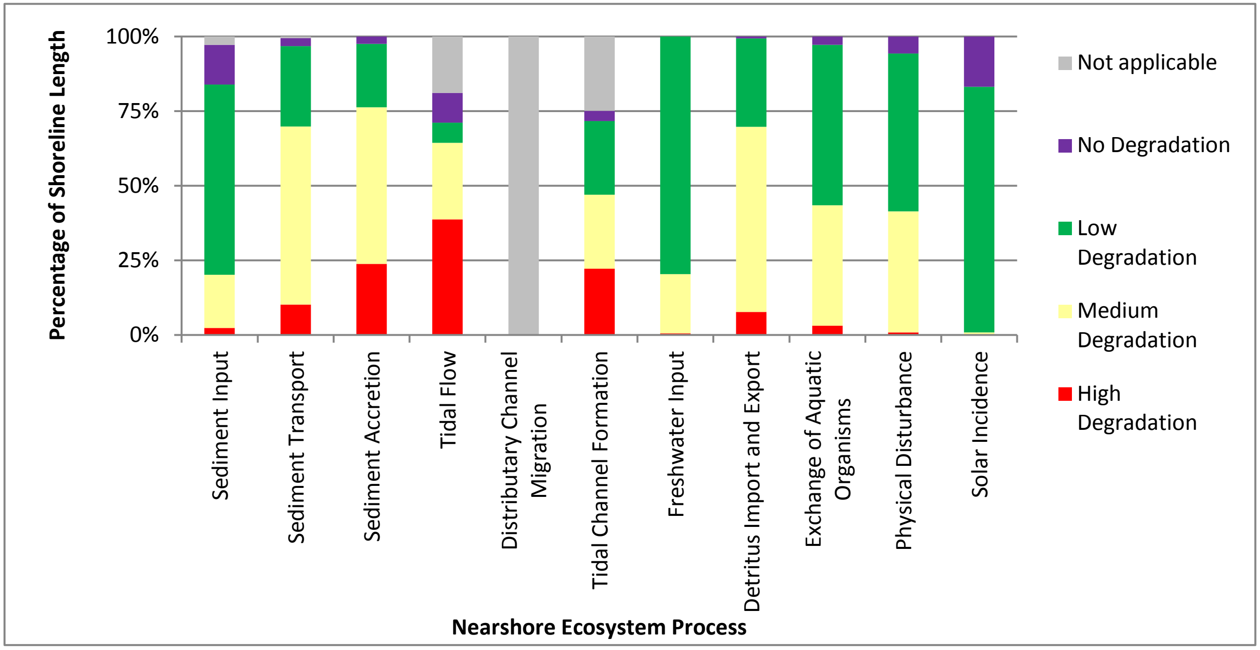


Figure 3-20
Future Nearshore Process Degradation in North Central Puget Sound Sub-basin by Percent of Total SPU Shoreline Length

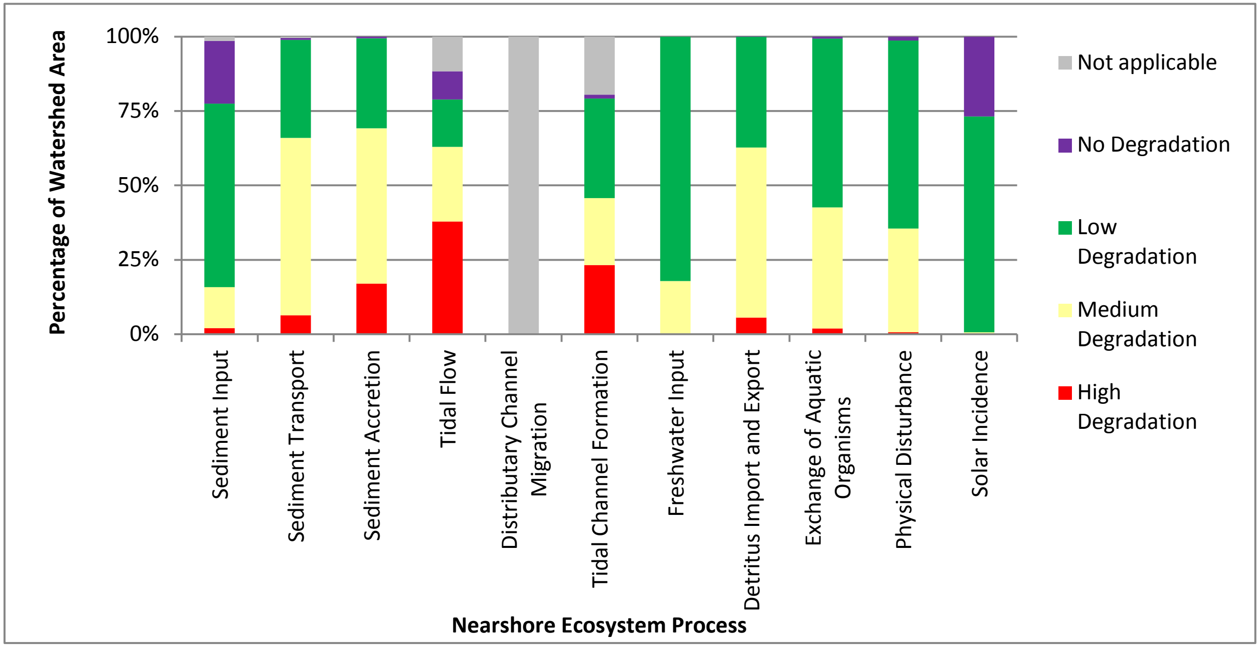


Figure 3-21
Future Nearshore Process Degradation in North Central Puget Sound Sub-basin by Percent of Total SPU Watershed Area

3.1.2.6 South Central Puget Sound Sub-basin

The South Central Puget Sound sub-basin is projected to be among the most degraded sub-basins in Puget Sound. More than 80 percent of the sub-basin watershed area will have incurred High or Medium Degradation for six nearshore processes including all three sediment processes, detritus import and export, exchange of aquatic organisms, and physical disturbance (Figures 3-22, 3-23, and 3-24). These processes are projected to be classified as High Degradation for more than 50 percent of the shoreline length.

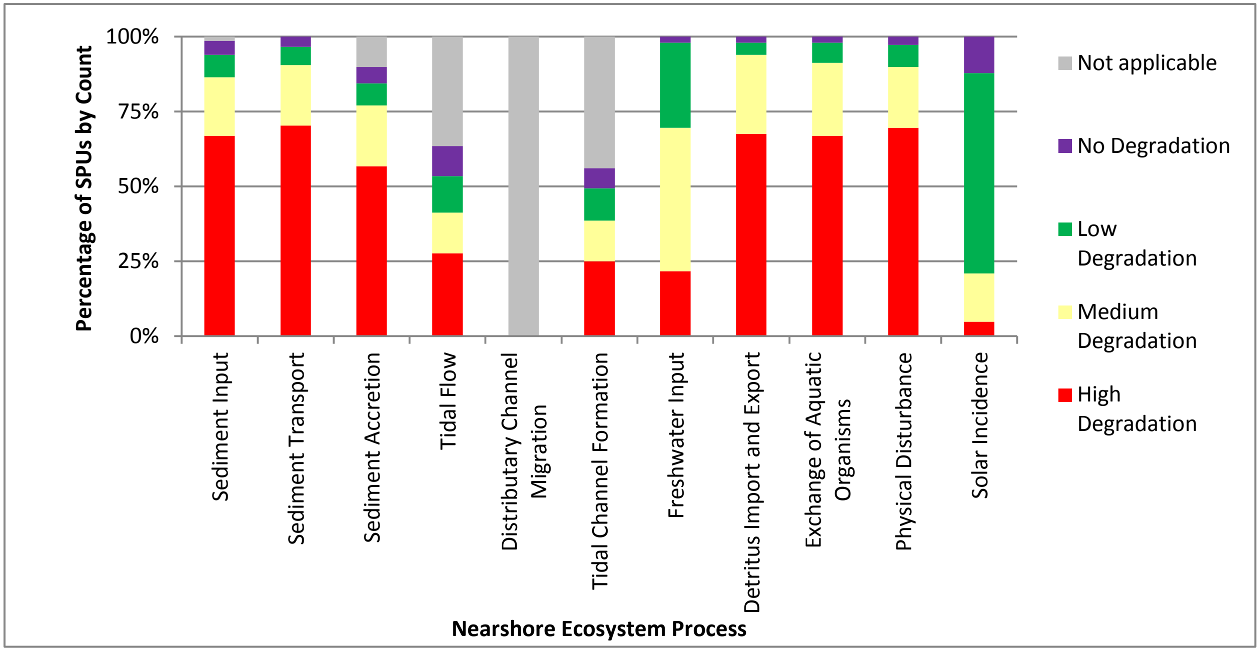


Figure 3-22
Future Nearshore Process Degradation in South Central Puget Sound Sub-basin by Percent of SPU Count

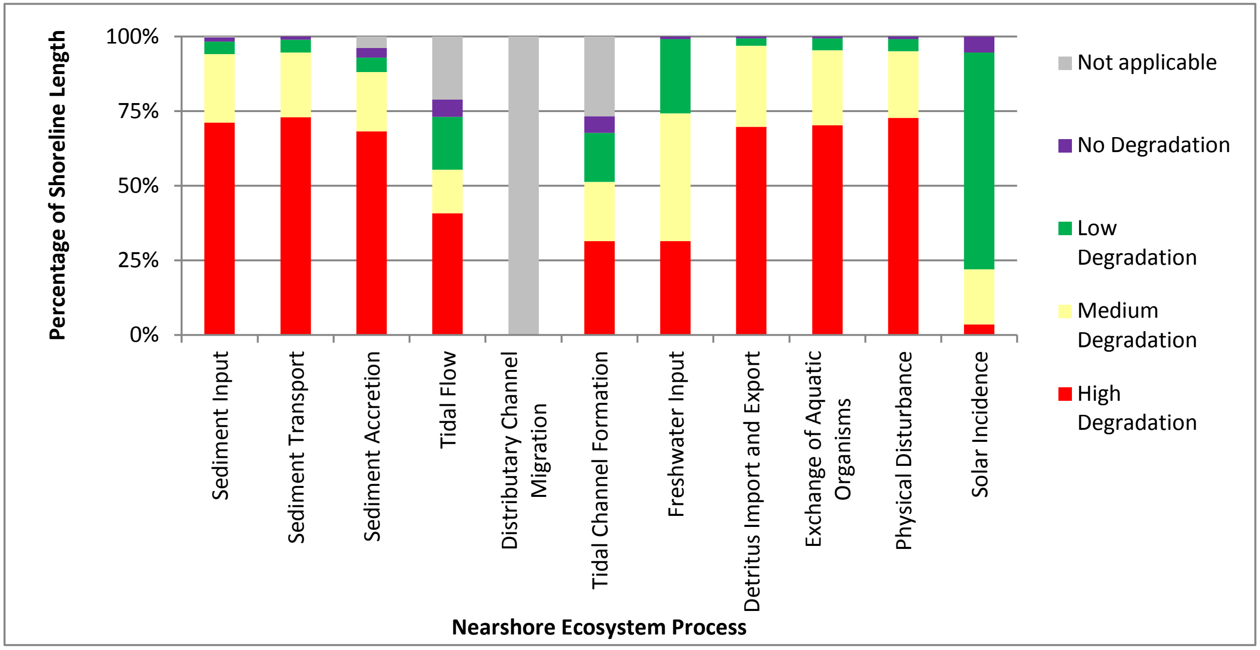


Figure 3-23
Future Nearshore Process Degradation in South Central Puget Sound Sub-basin by Percent of Total SPU Shoreline Length

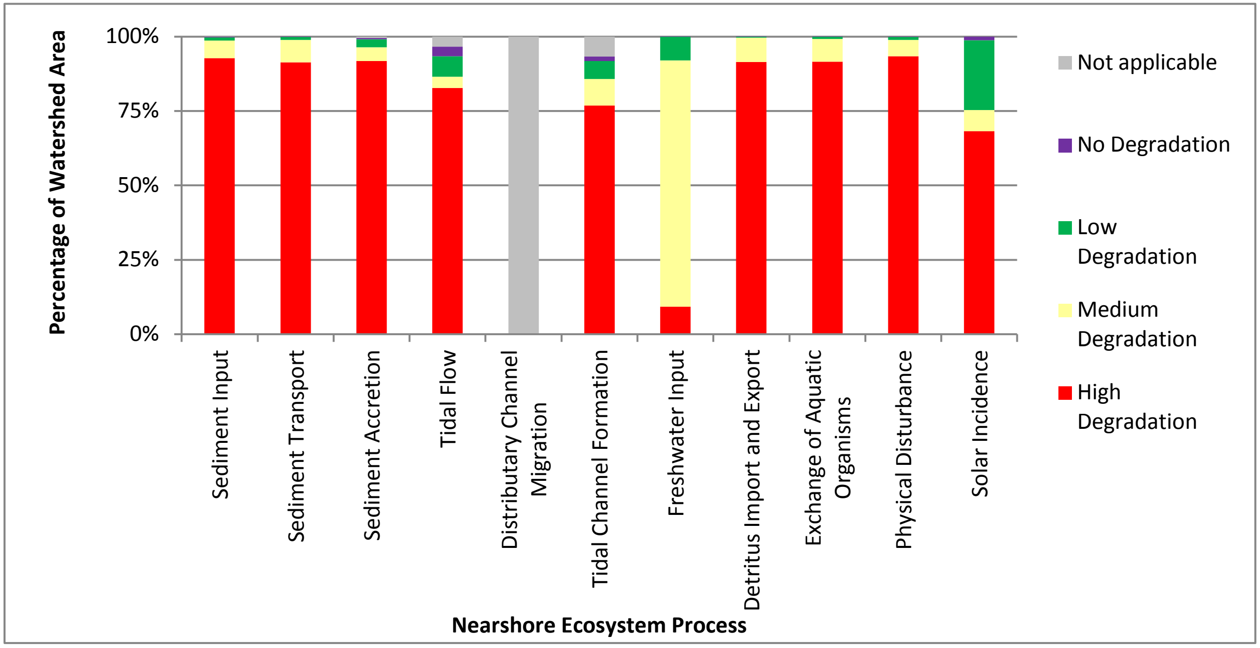


Figure 3-24
Future Nearshore Process Degradation in South Central Puget Sound Sub-basin by Percent of Total SPU Watershed Area

3.1.2.7 South Puget Sound Sub-basin

The South Puget Sound sub-basin is projected to be among the most degraded sub-basins in Puget Sound. Six nearshore processes are projected to incur High or Medium Degradation along 60 percent or more of the sub-basin shoreline length (Figures 3-25 and 3-26). The processes in this group include all three sediment processes, detritus import and export, exchange of aquatic organisms, and physical disturbance. The same six nearshore processes will be classified as having High or Medium Degradation in more than 60 percent of the watershed area of the sub-basin (Figure 3-27). The least degraded processes in the sub-basin are projected to be solar incidence and tidal channel formation.

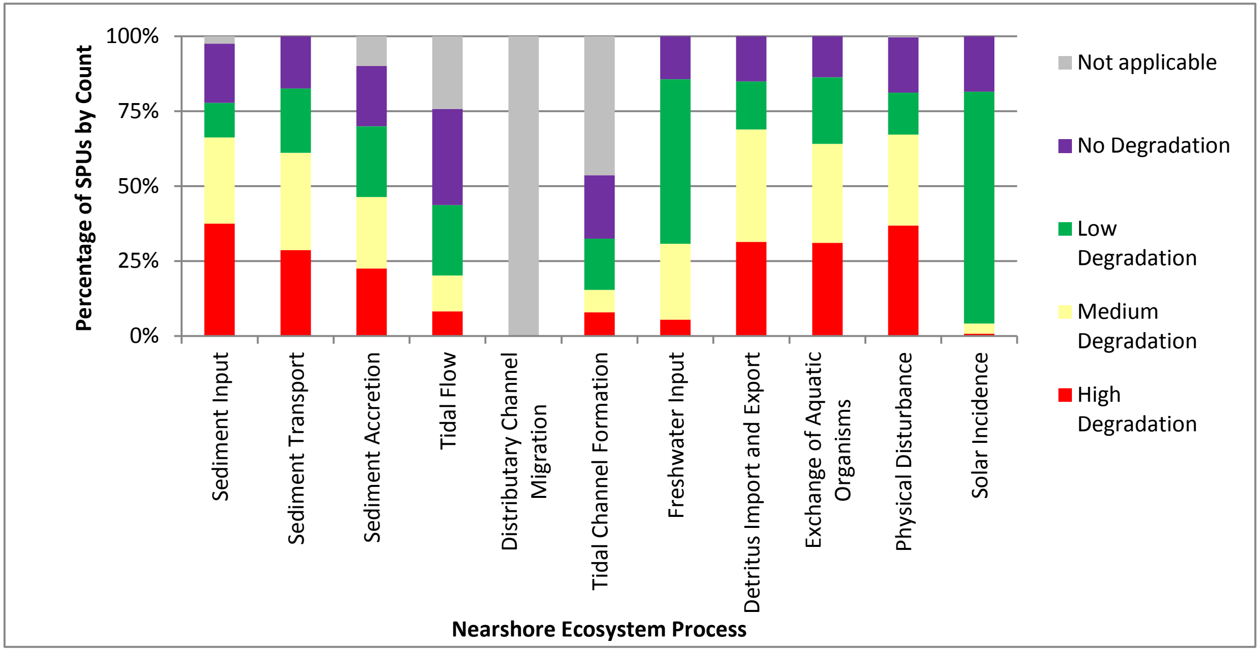


Figure 3-25
Future Nearshore Process Degradation in South Puget Sound Sub-basin by Percent of SPU Count

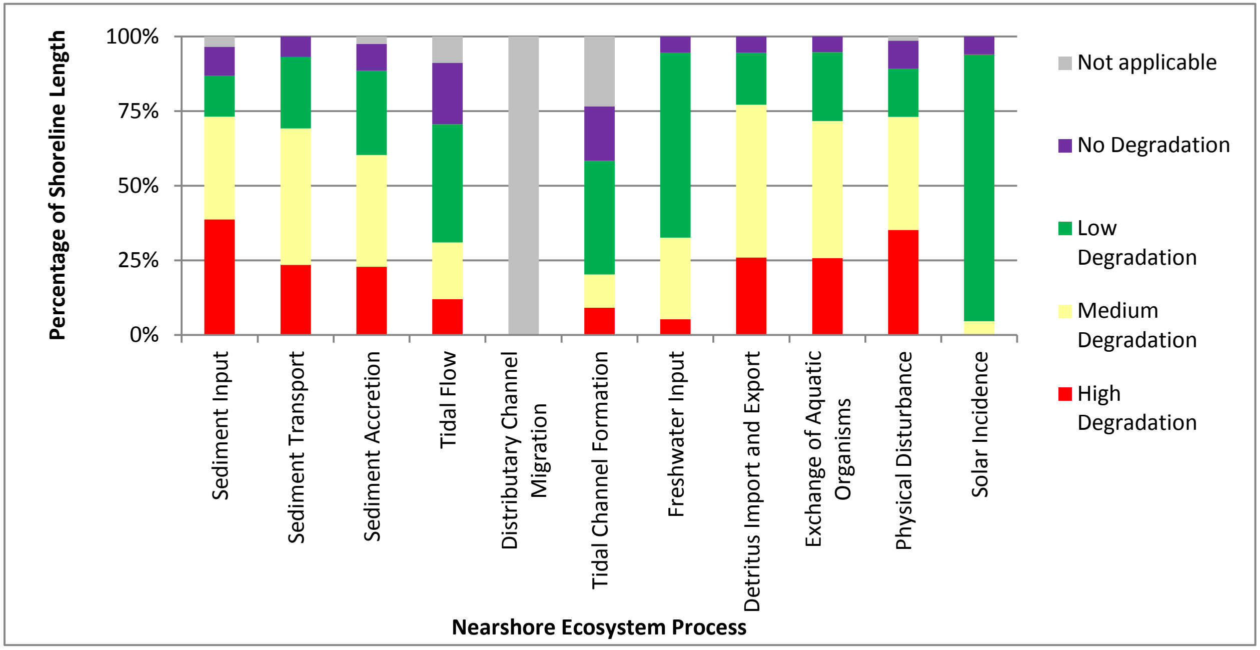


Figure 3-26
Future Nearshore Process Degradation in South Puget Sound Sub-basin by Percent of Total SPU Shoreline Length

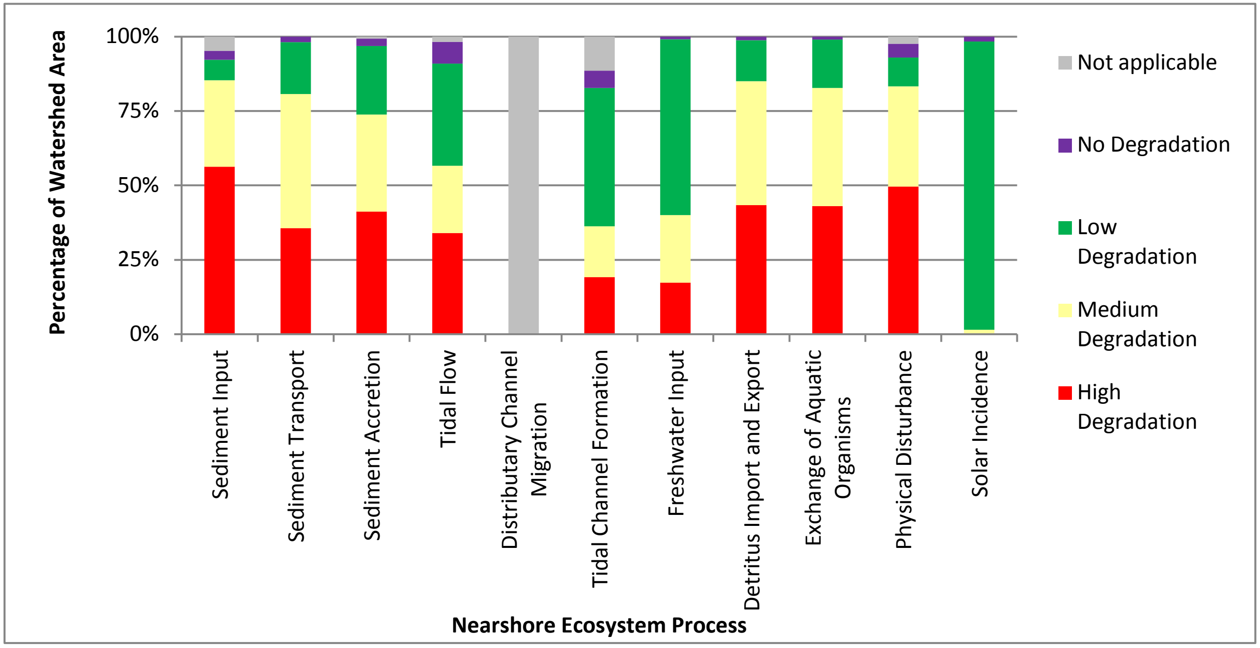


Figure 3-27
Future Nearshore Process Degradation in South Puget Sound Sub-basin by Percent of Total SPU Watershed Area

3.2 Overall Degradation of Nearshore Processes throughout Puget Sound

3.2.1 Distribution of Future Overall Degradation throughout Puget Sound

The future degradation analysis indicates that the geographic patterns observed in the current conditions analysis will continue into the future. The overall degradation categories assigned to process units reveal geographic differences in where higher degradation is projected compared to lesser degradation: higher degradation in the east and south, lesser degradation in the west and north (Figure 3-28). The eastern shoreline of Puget Sound, spanning from the Canadian border near Blaine to the Nisqually River in South Puget Sound, is projected to be entirely composed of process units categorized as being More Degraded or Most Degraded. These process units are in areas that will be among the most developed in the study area, and as a result, multiple shoreline and watershed stressors are contributing to degrade nearshore processes. Other areas projected to have extensive stretches of process units categorized as Most Degraded or More Degraded include central and southern Hood Canal, the eastern shoreline of the Kitsap Peninsula, Bainbridge Island, Skagit Bay, Anacortes, and Port Angeles. Process units categorized as Less Degraded and Least Degraded are projected to be widely distributed in the San Juan Islands; as well as along the Strait of Juan de Fuca sub-basin; in the northwestern portion of the Hood Canal sub-basin; on Whidbey Island; and in several smaller areas distributed in the South Puget Sound sub-basin west of McNeil Island.

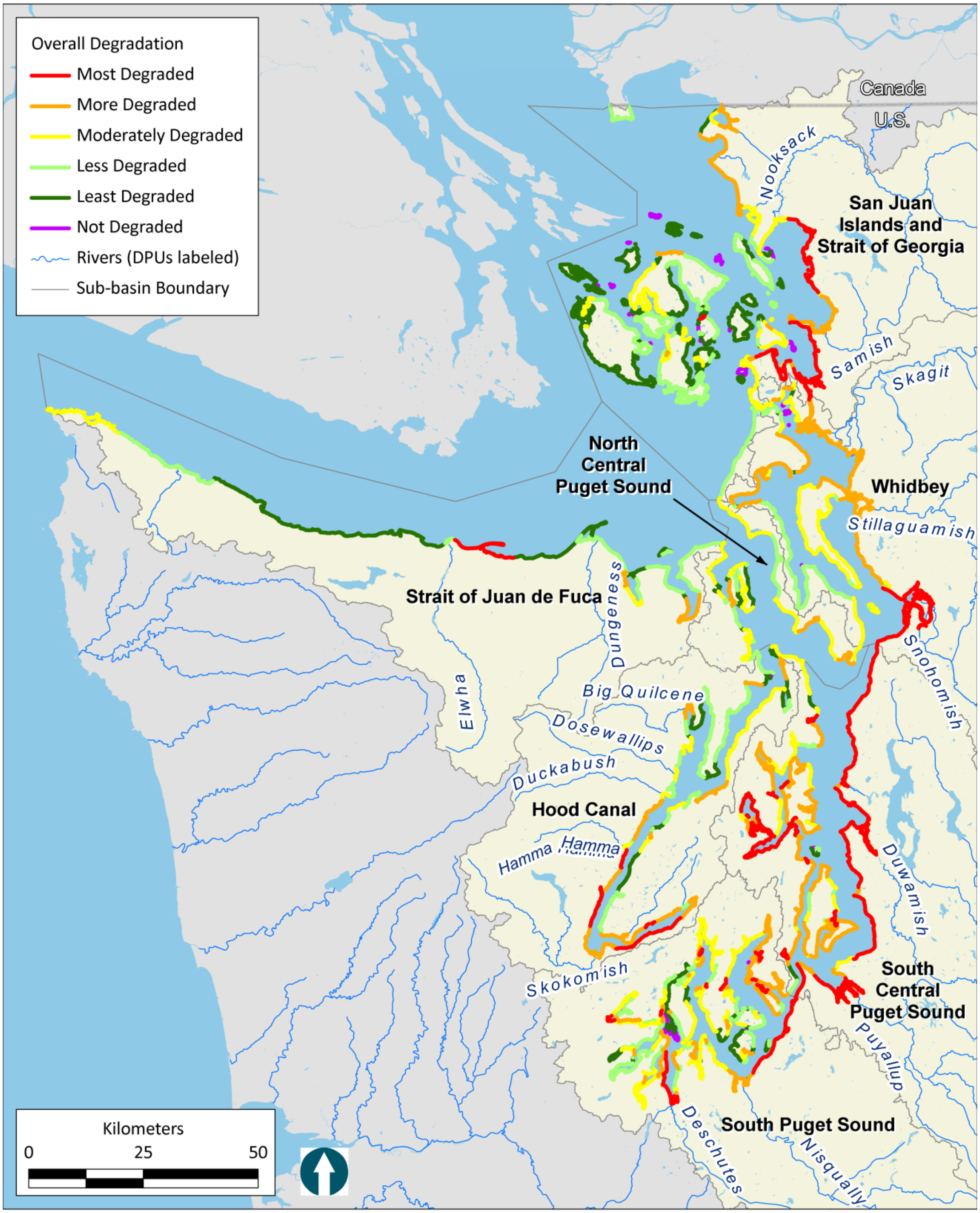


Figure 3-28
Map of Overall Future Nearshore Process Degradation by Process Unit

3.2.2 Changes from Current Conditions to Future Degradation Conditions

Approximately 19 percent of the process units in Puget Sound are projected to change to an increased overall degradation category in the future (Figure 3-29). The process units forecast to change comprise 20 percent of the shoreline length, but only 7 percent of the watershed area of Puget Sound. The sub-basins with the highest projected percentage of changes are the South Central Puget Sound and North Central Puget Sound sub-basins (27 and 23 percent, respectively). The sub-basins with the lowest projected percentage of changes are the Strait of Juan de Fuca, Whidbey, and the San Juan Islands – Strait of Georgia sub-basin (10, 11, and 12 percent, respectively).

The future conditions degradation analysis predicts increased overall degradation among numerous process units distributed throughout the full north-to-south extent of Puget Sound and concentrated along the mainland portions of the San Juan Islands – Strait of Georgia sub-basin, northern Hood Canal, eastern Kitsap Peninsula, and the southern and western inlets of South Puget Sound (Figure 3-30). The overall degradation changes include one DPU change, as Quilcene is projected to be categorized as More Degraded in the future.

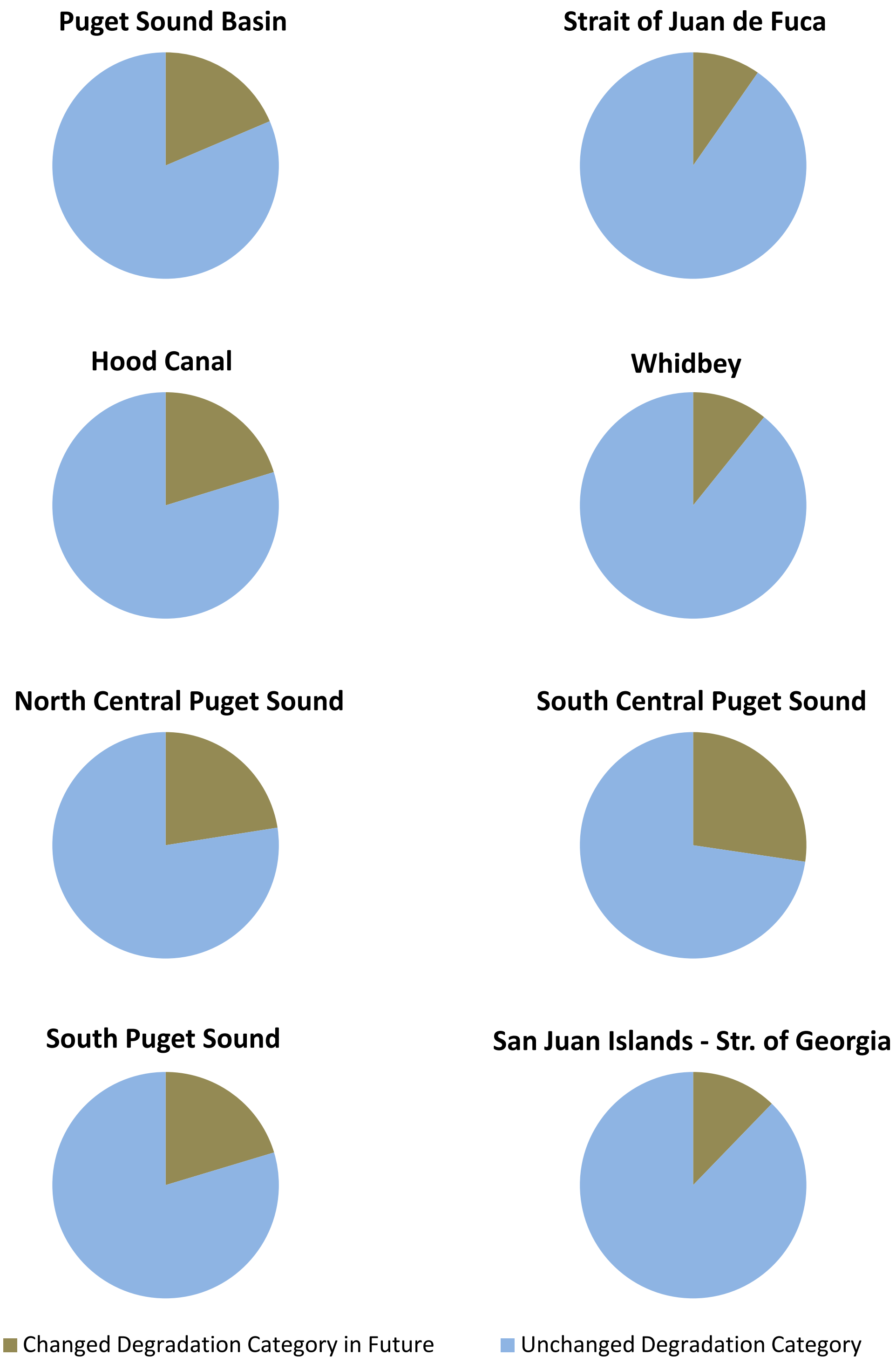


Figure 3-29

Proportion of the Number of Process Units in Each Sub-basin That the Overall Degradation Category Changed Between the Current Conditions and Future Conditions Analysis

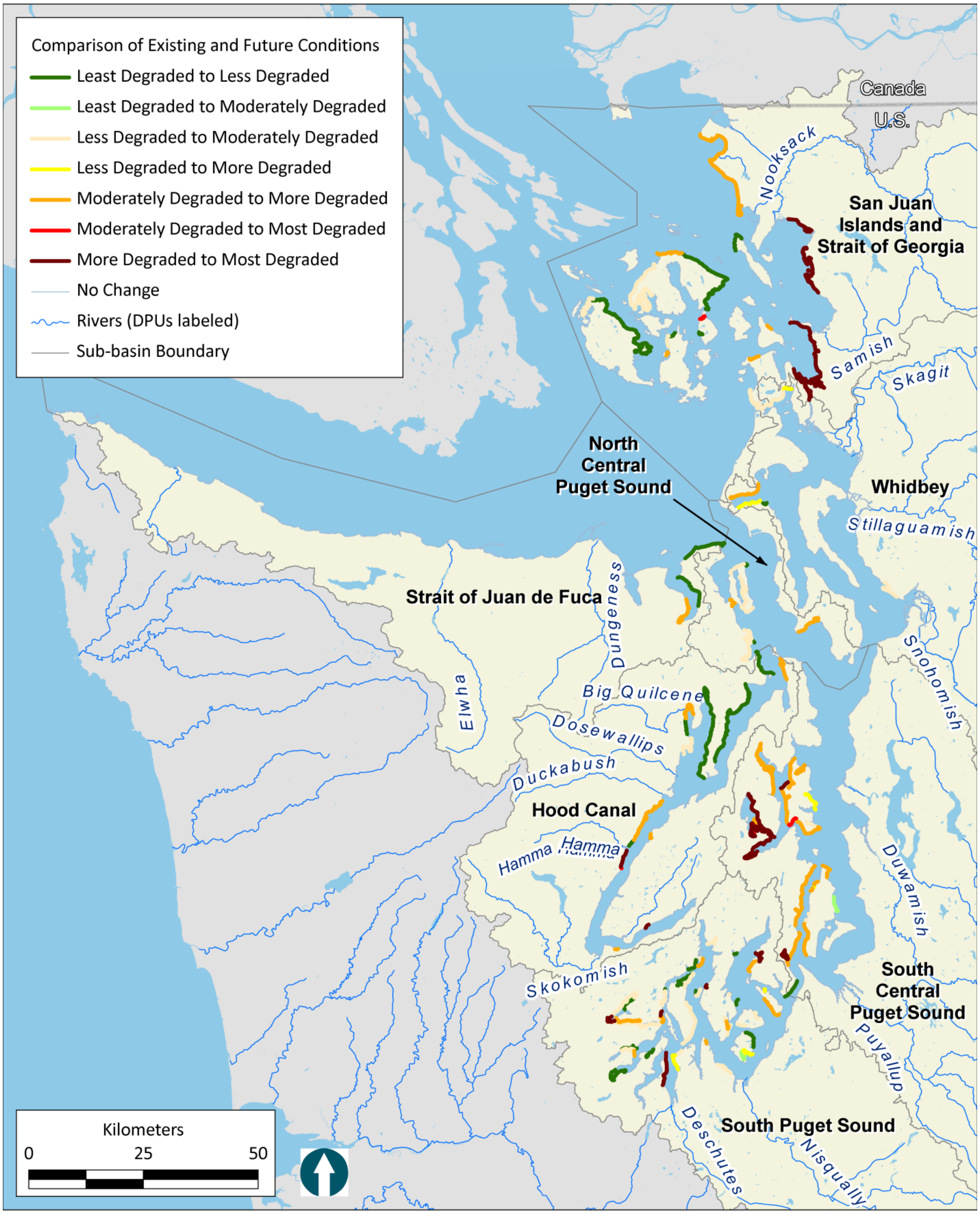
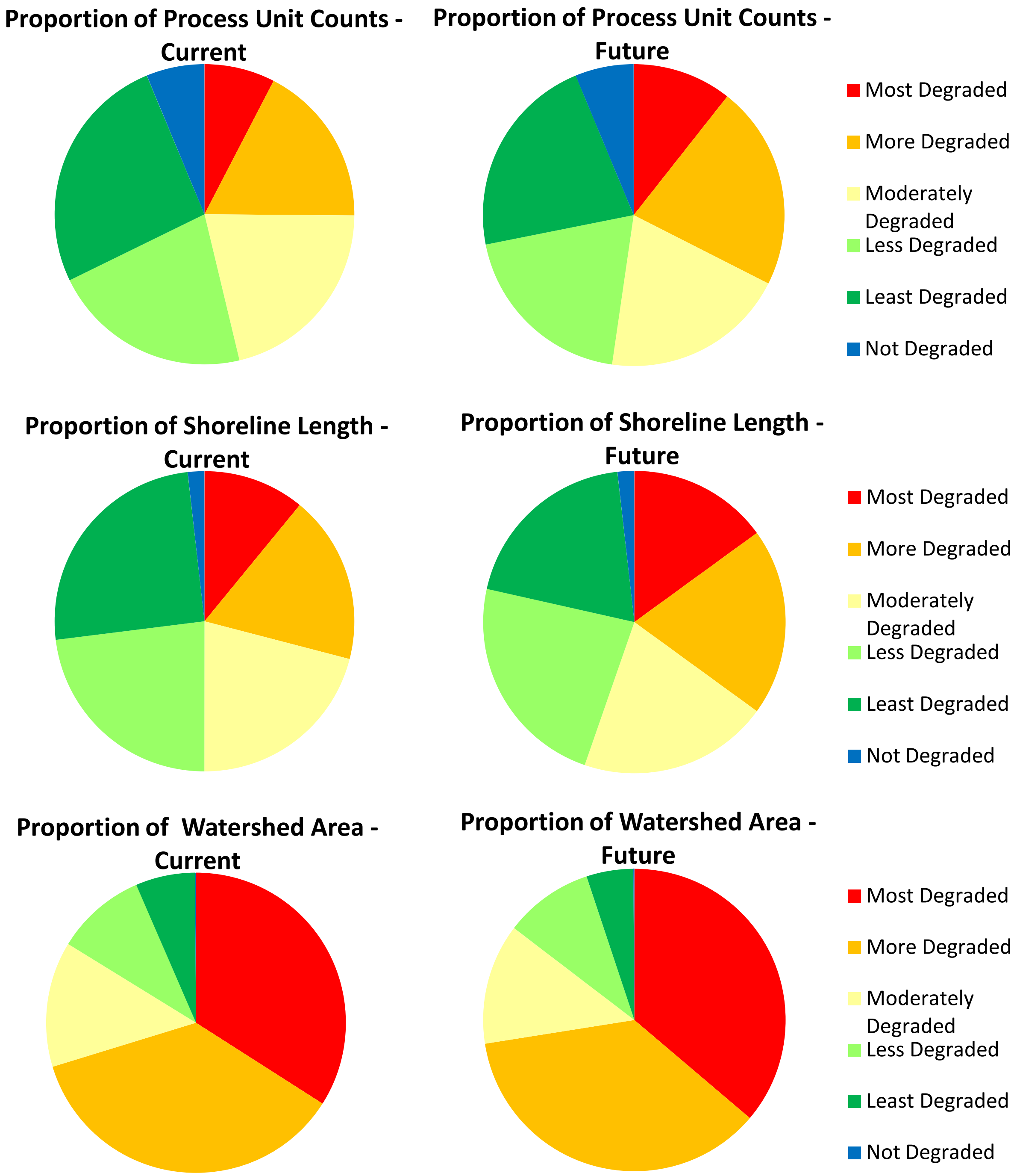


Figure 3-30

Map of Process Units Where the Overall Nearshore Process Degradation Category Changes between Current and Future Conditions

Figure 3-31 shows the proportions of process units (SPUs and DPUs) by count, shoreline length, and watershed area assigned to each overall degradation category in the current and future conditions analysis. The increased degradation is most notable in the increased proportions in the Most Degraded category and decreased proportions in the Least Degraded category. In the future degradation analysis, the highest percentages of process units will be in the Least Degraded and More Degraded categories (both with 22 percent, 181 process units). That is a notable change from current conditions in which the largest percentage of process units is in the Least Degraded category. Approximately 6 percent of the SPUs in Puget Sound are projected to have no degradation.

The percentages of shoreline length assigned to each overall degradation category are similar to the SPU count results and similar between the current and future conditions analyses. In contrast, the percentages of watershed area assigned to each category are distinctly different than the distributions found for counts and shoreline length. A much larger percentage of the watershed area of Puget Sound is forecast to be in the Most Degraded and More Degraded categories. More than 70 percent of the watershed area will be assigned to the Most and More Degraded categories combined. These degradation categories include many of the DPUs in the project area that are the largest process units in Puget Sound (Table 3-2).


Proportion of Process Unit Counts - Current

Proportion of Process Unit Counts - Future

Proportion of Shoreline Length - Current

Proportion of Shoreline Length - Future

Proportion of Watershed Area - Current

Proportion of Watershed Area - Future

Figure 3-31
Proportion of SPUs Assigned to Each Overall Degradation Category in the Current and Future Conditions Analysis

Table 3-2
Overall Degradation Categories Assigned to DPUs in the Current and Future Conditions Analysis

DPU	Sub-basin	Shoreline Length (km)	Watershed Area (km2)	Current Overall Degradation	Future Overall Degradation
Nooksack	SJ	41	2,084	Moderately Degraded	Moderately Degraded
Samish	SJ	29	403	More Degraded	More Degraded
Skagit	WH	96	7,301	More Degraded	More Degraded
Stillaguamish	WH	65	1,876	More Degraded	More Degraded
Snohomish	WH	95	4,748	Most Degraded	Most Degraded
Duwamish	SC	32	1,257	Most Degraded	Most Degraded
Puyallup	SC	46	2,535	Most Degraded	Most Degraded
Nisqually	SP	20	2,160	More Degraded	More Degraded
Deschutes	SP	9	466	Most Degraded	Most Degraded
Elwha	JF	4	838	Less Degraded	Less Degraded
Dungeness	JF	12	564	Less Degraded	Less Degraded
Quilcene	HC	8	295	Moderately Degraded	More Degraded
Dosewallips	HC	5	307	Moderately Degraded	Moderately Degraded
Duckabush	HC	4	204	Moderately Degraded	Moderately Degraded
Hamma Hamma	HC	5	222	Moderately Degraded	Moderately Degraded
Skokomish	HC	14	654	More Degraded	More Degraded

3.3 Overall Degradation of Nearshore Processes within Sub-basins

3.3.1 Comparison of Overall Degradation Among Sub-basins

By process unit count, the South Central Puget Sound and South Puget Sound sub-basins are forecast to have the highest combined number of process units in the Most Degraded and More Degraded categories (105 and 84, respectively; Figure 3-32). South Central Puget Sound and Whidbey sub-basins are projected to have the combined longest shoreline lengths in the Most Degraded and More Degraded categories (616 and 399 km, respectively; Figure 3-33). Similarly, the South Central Puget Sound and Whidbey sub-basins will have the largest extents of watershed area in the Most and More Degraded categories (8,068 and 14,277 km^2, respectively; Figure 3-34).

The South Puget Sound and the San Juan Islands – Strait of Georgia sub-basins will have the highest number of process units in both the Not Degraded (24 and 21, respectively) and Least Degraded (49 and 87, respectively) categories (Figure 3-32). Those two sub-basins are projected to contain 86 percent of the total number of process units throughout Puget Sound in the Not Degraded category and 73 percent of the total number of process units in the Least Degraded category. The Least Degraded process units in these sub-basins will comprise 127 km of shoreline length in the South Puget Sound sub-basin and 547 km of shoreline length in the San Juan Islands – Strait of Georgia sub-basin (Figure 3-33). These lengths represent a decrease of 32 percent and 16 percent compared to the current combined shoreline lengths in the Least Degraded category. The remaining 547 km of Least Degraded shoreline length in the San Juan Islands – Strait of Georgia sub-basin is projected to comprise 56 percent of the total shoreline length in the Puget Sound study area that is categorized as Least Degraded. The largest amount of watershed area in the Least Degraded and Less Degraded categories is projected to occur in the Strait of Juan de Fuca sub-basin (1,098 and 1,944 km^2, respectively; Figure 3-34). In three of the seven sub-basins, process units in the Least Degraded and Less Degraded categories will comprise more than 50 percent of the sub-basin's process units and shoreline length (Figure 3-35 and 3-36). For watershed area, this is projected to be the case for only the Strait of Juan de Fuca and North Central Puget Sound sub-basins (Figure 3-37).

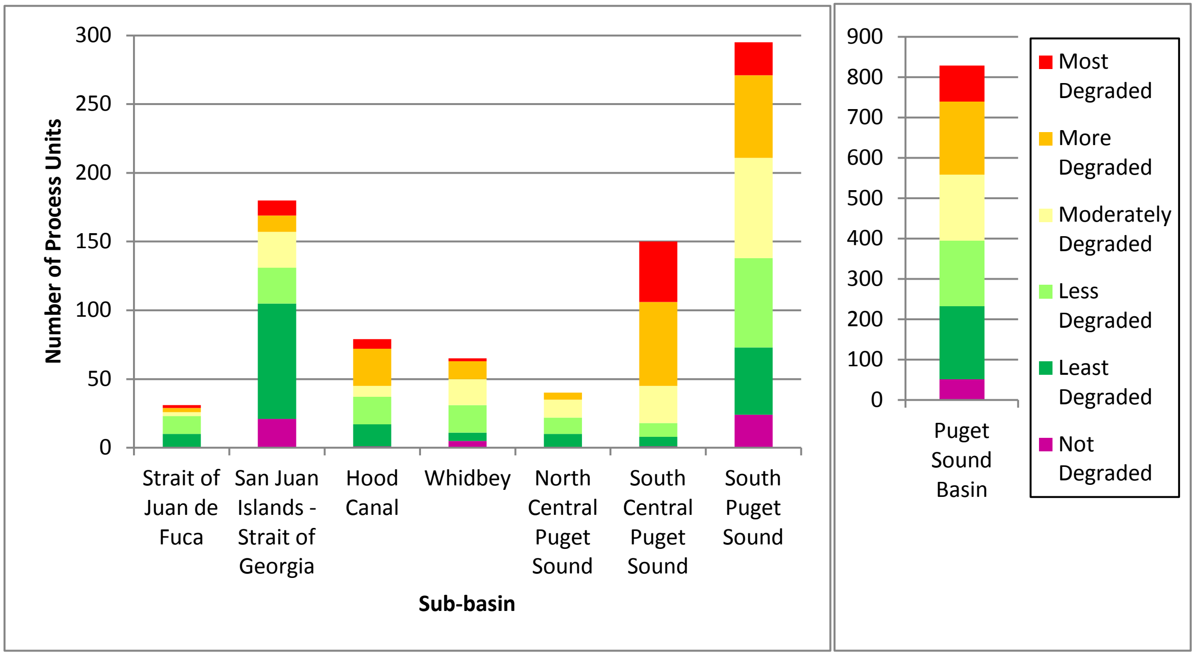


Figure 3-32
Number of Process Units in Each Sub-basin and Sound-wide Assigned to Each Overall Process Degradation Category

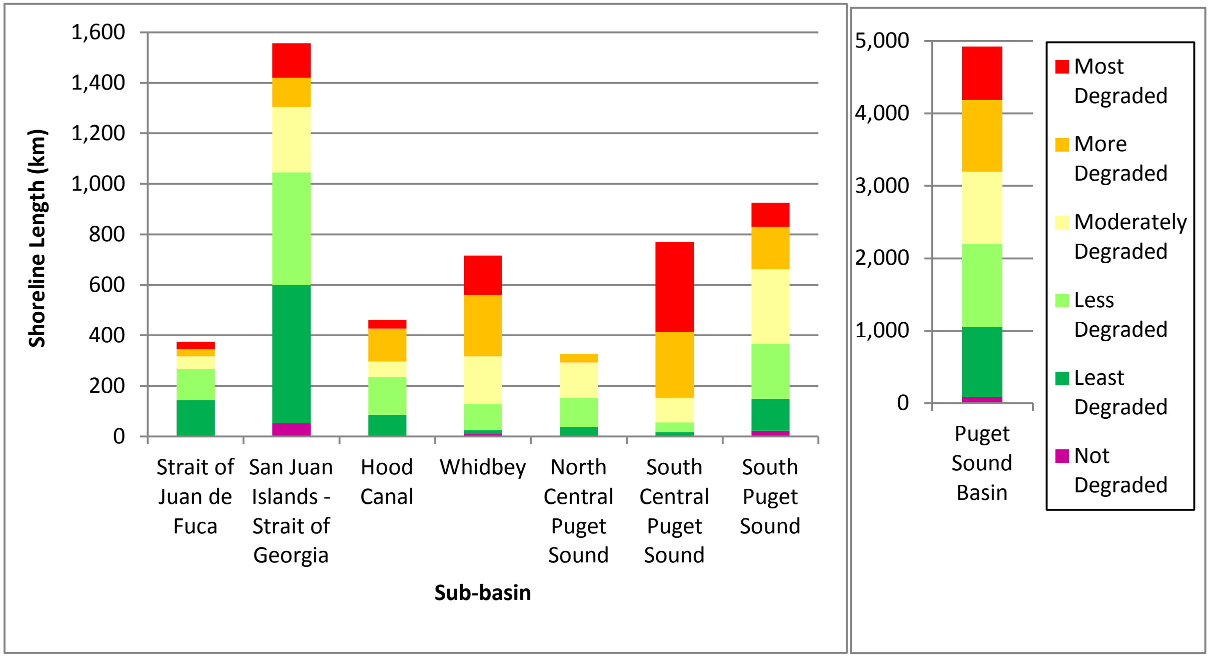


Figure 3-33
Shoreline Length Among Overall Process Degradation Categories in Process Units by Sub-basin and Sound-wide

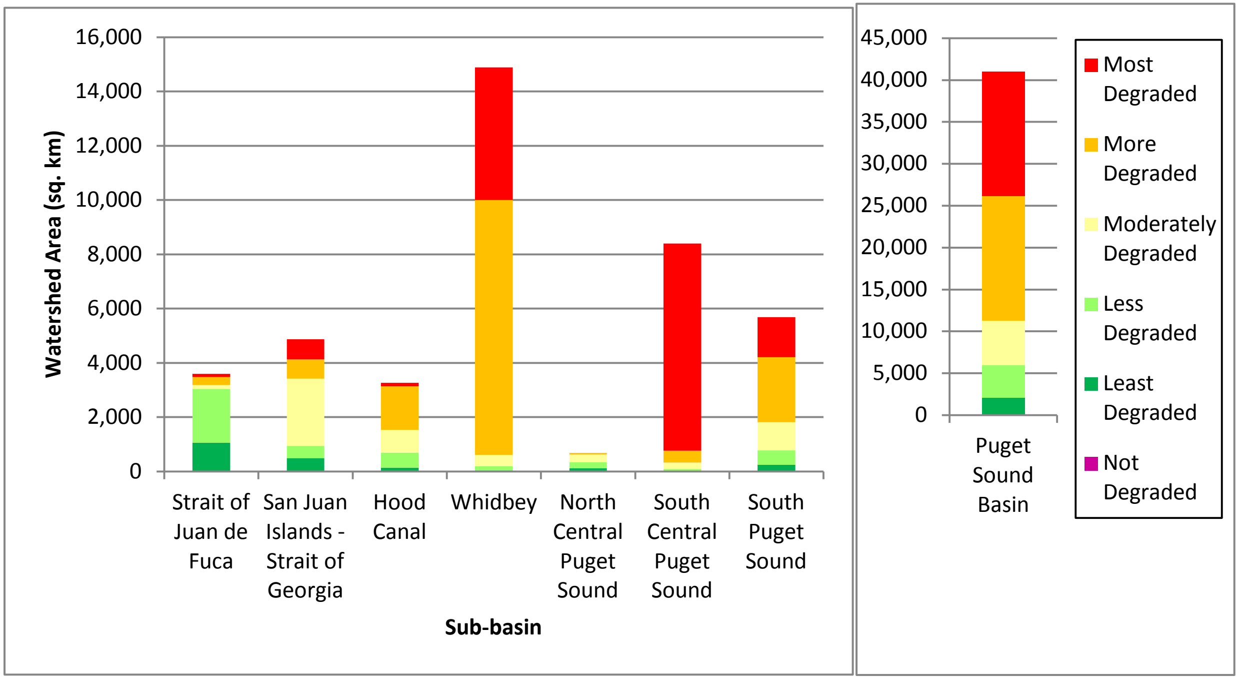


Figure 3-34
Watershed Area Among Overall Process Degradation Categories in Process Units by Sub-basin and Sound-wide

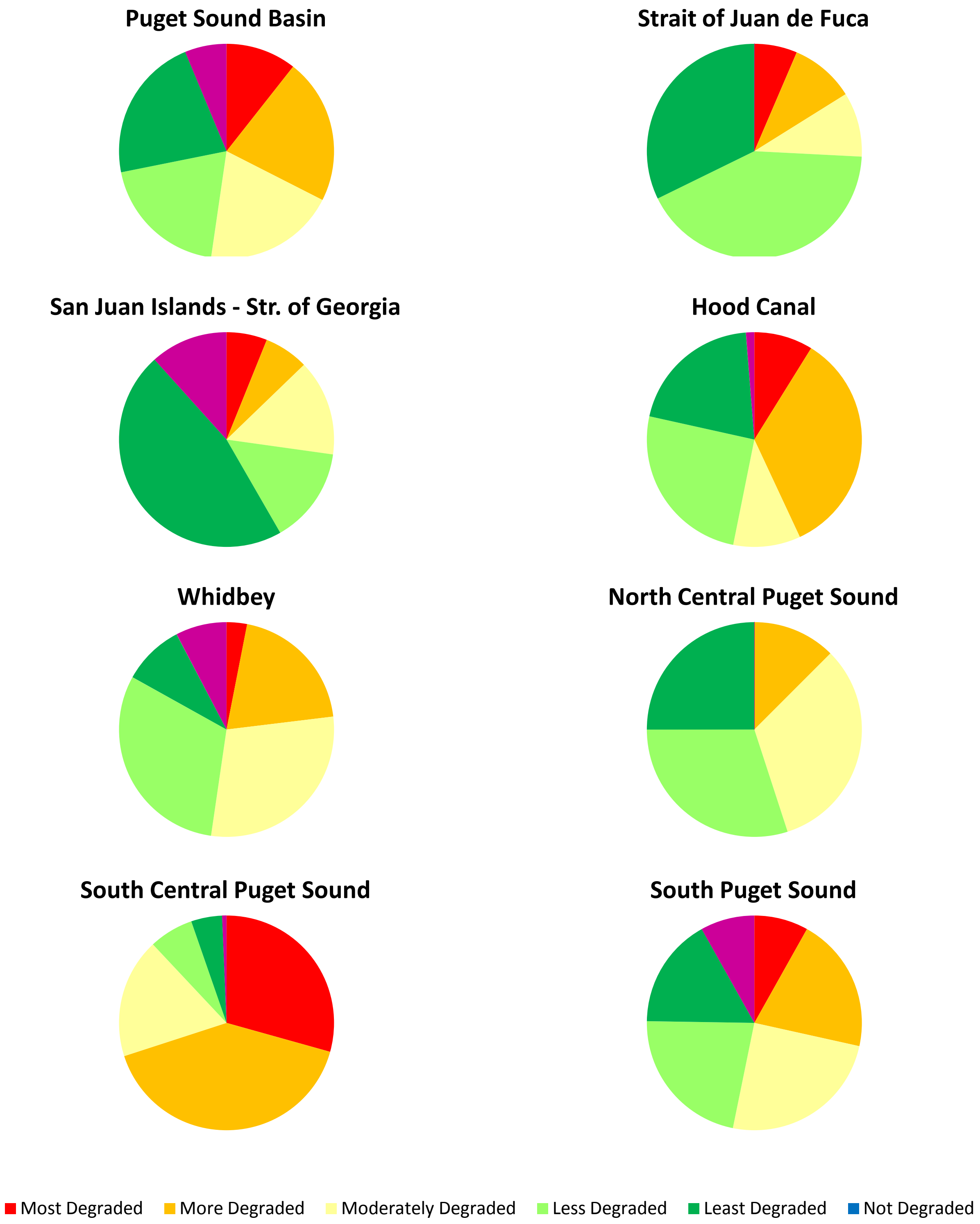


Figure 3-35
Proportion of Total Sub-basin Process Units, By Count, in Each Overall Degradation Category

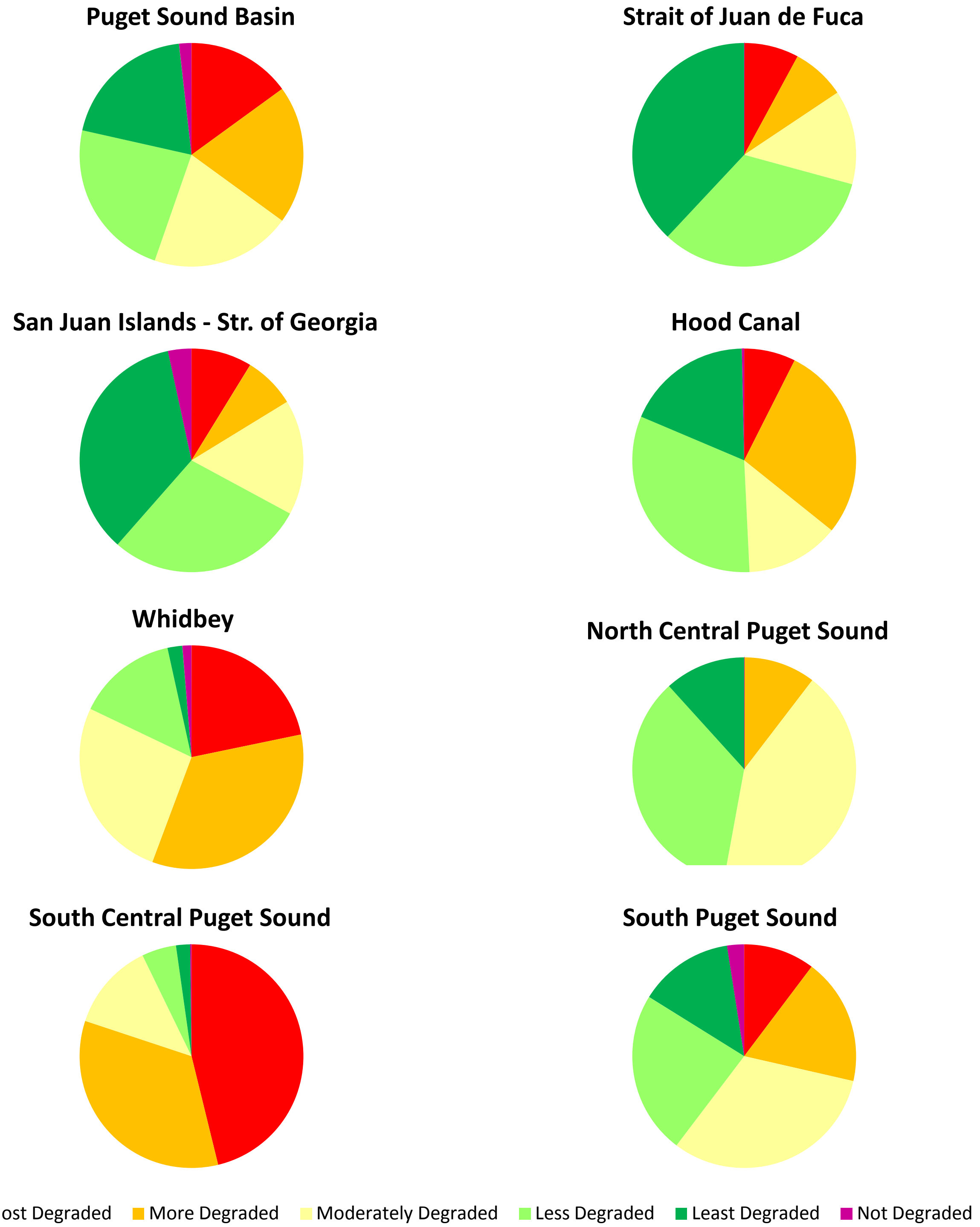
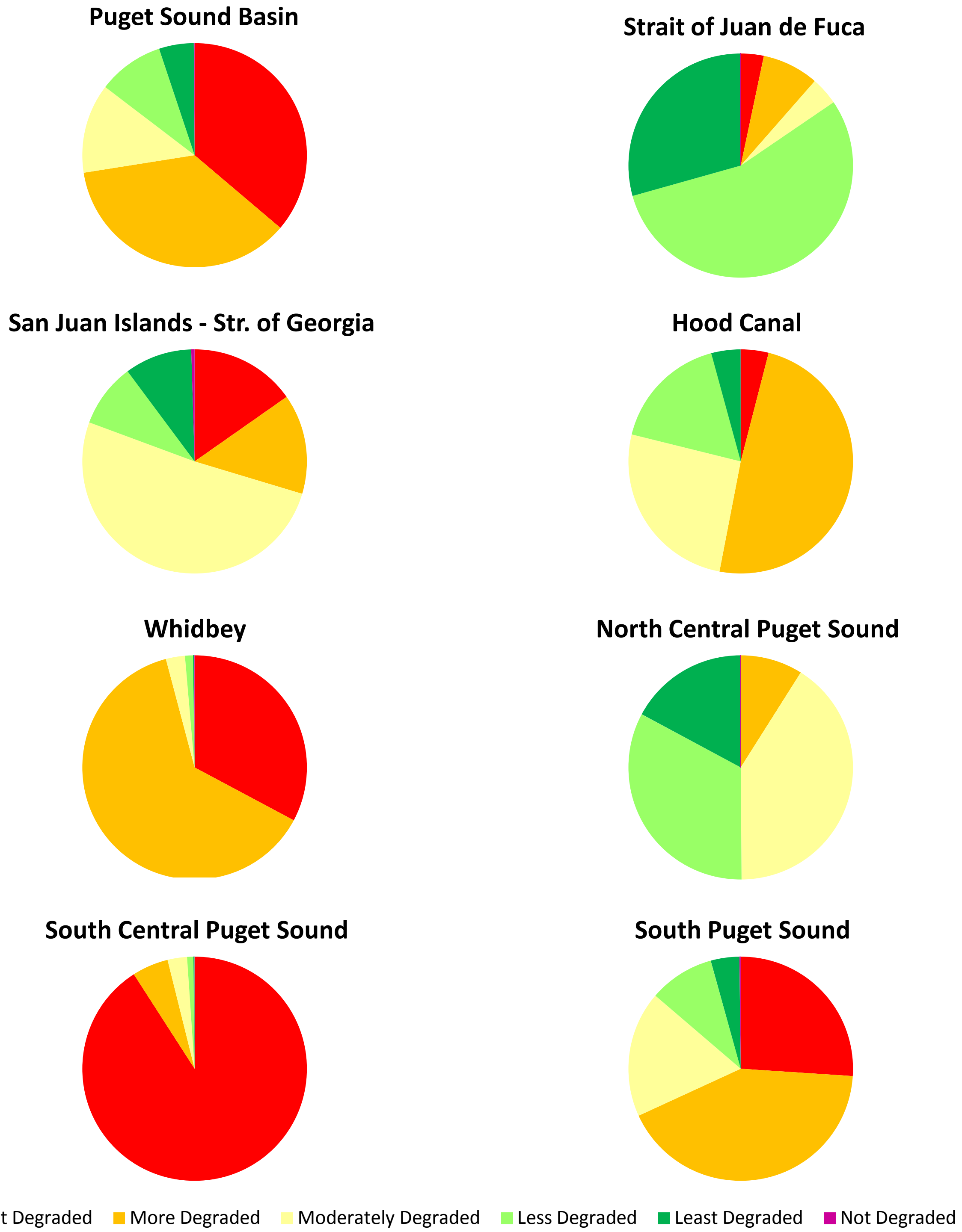


Figure 3-36
Proportion of Total Sub-basin Process Unit Shoreline Length in Each Overall Degradation Category



Puget Sound Basin

Strait of Juan de Fuca

San Juan Islands - Str. of Georgia

Hood Canal

Whidbey

North Central Puget Sound

South Central Puget Sound

South Puget Sound

Figure 3-37
Proportion of Total Sub-basin Process Unit Watershed Area in Each Overall Degradation Category

3.3.2 Strait of Juan de Fuca Sub-basin

Within the Strait of Juan de Fuca sub-basin, long portions of shoreline are projected to be in the Less Degraded or Least Degraded categories (Figure 3-38). The only process units that will be classified as Most Degraded encompass Port Angeles and Ediz Hook. The process units in the Moderately Degraded and More Degraded categories are projected to be limited to the interior portions of Discovery Bay and Sequim Bay, as well as the Neah Bay area.

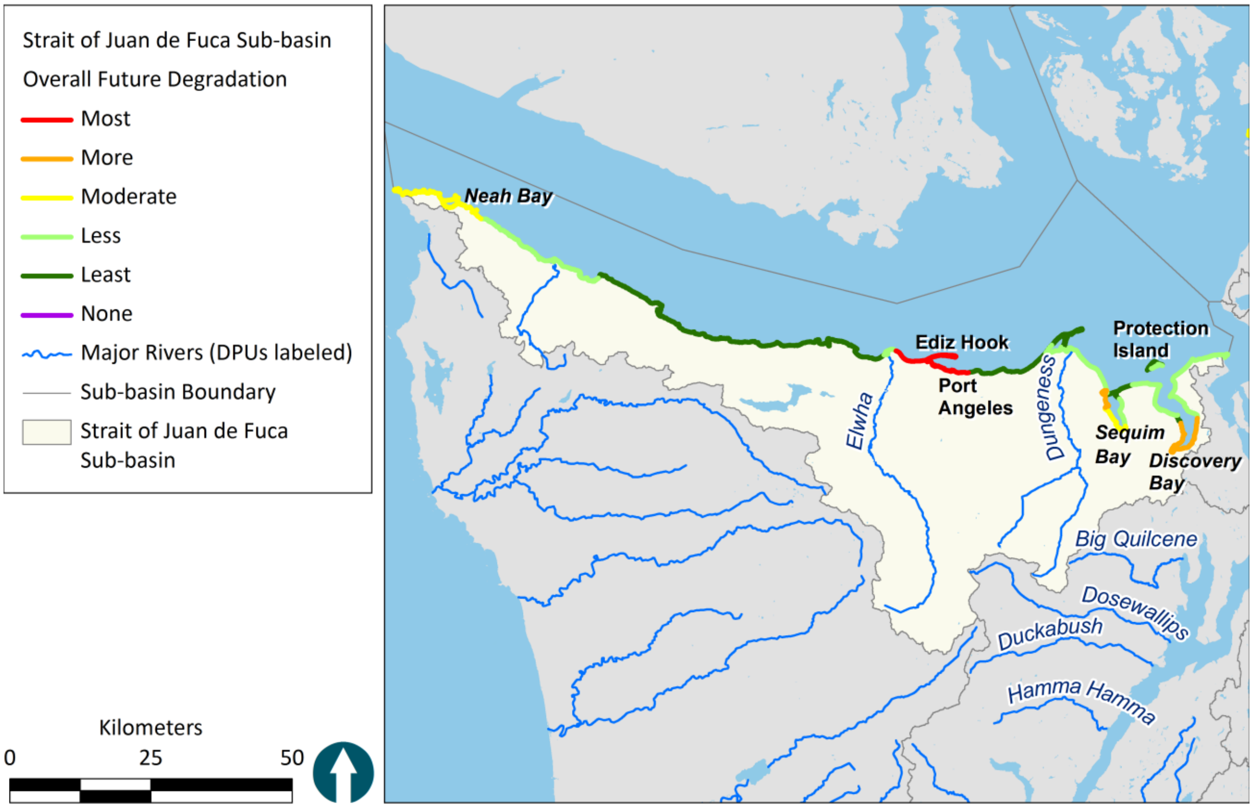


Figure 3-38

Sub-basin Scale Categories of Future Degradation in the Strait of Juan de Fuca Sub-basin

3.3.3 San Juan Islands – Strait of Georgia Sub-basin

In the San Juan Islands – Strait of Georgia sub-basin, much of the degradation is projected to occur along the mainland areas (Figure 3-39). Process units from Anacortes to the inner Bellingham Bay will be entirely classified as Most Degraded or More Degraded. From Lummi Bay north to Drayton Harbor, much of the area is also projected to be in the More Degraded category. The San Juan Islands are projected to be primarily classified as Less Degraded or Least Degraded, although much of the northern portion of Lopez Island and western Orcas Island will be in the Moderately Degraded category. Process units that will be classified as Not Degraded are small islands and some small shorelines on Shaw Island.

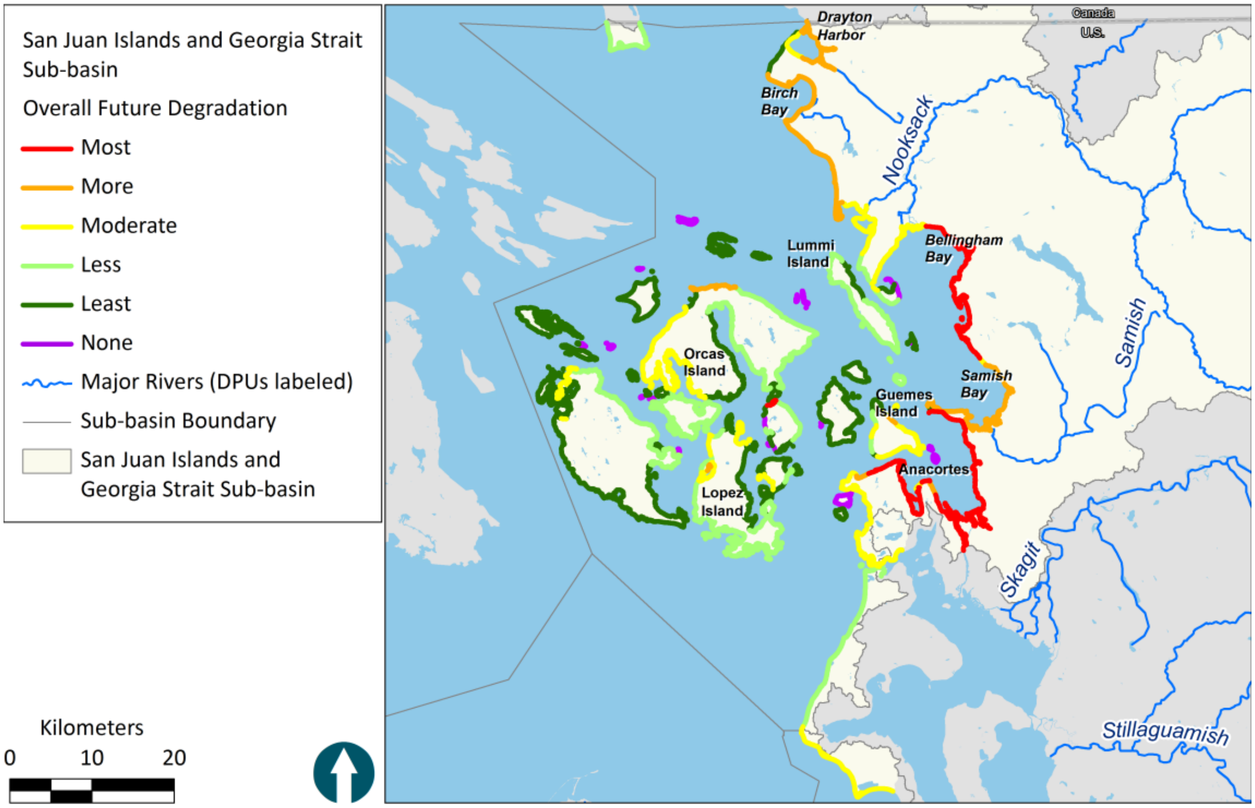


Figure 3-39

Sub-basin Scale Categories of Future Degradation in the San Juan Islands – Strait of Georgia Sub-basin

3.3.4 Hood Canal Sub-basin

In the Hood Canal sub-basin, the entire areas east of the Great Bend are projected to be in the Most or More Degraded categories. In addition, the western shoreline of Hood Canal from the Skokomish River DPU to the Duckabush River DPU is also projected to be classified as Most or More Degraded (Figure 3-40). For the remainder of the sub-basin, the eastern shoreline is projected to have greater degradation than the western shoreline.

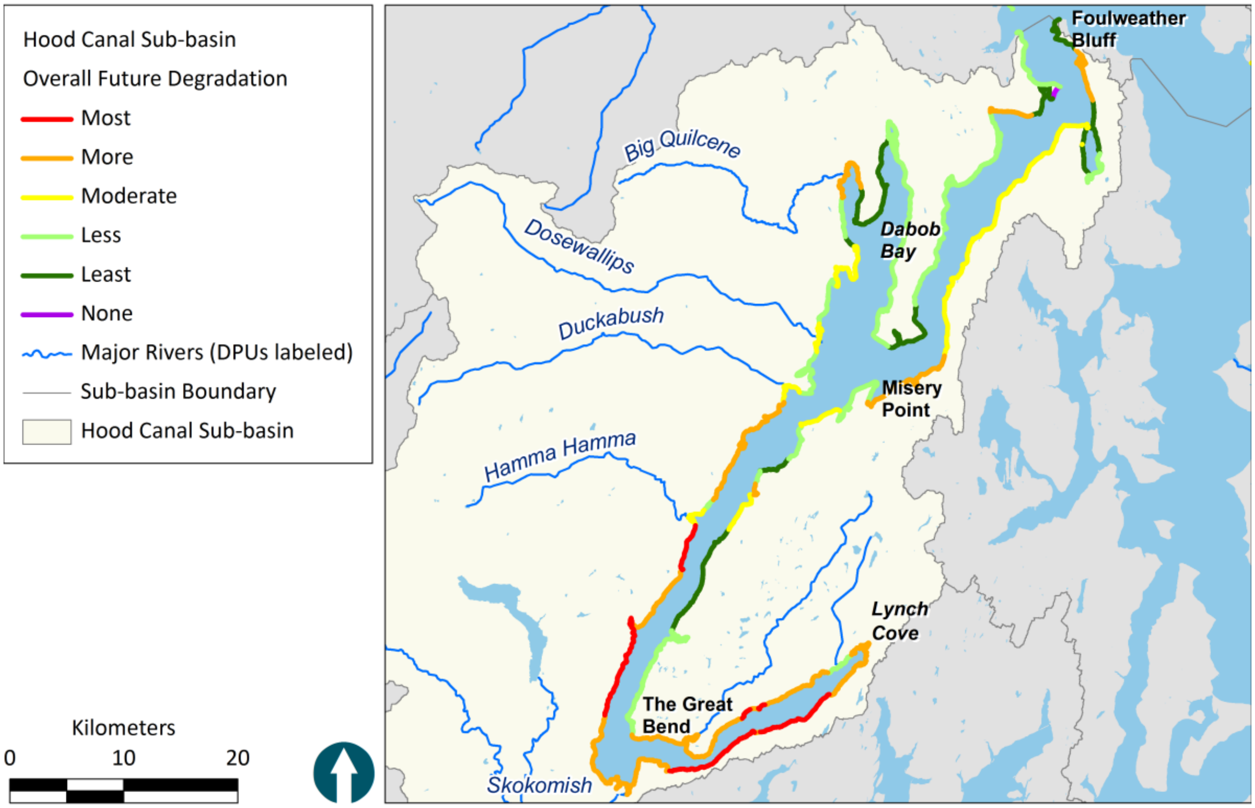


Figure 3-40

Sub-basin Scale Categories of Future Degradation in the Hood Canal Sub-basin

3.3.5 Whidbey Sub-basin

The three DPUs in the Whidbey sub-basin combine to cause nearly the entire extent of the mainland in the sub-basin is projected to be in the More Degraded or Most Degraded categories (Figure 3-41). The process units on Camano Island and Whidbey Island bordering Skagit Bay and extending through Penn Cove on Whidbey Island will be in the More Degraded category. The remaining process units in the southern portion of the islands and along the west side of Whidbey Island are projected to be largely Moderately Degraded or Less Degraded.

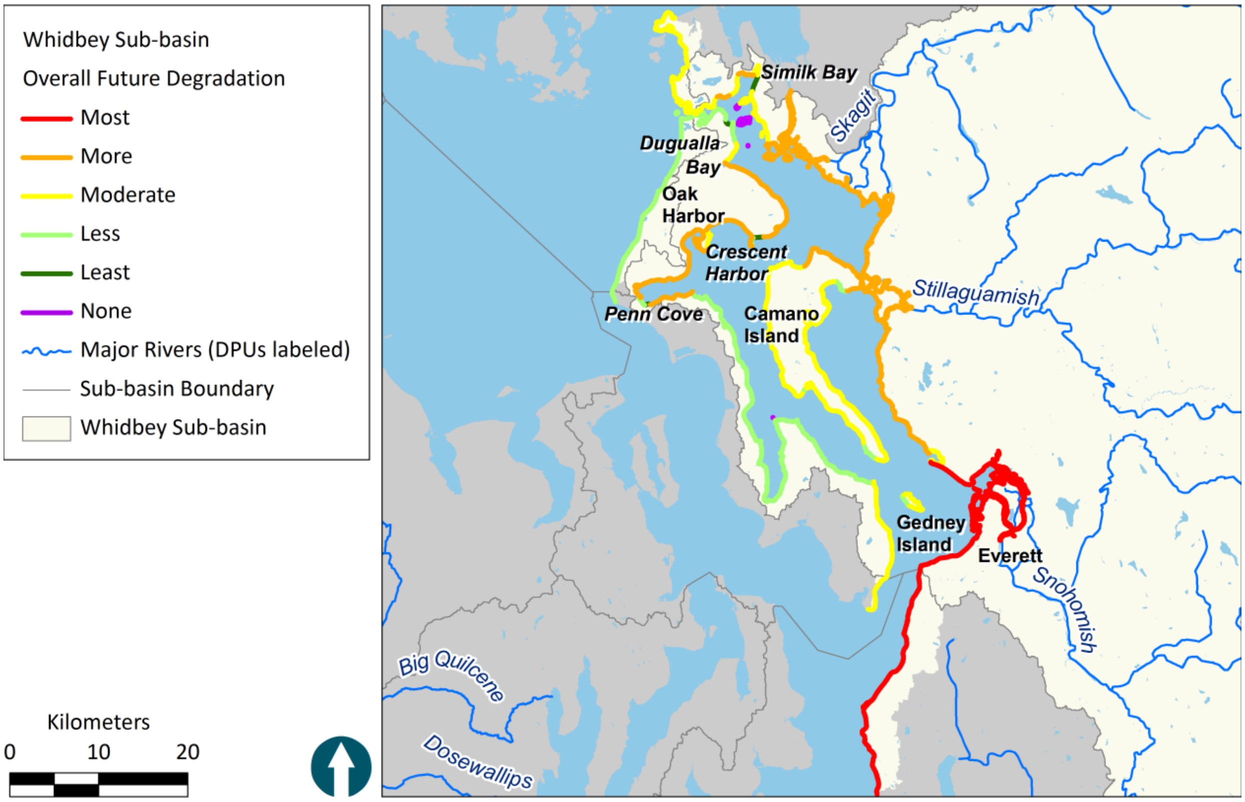


Figure 3-41

Sub-basin Scale Categories of Future Degradation in the Whidbey Sub-basin

3.3.6 North Central Puget Sound

Much of the North Central Puget Sound sub-basin is projected to be Moderately Degraded (Figure 3-42). The sub-basin includes three areas projected to be in the More Degraded category: Cultus Bay and Keystone Harbor on Whidbey Island, and Port Townsend Bay along the western portion of Indian Island. Process units projected to be categorized as Less Degraded and Least Degraded are scattered throughout the sub-basin.

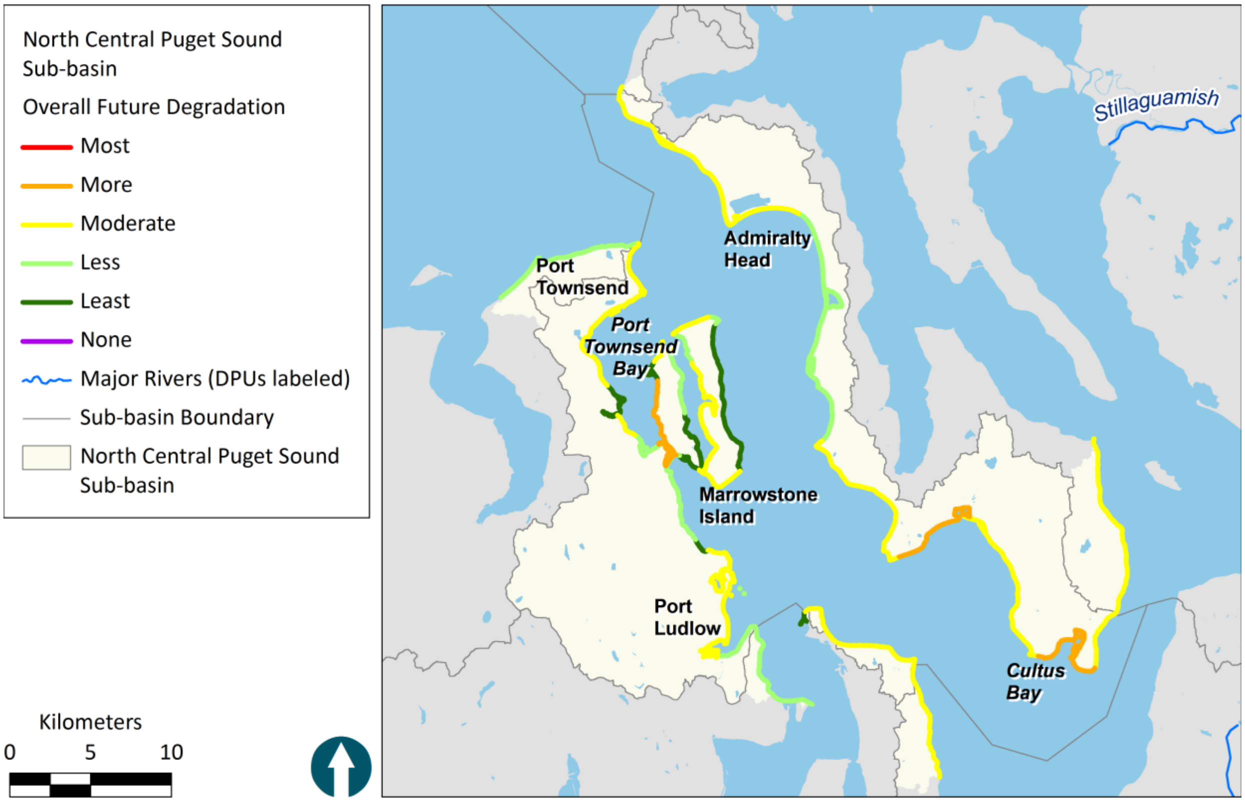


Figure 3-42

Sub-basin Scale Categories of Future Degradation in the North Central Puget Sound Sub-basin

3.3.7 South Central Puget Sound Sub-basin

In the South Central Puget Sound sub-basin, almost the entire eastern shoreline is projected to be classified as Most Degraded (Figure 3-43). The exceptions are two process units near Three Tree Point and Point Defiance that will be in the More Degraded category, as well as the process unit between Commencement Bay and Dumas Bay which is Moderately Degraded. The western portion of the sub-basin, including the islands of Bainbridge, Vashon, and Maury are largely projected to be in the Most Degraded or More Degraded categories. The Least Degraded and Less Degraded process units in the sub-basin are projected to be located along the western side of the Tacoma Narrows, the eastern portion of Vashon Island, Blake Island, and along a small area north of Kingston.

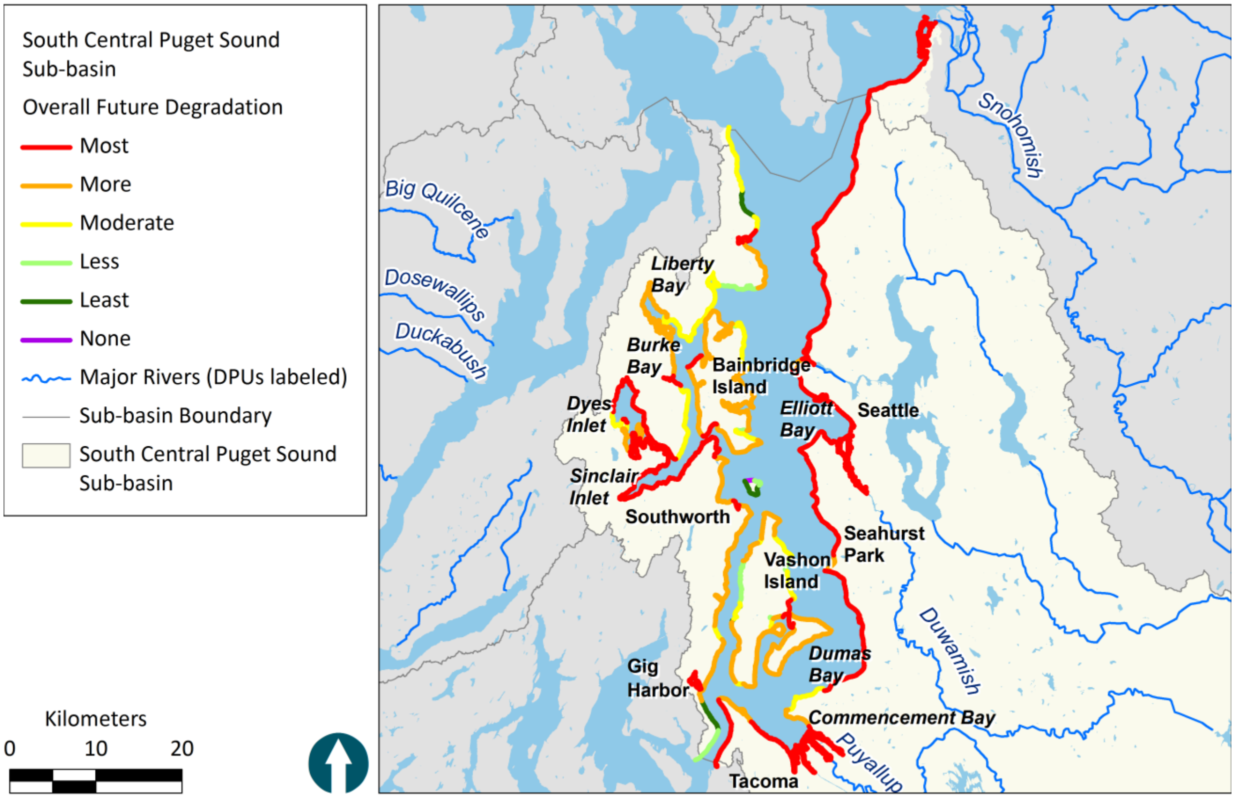


Figure 3-43

Sub-basin Scale Categories of Future Degradation in the South Central Puget Sound Sub-basin

3.3.8 South Puget Sound Sub-basin

The South Puget Sound sub-basin is projected to have large areas classified as More Degraded or Most Degraded, including the eastern shoreline between Tacoma and the Nisqually DPU, Carr Inlet, Fox Island, Henderson Inlet, and Budd Inlet (Figure 3-44). In addition, some isolated occurrences of Most Degraded process units are projected to be scattered throughout the sub-basin. The process units along the shorelines of Case Inlet, Hammersley Inlet, Oakland Bay, and Eld Inlet are projected to be largely Moderately Degraded or More Degraded. In contrast, Totten Inlet is projected to be largely Less Degraded. The larger islands, including Hartstene, Anderson, McNeil, and Ketron Island, will be in the Less Degraded or Least Degraded categories. Squaxin Island is projected to remain Not Degraded or Least Degraded.

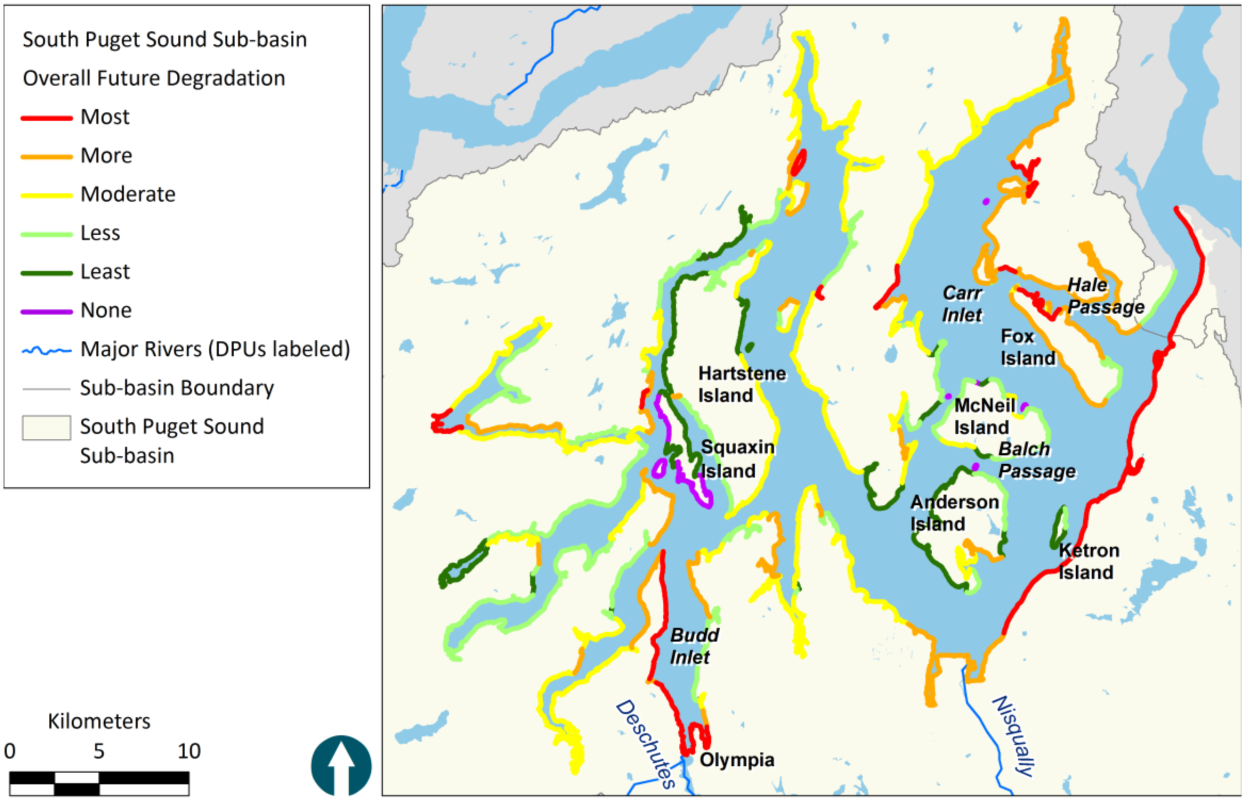


Figure 3-44

Sub-basin Scale Categories of Future Degradation in the South Puget Sound Sub-basin

4 DISCUSSION

Based on the future condition data projected by Bolte and Vache (2010), the Framework developed to estimate future nearshore process degradation in Puget Sound forecasts continued degradation throughout the region. This analysis forecasts process degradation that will extend beyond urban centers as land is developed over the next 50 years. The problems identified in the main text of the Strategic Needs Assessment Report will continue to be applicable to the region.

5 REFERENCES

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Bolte, J. and K. Vache. 2010. Envisioning Puget Sound Alternative Futures PSNERP Final Report. Prepared for Washington Department of Washington Department of Fish and Wildlife in support of Puget Sound Nearshore Ecosystem Restoration Project. Prepared by Department of Biological and Ecological Engineering, Oregon State University.

Johnson, P., D.L. Mock, A. McMillan, L. Driscoll, and T. Hruby. 2002. Washington State Wetland Mitigation Evaluation Study. Phase 2: Evaluating Success. Washington State Department of Ecology. February 2002. Publication No. 02-06-009.

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ADDENDUM APPENDIX A
MAPS OF FUTURE DEGRADATION OF INDIVIDUAL NEARSHORE PROCESSES

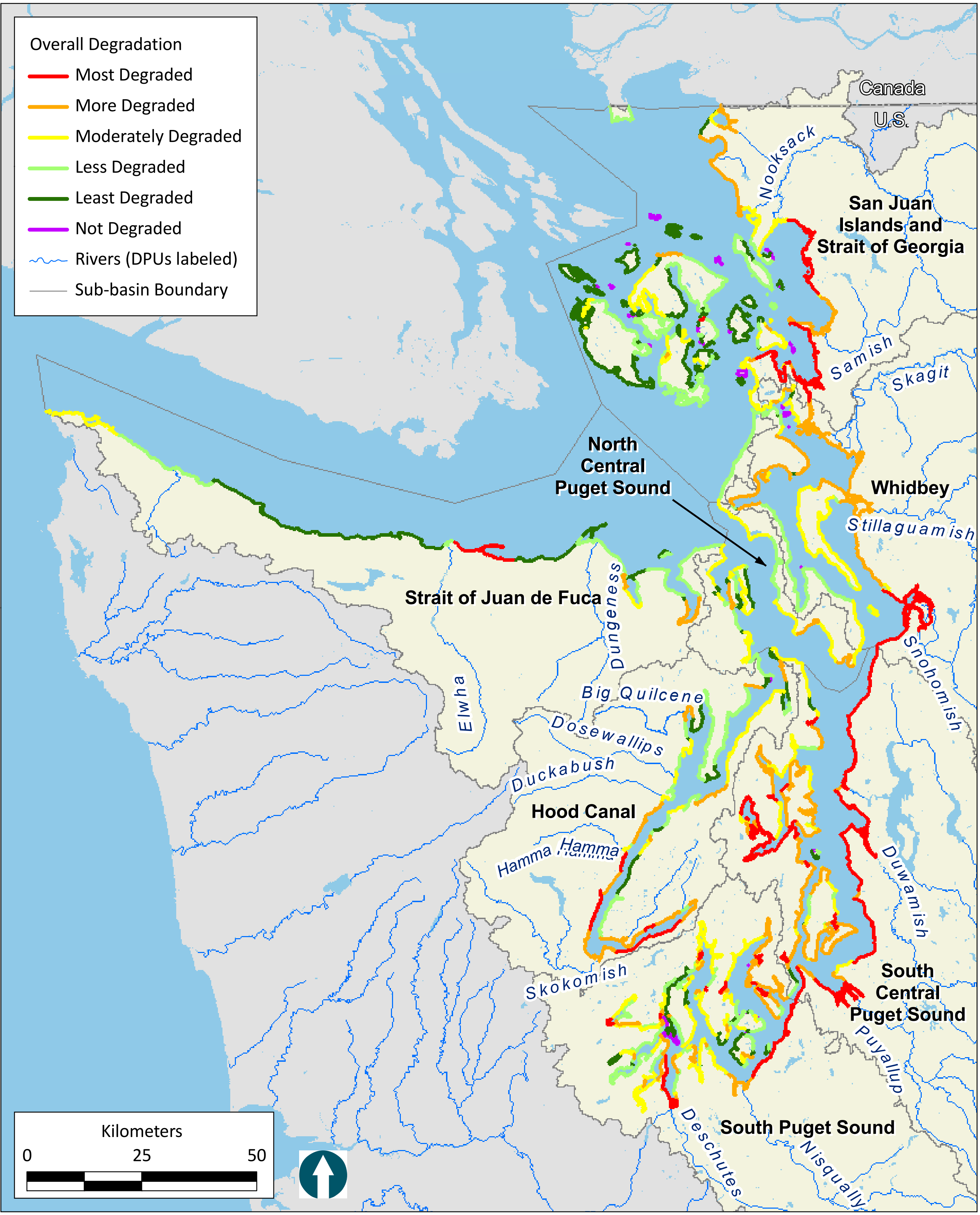

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Figure A-1

Future Projected Overall Degradation in Puget Sound
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

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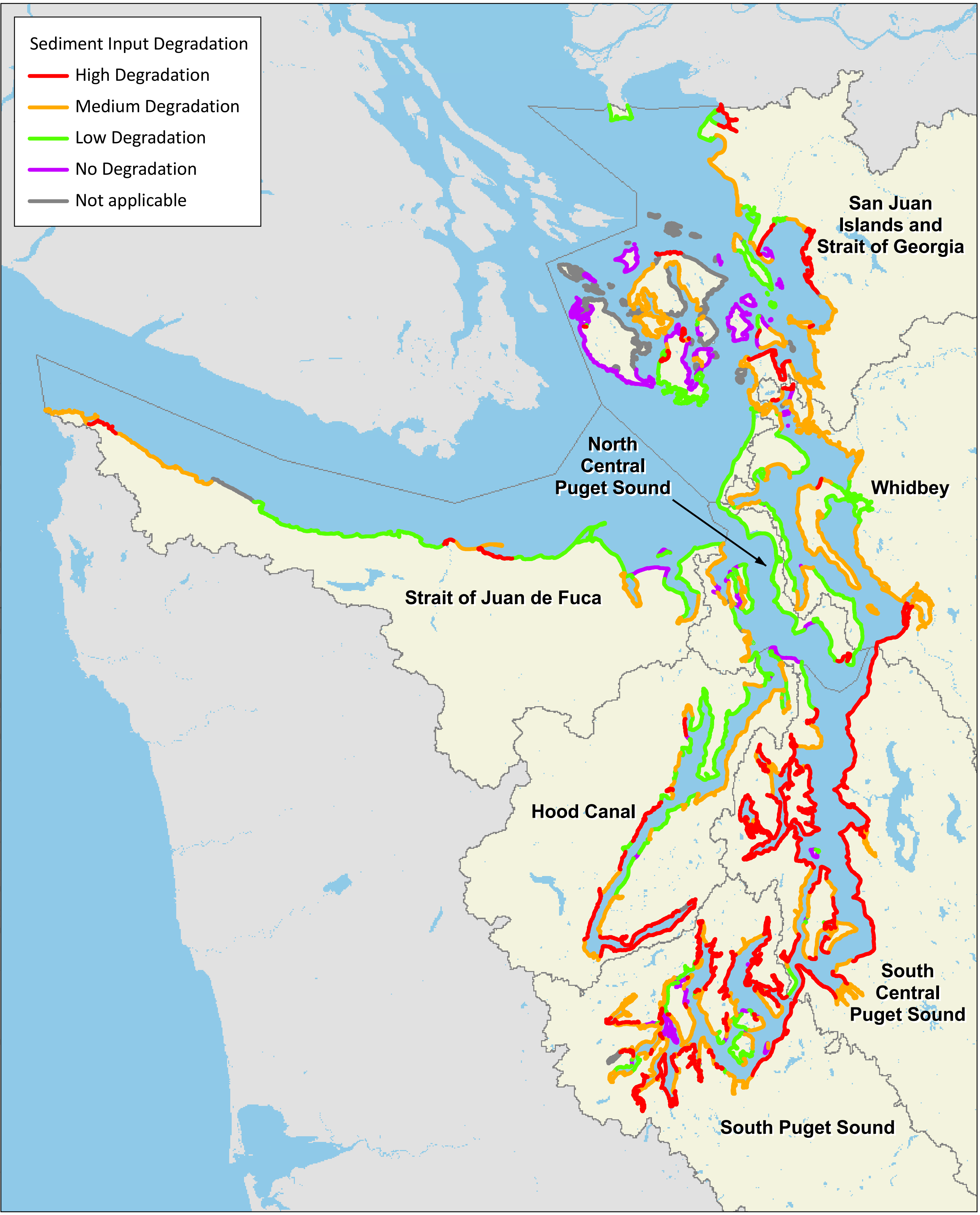

Kilometers
0 25 50

Figure A-2
Future Projected Degradation of Sediment Input in Puget Sound
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

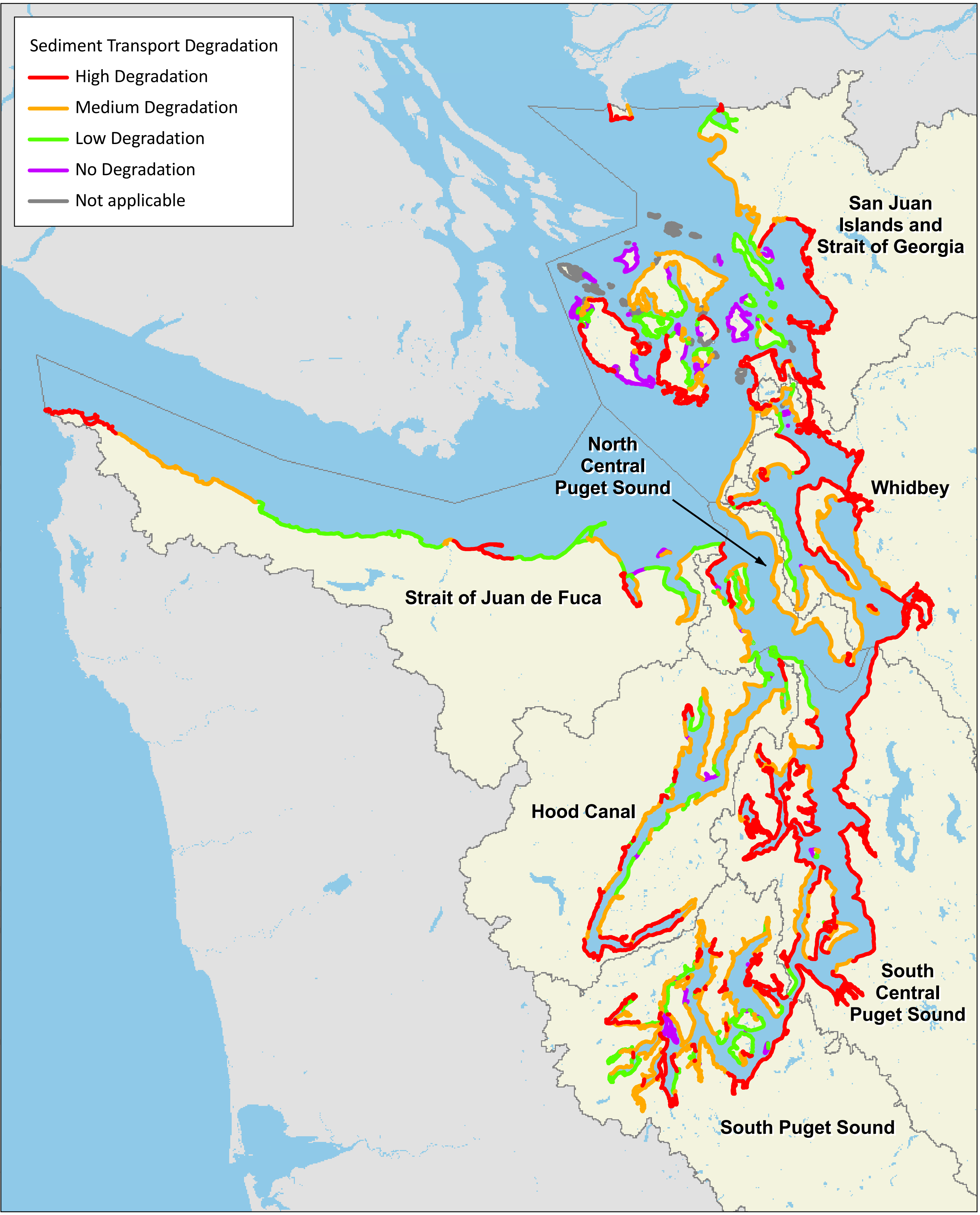

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Figure A-3

Future Projected Degradation of Sediment Transport in Puget Sound
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

Kilometers
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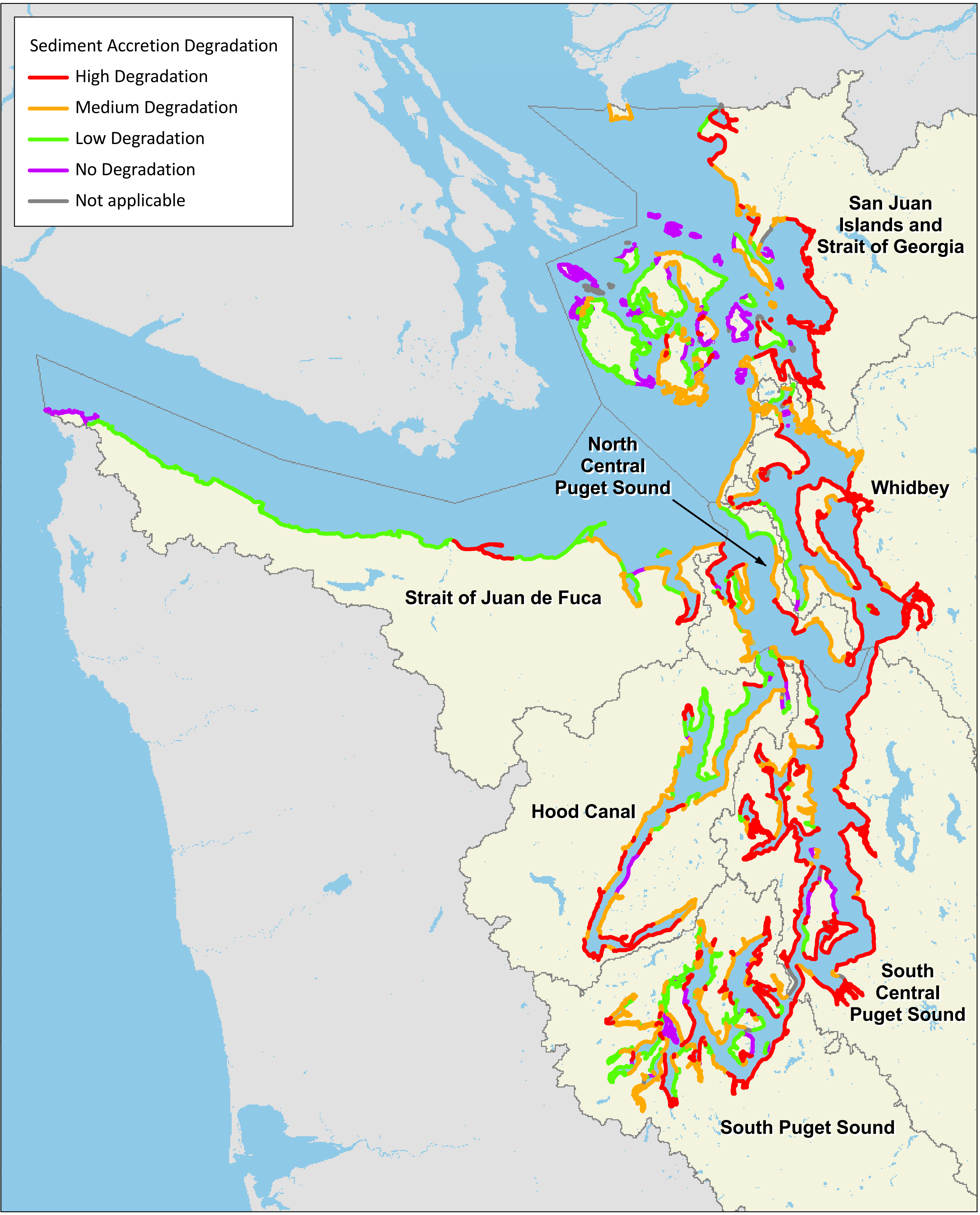

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Figure A-4

Future Projected Degradation of Sediment Erosion and Accretion in Puget Sound
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

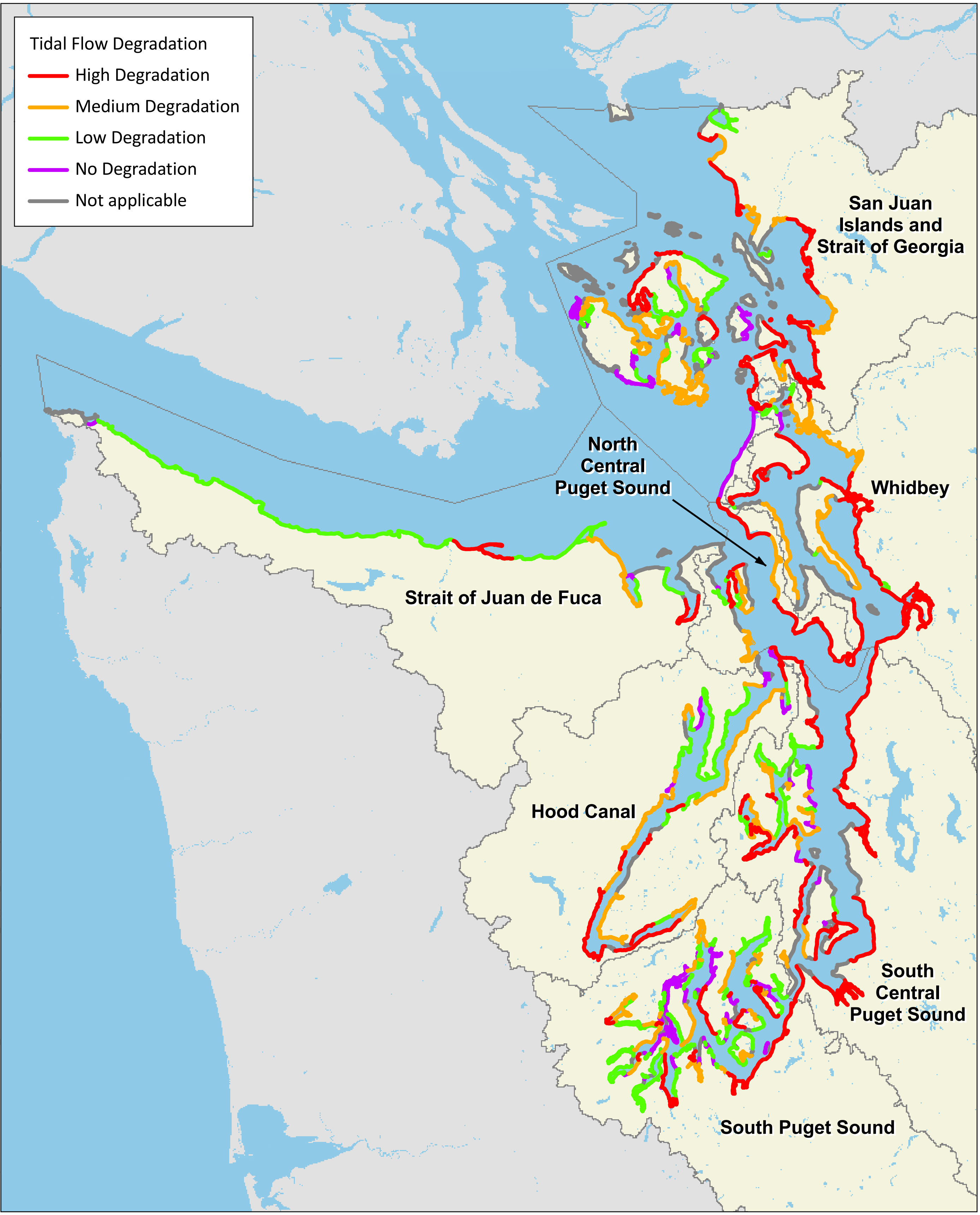

Figure A-5

Future Projected Degradation of Tidal Flow in Puget Sound

Degradation by Process Unit

Nearshore Process Evaluation Framework Results

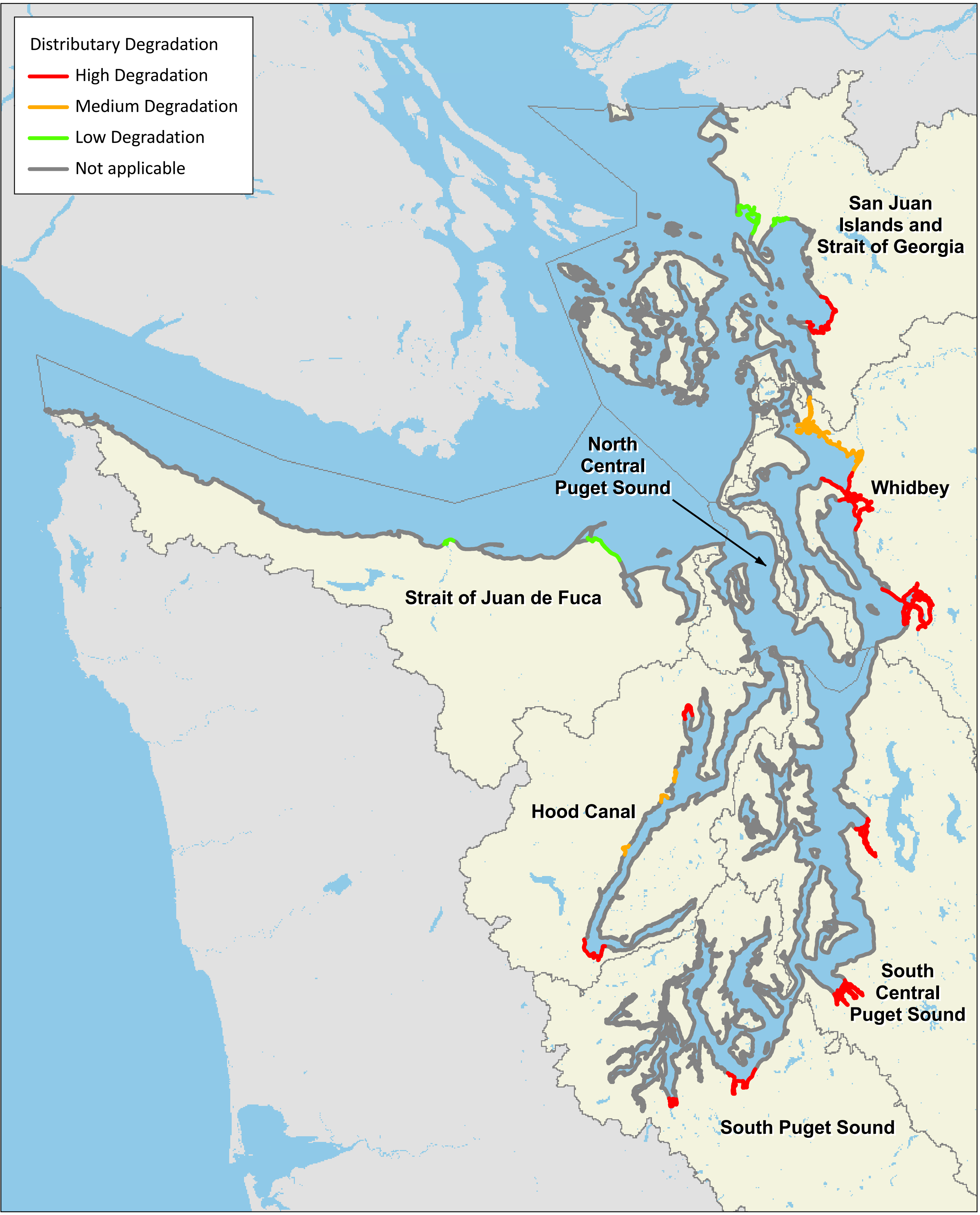

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Figure A-6

Future Projected Degradation of Distributary Channel Migration in Puget Sound
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

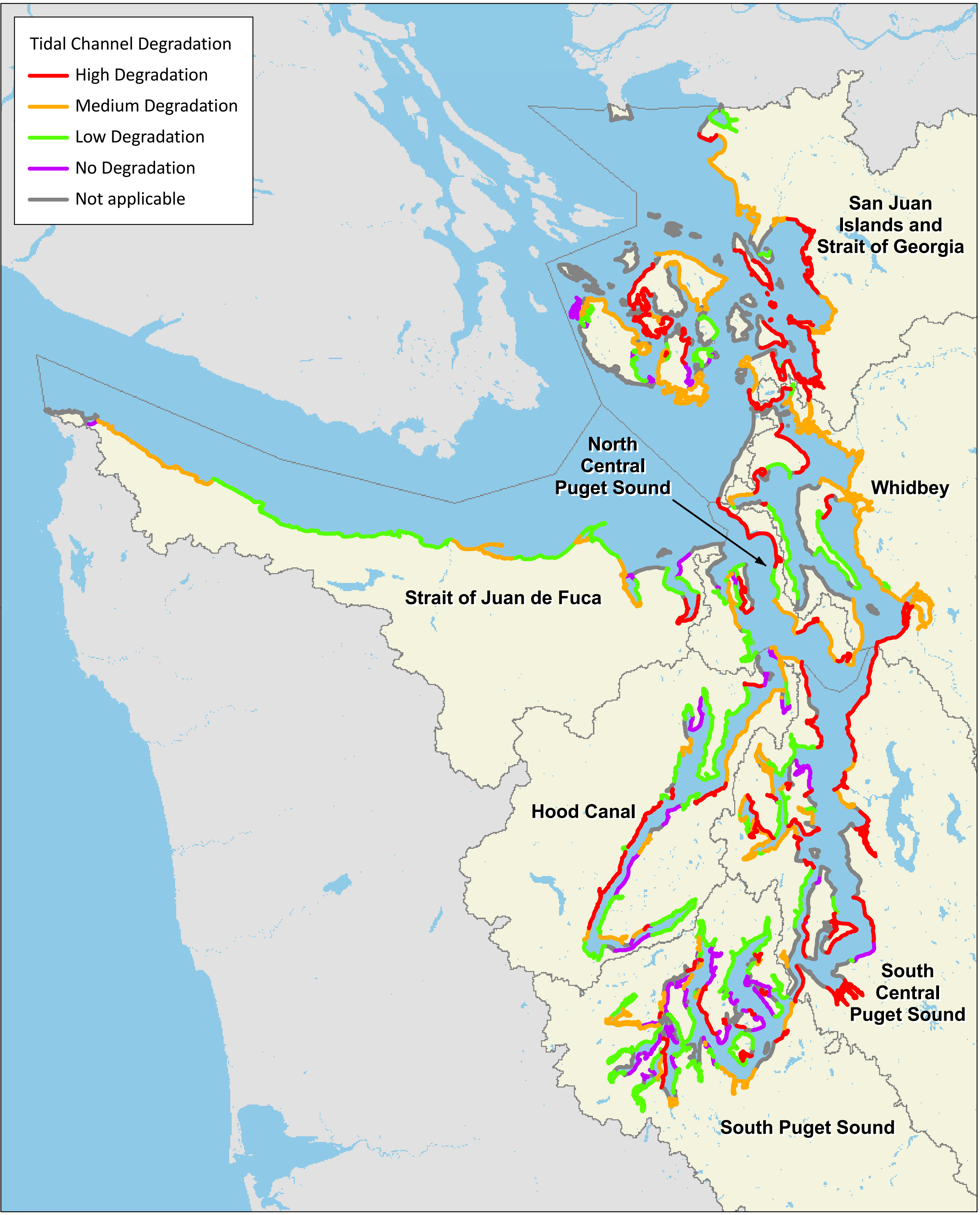

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Figure A-7

Future Projected Degradation of Tidal Channel Formation and Maintenance in Puget Sound
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

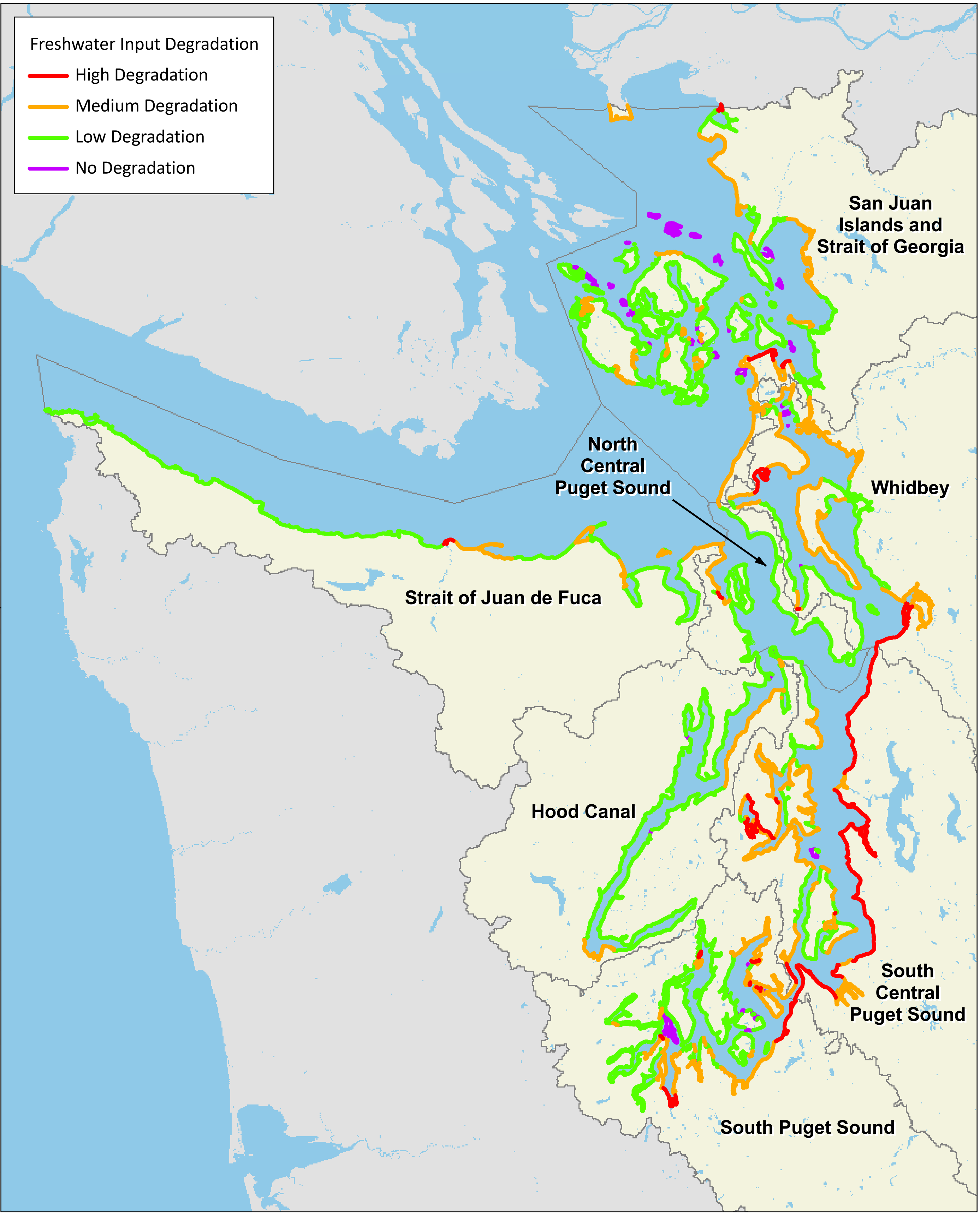

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Figure A-8

Future Projected Degradation of Freshwater Input in Puget Sound
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

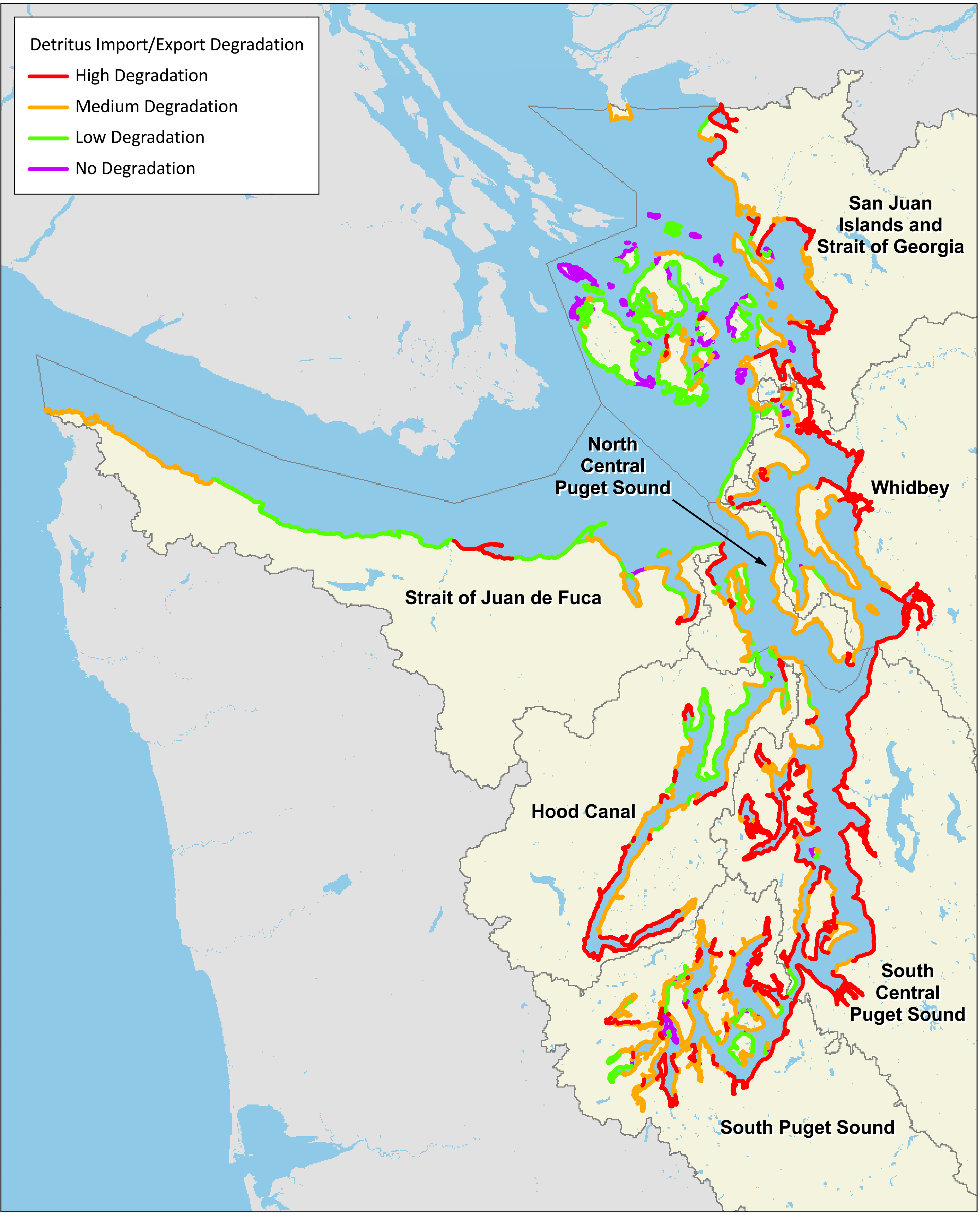

Figure A-9

Future Projected Degradation of Detritus Import and Export in Puget Sound
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

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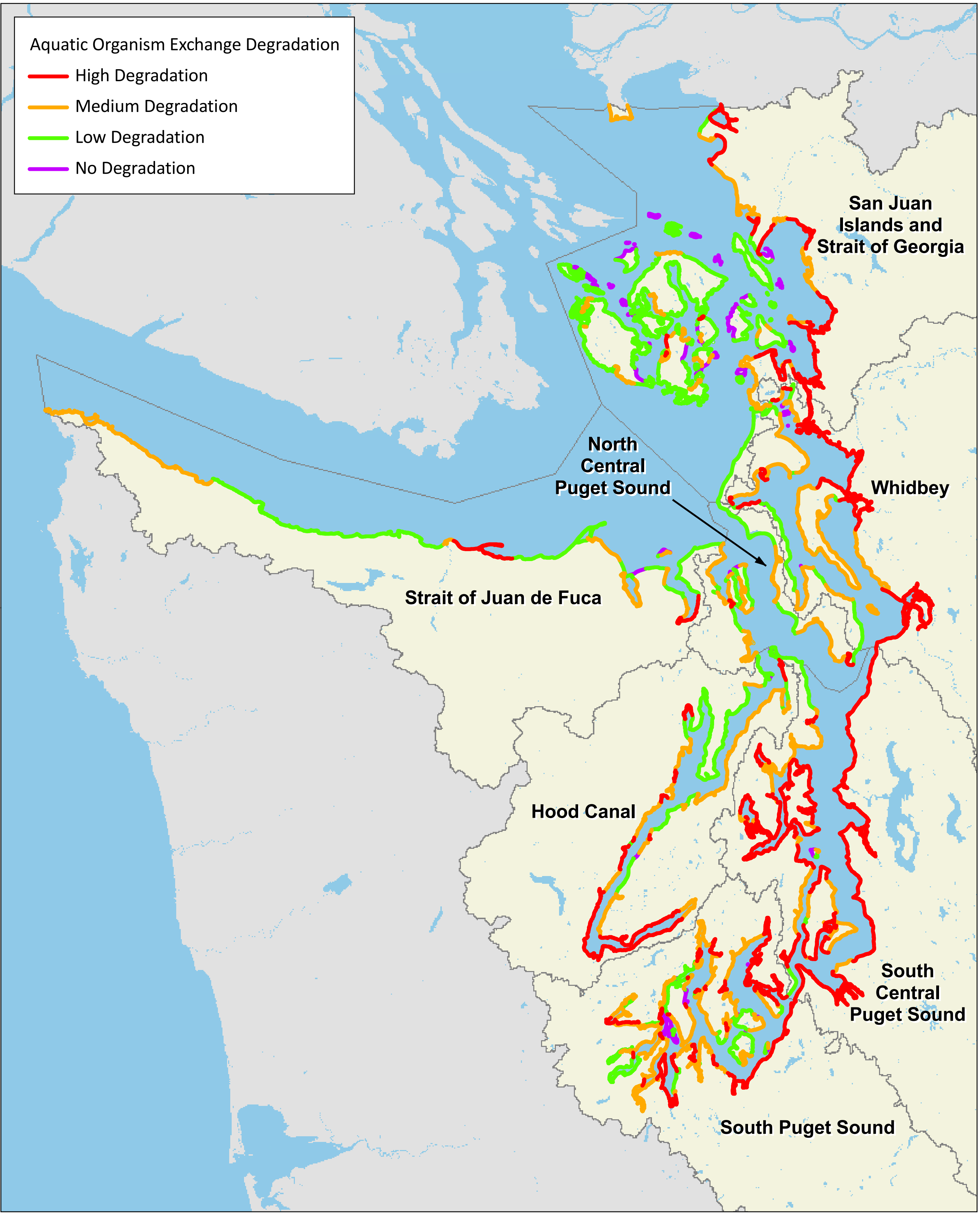

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Kilometers
0 25 50

Figure A-10

Future Projected Degradation of Exchange of Aquatic Organisms in Puget Sound
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

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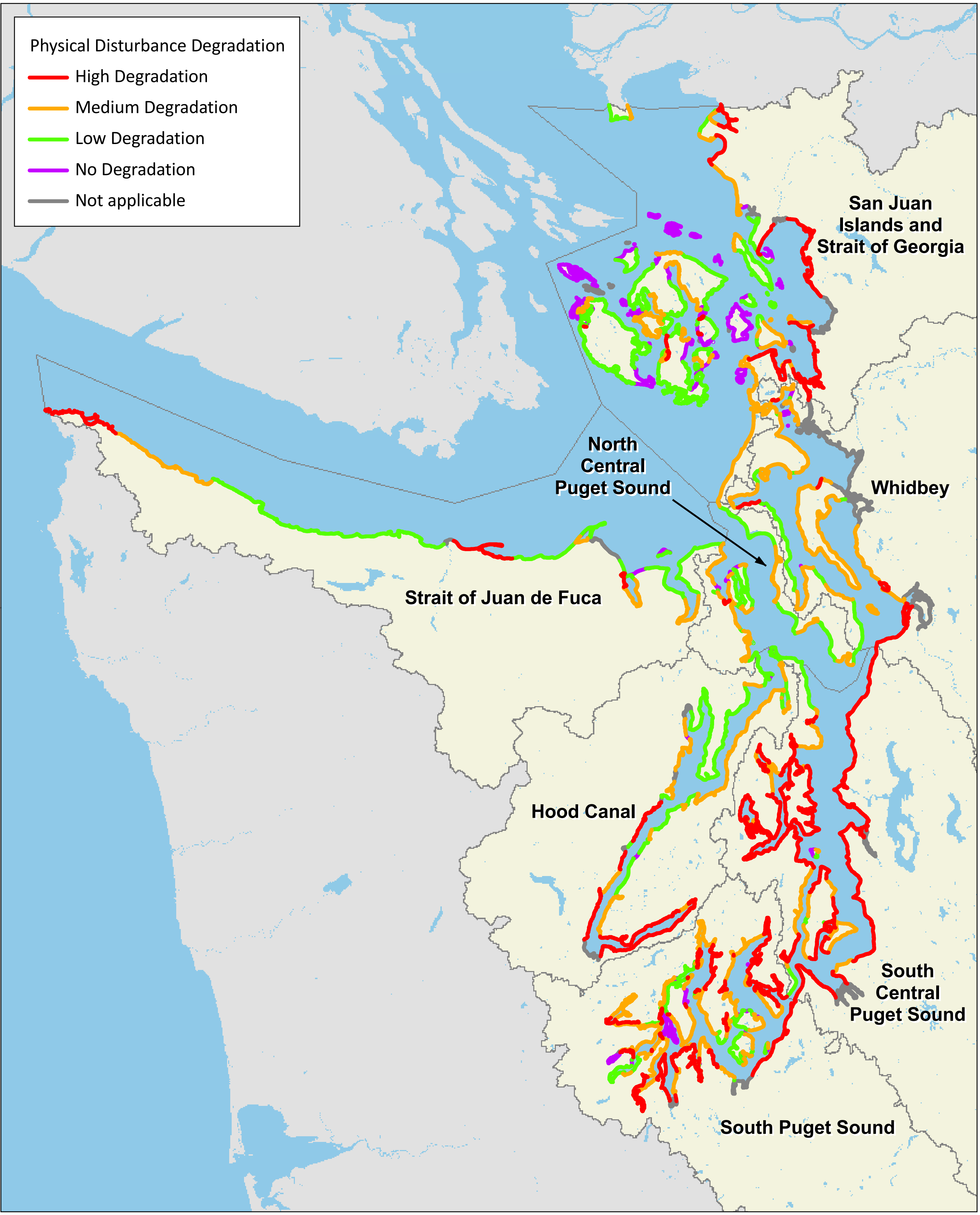

Figure A-11

Future Projected Degradation of Physical Disturbance in Puget Sound
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

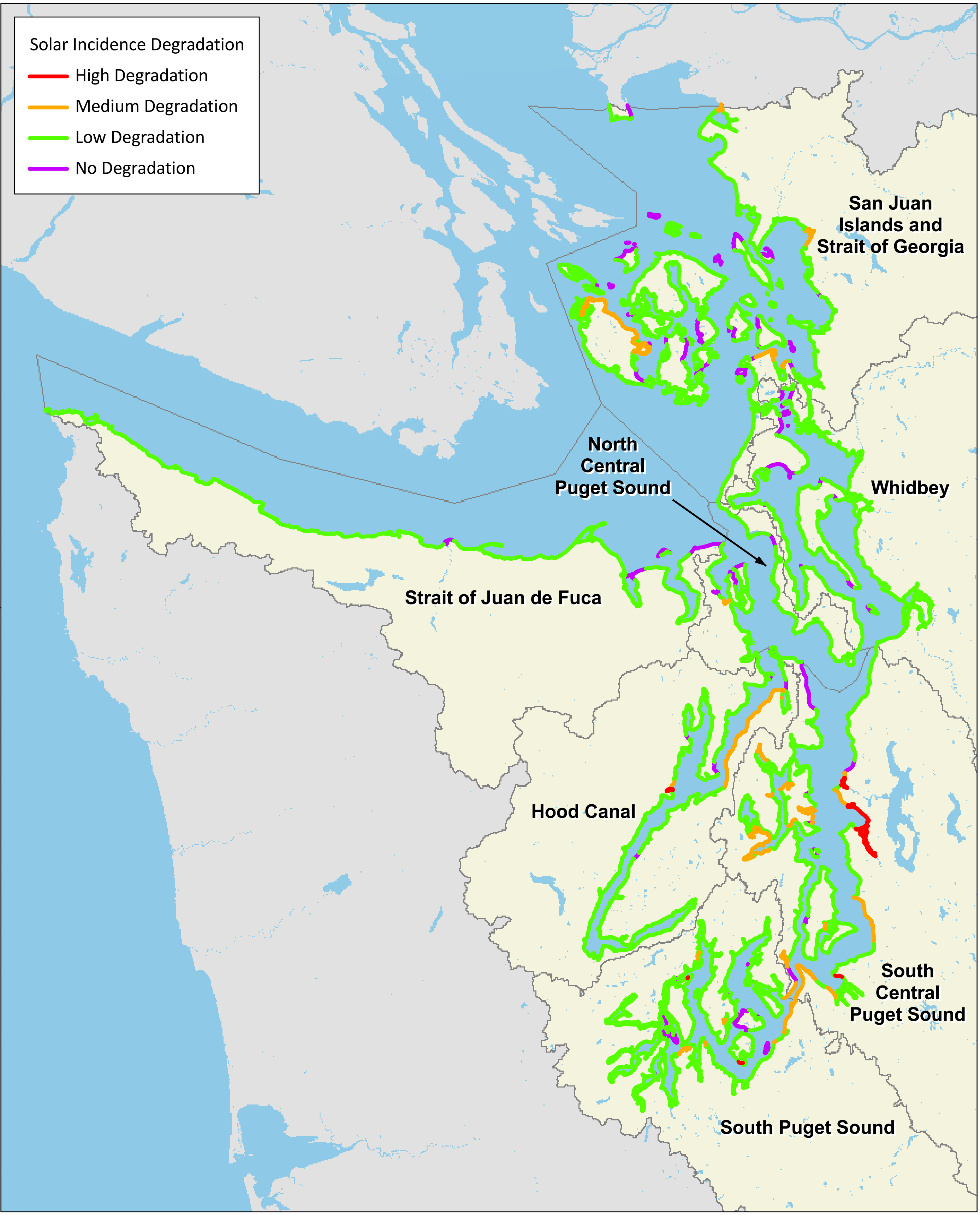

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Figure A-12
Future Projected Degradation of Solar Incidence in Puget Sound
Degradation by Process Unit
Nearshore Process Evaluation Framework Results

ADDENDUM APPENDIX B
TABLE OF FUTURE DEGRADATION CATEGORIES ASSIGNED TO EACH PROCESS UNIT

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
Deschutes DPU	SP	9.0	466.3	H	H	H	H	H	M	H	H	H	N/A	L		Deschutes DPU	Most
Dosewallips DPU	HC	4.7	306.8	L	H	M	M	M	L	L	H	H	N/A	L		Dosewallips DPU	Mod.
Duckabush DPU	HC	3.9	204.0	L	H	M	M	M	L	L	H	H	N/A	L		Duckabush DPU	Mod.
Dungeness DPU	JF	11.6	563.7	L	M	M	M	L	L	L	M	M	N/A	L		Dungeness DPU	Less
Duwamish DPU	SC	32.5	1,257.0	M	H	H	H	H	H	H	H	H	N/A	H		Duwamish DPU	Most
Elwha DPU	JF	4.1	837.9	H	M	L	L	L	L	H	L	M	N/A	N		Elwha DPU	Less
Hamma Hamma DPU	HC	5.1	222.0	L	H	M	M	M	L	L	H	H	N/A	L		Hamma Hamma DPU	Mod.
Nooksack DPU	SJ	40.5	2,083.8	L	M	M	M	L	M	L	M	M	N/A	L		Nooksack DPU	Mod.
Nisqually DPU	SP	20.2	2,159.6	M	H	H	H	H	M	M	H	H	N/A	L		Nisqually DPU	More
Puyallup DPU	SC	45.7	2,535.2	M	H	H	H	H	H	M	H	H	N/A	L		Puyallup DPU	Most
Quilcene DPU	HC	8.1	295.2	M	H	H	M	H	L	L	H	H	N/A	L		Quilcene DPU	More
Samish DPU	SJ	29.0	402.6	M	H	H	M	H	M	L	H	H	N/A	L		Samish DPU	More
Skagit DPU	WH	96.2	7,300.6	M	H	M	M	M	M	M	H	H	N/A	L		Skagit DPU	More
Skokomish DPU	HC	13.7	653.5	M	H	H	H	H	L	M	H	H	N/A	L		Skokomish DPU	More
Snohomish DPU	WH	95.3	4,747.7	M	H	H	H	H	M	M	H	H	N/A	L		Snohomish DPU	Most
Stillaguamish DPU	WH	65.5	1,875.5	L	H	H	H	H	M	L	H	H	N/A	L		Stillaguamish DPU	More
SPU 1008	JF	7.2	13.3	L	M	M	N/A	N/A	N	L	M	L	L	L		SPU 1008	Less
SPU 1009	JF	9.4	19.4	L	L	M	N/A	N/A	L	L	M	L	L	L		SPU 1009	Less
SPU 1010	JF	12.4	132.5	M	M	H	H	N/A	H	L	H	H	M	L		SPU 1010	More
SPU 1011	JF	9.5	122.0	L	M	H	H	N/A	H	L	M	M	M	L		SPU 1011	More
SPU 1012	JF	3.4	9.9	L	L	M	N/A	N/A	N/A	L	L	L	L	L		SPU 1012	Least
SPU 1013	JF	7.1	25.2	L	L	L	L	N/A	L	L	L	L	L	L		SPU 1013	Less
SPU 1014	JF	4.6	16.8	N	L	M	L	N/A	L	L	M	M	L	L		SPU 1014	Less
SPU 1015	JF	6.0	7.6	N	L	M	N/A	N/A	N/A	L	M	L	L	L		SPU 1015	Less
SPU 1016	JF	6.2	8.3	N	N	N	N/A	N/A	N/A	L	N	N	N	N		SPU 1016	Least
SPU 1017	JF	5.3	4.9	L	L	L	N	N/A	N	L	L	L	L	N		SPU 1017	Least
SPU 1018	JF	8.8	67.7	M	M	L	L	N/A	L	L	M	M	M	L		SPU 1018	Less

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 1019	JF	10.8	96.1	M	H	M	M	N/A	M	L	M	M	M	L		SPU 1019	Mod.
SPU 1020	JF	7.2	38.2	M	H	M	M	N/A	M	M	M	M	H	L		SPU 1020	More
SPU 1021	JF	6.5	24.9	L	L	L	M	N/A	M	M	L	L	L	L		SPU 1021	Less
SPU 1023	JF	5.0	6.5	L	L	L	L	N/A	M	M	L	L	M	L		SPU 1023	Less
SPU 1024	JF	9.0	2.9	N/A	L	L	L	N/A	L	M	L	L	N	L		SPU 1024	Least
SPU 1025	JF	36.2	338.0	L	L	L	L	N/A	L	L	L	L	L	L		SPU 1025	Least
SPU 1026	JF	11.0	84.3	H	H	H	H	N/A	M	M	H	H	H	L		SPU 1026	Most
SPU 1027	JF	59.4	594.2	L	L	L	L	N/A	L	L	L	L	L	L		SPU 1027	Least
SPU 1028	JF	16.6	88.0	N/A	M	L	L	N/A	L	L	L	L	L	L		SPU 1028	Least
SPU 1029	JF	39.0	379.5	M	M	L	L	N/A	M	L	M	M	M	L		SPU 1029	Less
SPU 1100	JF	8.8	27.3	H	H	L	N	N/A	N	L	M	M	H	L		SPU 1100	Mod.
SPU 1101	JF	31.4	21.2	M	H	N	N/A	N/A	N/A	L	M	M	H	L		SPU 1101	Mod.
SPU 1200	JF	3.2	6.2	N	N	L	N/A	N/A	N/A	L	L	N	N	N		SPU 1200	Least
SPU 1201	JF	3.1	1.2	L	M	M	N/A	N/A	N/A	M	M	M	L	L		SPU 1201	Less
SPU 1202	JF	1.9	1.1	L	N	L	N/A	N/A	N/A	M	L	L	L	N		SPU 1202	Least
SPU 1203	JF	1.6	3.3	N	N	N	N/A	N/A	N/A	M	N	N	N	N		SPU 1203	Least
SPU 1400	JF	18.7	34.8	M	H	H	H	N/A	M	M	H	H	H	L		SPU 1400	Most
SPU 2002	HC	29.8	66.1	M	M	M	M	N/A	M	M	M	M	M	M		SPU 2002	Mod.
SPU 2003	HC	3.9	2.3	L	M	H	H	N/A	N	L	M	L	L	L		SPU 2003	Mod.
SPU 2004	HC	3.8	7.4	L	L	M	L	N/A	N	L	M	L	L	L		SPU 2004	Less
SPU 2005	HC	3.5	6.2	L	L	L	N/A	N/A	N/A	L	L	L	L	L		SPU 2005	Least
SPU 2006	HC	1.6	1.0	M	M	M	N/A	N/A	N/A	N	M	M	M	L		SPU 2006	Less
SPU 2007	HC	5.2	20.8	L	L	H	H	N/A	M	L	M	M	L	L		SPU 2007	Mod.
SPU 2008	HC	2.8	3.0	N	N	N	N/A	N/A	N	L	M	N	N	N		SPU 2008	Least
SPU 2009	HC	9.6	7.5	L	L	N	N/A	N/A	N	L	M	L	L	L		SPU 2009	Least
SPU 2010	HC	3.9	59.1	L	L	M	M	N/A	N	L	M	M	L	L		SPU 2010	Less
SPU 2011	HC	15.6	93.1	M	M	M	M	N/A	L	L	M	M	M	L		SPU 2011	Less
SPU 2013	HC	9.1	131.5	H	H	H	M	N/A	M	L	H	H	H	L		SPU 2013	More
SPU 2014	HC	2.7	1.9	H	H	H	N/A	N/A	N/A	L	H	H	H	L		SPU 2014	More
SPU 2015	HC	0.9	0.5	M	M	H	H	N/A	N	L	M	M	M	L		SPU 2015	Mod.
SPU 2016	HC	1.1	0.7	H	M	M	N/A	N/A	N/A	L	H	H	H	L		SPU 2016	More
SPU 2017	HC	1.1	0.8	H	H	H	N/A	N/A	N/A	L	H	H	H	L		SPU 2017	More
SPU 2018	HC	3.3	4.1	H	H	H	H	N/A	M	L	H	H	H	L		SPU 2018	More

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 2019	HC	1.1	2.9	H	H	H	N/A	N/A	H	L	H	H	H	L		SPU 2019	Most
SPU 2020	HC	1.7	2.7	H	H	H	H	N/A	N	L	H	H	H	L		SPU 2020	More
SPU 2021	HC	0.8	0.2	H	H	H	H	N/A	N/A	L	H	H	H	L		SPU 2021	Most
SPU 2022	HC	5.5	10.7	H	H	M	L	N/A	L	L	H	H	H	L		SPU 2022	More
SPU 2023	HC	2.3	4.4	H	H	M	M	N/A	L	L	H	H	H	L		SPU 2023	More
SPU 2024	HC	10.4	116.9	N/A	M	M	M	N/A	L	L	M	M	M	L		SPU 2024	Less
SPU 2025	HC	10.4	81.2	H	M	M	M	N/A	L	L	M	M	H	L		SPU 2025	More
SPU 2026	HC	1.0	5.8	H	H	M	N/A	N/A	L	L	H	H	H	L		SPU 2026	More
SPU 2027	HC	7.4	16.4	H	H	H	H	N/A	L	L	H	H	H	L		SPU 2027	Most
SPU 2028	HC	1.3	2.4	H	M	M	H	N/A	N	L	H	H	H	L		SPU 2028	More
SPU 2029	HC	9.1	10.8	H	H	H	H	N/A	N	L	H	H	H	L		SPU 2029	Most
SPU 2030	HC	0.9	4.2	H	H	H	N/A	N/A	N/A	L	H	H	H	L		SPU 2030	More
SPU 2031	HC	5.4	5.6	H	H	M	N/A	N/A	N/A	M	H	H	H	L		SPU 2031	More
SPU 2032	HC	4.9	19.4	H	M	M	H	N/A	M	L	H	H	H	L		SPU 2032	More
SPU 2034	HC	10.7	82.2	H	H	H	H	N/A	H	L	H	H	H	L		SPU 2034	Most
SPU 2035	HC	2.5	47.4	M	H	H	H	N/A	H	L	H	H	M	L		SPU 2035	More
SPU 2036	HC	6.7	18.9	M	M	M	M	N/A	H	L	H	M	M	L		SPU 2036	More
SPU 2037	HC	1.3	2.5	H	H	H	H	N/A	M	L	H	H	H	L		SPU 2037	Most
SPU 2038	HC	3.8	15.5	H	H	H	H	N/A	H	L	H	H	H	L		SPU 2038	Most
SPU 2039	HC	2.4	21.3	L	L	M	M	N/A	H	L	L	L	L	L		SPU 2039	Less
SPU 2041	HC	1.0	2.9	H	H	H	N/A	N/A	N/A	L	H	H	H	L		SPU 2041	More
SPU 2042	HC	13.4	47.3	H	M	M	M	N/A	H	L	M	M	H	L		SPU 2042	More
SPU 2047	HC	3.7	5.1	L	L	M	N/A	N/A	N/A	L	M	M	L	L		SPU 2047	Less
SPU 2048	HC	3.1	2.1	H	L	M	N	N/A	N/A	L	L	M	M	H		SPU 2048	Less
SPU 2049	HC	4.0	2.8	M	L	M	N	N/A	N/A	L	L	M	M	M		SPU 2049	Less
SPU 2050	HC	4.5	9.0	M	M	L	L	N/A	L	L	M	M	M	L		SPU 2050	Less
SPU 2051	HC	1.7	0.4	N/A	L	M	N	N/A	N	L	L	L	M	L		SPU 2051	Less
SPU 2052	HC	8.8	21.0	L	M	M	L	N/A	M	L	M	M	M	L		SPU 2052	Mod.
SPU 2054	HC	1.9	2.2	N	N	N	N/A	N/A	N/A	N	L	L	N	N		SPU 2054	Least
SPU 2055	HC	3.7	6.3	H	M	L	N/A	N/A	N/A	L	L	L	M	L		SPU 2055	Less
SPU 2056	HC	5.6	5.4	L	L	L	L	N/A	N	L	L	L	L	L		SPU 2056	Least
SPU 2059	HC	17.9	51.4	L	L	L	N	N/A	N	L	L	L	L	L		SPU 2059	Least
SPU 2062	HC	30.7	66.7	L	M	L	L	N/A	L	L	L	L	L	L		SPU 2062	Less

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 2063	HC	8.1	6.7	L	N	L	L	N/A	L	L	L	L	L	L		SPU 2063	Least
SPU 2064	HC	4.3	4.5	L	L	M	L	N/A	L	L	L	L	L	N		SPU 2064	Least
SPU 2065	HC	28.4	68.1	L	M	L	L	N/A	L	L	L	L	L	L		SPU 2065	Less
SPU 2066	HC	4.7	28.9	M	M	H	M	N/A	H	L	M	M	M	L		SPU 2066	More
SPU 2067	HC	6.6	4.5	L	L	L	N	N/A	N	L	L	L	L	L		SPU 2067	Least
SPU 2068	HC	3.8	2.8	L	L	N	N	N/A	N/A	L	L	L	L	L		SPU 2068	Least
SPU 2069	HC	1.6	0.6	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 2069	None
SPU 2071	HC	3.1	2.5	L	L	N/A	N/A	N/A	N/A	L	L	M	L	L		SPU 2071	Least
SPU 2072	HC	4.2	24.7	L	L	N	N	N/A	N	L	L	L	L	L		SPU 2072	Least
SPU 2073	HC	4.9	30.5	M	M	L	N	N/A	N	L	M	M	M	L		SPU 2073	Less
SPU 2074	HC	3.2	6.7	L	L	N	L	N/A	L	L	L	L	L	L		SPU 2074	Least
SPU 2075	HC	3.0	6.4	L	L	N	L	N/A	L	L	L	L	L	N		SPU 2075	Least
SPU 2076	HC	7.1	9.6	M	H	H	H	N/A	M	L	H	H	M	L		SPU 2076	More
SPU 2077	HC	4.9	2.2	L	L	L	N	N/A	N	L	L	L	L	L		SPU 2077	Least
SPU 2080	HC	3.8	15.7	M	L	L	L	N/A	L	L	M	M	M	L		SPU 2080	Less
SPU 2081	HC	8.2	21.6	L	L	L	L	N/A	L	L	L	L	L	L		SPU 2081	Less
SPU 2082	HC	3.1	16.0	M	L	M	L	N/A	L	L	M	M	M	L		SPU 2082	Less
SPU 2083	HC	1.4	16.8	M	M	H	H	N/A	M	L	H	H	M	L		SPU 2083	More
SPU 2084	HC	5.0	127.1	H	H	M	M	N/A	M	L	H	H	H	L		SPU 2084	More
SPU 2088	HC	11.4	73.1	M	M	M	M	N/A	H	L	H	M	M	L		SPU 2088	More
SPU 2098	HC	2.6	1.4	M	M	L	M	N/A	H	L	M	M	M	L		SPU 2098	Less
SPU 2099	HC	3.6	2.4	L	H	H	H	N/A	M	M	H	H	L	L		SPU 2099	More
SPU 2100	HC	1.5	1.5	H	M	N/A	N/A	N/A	N/A	L	H	H	H	L		SPU 2100	More
SPU 3001	SP	4.2	6.0	H	H	H	H	N/A	M	H	H	H	H	M		SPU 3001	Most
SPU 3002	SP	10.2	11.6	H	H	H	H	N/A	M	H	H	H	H	M		SPU 3002	Most
SPU 3003	SP	3.0	242.9	H	M	H	H	N/A	H	H	H	H	H	L		SPU 3003	Most
SPU 3004	SP	5.9	249.9	H	H	H	H	N/A	H	H	H	H	H	L		SPU 3004	Most
SPU 3005	SP	0.7	2.0	H	H	H	H	N/A	N/A	M	H	H	H	M		SPU 3005	Most
SPU 3006	SP	9.3	129.1	H	H	H	H	N/A	N/A	M	H	H	H	L		SPU 3006	Most
SPU 3007	SP	1.0	0.9	M	L	N	N/A	N/A	N/A	M	L	L	L	L		SPU 3007	Less
SPU 3008	SP	1.7	4.7	M	M	L	L	N/A	M	M	M	M	M	L		SPU 3008	Mod.
SPU 3009	SP	3.9	11.2	L	M	M	M	N/A	M	M	M	M	M	L		SPU 3009	Mod.
SPU 3010	SP	2.6	6.6	H	M	M	L	N/A	L	L	M	M	M	L		SPU 3010	Mod.

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 3011	SP	1.6	2.5	H	M	L	L	N/A	L	L	M	M	H	L		SPU 3011	Mod.
SPU 3012	SP	0.9	1.4	M	M	M	N	N/A	N	L	H	H	M	L		SPU 3012	Mod.
SPU 3013	SP	2.0	2.7	M	M	M	N	N/A	N	L	H	H	H	L		SPU 3013	Mod.
SPU 3014	SP	3.3	3.4	H	M	L	L	N/A	L	M	M	M	H	L		SPU 3014	Mod.
SPU 3015	SP	1.4	2.0	M	L	L	L	N/A	L	L	L	L	M	N		SPU 3015	Less
SPU 3016	SP	3.2	2.3	M	M	L	N	N/A	N	L	M	M	M	L		SPU 3016	Less
SPU 3017	SP	0.6	0.4	M	M	H	L	N/A	M	M	M	M	M	M		SPU 3017	More
SPU 3018	SP	1.5	0.7	M	M	M	N	N/A	N	M	M	M	M	L		SPU 3018	Mod.
SPU 3019	SP	5.4	3.9	M	M	H	N/A	N/A	N/A	L	M	M	M	L		SPU 3019	Mod.
SPU 3020	SP	1.3	1.5	M	M	M	N	N/A	N/A	L	M	M	H	L		SPU 3020	Mod.
SPU 3021	SP	1.2	1.5	H	M	L	N	N/A	N/A	L	M	M	H	L		SPU 3021	Mod.
SPU 3022	SP	0.4	0.3	M	L	N	N	N/A	N/A	L	L	L	M	L		SPU 3022	Least
SPU 3023	SP	0.9	2.1	N	N	N	N	N/A	N/A	M	N	L	N	L		SPU 3023	Least
SPU 3024	SP	17.0	105.5	L	M	M	M	N/A	L	M	M	M	L	L		SPU 3024	Less
SPU 3025	SP	16.9	105.2	H	M	M	M	N/A	L	M	M	M	H	L		SPU 3025	Mod.
SPU 3026	SP	0.3	0.2	M	H	N/A	N/A	N/A	N/A	N	H	H	H	N		SPU 3026	Mod.
SPU 3027	SP	0.2	0.3	M	M	N/A	N/A	N/A	N/A	N	M	M	M	L		SPU 3027	Less
SPU 3028	SP	5.5	7.3	H	L	H	H	N/A	N/A	L	H	H	H	L		SPU 3028	More
SPU 3029	SP	1.8	1.2	H	H	M	N/A	N/A	N/A	M	H	H	H	L		SPU 3029	More
SPU 3030	SP	0.9	1.0	H	H	M	L	N/A	N/A	L	H	H	H	L		SPU 3030	More
SPU 3031	SP	2.0	1.0	M	M	M	L	N/A	N/A	L	M	M	M	L		SPU 3031	Mod.
SPU 3032	SP	3.3	2.1	M	L	N	N	N/A	N/A	L	L	L	M	L		SPU 3032	Least
SPU 3033	SP	6.0	3.9	H	M	L	L	N/A	L	L	M	M	H	M		SPU 3033	Less
SPU 3034	SP	1.6	1.9	M	M	L	N	N/A	N/A	M	M	M	M	N		SPU 3034	Mod.
SPU 3035	SP	1.6	1.3	M	M	M	L	N/A	L	M	M	M	H	L		SPU 3035	Mod.
SPU 3036	SP	0.7	0.5	H	H	H	N	N/A	N/A	M	H	H	H	L		SPU 3036	More
SPU 3037	SP	4.4	2.3	H	H	M	N	N/A	N	M	H	H	H	L		SPU 3037	More
SPU 3038	SP	3.1	6.8	N	N	N	L	N/A	L	L	M	L	N	L		SPU 3038	Least
SPU 3039	SP	8.4	14.0	M	L	L	L	N/A	L	M	M	L	M	L		SPU 3039	Less
SPU 3040	SP	1.4	3.6	N	N	L	L	N/A	N/A	M	L	N	N	N		SPU 3040	Least
SPU 3041	SP	2.0	6.4	H	M	L	L	N/A	N/A	M	M	M	M	L		SPU 3041	Mod.
SPU 3042	SP	1.4	1.7	H	H	N/A	N/A	N/A	N/A	H	H	H	H	L		SPU 3042	More
SPU 3043	SP	3.5	5.1	H	H	H	H	N/A	N/A	H	H	H	H	L		SPU 3043	Most

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 3044	SP	1.0	2.5	H	H	H	N	N/A	N/A	M	H	H	H	L		SPU 3044	More
SPU 3045	SP	0.6	2.2	M	H	H	N	N/A	N/A	M	H	H	M	L		SPU 3045	Mod.
SPU 3046	SP	7.7	5.1	H	H	H	H	N/A	H	M	H	H	H	L		SPU 3046	Most
SPU 3047	SP	6.5	4.1	H	H	M	L	N/A	M	M	H	H	H	L		SPU 3047	More
SPU 3048	SP	1.0	9.1	M	M	N	N	N/A	N/A	M	M	M	H	L		SPU 3048	Less
SPU 3049	SP	25.3	76.8	M	M	M	L	N/A	L	L	M	M	M	L		SPU 3049	Mod.
SPU 3050	SP	22.7	65.6	H	M	M	L	N/A	L	L	M	M	H	L		SPU 3050	Mod.
SPU 3051	SP	0.9	0.5	H	H	N/A	N/A	N/A	N/A	L	H	H	H	L		SPU 3051	More
SPU 3052	SP	1.1	0.8	H	H	N/A	N/A	N/A	N/A	L	H	H	H	L		SPU 3052	More
SPU 3053	SP	0.3	0.5	H	H	N/A	N/A	N/A	N/A	L	H	H	H	L		SPU 3053	Mod.
SPU 3054	SP	2.9	5.6	H	M	M	N	N/A	N	L	M	M	H	L		SPU 3054	Mod.
SPU 3055	SP	2.8	5.2	H	M	L	L	N/A	N	L	M	M	H	L		SPU 3055	Mod.
SPU 3056	SP	2.0	1.4	M	M	N	N/A	N/A	N/A	L	M	M	M	L		SPU 3056	Mod.
SPU 3057	SP	0.8	0.3	M	M	M	L	N/A	N	L	M	M	M	N		SPU 3057	Mod.
SPU 3058	SP	1.7	5.4	M	M	L	L	N/A	N	L	M	M	M	L		SPU 3058	Less
SPU 3059	SP	1.5	5.2	L	L	N	N	N/A	N/A	L	L	L	M	N		SPU 3059	Least
SPU 3060	SP	5.9	6.1	M	M	L	L	N/A	L	L	M	M	M	L		SPU 3060	Less
SPU 3061	SP	2.1	3.0	M	L	L	N	N/A	N	L	L	L	M	L		SPU 3061	Less
SPU 3062	SP	4.4	2.7	M	H	M	M	N/A	H	M	M	M	M	L		SPU 3062	More
SPU 3063	SP	0.2	0.5	M	L	N	N	N/A	N/A	H	L	L	M	N		SPU 3063	Less
SPU 3064	SP	0.9	0.3	H	H	H	N/A	N/A	N/A	H	H	H	H	L		SPU 3064	More
SPU 3065	SP	4.4	2.3	M	M	L	N	N/A	N	M	M	M	M	L		SPU 3065	Mod.
SPU 3066	SP	0.5	0.3	H	M	L	N	N/A	N/A	L	M	M	H	L		SPU 3066	Mod.
SPU 3067	SP	0.7	1.1	M	M	L	N	N/A	N	L	M	M	M	L		SPU 3067	Less
SPU 3068	SP	0.4	0.2	H	M	L	N	N/A	N	M	M	M	M	L		SPU 3068	Less
SPU 3069	SP	0.8	1.3	M	M	N	N	N/A	N	M	M	M	M	N		SPU 3069	Less
SPU 3070	SP	2.2	2.8	L	L	L	L	N/A	N	L	L	L	L	L		SPU 3070	Less
SPU 3071	SP	2.4	1.5	M	M	L	N	N/A	N	M	M	M	M	L		SPU 3071	Less
SPU 3072	SP	1.6	1.3	M	M	L	N/A	N/A	N/A	L	M	M	M	L		SPU 3072	Less
SPU 3073	SP	1.6	1.4	L	L	M	H	N/A	N	L	M	L	L	L		SPU 3073	Less
SPU 3074	SP	1.2	0.8	N	N	N	N	N/A	N/A	L	N	L	N	L		SPU 3074	Least
SPU 3075	SP	4.8	6.1	L	L	M	M	N/A	N	L	M	L	L	L		SPU 3075	Less
SPU 3076	SP	2.2	3.4	M	L	L	N	N/A	N/A	L	M	L	M	L		SPU 3076	Less

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 3077	SP	9.4	82.5	M	L	L	L	N/A	L	L	L	L	L	L		SPU 3077	Less
SPU 3078	SP	5.9	8.8	L	M	L	L	N/A	N/A	L	L	L	L	L		SPU 3078	Less
SPU 3079	SP	1.8	2.4	N	L	N	N/A	N/A	N/A	L	N	L	N	L		SPU 3079	Least
SPU 3080	SP	0.8	0.5	L	L	H	N/A	N/A	N/A	L	M	L	L	L		SPU 3080	Less
SPU 3081	SP	1.2	0.7	M	H	H	N/A	N/A	N/A	L	H	H	H	L		SPU 3081	More
SPU 3082	SP	5.8	3.9	H	M	M	L	N/A	N/A	L	M	M	H	L		SPU 3082	Mod.
SPU 3083	SP	12.8	61.7	N/A	L	L	L	N/A	L	L	L	L	N	L		SPU 3083	Least
SPU 3084	SP	12.1	74.4	N/A	L	L	L	N/A	L	L	L	L	N/A	L		SPU 3084	Least
SPU 3085	SP	4.8	12.3	M	L	L	L	N/A	L	L	M	L	M	L		SPU 3085	Less
SPU 3086	SP	10.6	9.3	M	M	M	M	N/A	L	L	M	M	M	L		SPU 3086	Less
SPU 3087	SP	12.6	85.3	M	M	M	L	N/A	M	L	M	M	M	L		SPU 3087	Mod.
SPU 3088	SP	1.3	1.2	M	M	N/A	N/A	N/A	N/A	M	M	M	M	L		SPU 3088	Mod.
SPU 3089	SP	0.2	0.1	N	N	N/A	N/A	N/A	N/A	N	N	N	N	N		SPU 3089	None
SPU 3090	SP	4.9	161.0	H	H	H	H	N/A	M	L	H	H	H	L		SPU 3090	Most
SPU 3091	SP	3.7	160.7	H	H	H	H	N/A	M	L	H	H	H	L		SPU 3091	Most
SPU 3092	SP	10.9	117.9	M	H	M	M	N/A	L	L	M	M	M	L		SPU 3092	Mod.
SPU 3093	SP	6.5	87.5	M	L	L	L	N/A	L	L	L	L	M	L		SPU 3093	Less
SPU 3094	SP	5.3	20.3	N	L	M	M	N/A	M	L	M	M	N	L		SPU 3094	Less
SPU 3095	SP	7.5	21.9	M	M	M	M	N/A	M	L	M	M	M	L		SPU 3095	Less
SPU 3096	SP	6.6	7.3	H	H	M	L	N/A	M	L	H	H	H	L		SPU 3096	More
SPU 3097	SP	1.5	3.2	M	M	L	L	N/A	M	L	M	M	M	L		SPU 3097	Mod.
SPU 3098	SP	1.0	0.4	M	M	N/A	N/A	N/A	N/A	L	M	M	M	L		SPU 3098	Less
SPU 3099	SP	0.8	0.6	M	M	N/A	N/A	N/A	N/A	L	M	M	M	L		SPU 3099	Less
SPU 3100	SP	4.0	6.1	N	L	M	M	N/A	N	L	M	L	L	L		SPU 3100	Less
SPU 3101	SP	1.6	0.9	L	L	H	H	N/A	N/A	L	L	L	L	L		SPU 3101	Mod.
SPU 3102	SP	2.0	1.8	H	H	L	N	N/A	N/A	L	H	H	H	L		SPU 3102	More
SPU 3103	SP	0.6	0.5	H	H	N	N	N/A	N/A	M	H	H	H	L		SPU 3103	Mod.
SPU 3104	SP	1.1	1.1	H	H	H	M	N/A	H	M	H	H	H	L		SPU 3104	Most
SPU 3105	SP	0.4	0.1	H	L	L	L	N/A	L	L	M	M	H	L		SPU 3105	Mod.
SPU 3106	SP	2.3	0.5	H	M	M	L	N/A	M	M	H	H	H	L		SPU 3106	More
SPU 3107	SP	2.1	2.1	M	L	M	L	N/A	L	L	M	M	L	L		SPU 3107	Less
SPU 3108	SP	6.4	6.5	M	M	L	L	N/A	M	L	M	M	M	L		SPU 3108	Mod.
SPU 3109	SP	1.6	3.6	M	L	L	N	N/A	N/A	L	L	L	M	L		SPU 3109	Less

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 3110	SP	3.1	8.8	M	M	M	N	N/A	N/A	L	M	M	M	L		SPU 3110	Less
SPU 3111	SP	0.9	5.5	N/A	N	L	N	N/A	N/A	L	L	L	M	L		SPU 3111	Least
SPU 3112	SP	2.6	4.9	M	M	L	N	N/A	N/A	L	M	M	M	L		SPU 3112	Less
SPU 3113	SP	0.9	4.2	N	N	N	N	N/A	N/A	L	N	L	N	L		SPU 3113	Least
SPU 3114	SP	0.6	1.2	N	N	N	N	N/A	N/A	L	N	N	N	N		SPU 3114	Least
SPU 3115	SP	0.5	1.2	N	N	N	N	N/A	N/A	L	N	N	N	N		SPU 3115	Least
SPU 3116	SP	0.5	0.2	N	N	N	N	N/A	N/A	N	N	N	N	N		SPU 3116	None
SPU 3117	SP	0.5	0.2	N	N	N	N	N/A	N/A	L	N	N	N	N		SPU 3117	Least
SPU 3118	SP	5.9	6.8	L	L	L	N	N/A	N/A	L	L	L	L	L		SPU 3118	Least
SPU 3119	SP	0.9	1.2	N	N	N	N	N/A	N/A	L	N	N	N	N		SPU 3119	Least
SPU 3120	SP	4.4	3.4	L	L	L	M	N/A	H	L	M	L	L	L		SPU 3120	Less
SPU 3121	SP	2.1	2.2	N/A	L	L	N	N/A	N/A	L	L	L	N	L		SPU 3121	Least
SPU 3122	SP	0.9	0.3	H	M	M	N/A	N/A	N/A	M	M	M	M	L		SPU 3122	Mod.
SPU 3123	SP	0.7	0.1	H	H	M	N/A	N/A	N/A	L	H	H	H	L		SPU 3123	More
SPU 3124	SP	1.3	0.6	H	H	H	N	N/A	N	L	H	H	H	M		SPU 3124	More
SPU 3125	SP	1.2	0.6	N/A	H	H	N	N/A	N	L	H	H	H	M		SPU 3125	More
SPU 3126	SP	0.9	0.6	N/A	H	H	N	N/A	N/A	L	H	H	H	L		SPU 3126	Mod.
SPU 3127	SP	1.4	1.0	H	H	M	N	N/A	N/A	L	H	H	H	L		SPU 3127	More
SPU 3128	SP	6.0	6.0	H	M	L	L	N/A	M	L	M	M	M	L		SPU 3128	Mod.
SPU 3129	SP	2.5	2.8	H	M	M	M	N/A	M	L	M	M	L	L		SPU 3129	Mod.
SPU 3130	SP	6.1	128.2	H	M	L	M	N/A	L	L	M	M	M	L		SPU 3130	Mod.
SPU 3131	SP	8.3	49.3	M	M	M	M	N/A	L	L	M	M	M	L		SPU 3131	Mod.
SPU 3132	SP	4.7	51.4	H	M	M	L	N/A	L	L	M	M	M	L		SPU 3132	Mod.
SPU 3133	SP	2.6	50.6	M	H	H	L	N/A	L	L	H	H	M	L		SPU 3133	Mod.
SPU 3134	SP	0.3	0.7	H	H	N/A	N/A	N/A	N/A	L	H	H	H	L		SPU 3134	Mod.
SPU 3135	SP	2.7	1.2	H	H	M	N	N/A	N	L	H	H	H	L		SPU 3135	Mod.
SPU 3136	SP	3.6	13.2	H	H	L	N	N/A	N	L	H	H	H	L		SPU 3136	Mod.
SPU 3137	SP	7.8	16.0	H	M	L	N	N/A	N	L	M	M	H	L		SPU 3137	Mod.
SPU 3138	SP	3.3	8.0	M	L	L	N	N/A	N	L	L	L	M	L		SPU 3138	Less
SPU 3139	SP	7.7	13.0	H	M	L	N	N/A	N	L	M	M	H	L		SPU 3139	Less
SPU 3140	SP	1.4	4.0	H	H	H	H	N/A	H	L	H	H	H	L		SPU 3140	Most
SPU 3141	SP	13.3	24.8	M	M	M	H	N/A	H	L	M	M	M	L		SPU 3141	Mod.
SPU 3142	SP	2.5	3.0	L	L	M	L	N/A	N	L	M	L	L	L		SPU 3142	Least

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 3143	SP	5.1	4.5	L	L	M	L	N/A	N	L	L	L	L	L		SPU 3143	Least
SPU 3144	SP	2.3	1.2	N	L	M	N	N/A	N	L	M	L	L	L		SPU 3144	Least
SPU 3145	SP	0.7	0.9	N	N	N	N	N/A	N	L	N	N	N	N		SPU 3145	Least
SPU 3146	SP	4.4	2.6	M	M	M	L	N/A	N	L	M	M	M	L		SPU 3146	Mod.
SPU 3147	SP	2.5	1.7	H	H	M	L	N/A	N/A	L	H	H	H	L		SPU 3147	More
SPU 3148	SP	2.3	7.5	H	M	L	M	N/A	H	L	M	M	H	L		SPU 3148	Mod.
SPU 3149	SP	1.9	7.4	M	M	L	M	N/A	H	L	M	M	H	M		SPU 3149	Mod.
SPU 3150	SP	2.0	3.7	H	M	L	N	N/A	N/A	L	M	M	H	L		SPU 3150	Mod.
SPU 3151	SP	3.8	5.1	M	L	L	N	N/A	N/A	L	M	M	M	L		SPU 3151	Less
SPU 3152	SP	2.4	1.2	L	L	L	N/A	N/A	N/A	L	L	L	L	L		SPU 3152	Least
SPU 3153	SP	3.2	2.9	M	M	L	N/A	N/A	N/A	L	M	M	M	L		SPU 3153	Less
SPU 3154	SP	1.4	0.4	L	L	N	N/A	N/A	N/A	L	L	L	L	L		SPU 3154	Less
SPU 3155	SP	0.5	0.3	M	M	N	N/A	N/A	N/A	L	M	M	M	N		SPU 3155	Less
SPU 3156	SP	1.5	1.5	L	L	L	N	N/A	N	L	L	L	L	L		SPU 3156	Least
SPU 3157	SP	2.8	2.6	M	M	H	N	N/A	N	L	M	M	M	L		SPU 3157	Mod.
SPU 3158	SP	1.2	0.8	N	L	M	H	N/A	N/A	N	N	N	N	N		SPU 3158	Less
SPU 3159	SP	0.3	0.3	H	M	N	N/A	N/A	N/A	L	M	M	M	N		SPU 3159	Mod.
SPU 3160	SP	2.1	4.0	M	M	M	L	N/A	L	L	M	M	M	L		SPU 3160	Less
SPU 3161	SP	4.2	5.1	H	M	M	L	N/A	L	L	M	M	M	L		SPU 3161	Mod.
SPU 3162	SP	2.4	11.8	H	H	H	L	N/A	N/A	L	H	H	H	L		SPU 3162	More
SPU 3163	SP	3.1	12.2	H	H	H	M	N/A	L	L	H	H	H	L		SPU 3163	Most
SPU 3164	SP	9.7	17.5	H	M	M	M	N/A	L	L	M	M	M	L		SPU 3164	Mod.
SPU 3165	SP	1.5	9.5	M	M	H	M	N/A	L	M	H	M	M	L		SPU 3165	Mod.
SPU 3166	SP	0.4	0.1	H	M	N	N	N/A	N	N	M	M	H	L		SPU 3166	Less
SPU 3167	SP	1.0	0.3	H	M	N	N	N/A	N	L	M	M	M	L		SPU 3167	Less
SPU 3168	SP	15.3	53.8	M	M	M	L	N/A	L	M	M	M	M	L		SPU 3168	Mod.
SPU 3169	SP	2.0	0.9	H	L	H	N/A	N/A	L	M	H	H	H	L		SPU 3169	More
SPU 3170	SP	6.3	32.2	H	L	H	L	N/A	L	M	H	H	H	L		SPU 3170	More
SPU 3171	SP	15.9	56.2	H	M	H	L	N/A	L	M	H	H	H	L		SPU 3171	More
SPU 3172	SP	3.5	5.0	H	H	H	M	N/A	H	M	H	H	H	L		SPU 3172	Most
SPU 3173	SP	2.4	4.7	H	H	H	M	N/A	H	M	H	H	H	L		SPU 3173	Most
SPU 3174	SP	0.5	0.2	H	H	N/A	N/A	N/A	N/A	M	H	H	H	L		SPU 3174	More
SPU 3175	SP	0.3	0.1	H	H	N/A	N/A	N/A	H	H	H	H	H	L		SPU 3175	More

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 3176	SP	2.0	1.4	H	H	H	M	N/A	M	M	H	H	H	L		SPU 3176	Most
SPU 3177	SP	3.1	6.8	H	H	H	L	N/A	M	M	H	H	H	L		SPU 3177	More
SPU 3178	SP	0.6	0.4	H	H	N/A	N/A	N/A	N/A	M	H	H	H	L		SPU 3178	More
SPU 3179	SP	3.1	3.3	H	H	H	M	N/A	L	L	H	H	H	L		SPU 3179	More
SPU 3180	SP	3.6	2.2	H	H	H	L	N/A	N/A	M	H	H	H	L		SPU 3180	More
SPU 3181	SP	5.3	1.7	H	H	M	L	N/A	N	M	H	H	M	L		SPU 3181	More
SPU 3182	SP	1.5	0.3	M	M	L	N	N/A	N/A	M	M	M	M	L		SPU 3182	Less
SPU 3183	SP	0.7	0.2	H	H	L	N	N/A	N/A	H	H	H	H	L		SPU 3183	More
SPU 3184	SP	0.4	0.1	H	H	N/A	N/A	N/A	N/A	H	H	H	H	L		SPU 3184	More
SPU 3185	SP	0.5	0.6	H	H	H	N/A	N/A	N/A	M	H	H	H	L		SPU 3185	More
SPU 3186	SP	0.9	1.0	H	H	M	H	N/A	N	M	H	H	H	L		SPU 3186	Most
SPU 3187	SP	5.4	7.0	H	H	H	N	N/A	N	M	H	H	H	L		SPU 3187	More
SPU 3188	SP	6.9	19.6	H	H	M	L	N/A	L	M	H	H	H	L		SPU 3188	More
SPU 3189	SP	10.0	29.3	H	H	M	L	N/A	L	M	H	H	H	L		SPU 3189	More
SPU 3190	SP	1.2	0.2	M	L	N	N/A	N/A	N/A	L	M	M	M	N		SPU 3190	Less
SPU 3191	SP	1.8	0.4	N	N	N	N/A	N/A	N/A	L	N	N	N	N		SPU 3191	Least
SPU 3192	SP	2.7	0.9	N	N	L	N	N/A	N/A	L	L	L	L	N		SPU 3192	Least
SPU 3193	SP	0.2	0.1	N	N	N	N	N/A	N/A	N	N	N	N	N		SPU 3193	None
SPU 3194	SP	0.7	0.4	N/A	N	N	N	N/A	N/A	N	N	N	N	N		SPU 3194	None
SPU 3195	SP	2.2	0.9	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3195	None
SPU 3196	SP	2.4	1.4	N	N	N	N	N/A	N	N	N	N	N	L		SPU 3196	Least
SPU 3197	SP	2.5	1.3	N	N	N	N	N/A	N	N	N	N	N	L		SPU 3197	Least
SPU 3198	SP	4.0	1.7	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3198	None
SPU 3199	SP	4.5	2.9	N	N	N	N	N/A	N/A	N	N	N	N	L		SPU 3199	Least
SPU 3200	SP	1.4	0.7	N	N	N	N	N/A	N	N	N	N	N	L		SPU 3200	Least
SPU 3201	SP	1.7	1.3	N	N	N	N	N/A	N/A	N	N	L	N	L		SPU 3201	Least
SPU 3202	SP	0.8	0.4	N	N	N	N	N/A	N/A	N	N	L	N	L		SPU 3202	Least
SPU 3203	SP	3.3	1.7	N	N	N	N	N/A	N/A	N	N	N	N	N		SPU 3203	None
SPU 3204	SP	4.2	1.8	N	N	N	N	N/A	N	N	N	N	N	N		SPU 3204	None
SPU 3205	SP	1.2	0.8	N	N	N	N	N/A	N	N	L	N	N	N		SPU 3205	None
SPU 3206	SP	1.4	0.8	N	N	N	N	N/A	N	N	N	N	N	N		SPU 3206	None
SPU 3207	SP	1.2	0.5	N	N	N	N	N/A	N	N	L	N	N	N		SPU 3207	None
SPU 3208	SP	10.1	17.0	M	M	M	L	N/A	L	L	M	M	M	L		SPU 3208	Less

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 3209	SP	0.6	3.0	H	H	M	L	N/A	L	L	H	H	H	N		SPU 3209	More
SPU 3210	SP	9.4	6.4	L	L	L	N	N/A	N	L	L	L	L	L		SPU 3210	Least
SPU 3211	SP	2.8	1.3	L	L	L	N	N/A	N/A	L	L	L	L	L		SPU 3211	Least
SPU 3212	SP	6.9	7.5	N	M	L	N	N/A	N	L	M	L	L	L		SPU 3212	Less
SPU 3213	SP	0.4	0.2	H	H	H	N	N/A	N	L	H	H	H	H		SPU 3213	More
SPU 3214	SP	1.1	0.2	L	L	H	N/A	N/A	N/A	L	L	L	L	L		SPU 3214	Less
SPU 3215	SP	4.5	2.3	M	M	H	L	N/A	M	L	M	M	M	L		SPU 3215	Mod.
SPU 3216	SP	1.0	1.8	N	N	N/A	N/A	N/A	N/A	L	N	L	N	L		SPU 3216	Least
SPU 3217	SP	3.3	3.0	N	N	N	N	N/A	N	L	L	N	N	L		SPU 3217	Least
SPU 3218	SP	2.5	2.2	N	N	N	N/A	N/A	N/A	L	N	N	N	L		SPU 3218	Least
SPU 3219	SP	0.8	4.1	H	L	N/A	N/A	N/A	N/A	L	H	H	H	L		SPU 3219	Mod.
SPU 3220	SP	1.0	4.4	M	M	H	M	N/A	N	L	M	M	M	L		SPU 3220	Mod.
SPU 3221	SP	10.3	11.6	M	M	H	M	N/A	L	L	M	M	M	L		SPU 3221	Mod.
SPU 3222	SP	2.5	1.1	M	M	M	L	N/A	N/A	M	M	M	H	L		SPU 3222	Mod.
SPU 3223	SP	0.6	0.1	N	M	M	N/A	N/A	N/A	M	M	M	M	L		SPU 3223	Less
SPU 3224	SP	0.7	0.2	M	M	N	M	N/A	H	M	M	M	M	L		SPU 3224	Mod.
SPU 3225	SP	2.3	0.8	M	M	M	L	N/A	M	M	M	M	M	L		SPU 3225	More
SPU 3226	SP	0.9	0.2	H	H	H	L	N/A	L	H	H	H	H	L		SPU 3226	Most
SPU 3227	SP	2.8	0.9	H	H	H	L	N/A	L	H	H	H	H	L		SPU 3227	Most
SPU 3228	SP	0.6	0.4	H	H	M	N	N/A	N/A	L	H	H	H	L		SPU 3228	More
SPU 3229	SP	2.1	0.8	M	M	M	N/A	N/A	M	L	M	M	M	L		SPU 3229	Mod.
SPU 3230	SP	2.4	0.5	L	L	L	L	N/A	L	L	L	L	L	L		SPU 3230	Less
SPU 3231	SP	1.1	0.5	H	H	M	N	N/A	N/A	L	H	H	H	L		SPU 3231	More
SPU 3232	SP	4.6	5.3	L	L	L	H	N/A	N/A	L	L	L	L	N		SPU 3232	Less
SPU 3233	SP	1.4	2.1	N	L	L	H	N/A	N/A	N	L	L	L	N		SPU 3233	Less
SPU 3234	SP	0.8	0.5	N	N	N/A	N/A	N/A	N	N	N	N	N	N		SPU 3234	None
SPU 3235	SP	1.0	2.0	N	N	N	N	N/A	N	L	N	L	N	N		SPU 3235	Least
SPU 3236	SP	1.5	1.4	L	L	H	M	N/A	H	N	L	L	L	L		SPU 3236	Less
SPU 3237	SP	0.6	1.0	N	L	H	M	N/A	H	L	L	L	L	L		SPU 3237	Less
SPU 3238	SP	1.9	1.5	H	M	M	M	N/A	N	N	M	M	M	L		SPU 3238	Mod.
SPU 3239	SP	5.8	6.0	M	L	L	L	N/A	N	L	M	M	M	L		SPU 3239	Less
SPU 3240	SP	1.7	0.7	M	L	N/A	N/A	N/A	N/A	N	M	M	M	L		SPU 3240	Less
SPU 3241	SP	1.1	0.6	L	L	N/A	N/A	N/A	N/A	N	M	L	L	N		SPU 3241	Least

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 3242	SP	0.6	0.2	L	N	N/A	N/A	N/A	N/A	N	L	L	L	N		SPU 3242	Least
SPU 3243	SP	1.9	4.3	L	L	M	H	N/A	H	L	M	L	L	N		SPU 3243	Mod.
SPU 3244	SP	0.1	0.0	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3244	None
SPU 3245	SP	0.1	0.0	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3245	None
SPU 3246	SP	0.1	0.0	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3246	None
SPU 3247	SP	0.2	0.0	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3247	None
SPU 3248	SP	0.5	0.1	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3248	None
SPU 3249	SP	0.4	0.1	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3249	None
SPU 3250	SP	0.2	0.1	N	N	N/A	N/A	N/A	N/A	N	N	N	N	N		SPU 3250	None
SPU 3251	SP	0.2	0.0	N	N	N/A	N/A	N/A	N/A	N	N	N	N	N		SPU 3251	None
SPU 3252	SP	0.2	0.0	N	N	N/A	N/A	N/A	N/A	N	N	N	N	N		SPU 3252	None
SPU 3253	SP	0.3	0.2	N	N	N/A	N/A	N/A	N/A	N	N	N	N	N		SPU 3253	None
SPU 3254	SP	0.3	0.4	N	N	N/A	N/A	N/A	N/A	L	N	N	N	N		SPU 3254	Least
SPU 3255	SP	0.2	0.0	N	N	N/A	N/A	N/A	N/A	L	N	N	N	N		SPU 3255	Least
SPU 3256	SP	5.1	3.7	L	L	L	L	N/A	L	L	L	L	L	L		SPU 3256	Least
SPU 3257	SP	2.4	1.6	L	L	L	N	N/A	N/A	L	L	L	L	L		SPU 3257	Least
SPU 3258	SP	7.8	3.7	L	L	L	L	N/A	L	L	L	L	L	L		SPU 3258	Least
SPU 3259	SP	1.3	0.4	L	L	L	N	N/A	N	L	L	L	L	H		SPU 3259	Least
SPU 3260	SP	1.0	0.4	N	N	N	N	N/A	N	L	L	L	N	L		SPU 3260	Least
SPU 3261	SP	2.0	0.6	M	M	M	L	N/A	L	L	M	M	M	L		SPU 3261	Less
SPU 3262	SP	4.5	6.3	L	M	H	M	N/A	H	L	M	M	L	L		SPU 3262	Mod.
SPU 3263	SP	3.3	1.6	N	M	H	M	N/A	H	L	M	M	N	L		SPU 3263	Mod.
SPU 3264	SP	4.7	2.4	L	H	H	M	N/A	H	L	M	M	M	L		SPU 3264	More
SPU 3265	SP	2.1	3.5	L	L	N	N/A	N/A	N/A	M	L	L	L	L		SPU 3265	Least
SPU 3266	SP	1.9	0.7	L	L	N	N/A	N/A	N/A	L	L	L	L	L		SPU 3266	Least
SPU 3267	SP	4.8	2.8	M	L	N	L	N/A	L	L	L	L	M	L		SPU 3267	Less
SPU 3268	SP	0.2	0.2	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3268	None
SPU 3269	SP	0.3	0.2	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 3269	None
SPU 3270	SP	2.4	1.0	H	H	M	N/A	N/A	N/A	M	H	H	H	L		SPU 3270	More
SPU 3271	SP	1.6	0.7	H	H	M	N/A	N/A	N/A	H	H	H	H	L		SPU 3271	More
SPU 3272	SP	1.4	0.5	H	M	M	N	N/A	N/A	L	H	H	H	L		SPU 3272	Mod.
SPU 3273	SP	0.5	0.2	H	H	N	N	N/A	N/A	M	H	H	H	L		SPU 3273	More
SPU 3274	SP	2.1	1.1	H	H	H	H	N/A	N/A	H	H	H	H	L		SPU 3274	Most

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 3275	SP	0.7	0.3	H	H	N/A	N/A	N/A	N/A	M	H	H	H	L		SPU 3275	More
SPU 3276	SP	2.0	1.0	H	H	H	M	N/A	H	M	H	H	H	L		SPU 3276	Most
SPU 3277	SP	1.8	0.9	H	H	H	M	N/A	H	M	H	H	H	L		SPU 3277	Most
SPU 3278	SP	0.4	1.3	M	H	H	N	N/A	N/A	M	H	H	M	L		SPU 3278	Mod.
SPU 3279	SP	0.4	1.3	H	H	M	N	N/A	N	M	H	H	H	N		SPU 3279	More
SPU 3280	SP	0.2	0.1	H	H	H	N	N/A	N	M	H	H	H	N		SPU 3280	More
SPU 3281	SP	0.8	0.3	H	H	L	N	N/A	N	M	H	H	H	L		SPU 3281	More
SPU 3282	SP	1.1	0.9	H	H	M	N	N/A	N	M	H	H	H	L		SPU 3282	More
SPU 3283	SP	3.1	3.6	H	H	H	N	N/A	N/A	M	H	H	H	L		SPU 3283	More
SPU 3284	SP	1.5	1.9	H	M	L	L	N/A	L	M	M	M	H	L		SPU 3284	Less
SPU 3285	SP	5.6	3.7	M	L	L	L	N/A	L	M	L	L	M	L		SPU 3285	Less
SPU 3286	SP	5.3	3.5	M	M	H	H	N/A	N	M	M	M	M	L		SPU 3286	More
SPU 3287	SP	5.0	2.4	M	M	H	H	N/A	N	M	M	M	M	L		SPU 3287	More
SPU 3288	SP	0.6	0.2	M	H	H	N/A	N/A	N/A	N	H	H	H	L		SPU 3288	More
SPU 3289	SP	1.0	0.3	M	H	H	N/A	N/A	N/A	N	H	H	H	L		SPU 3289	Mod.
SPU 3290	SP	0.6	0.1	H	H	H	N/A	N/A	N/A	L	H	H	H	L		SPU 3290	More
SPU 3291	SP	0.3	0.1	H	H	H	N/A	N/A	N/A	L	H	H	H	L		SPU 3291	More
SPU 4002	SC	4.5	11.8	H	H	H	H	N/A	M	H	H	H	H	N		SPU 4002	Most
SPU 4003	SC	3.2	0.9	H	H	H	H	N/A	H	M	H	H	H	M		SPU 4003	Most
SPU 4004	SC	5.6	1,561.7	H	H	H	H	N/A	H	M	H	H	H	H		SPU 4004	Most
SPU 4005	SC	2.5	1,562.0	H	H	H	H	N/A	H	M	H	H	H	H		SPU 4005	Most
SPU 4006	SC	2.5	2.4	H	H	M	N/A	N/A	H	M	H	H	H	L		SPU 4006	More
SPU 4007	SC	9.8	10.2	H	H	H	H	N/A	M	H	H	H	H	M		SPU 4007	Most
SPU 4008	SC	5.0	3.7	H	H	H	H	N/A	M	H	H	H	H	H		SPU 4008	Most
SPU 4009	SC	3.4	3.4	H	H	H	H	N/A	N/A	H	H	H	H	H		SPU 4009	Most
SPU 4010	SC	4.1	2.5	H	H	H	H	N/A	H	H	H	H	H	H		SPU 4010	Most
SPU 4013	SC	22.5	34.4	H	H	H	N/A	N/A	N/A	H	H	H	H	L		SPU 4013	Most
SPU 4014	SC	2.9	2.0	H	H	M	N/A	N/A	N/A	H	H	H	H	L		SPU 4014	More
SPU 4015	SC	13.8	61.6	H	H	H	H	N/A	H	H	H	H	H	M		SPU 4015	Most
SPU 4016	SC	7.8	31.9	H	H	H	H	N/A	N	H	H	H	H	L		SPU 4016	Most
SPU 4017	SC	0.7	0.4	N	M	H	H	N/A	L	M	M	L	L	L		SPU 4017	Less
SPU 4018	SC	3.8	4.8	M	M	H	N/A	N/A	N/A	M	M	M	M	L		SPU 4018	Mod.
SPU 4019	SC	1.6	1.7	L	M	H	N/A	N/A	N/A	H	M	M	M	L		SPU 4019	Mod.

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 4020	SC	1.9	2.2	M	M	M	N/A	N/A	N/A	H	M	M	M	L		SPU 4020	Mod.
SPU 4021	SC	2.0	0.6	H	H	M	N/A	N/A	N/A	H	H	H	H	L		SPU 4021	More
SPU 4022	SC	1.7	0.9	H	H	N/A	N/A	N/A	N/A	H	H	H	H	H		SPU 4022	More
SPU 4023	SC	2.1	1.6	H	H	N/A	N/A	N/A	N/A	M	H	H	H	L		SPU 4023	More
SPU 4024	SC	3.0	2.9	H	H	H	H	N/A	H	H	H	H	H	M		SPU 4024	Most
SPU 4025	SC	4.3	12.4	H	H	H	H	N/A	N/A	H	H	H	H	L		SPU 4025	Most
SPU 4026	SC	7.1	10.7	H	H	M	N/A	N/A	N/A	H	H	H	H	M		SPU 4026	More
SPU 4029	SC	4.8	4.2	L	L	N/A	N/A	N/A	N/A	H	L	L	L	N		SPU 4029	Least
SPU 4030	SC	5.5	23.3	M	H	H	M	N/A	M	M	H	H	M	M		SPU 4030	More
SPU 4031	SC	5.7	23.5	H	H	H	M	N/A	M	M	H	H	H	M		SPU 4031	Most
SPU 4032	SC	0.5	0.2	H	H	H	N/A	N/A	N/A	M	H	H	H	M		SPU 4032	More
SPU 4033	SC	0.9	0.1	H	H	M	N/A	N/A	N/A	M	H	H	H	L		SPU 4033	More
SPU 4034	SC	6.7	4.4	H	H	H	N/A	N/A	N/A	M	H	H	H	L		SPU 4034	More
SPU 4035	SC	2.9	2.9	M	M	H	N/A	N/A	N/A	M	M	M	M	L		SPU 4035	Mod.
SPU 4036	SC	17.5	40.0	M	M	H	H	N/A	L	L	M	M	M	L		SPU 4036	More
SPU 4037	SC	2.3	1.9	H	H	M	N/A	N/A	H	M	H	H	H	L		SPU 4037	More
SPU 4038	SC	0.8	2.4	H	H	H	H	N/A	H	M	H	H	H	L		SPU 4038	Most
SPU 4039	SC	1.6	3.1	H	H	H	H	N/A	H	M	H	H	H	L		SPU 4039	Most
SPU 4040	SC	2.3	42.3	H	H	H	N	N/A	N/A	M	H	H	H	L		SPU 4040	More
SPU 4041	SC	3.6	39.6	H	H	H	N	N/A	N/A	M	H	H	H	L		SPU 4041	More
SPU 4042	SC	4.5	9.5	H	H	H	M	N/A	H	M	M	M	H	L		SPU 4042	More
SPU 4043	SC	13.9	55.8	H	H	H	H	N/A	M	M	H	H	H	L		SPU 4043	Most
SPU 4044	SC	3.8	41.8	H	H	H	H	N/A	L	M	H	H	H	M		SPU 4044	Most
SPU 4045	SC	11.5	46.1	H	H	H	H	N/A	M	M	H	H	H	L		SPU 4045	Most
SPU 4046	SC	20.2	52.2	H	H	H	H	N/A	M	M	H	H	H	M		SPU 4046	Most
SPU 4047	SC	3.8	2.7	H	H	M	M	N/A	H	H	H	H	H	L		SPU 4047	More
SPU 4048	SC	4.8	1.6	M	H	H	M	N/A	M	M	M	M	M	L		SPU 4048	More
SPU 4049	SC	2.5	0.6	H	H	H	M	N/A	L	H	H	H	H	L		SPU 4049	Most
SPU 4050	SC	0.5	0.3	N/A	H	H	H	N/A	N	M	H	H	H	L		SPU 4050	Most
SPU 4051	SC	2.3	0.8	H	H	H	H	N/A	N/A	M	H	H	H	L		SPU 4051	Most
SPU 4052	SC	1.2	0.3	M	H	H	M	N/A	H	H	H	H	M	N		SPU 4052	More
SPU 4053	SC	3.5	1.9	H	H	H	M	N/A	H	H	H	H	H	M		SPU 4053	Most
SPU 4054	SC	3.7	1.6	H	H	H	L	N/A	L	H	H	H	H	L		SPU 4054	Most

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 4055	SC	4.2	5.4	H	H	M	L	N/A	L	H	H	H	H	L		SPU 4055	More
SPU 4056	SC	2.3	1.9	M	M	M	L	N/A	L	H	M	M	M	L		SPU 4056	Mod.
SPU 4057	SC	0.8	0.3	H	H	H	H	N/A	L	M	H	H	H	L		SPU 4057	Most
SPU 4058	SC	2.6	44.2	H	M	L	L	N/A	M	L	M	M	H	L		SPU 4058	Mod.
SPU 4059	SC	3.9	47.3	H	M	L	L	N/A	L	L	M	M	H	L		SPU 4059	Mod.
SPU 4060	SC	5.9	37.0	H	H	H	H	N/A	M	M	H	H	H	L		SPU 4060	Most
SPU 4061	SC	14.9	54.3	H	H	H	M	N/A	H	H	H	H	H	L		SPU 4061	Most
SPU 4062	SC	9.8	12.2	H	H	M	L	N/A	L	M	H	H	H	L		SPU 4062	Mod.
SPU 4063	SC	1.2	1.7	H	H	L	N	N/A	N	H	H	M	H	L		SPU 4063	Mod.
SPU 4064	SC	3.5	15.2	H	H	H	H	N/A	H	M	H	H	H	L		SPU 4064	Most
SPU 4065	SC	2.3	13.8	M	H	H	H	N/A	M	M	H	H	H	M		SPU 4065	Most
SPU 4066	SC	12.4	9.4	M	H	H	M	N/A	M	M	M	M	M	L		SPU 4066	More
SPU 4067	SC	3.9	3.3	H	M	M	M	N/A	M	M	M	M	H	L		SPU 4067	Mod.
SPU 4068	SC	2.8	0.7	H	M	M	M	N/A	M	M	M	M	H	L		SPU 4068	More
SPU 4069	SC	2.3	1.1	H	M	M	M	N/A	M	M	M	M	M	L		SPU 4069	More
SPU 4070	SC	0.9	0.9	H	H	M	L	N/A	N/A	M	H	H	H	L		SPU 4070	More
SPU 4071	SC	2.5	3.1	H	H	M	L	N/A	N/A	M	H	H	H	L		SPU 4071	More
SPU 4072	SC	6.9	37.9	M	M	H	L	N/A	M	M	H	H	M	L		SPU 4072	More
SPU 4073	SC	6.3	21.6	H	H	H	L	N/A	M	M	H	H	H	M		SPU 4073	More
SPU 4074	SC	1.4	1.2	H	H	M	N	N/A	N/A	M	H	H	H	L		SPU 4074	More
SPU 4075	SC	7.0	13.4	M	M	M	L	N/A	L	M	M	M	M	L		SPU 4075	Mod.
SPU 4076	SC	16.5	42.1	H	M	M	L	N/A	L	L	M	M	H	L		SPU 4076	Mod.
SPU 4077	SC	16.2	43.0	M	M	M	L	N/A	L	L	M	M	M	L		SPU 4077	Less
SPU 4078	SC	10.3	15.7	M	H	H	H	N/A	H	M	M	M	M	L		SPU 4078	More
SPU 4079	SC	6.3	12.4	H	H	H	H	N/A	H	M	H	H	H	L		SPU 4079	Most
SPU 4080	SC	2.5	1.9	H	M	L	N/A	N/A	N/A	M	M	M	M	L		SPU 4080	Mod.
SPU 4081	SC	4.7	4.3	L	L	L	N/A	N/A	N/A	L	L	L	L	N		SPU 4081	Least
SPU 4082	SC	0.5	0.6	N	N	N/A	N/A	N/A	N/A	L	N	N	N	N		SPU 4082	Least
SPU 4084	SC	1.6	1.3	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 4084	None
SPU 4085	SC	1.6	0.8	L	M	M	N/A	N/A	N/A	L	M	M	M	L		SPU 4085	Less
SPU 4086	SC	2.1	1.1	N	L	M	N/A	N/A	N/A	N	L	L	L	N		SPU 4086	Least
SPU 4087	SC	2.6	0.9	N	N	N	N/A	N/A	N/A	N	N	N	N	L		SPU 4087	Least
SPU 4088	SC	0.6	0.3	M	H	N/A	N/A	N/A	N/A	L	H	H	H	N		SPU 4088	Mod.

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 4089	SC	2.2	1.7	H	H	H	N/A	N/A	N/A	M	H	H	H	L		SPU 4089	More
SPU 4090	SC	2.1	1.2	H	H	H	N/A	N/A	N/A	L	H	H	H	L		SPU 4090	More
SPU 4091	SC	4.0	4.0	M	M	N	N/A	N/A	N/A	L	M	M	M	L		SPU 4091	Mod.
SPU 4092	SC	2.6	4.5	M	M	N	N/A	N/A	N/A	M	M	M	M	L		SPU 4092	Less
SPU 4093	SC	4.2	2.1	H	H	N	L	N/A	L	L	H	M	H	L		SPU 4093	Mod.
SPU 4094	SC	0.3	0.1	H	H	N/A	N/A	N/A	N/A	H	H	H	H	N		SPU 4094	More
SPU 4095	SC	0.5	2.9	H	H	H	H	N/A	H	M	H	H	H	L		SPU 4095	Most
SPU 4096	SC	1.0	4.7	H	H	H	H	N/A	H	M	H	H	H	L		SPU 4096	Most
SPU 4097	SC	6.5	5.0	M	M	H	H	N/A	H	L	M	M	M	L		SPU 4097	More
SPU 4098	SC	9.5	5.4	M	M	H	H	N/A	H	M	M	M	M	L		SPU 4098	More
SPU 4099	SC	5.7	5.4	H	H	H	N/A	N/A	N/A	L	H	H	H	L		SPU 4099	More
SPU 4100	SC	0.9	1.5	L	M	H	N/A	N/A	N/A	L	M	M	M	L		SPU 4100	Mod.
SPU 4101	SC	3.7	6.3	M	M	H	H	N/A	H	L	M	M	M	L		SPU 4101	More
SPU 4102	SC	0.8	0.4	M	H	H	H	N/A	H	M	H	H	M	N		SPU 4102	Most
SPU 4103	SC	1.9	1.0	H	H	H	N/A	N/A	H	M	H	H	H	L		SPU 4103	Most
SPU 4104	SC	1.0	0.5	H	H	H	N/A	N/A	H	M	H	H	H	L		SPU 4104	Most
SPU 4105	SC	0.6	1.9	H	H	N/A	N/A	N/A	N/A	M	H	H	H	L		SPU 4105	More
SPU 4106	SC	0.9	0.9	H	H	N/A	N/A	N/A	N/A	M	H	H	H	L		SPU 4106	More
SPU 4107	SC	0.8	12.7	L	L	H	N	N/A	N/A	L	M	M	L	L		SPU 4107	Less
SPU 4108	SC	0.9	1.5	N	N	H	N	N/A	N/A	L	M	M	N	L		SPU 4108	Less
SPU 4109	SC	1.3	1.2	H	H	N/A	N/A	N/A	N/A	M	H	H	H	M		SPU 4109	Mod.
SPU 4110	SC	1.8	1.3	H	H	H	N/A	N/A	N/A	M	H	H	H	L		SPU 4110	More
SPU 4111	SC	0.7	0.6	H	H	H	N/A	N/A	N/A	L	H	H	H	L		SPU 4111	More
SPU 4112	SC	9.6	13.8	M	H	H	H	N/A	N/A	L	H	H	H	L		SPU 4112	More
SPU 4113	SC	1.8	5.0	H	H	H	N/A	N/A	N/A	L	H	H	H	L		SPU 4113	More
SPU 4114	SC	2.0	4.9	M	M	H	N/A	N/A	N/A	L	M	M	M	L		SPU 4114	Mod.
SPU 4115	SC	7.7	6.4	M	M	L	M	N/A	H	L	H	H	M	L		SPU 4115	More
SPU 4116	SC	0.7	0.3	L	L	N/A	N/A	N/A	N/A	L	L	L	L	N		SPU 4116	Least
SPU 4117	SC	0.7	2.3	L	M	H	H	N/A	N	L	M	L	L	N		SPU 4117	Mod.
SPU 4118	SC	1.2	0.9	N	M	H	H	N/A	H	L	M	L	L	N		SPU 4118	Mod.
SPU 4119	SC	0.3	1.3	L	L	N/A	N/A	N/A	N/A	L	L	L	L	N		SPU 4119	Least
SPU 4120	SC	0.3	0.3	M	H	N/A	N/A	N/A	N/A	L	M	M	M	N		SPU 4120	Mod.
SPU 4121	SC	5.6	4.6	M	M	N	N/A	N/A	N/A	L	M	M	M	L		SPU 4121	Less

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 4122	SC	0.9	1.1	H	H	N	N/A	N/A	N/A	L	H	H	H	L		SPU 4122	More
SPU 4123	SC	1.6	1.6	H	H	H	N/A	N/A	N/A	M	H	H	H	L		SPU 4123	More
SPU 4124	SC	1.2	0.6	M	H	H	N/A	N/A	N/A	M	H	H	H	L		SPU 4124	More
SPU 4125	SC	0.5	8.7	H	H	L	N	N/A	N	L	H	H	H	L		SPU 4125	Mod.
SPU 4126	SC	1.0	1.2	H	H	N	N	N/A	N	L	H	H	H	L		SPU 4126	Mod.
SPU 4127	SC	3.0	2.2	H	H	N/A	N/A	N/A	N/A	L	H	H	H	L		SPU 4127	More
SPU 4128	SC	1.3	0.8	H	H	H	N/A	N/A	N/A	L	H	H	H	L		SPU 4128	More
SPU 4129	SC	8.2	7.4	H	H	H	L	N/A	N	L	H	H	H	L		SPU 4129	More
SPU 4130	SC	6.7	6.0	M	H	H	L	N/A	N	M	H	H	M	L		SPU 4130	More
SPU 4131	SC	3.3	1.8	M	L	M	N	N/A	N	L	M	M	M	L		SPU 4131	Less
SPU 4132	SC	8.7	6.7	H	M	M	N	N/A	N	M	M	H	H	L		SPU 4132	Mod.
SPU 4133	SC	2.6	8.3	H	H	M	M	N/A	H	M	H	H	H	N		SPU 4133	More
SPU 4134	SC	5.6	9.6	H	H	M	N	N/A	N/A	M	H	H	H	L		SPU 4134	More
SPU 4135	SC	7.4	10.9	H	H	M	L	N/A	L	M	H	H	H	M		SPU 4135	More
SPU 4136	SC	8.7	10.3	H	H	M	M	N/A	M	M	H	H	H	M		SPU 4136	More
SPU 4137	SC	2.1	2.6	N/A	N	L	N	N/A	N/A	L	M	M	H	N		SPU 4137	Less
SPU 4138	SC	4.7	5.2	H	H	L	N	N/A	N/A	L	M	M	H	L		SPU 4138	Mod.
SPU 4139	SC	8.5	9.2	H	H	H	M	N/A	H	M	H	H	H	L		SPU 4139	More
SPU 4140	SC	2.4	4.9	H	H	H	M	N/A	H	M	H	H	H	M		SPU 4140	Most
SPU 4141	SC	12.5	13.6	H	H	H	L	N/A	L	L	H	H	H	L		SPU 4141	More
SPU 4142	SC	2.2	1.9	H	H	H	N/A	N/A	M	M	H	H	H	M		SPU 4142	Most
SPU 4143	SC	1.9	1.6	H	H	L	M	N/A	H	L	H	H	H	M		SPU 4143	More
SPU 4144	SC	1.5	1.4	H	H	L	M	N/A	H	L	H	H	H	M		SPU 4144	More
SPU 4145	SC	1.6	5.7	H	H	M	N	N/A	N/A	M	H	H	H	M		SPU 4145	More
SPU 4146	SC	2.4	6.2	H	H	M	N	N/A	N/A	M	H	H	H	L		SPU 4146	More
SPU 4147	SC	5.1	3.5	H	H	H	N/A	N/A	N/A	M	H	H	H	L		SPU 4147	More
SPU 4148	SC	2.6	10.4	H	H	H	N/A	N/A	N/A	H	H	H	H	M		SPU 4148	Most
SPU 4149	SC	5.2	1.9	H	H	N/A	N/A	N/A	N/A	H	H	H	H	L		SPU 4149	More
SPU 4150	SC	2.6	4.2	H	H	H	H	N/A	H	H	H	H	H	H		SPU 4150	Most
SPU 5001	NC	8.6	9.5	N	L	M	H	N/A	M	L	M	L	L	L		SPU 5001	Mod.
SPU 5002	NC	9.7	43.4	L	L	M	M	N/A	L	L	L	M	L	L		SPU 5002	Less
SPU 5003	NC	19.6	48.8	M	M	M	M	N/A	L	L	M	M	M	L		SPU 5003	Mod.
SPU 5004	NC	0.7	0.9	N/A	N	L	N/A	N/A	N/A	L	L	L	L	L		SPU 5004	Least

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 5005	NC	1.9	3.0	N/A	N/A	L	N/A	N/A	N/A	L	L	L	L	L		SPU 5005	Least
SPU 5006	NC	6.2	8.4	L	M	M	N/A	N/A	M	L	M	L	M	L		SPU 5006	Less
SPU 5007	NC	3.8	3.5	L	M	M	M	N/A	H	L	M	M	M	L		SPU 5007	Mod.
SPU 5008	NC	12.2	10.2	L	L	M	N/A	N/A	N/A	L	L	L	L	L		SPU 5008	Least
SPU 5009	NC	1.8	1.3	L	M	M	N/A	N/A	N/A	L	M	M	M	N		SPU 5009	Less
SPU 5010	NC	3.9	3.1	N	M	H	H	N/A	L	L	M	N	N	N		SPU 5010	Mod.
SPU 5011	NC	4.1	3.3	L	L	M	M	N/A	L	L	L	L	L	L		SPU 5011	Less
SPU 5012	NC	10.4	10.1	M	M	M	M	N/A	H	L	M	M	L	L		SPU 5012	Mod.
SPU 5015	NC	4.4	5.9	L	L	L	H	N/A	N	L	M	L	L	N		SPU 5015	Less
SPU 5016	NC	1.4	0.9	L	M	H	H	N/A	M	L	M	M	M	N		SPU 5016	Mod.
SPU 5017	NC	3.2	1.2	N	L	L	L	N/A	L	L	L	L	N	L		SPU 5017	Least
SPU 5018	NC	1.1	0.7	N	N	N	N	N/A	N	L	L	N	N	N		SPU 5018	Least
SPU 5019	NC	8.2	5.0	M	H	H	H	N/A	M	L	M	M	M	L		SPU 5019	More
SPU 5020	NC	3.4	1.0	N/A	H	H	H	N/A	M	L	H	H	N	L		SPU 5020	More
SPU 5021	NC	3.0	4.8	N/A	L	M	L	N/A	L	M	M	M	H	M		SPU 5021	Less
SPU 5022	NC	3.6	4.6	M	L	L	L	N/A	L	M	M	M	M	L		SPU 5022	Less
SPU 5023	NC	1.8	1.1	M	M	H	N/A	N/A	N	H	M	M	M	N		SPU 5023	Mod.
SPU 5024	NC	2.8	91.9	N	L	L	L	N/A	L	L	L	L	L	N		SPU 5024	Least
SPU 5025	NC	2.0	0.6	N	N	N	N	N/A	N	M	N	N	N	N		SPU 5025	Least
SPU 5026	NC	3.0	2.1	N	N	N	N/A	N/A	N/A	M	L	L	N	L		SPU 5026	Least
SPU 5027	NC	15.0	25.3	M	H	H	N/A	N/A	N/A	M	H	M	M	L		SPU 5027	Mod.
SPU 5029	NC	15.1	41.6	L	M	L	M	N/A	H	L	M	L	L	N		SPU 5029	Less
SPU 5030	NC	21.1	21.9	L	M	M	M	N/A	L	L	M	M	M	L		SPU 5030	Less
SPU 5031	NC	12.9	21.8	L	M	H	H	N/A	M	L	M	L	L	L		SPU 5031	Mod.
SPU 5032	NC	7.7	29.0	N	M	M	H	N/A	H	L	M	M	M	L		SPU 5032	More
SPU 5033	NC	16.9	65.7	L	M	M	H	N/A	M	L	M	M	L	L		SPU 5033	Mod.
SPU 5034	NC	7.7	14.4	H	M	M	H	N/A	H	L	M	M	M	L		SPU 5034	More
SPU 5035	NC	7.0	12.4	L	H	H	H	N/A	M	L	H	H	M	L		SPU 5035	More
SPU 5036	NC	9.3	7.0	N	L	L	L	N/A	L	L	L	L	L	L		SPU 5036	Least
SPU 6002	WH	7.4	14.8	L	M	M	N/A	N/A	N/A	L	M	M	M	L		SPU 6002	Less
SPU 6003	WH	7.2	12.8	L	M	M	N/A	N/A	N/A	L	L	L	L	L		SPU 6003	Less
SPU 6004	WH	10.3	20.2	M	M	M	N/A	N/A	N/A	L	M	M	M	L		SPU 6004	Less
SPU 6005	WH	0.1	0.2	N	N	N/A	N/A	N/A	N/A	N	N	N	N	N		SPU 6005	None

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 6006	WH	0.1	0.1	N	N	N/A	N/A	N/A	N/A	N	N	N	N	N		SPU 6006	None
SPU 6007	WH	4.8	17.9	M	M	L	N/A	N/A	N/A	L	M	M	M	L		SPU 6007	Less
SPU 6008	WH	0.6	4.8	N	N	N	N/A	N/A	N/A	M	N	N	N	L		SPU 6008	Least
SPU 6009	WH	0.7	0.5	L	N	N/A	N/A	N/A	N/A	H	M	M	M	N		SPU 6009	Less
SPU 6010	WH	4.3	3.7	M	M	N	N/A	N/A	N/A	M	M	M	M	L		SPU 6010	Less
SPU 6011	WH	28.6	36.3	L	L	L	M	N/A	L	L	L	L	L	L		SPU 6011	Less
SPU 6012	WH	1.1	1.8	N	N	N	M	N/A	H	L	N	N	N	N		SPU 6012	Less
SPU 6013	WH	1.3	2.2	L	L	L	N/A	N/A	N/A	L	L	L	L	L		SPU 6013	Less
SPU 6014	WH	5.5	4.8	M	H	H	N/A	N/A	N/A	M	H	H	H	L		SPU 6014	More
SPU 6015	WH	2.9	2.8	L	L	M	N/A	N/A	N/A	L	L	L	L	L		SPU 6015	Least
SPU 6016	WH	2.2	2.0	L	L	L	L	N/A	L	L	L	L	M	L		SPU 6016	Less
SPU 6017	WH	3.2	6.7	M	H	H	H	N/A	M	L	H	H	M	L		SPU 6017	More
SPU 6018	WH	9.0	21.1	M	M	M	H	N/A	M	M	M	M	M	L		SPU 6018	More
SPU 6019	WH	10.5	19.6	L	M	M	H	N/A	H	H	M	M	L	L		SPU 6019	More
SPU 6020	WH	8.4	6.1	L	H	H	H	N/A	N/A	H	H	H	M	L		SPU 6020	More
SPU 6021	WH	3.7	4.6	M	M	N/A	N/A	N/A	N/A	H	M	M	M	L		SPU 6021	Mod.
SPU 6022	WH	7.6	33.1	M	M	H	H	N/A	L	M	M	M	M	N		SPU 6022	More
SPU 6023	WH	1.3	0.5	L	N	M	N/A	N/A	N/A	M	M	L	M	N		SPU 6023	Less
SPU 6024	WH	2.6	3.0	L	L	M	N/A	N/A	N/A	M	L	L	L	N		SPU 6024	Least
SPU 6025	WH	15.3	48.1	L	H	H	H	N/A	H	M	M	M	M	L		SPU 6025	More
SPU 6026	WH	2.7	4.7	L	L	H	N/A	N/A	H	M	M	M	M	N		SPU 6026	Mod.
SPU 6027	WH	4.3	3.5	M	L	M	N	N/A	N/A	M	M	M	M	N		SPU 6027	Less
SPU 6028	WH	2.9	4.3	L	L	L	N	N/A	N/A	L	L	L	L	L		SPU 6028	Least
SPU 6030	WH	1.5	19.8	H	H	N/A	N/A	N/A	N/A	L	H	H	H	L		SPU 6030	More
SPU 6031	WH	4.0	6.6	M	M	L	N/A	N/A	H	M	M	M	M	N		SPU 6031	Mod.
SPU 6032	WH	2.1	3.7	H	M	M	N/A	N/A	H	M	H	H	M	L		SPU 6032	More
SPU 6033	WH	3.6	4.4	H	L	L	L	N/A	L	M	M	L	M	L		SPU 6033	Mod.
SPU 6034	WH	5.5	7.5	N	L	L	L	N/A	L	M	L	L	N	N		SPU 6034	Least
SPU 6035	WH	2.7	2.7	N	M	H	H	N/A	M	L	L	L	L	N		SPU 6035	Mod.
SPU 6036	WH	11.3	14.6	M	M	M	M	N/A	M	L	M	M	M	L		SPU 6036	Mod.
SPU 6037	WH	4.0	5.3	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 6037	None
SPU 6038	WH	4.0	5.3	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 6038	None
SPU 6039	WH	1.2	0.2	N/A	N/A	N/A	N/A	N/A	N/A	N	N	N	N/A	N		SPU 6039	None

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 6041	WH	2.2	8.6	H	H	H	N/A	N/A	N/A	M	H	H	H	N		SPU 6041	More
SPU 6042	WH	22.3	47.9	M	H	H	N/A	N/A	N/A	M	M	M	M	L		SPU 6042	Mod.
SPU 6043	WH	3.4	5.5	M	L	L	L	N/A	L	L	M	L	M	L		SPU 6043	Less
SPU 6044	WH	11.9	16.6	M	H	M	M	N/A	L	M	M	M	M	L		SPU 6044	Mod.
SPU 6045	WH	3.0	3.7	M	M	L	N/A	N/A	N/A	L	M	M	M	N		SPU 6045	Less
SPU 6046	WH	2.8	2.0	M	M	M	N/A	N/A	N/A	L	M	M	M	N		SPU 6046	Less
SPU 6047	WH	25.0	40.2	M	M	H	M	N/A	L	M	M	M	M	L		SPU 6047	Mod.
SPU 6048	WH	5.6	15.8	N	L	H	M	N/A	L	M	M	M	L	L		SPU 6048	Mod.
SPU 6049	WH	8.0	17.8	L	M	M	M	N/A	H	L	M	M	M	L		SPU 6049	Mod.
SPU 6050	WH	3.5	12.1	L	M	M	N/A	N/A	N/A	L	M	L	M	N		SPU 6050	Less
SPU 6051	WH	2.1	13.7	L	M	M	N/A	N/A	N/A	M	L	L	L	L		SPU 6051	Less
SPU 6052	WH	16.1	45.9	M	M	H	H	N/A	M	L	M	M	M	L		SPU 6052	More
SPU 6053	WH	5.6	66.1	M	M	M	L	N/A	L	L	M	M	H	L		SPU 6053	Mod.
SPU 6054	WH	7.9	68.8	M	M	M	L	N/A	L	L	M	M	M	L		SPU 6054	Mod.
SPU 6056	WH	5.2	11.1	M	M	H	N/A	N/A	N/A	M	H	H	M	L		SPU 6056	Mod.
SPU 6057	WH	0.9	0.4	L	L	L	N/A	N/A	N/A	L	L	L	L	N		SPU 6057	Least
SPU 6058	WH	3.0	1.6	M	M	L	N/A	N/A	N/A	L	M	M	M	N		SPU 6058	Less
SPU 6059	WH	2.7	2.2	M	M	H	N/A	N/A	N/A	L	M	M	M	L		SPU 6059	Mod.
SPU 6060	WH	2.7	1.2	M	H	H	N/A	N/A	N/A	L	M	M	M	L		SPU 6060	Mod.
SPU 6061	WH	8.5	6.6	M	M	M	L	N/A	N/A	L	L	L	M	L		SPU 6061	Less
SPU 6062	WH	3.6	9.3	M	M	L	L	N/A	M	L	M	M	M	N		SPU 6062	Less
SPU 7001	SJ	7.3	1.5	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7001	None
SPU 7002	SJ	30.1	5.4	N/A	N/A	N	N/A	N/A	N/A	N	L	L	N	L		SPU 7002	Least
SPU 7003	SJ	6.9	1.0	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	L		SPU 7003	Least
SPU 7004	SJ	2.0	0.4	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7004	None
SPU 7005	SJ	4.6	0.7	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7005	None
SPU 7006	SJ	1.8	0.2	N/A	N/A	N/A	N/A	N/A	N/A	N	N	N	N/A	N		SPU 7006	None
SPU 7007	SJ	6.9	4.7	N	N	N	N/A	N/A	N/A	L	N	N	N	N		SPU 7007	Least
SPU 7008	SJ	12.6	10.3	N	N	L	N/A	N/A	N/A	L	L	L	L	L		SPU 7008	Least
SPU 7009	SJ	2.5	0.3	N/A	N/A	N/A	N/A	N/A	N/A	N	N	N	N/A	N		SPU 7009	None
SPU 7010	SJ	11.4	2.5	N/A	N/A	N/A	N/A	N/A	N/A	L	L	L	N/A	L		SPU 7010	Least
SPU 7011	SJ	1.7	0.2	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7011	None
SPU 7012	SJ	0.8	0.1	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	L		SPU 7012	Least

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 7013	SJ	7.3	1.6	N	N	N	N/A	N/A	N/A	N	N	N	N	L		SPU 7013	Least
SPU 7014	SJ	5.0	0.9	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	L		SPU 7014	Least
SPU 7015	SJ	8.4	2.2	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7015	Least
SPU 7016	SJ	5.4	1.5	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7016	Least
SPU 7017	SJ	16.5	7.5	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7017	Least
SPU 7018	SJ	0.4	0.1	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7018	Least
SPU 7019	SJ	2.5	0.6	N/A	N/A	N	N/A	N/A	N/A	M	N	L	N	L		SPU 7019	Least
SPU 7020	SJ	7.5	2.4	N/A	M	M	M	N/A	M	M	L	M	M	M		SPU 7020	Mod.
SPU 7021	SJ	2.1	0.3	N/A	N	L	N/A	N/A	N	M	M	L	L	L		SPU 7021	Least
SPU 7022	SJ	34.1	44.8	N/A	H	L	M	N/A	M	L	L	L	L	M		SPU 7022	Less
SPU 7023	SJ	36.5	46.9	N/A	M	L	L	N/A	L	L	L	L	L	M		SPU 7023	Less
SPU 7024	SJ	8.7	10.8	N/A	N	L	N	N/A	N	M	L	L	L	L		SPU 7024	Least
SPU 7025	SJ	5.7	7.7	N/A	N/A	N	N/A	N/A	L	L	L	N	N	L		SPU 7025	Least
SPU 7026	SJ	4.5	5.3	N	N	N	L	N/A	L	L	N	N	N	N		SPU 7026	Least
SPU 7027	SJ	4.6	1.8	N	N	N	N	N/A	N	L	N	L	N	L		SPU 7027	Least
SPU 7028	SJ	19.7	14.0	N	N	N	N	N/A	N/A	L	N	L	N	L		SPU 7028	Least
SPU 7029	SJ	11.8	38.9	N/A	N/A	L	N/A	N/A	N/A	M	L	M	L	L		SPU 7029	Least
SPU 7030	SJ	22.9	59.2	N/A	N	L	N/A	N/A	N/A	L	L	L	L	L		SPU 7030	Least
SPU 7031	SJ	21.6	26.8	N	H	L	N/A	N/A	N/A	L	L	L	L	L		SPU 7031	Least
SPU 7032	SJ	0.4	0.1	N/A	N/A	L	N/A	N/A	N/A	L	L	L	L	L		SPU 7032	Least
SPU 7033	SJ	0.7	0.7	H	N	N/A	N/A	N/A	N/A	L	M	M	H	L		SPU 7033	Mod.
SPU 7034	SJ	0.4	0.2	L	N	N/A	N/A	N/A	N/A	L	L	L	L	L		SPU 7034	Least
SPU 7035	SJ	1.4	0.5	N	N	L	N	N/A	N	L	L	L	N	L		SPU 7035	Least
SPU 7036	SJ	1.8	0.6	N	N	L	N	N/A	N	L	L	L	N	L		SPU 7036	Least
SPU 7037	SJ	7.3	8.6	N/A	L	L	L	N/A	L	L	L	L	L	L		SPU 7037	Least
SPU 7038	SJ	11.1	14.1	N	L	L	L	N/A	L	L	L	L	L	L		SPU 7038	Least
SPU 7039	SJ	1.9	3.0	N	N	N	L	N/A	L	M	N	L	N	L		SPU 7039	Least
SPU 7040	SJ	4.7	2.5	N/A	N	L	L	N/A	L	M	L	L	L	L		SPU 7040	Least
SPU 7041	SJ	7.3	2.3	N/A	M	M	M	N/A	M	M	L	L	L	M		SPU 7041	Mod.
SPU 7042	SJ	16.3	5.7	N	N	N	N	N/A	N	L	N	L	N	L		SPU 7042	Least
SPU 7043	SJ	1.5	0.6	N	L	L	N	N/A	N	L	L	L	M	L		SPU 7043	Least
SPU 7044	SJ	0.4	0.1	N	N	N	N/A	N/A	N/A	L	N	N	N	N		SPU 7044	Least
SPU 7045	SJ	0.9	0.3	N	N	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7045	Least

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 7046	SJ	0.9	0.2	N	N	N	N	N/A	N	L	N	N	N	L		SPU 7046	Least
SPU 7047	SJ	0.5	0.2	N	N	N	N	N/A	N	N	N	N	N	N		SPU 7047	None
SPU 7048	SJ	5.2	1.0	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	L		SPU 7048	Least
SPU 7049	SJ	2.7	0.4	N/A	N/A	N	N/A	N/A	N/A	N	N	L	N	L		SPU 7049	Least
SPU 7050	SJ	1.1	0.2	N/A	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7050	None
SPU 7051	SJ	1.6	0.2	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7051	None
SPU 7052	SJ	5.0	1.3	N/A	N/A	N	N/A	N/A	N/A	L	L	L	N	L		SPU 7052	Least
SPU 7053	SJ	34.5	18.7	M	L	L	L	N/A	M	L	L	L	M	L		SPU 7053	Less
SPU 7054	SJ	39.0	18.7	M	L	L	M	N/A	H	L	L	L	L	L		SPU 7054	Less
SPU 7055	SJ	38.3	28.0	M	M	L	H	N/A	H	L	L	L	L	L		SPU 7055	Mod.
SPU 7056	SJ	5.1	3.4	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7056	Least
SPU 7057	SJ	7.9	8.0	H	M	M	H	N/A	M	M	M	M	M	L		SPU 7057	More
SPU 7058	SJ	29.7	31.5	N/A	M	L	L	N/A	M	L	L	L	L	L		SPU 7058	Less
SPU 7059	SJ	23.9	24.9	N/A	N/A	N	N/A	N/A	N/A	L	L	L	N	L		SPU 7059	Least
SPU 7060	SJ	2.7	1.2	N/A	N/A	N	N/A	N/A	N/A	M	N	L	N	L		SPU 7060	Least
SPU 7061	SJ	22.6	42.7	M	M	M	M	N/A	M	L	L	L	M	L		SPU 7061	Less
SPU 7062	SJ	22.1	25.4	N/A	N	N	N	N/A	N/A	L	N	L	N	L		SPU 7062	Least
SPU 7063	SJ	19.2	19.3	N/A	L	L	L	N/A	N/A	L	L	L	L	L		SPU 7063	Least
SPU 7064	SJ	10.6	26.5	M	M	M	L	N/A	N/A	L	M	M	M	L		SPU 7064	Mod.
SPU 7065	SJ	4.4	1.6	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7065	Least
SPU 7066	SJ	1.0	0.4	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7066	Least
SPU 7067	SJ	2.3	1.4	M	H	H	H	N/A	L	L	H	H	H	L		SPU 7067	Most
SPU 7068	SJ	8.1	5.1	N/A	H	M	H	N/A	L	L	M	L	L	L		SPU 7068	Less
SPU 7069	SJ	4.6	3.8	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7069	Least
SPU 7070	SJ	2.5	1.1	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7070	None
SPU 7071	SJ	2.1	7.2	N/A	N/A	N	N/A	N/A	N/A	M	N	M	N	N		SPU 7071	Least
SPU 7072	SJ	1.4	0.7	N	N	H	N/A	N/A	N/A	L	L	L	H	N		SPU 7072	Less
SPU 7073	SJ	2.4	1.4	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7073	None
SPU 7074	SJ	1.7	0.8	L	L	N	N/A	N/A	N/A	L	L	L	L	N		SPU 7074	Least
SPU 7075	SJ	3.9	0.6	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	L		SPU 7075	Least
SPU 7077	SJ	11.5	5.7	N	L	L	L	N/A	L	L	L	L	L	L		SPU 7077	Least
SPU 7078	SJ	3.1	1.0	N	M	H	N	N/A	N	L	M	M	M	L		SPU 7078	Less
SPU 7079	SJ	8.0	3.0	N	N	N	N/A	N/A	N/A	L	N	N	N	N		SPU 7079	Least

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 7080	SJ	4.0	4.4	M	M	M	L	N/A	L	M	M	M	M	L		SPU 7080	Mod.
SPU 7081	SJ	3.4	1.0	N/A	N	L	N/A	N/A	N/A	M	L	L	L	L		SPU 7081	Least
SPU 7082	SJ	7.2	2.3	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7082	None
SPU 7083	SJ	5.0	1.4	N/A	N/A	N	N/A	N/A	N/A	L	N	L	N	L		SPU 7083	Least
SPU 7084	SJ	4.7	1.7	N	N	N	N	N/A	N	L	L	N	N	L		SPU 7084	Least
SPU 7085	SJ	64.5	43.9	L	M	M	M	N/A	M	L	L	L	L	L		SPU 7085	Less
SPU 7086	SJ	64.9	43.1	L	H	M	M	N/A	M	L	L	L	L	L		SPU 7086	Less
SPU 7087	SJ	1.5	0.6	N	H	H	M	N/A	H	M	H	H	M	L		SPU 7087	More
SPU 7088	SJ	4.0	1.7	L	M	M	L	N/A	M	L	M	M	L	L		SPU 7088	Mod.
SPU 7089	SJ	3.3	2.9	H	H	M	L	N/A	L	L	M	M	M	L		SPU 7089	Mod.
SPU 7090	SJ	3.0	3.3	H	H	L	L	N/A	L	L	M	M	H	L		SPU 7090	Mod.
SPU 7091	SJ	2.6	3.5	M	M	L	L	N/A	L	M	M	M	M	L		SPU 7091	Less
SPU 7092	SJ	2.9	1.1	N	H	H	N/A	N/A	N/A	L	H	H	H	N		SPU 7092	Mod.
SPU 7093	SJ	2.0	1.2	N	L	M	N/A	N/A	N/A	L	L	M	L	L		SPU 7093	Less
SPU 7094	SJ	6.7	5.0	N	N	L	N	N/A	N/A	L	L	L	L	L		SPU 7094	Least
SPU 7095	SJ	4.2	1.1	H	M	L	N	N/A	N/A	M	L	L	M	L		SPU 7095	Less
SPU 7096	SJ	5.4	8.3	H	M	M	M	N/A	H	L	M	M	M	L		SPU 7096	Mod.
SPU 7097	SJ	1.5	7.1	M	L	M	N/A	N/A	H	L	M	M	M	N		SPU 7097	Mod.
SPU 7098	SJ	2.5	0.7	N	L	L	M	N/A	L	L	L	L	N	N		SPU 7098	Least
SPU 7099	SJ	5.4	7.5	N	N	N	N/A	N/A	H	L	M	N	N	N		SPU 7099	Least
SPU 7100	SJ	11.0	11.5	N	L	L	M	N/A	N	L	L	L	L	L		SPU 7100	Least
SPU 7101	SJ	3.8	3.9	N	M	M	M	N/A	M	L	M	M	N	L		SPU 7101	Less
SPU 7102	SJ	1.7	0.6	N	L	M	L	N/A	L	L	M	M	N	L		SPU 7102	Less
SPU 7103	SJ	1.6	0.4	N	N	M	N	N/A	N	L	M	M	N	N		SPU 7103	Least
SPU 7104	SJ	2.7	0.4	N/A	N/A	N	N/A	N/A	N/A	N	N	L	N	L		SPU 7104	Least
SPU 7107	SJ	4.2	1.4	N	N	N	N/A	N/A	N/A	N	N	N	N	L		SPU 7107	Least
SPU 7108	SJ	2.3	0.6	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7108	None
SPU 7109	SJ	5.8	7.1	M	L	N	N/A	N/A	N/A	L	M	L	M	N		SPU 7109	Less
SPU 7110	SJ	2.8	5.1	N/A	L	L	N/A	N/A	N/A	L	L	L	L	N		SPU 7110	Least
SPU 7111	SJ	26.7	21.5	L	L	L	N/A	N/A	N/A	L	L	L	L	L		SPU 7111	Least
SPU 7112	SJ	30.7	22.2	L	L	M	N/A	N/A	H	L	M	L	L	L		SPU 7112	Less
SPU 7113	SJ	2.3	3.6	N	N	N	N/A	N/A	N/A	L	N	N	N	L		SPU 7113	Least
SPU 7114	SJ	6.0	5.0	N	L	L	N/A	N/A	N/A	L	L	L	L	L		SPU 7114	Least

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 7115	SJ	5.1	2.5	N	N	L	N/A	N/A	N/A	L	L	L	L	L		SPU 7115	Least
SPU 7116	SJ	0.7	0.4	N	N	N	N/A	N/A	N/A	M	N	N	N	N		SPU 7116	Least
SPU 7117	SJ	5.1	4.8	N/A	N	N	N/A	N/A	N/A	L	N	N	N	L		SPU 7117	Least
SPU 7118	SJ	12.5	10.0	N	N	N	N	N/A	N/A	L	L	L	N	L		SPU 7118	Least
SPU 7119	SJ	9.4	7.2	N	N	N	N	N/A	N/A	L	L	L	N	L		SPU 7119	Least
SPU 7120	SJ	5.6	3.4	N	N	N	N/A	N/A	N/A	L	L	L	N	L		SPU 7120	Least
SPU 7121	SJ	3.4	6.1	N	N	N	N/A	N/A	N/A	L	N	N	N	N		SPU 7121	Least
SPU 7122	SJ	0.9	3.5	N	N	N	N/A	N/A	N/A	L	N	N	N	N		SPU 7122	Least
SPU 7123	SJ	2.9	2.7	N	N	N	N/A	N/A	N/A	L	N	N	N	L		SPU 7123	Least
SPU 7124	SJ	4.8	4.6	N	N	N	N/A	N/A	N/A	L	N	N	N	L		SPU 7124	Least
SPU 7125	SJ	1.2	0.2	N/A	N/A	N/A	N/A	N/A	N/A	N	N	N	N/A	N		SPU 7125	None
SPU 7126	SJ	2.1	5.0	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7126	None
SPU 7127	SJ	2.6	3.9	N/A	N/A	N/A	N/A	N/A	N/A	N	N	N	N/A	N		SPU 7127	None
SPU 7128	SJ	2.3	2.0	L	N	N/A	N/A	N/A	N/A	L	L	L	L	N		SPU 7128	Least
SPU 7129	SJ	1.7	1.7	N	L	N/A	N/A	N/A	N/A	L	L	L	L	L		SPU 7129	Least
SPU 7130	SJ	1.3	1.0	N	L	N/A	N/A	N/A	N/A	L	L	L	L	L		SPU 7130	Least
SPU 7131	SJ	2.7	4.7	N	M	H	H	N/A	H	L	M	L	M	L		SPU 7131	Mod.
SPU 7132	SJ	1.2	4.3	N	H	H	H	N/A	H	L	M	M	M	N		SPU 7132	More
SPU 7133	SJ	13.1	12.9	M	L	L	H	N/A	H	L	M	L	M	L		SPU 7133	Mod.
SPU 7134	SJ	2.1	2.2	N	N	N	N/A	N/A	N/A	L	N	N	N	N		SPU 7134	Least
SPU 7135	SJ	2.4	3.9	N	L	H	N/A	N/A	N/A	L	L	L	L	L		SPU 7135	Less
SPU 7136	SJ	1.6	2.8	H	M	M	N/A	N/A	N/A	L	M	M	M	L		SPU 7136	Mod.
SPU 7137	SJ	2.0	1.3	L	L	H	N/A	N/A	N/A	L	L	L	L	N		SPU 7137	Less
SPU 7138	SJ	10.4	16.6	L	H	M	N/A	N/A	N/A	M	M	M	L	L		SPU 7138	Less
SPU 7139	SJ	3.6	10.6	L	M	M	N/A	N/A	N/A	M	M	M	M	N		SPU 7139	Less
SPU 7140	SJ	6.4	6.8	H	H	N/A	N/A	N/A	N/A	H	H	H	H	M		SPU 7140	More
SPU 7141	SJ	16.9	142.0	H	L	H	L	N/A	L	L	H	H	H	L		SPU 7141	More
SPU 7142	SJ	20.2	146.5	L	L	H	L	N/A	L	L	H	H	M	L		SPU 7142	Mod.
SPU 7143	SJ	7.6	8.9	L	L	L	N/A	N/A	N/A	L	L	L	L	L		SPU 7143	Least
SPU 7144	SJ	6.5	13.8	L	M	H	H	N/A	H	M	M	M	M	L		SPU 7144	More
SPU 7145	SJ	10.1	66.8	M	M	H	M	N/A	M	M	H	H	H	L		SPU 7145	More
SPU 7146	SJ	22.8	34.2	M	M	M	H	N/A	M	M	M	M	M	L		SPU 7146	More
SPU 7150	SJ	2.3	2.4	L	L	M	N/A	N/A	N/A	M	L	L	L	L		SPU 7150	Less

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 7151	SJ	7.1	7.6	M	L	L	N/A	N/A	N/A	L	M	L	L	L		SPU 7151	Less
SPU 7152	SJ	4.6	4.1	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7152	None
SPU 7153	SJ	1.4	0.7	N	N	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7153	None
SPU 7154	SJ	3.2	2.7	N	N	N	L	N/A	L	N	L	N	N	N		SPU 7154	Least
SPU 7155	SJ	2.4	3.1	H	M	M	N/A	N/A	N/A	L	H	H	H	L		SPU 7155	Mod.
SPU 7156	SJ	5.9	18.7	H	H	N/A	N/A	N/A	N/A	L	H	H	H	L		SPU 7156	Mod.
SPU 7157	SJ	11.6	80.1	M	H	H	H	N/A	H	M	H	H	H	L		SPU 7157	Most
SPU 7158	SJ	6.1	174.2	H	H	H	H	N/A	H	M	H	H	H	M		SPU 7158	Most
SPU 7159	SJ	4.8	172.9	H	H	H	H	N/A	H	M	H	H	H	M		SPU 7159	Most
SPU 7160	SJ	1.2	17.1	H	H	H	H	N/A	H	M	H	H	H	L		SPU 7160	Most
SPU 7161	SJ	25.8	52.4	H	H	H	H	N/A	H	M	M	M	H	L		SPU 7161	Most
SPU 7162	SJ	1.2	1.8	N/A	N/A	H	N/A	N/A	N/A	L	H	H	H	N		SPU 7162	Mod.
SPU 7163	SJ	7.8	8.2	M	H	H	H	N/A	H	M	M	M	M	L		SPU 7163	More
SPU 7164	SJ	2.6	1.2	L	L	N	N/A	N/A	N/A	L	L	L	L	N		SPU 7164	Least
SPU 7165	SJ	58.6	203.4	M	H	H	H	N/A	H	L	H	H	H	L		SPU 7165	Most
SPU 7166	SJ	3.0	10.8	M	M	H	H	N/A	H	M	M	M	M	N		SPU 7166	More
SPU 7167	SJ	1.1	4.1	H	H	H	H	N/A	H	H	H	H	H	L		SPU 7167	Most
SPU 7168	SJ	4.0	3.9	H	M	M	L	N/A	L	H	M	M	M	M		SPU 7168	Mod.
SPU 7169	SJ	13.2	23.4	H	H	H	M	N/A	H	M	H	H	H	L		SPU 7169	Most
SPU 7170	SJ	2.6	4.9	H	H	H	H	N/A	H	H	H	H	H	M		SPU 7170	Most
SPU 7171	SJ	9.5	8.8	H	H	H	H	N/A	N/A	H	H	H	H	M		SPU 7171	Most
SPU 7172	SJ	3.3	3.0	H	H	L	N/A	N/A	N/A	H	M	M	H	N		SPU 7172	More
SPU 7174	SJ	1.0	0.3	H	H	N	N/A	N/A	N/A	M	H	H	H	L		SPU 7174	Mod.
SPU 7175	SJ	9.8	15.8	L	L	H	N/A	N/A	N/A	L	H	H	L	N		SPU 7175	Mod.
SPU 7176	SJ	0.9	3.5	N	M	H	H	N/A	N/A	L	N	N	N	N		SPU 7176	Less
SPU 7177	SJ	0.5	0.4	N	N	N/A	N/A	N/A	N/A	M	N	N	N	N		SPU 7177	Least
SPU 7179	SJ	0.8	0.1	N/A	N/A	N/A	N/A	N/A	N/A	N	N	N	N/A	N		SPU 7179	None
SPU 7180	SJ	2.6	0.5	N/A	N/A	L	N/A	N/A	N/A	L	N	L	L	L		SPU 7180	Least
SPU 7181	SJ	1.2	0.2	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7181	None
SPU 7182	SJ	1.4	0.2	N/A	N/A	N	N/A	N/A	N/A	N	N	N	N	N		SPU 7182	None
SPU 8001	WH/NC	16.5	30.7	L	M	H	H	N/A	M	L	M	L	L	L		SPU 8001	Mod.
SPU 8055	WH/SC	60.4	135.7	H	H	H	H	N/A	H	H	H	H	H	L		SPU 8055	Most
SPU 8056	WH/SJ	31.8	24.7	M	H	M	H	N/A	M	M	M	M	M	L		SPU 8056	Mod.

Process Units	Sub-basin	Shoreline Length (km)	Watershed Area (km^2)	Sediment Input	Sediment Transport	Sediment Accretion	Tidal Flow	Distributary Channel Migration	Tidal Channel Formation	Freshwater Input	Detritus Import and Export	Exchange of Aquatic Organisms	Physical Disturbance	Solar Incidence		Process Units	Overall Degradation Category
SPU 8057	NC/SJ	27.7	63.3	L	M	M	N	N/A	N/A	M	L	L	M	L		SPU 8057	Less
SPU 8058	NC/SJ	20.0	45.3	L	M	L	H	N/A	H	L	M	L	L	L		SPU 8058	Mod.
SPU 8201	SC/SP	9.1	8.3	H	H	H	H	N/A	H	H	H	H	H	M		SPU 8201	Most
SPU 8202	SC/SP	4.5	4.7	L	L	N/A	N/A	N/A	N/A	M	L	L	L	M		SPU 8202	Less
SPU 8211	SC/NC	7.8	16.0	L	L	H	H	N/A	H	L	M	L	L	N		SPU 8211	Mod.
SPU 8220	HC/NC	1.9	0.6	N	N	N	N	N/A	N	L	L	N	N	N		SPU 8220	Least
SPU 8230	HC/NC	8.2	7.0	L	L	L	N/A	N/A	N/A	L	L	L	L	L		SPU 8230	Less
SPU 8400	JF/NC	10.8	21.4	L	L	M	N/A	N/A	N/A	M	L	L	L	N		SPU 8400	Less
SPU 8401	WH/SJ	16.0	28.3	M	M	L	M	N/A	H	L	L	L	M	L		SPU 8401	Mod.

PUGET SOUND
NEARSHORE
ECOSYSTEM RESTORATION PROJECT

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