

Developing a Geomorphic Model for Nearshore Habitat Mapping and Analysis

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Introduction

We classify things—name them and break them down into parts—to transform an infinitely complex universe into understandable, organized bits. Classifying the complex helps us focus the lens so that the essence we are trying to understand stands out clearly amidst the background clutter. This means that classification systems are need-specific—the object of focus determines what the classification system looks like. The Skagit River System Cooperative (SRSC) needed a classification system for Puget Sound shorelines to help understand salmon ecology in the nearshore to recover ESA listed salmon. In the hopes of developing hypotheses about how to sustainably restore nearshore salmon habitats that have been impacted by human activities (Figure 1a and b) we created a classification system for the Puget Sound nearshore based on landscape processes acting at a small scale, herein referred to as the McBride Model.

Rationale for a New Classification

Many shoreline classifications exist. Classifications for estuaries in particular are many and diverse: Pritchard 1952, Davies 1973, Day et al. 1989, and so on. These are based on varying combinations of geomorphic, oceanographic, chemical, and biological characteristics and can be applied at a regional scale. The Puget Sound Estuary can be classified using these descriptive systems as a well mixed, oligohaline fjord. Its major river systems could also be classified. However, a regional classification is not effective for achieving the goal of examining juvenile salmon ecology at a relevant scale. Both the size of juvenile salmon using nearshore habitat and the extent of the typical human impact on the nearshore necessitate a finer scale framework.

Most recently, Shipman (2008) developed a ‘typology’ for the Puget Sound nearshore based on geomorphic characteristics, but still too coarse in resolution for our needs. See Appendix A for a comparison of the Shipman Typology and McBride Model. The fine scale substrate and vegetation characteristics of Puget Sound habitats have been classified by many, including Dethier et al (1990), Ritter et al. (1996), and the Washington Department of Natural Resources Shorezone mapping effort (Berry et al. 2000) using a combination of descriptors for beach sediment grain size, aquatic vegetation, and shoreline geology. Though detailed, these classification systems were not process based. We were looking to add power to descriptive classifications like Dethier’s by linking fine scale habitat characteristics to geomorphic processes that form those habitats. The conceptual framework of linking habitat conditions to the processes that form them has also been used to plan salmon recovery actions in freshwater (Beechie et al. 2003), and to describe nearshore and estuarine landscapes (Fresh 2006; Simenstad et al. 2006). The methods for developing the McBride Model relied on previous detailed mapping and shoreline classification and the landscape process based approach to habitat analysis.

Figure 1: Diagram of habitat forming processes and how land use disrupts processes and changes habitats.

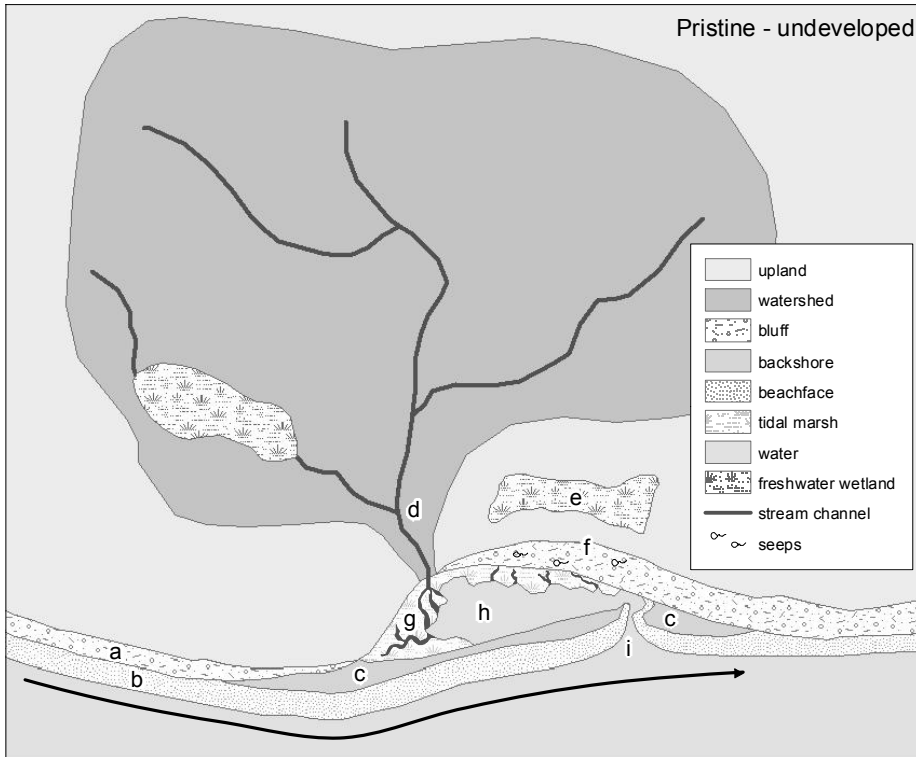


Figure 1a. Diagram of a drift cell and delta lagoon. Waves erode a vegetated sediment source bluff (a) inputting sediment to the beach and drift cell (b). Waves move beach sediment down drift (arrow indicates net drift direction) to depositional beaches (c). Wave deposition across creates spits (c) that enclose a lagoon (h). The adjacent watershed with small stream (d), wetland (e), and associated bluff seeps (f) contributes freshwater to the lagoon and creates delta distributaries (above g) and seep channels (below f). The lagoon is lower energy and less saline than adjacent marine waters. Tides moving in and out of the lagoon via the opening to the lagoon (i) have carved tidal channels (below g) and built up salt marsh within the lagoon.

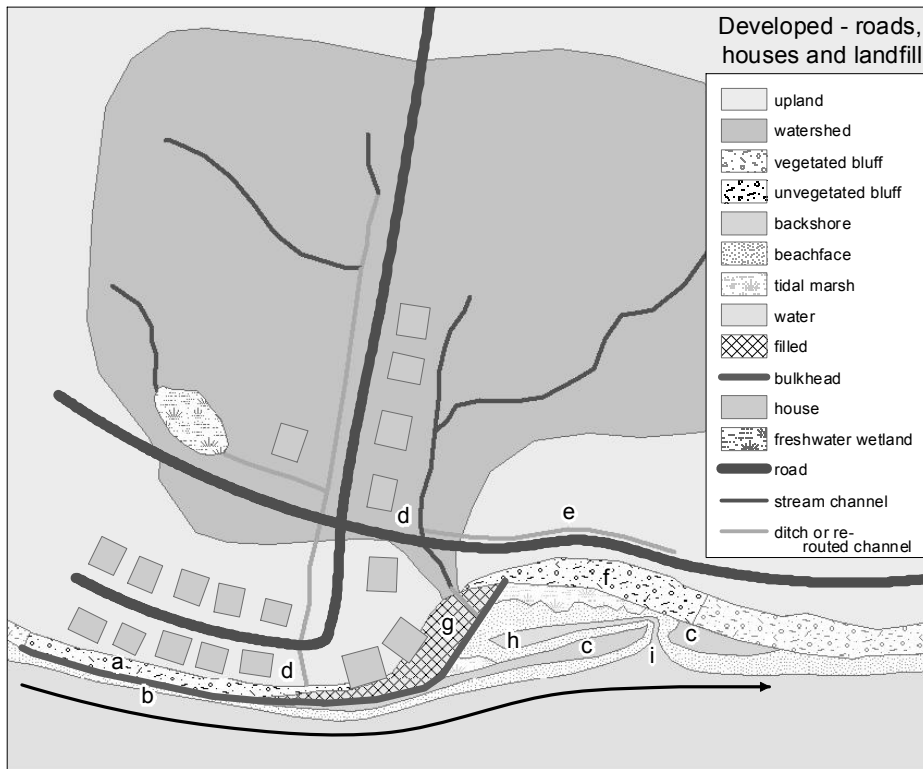


Figure 1b. Diagram of the drift cell after land use has disrupted natural processes. The vegetated bluff (a) has been cleared and is thus more prone to landslide. To prevent property loss, the toe of the bluff has been armored (b); preventing wave processes from recruiting bluff sediments to the beach. Thus the beach is shrinking, as are down drift beaches in the cell (c). Spit beaches may eventually disappear altogether, exposing the inner marsh habitat and stream mouth to higher wave energy and erosion. The stream (d) has been ditched and re-routed partially out of the lagoon (h). The wetland (e) has been drained and its associated seeps and channels have disappeared (f). Salinity in the lagoon has increased due to the loss of freshwater inputs and the hydrology has become more flashy. Part of the lagoon has been filled (g), decreasing the lagoon footprint and burying channel/marsh habitat. The stream mouth has been piped (g), eliminating former delta distributary channels. Because fill has decreased the lagoon footprint, the lagoon's tidal prism (h) and thus tide's power to carve and maintain a lagoon opening (i) is decreased. The channel will become narrower and shallower with time due to the smaller tidal prism. A shallower opening means less opportunity for fish to access the lagoon because it is wet over a narrower tidal range.

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Project History

A working draft of the model was completed in 2003 and used by SRSC to identify pocket estuaries within the Whidbey Basin in order to develop habitat restoration and protection plans for salmon recovery (Beamer et al. 2003, McBride et al. 2005, Beamer et al. 2005, SRSC & WDFW 2005). Following the initial test of the model, SRSC partnered with the Northwest Indian Fisheries Commission Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP) and the Point No Point Treat Council (PNPTC) to create a more mechanistic GIS mapping method and to test the model throughout Puget Sound. SSHIAP contributed to the development of the final theoretical model (Table 1) for classifying the nearshore.

SSHIAP's objective in mapping Puget Sound is to develop a comprehensive nearshore geomorphology dataset to support tribal priorities in salmonid habitat recovery, nearshore protection and restoration, review of shoreline management plans, as well as complement an existing SSHIAP freshwater/watersheds dataset. SSHIAP is building a dataset that can be related with various other datasets ranging from water quality and forage fish spawning locations to habitat conditions in the nearshore. SSHIAP developed the GIS mapping methodology to apply the theoretical model (Fitzpatrick 2007, Todd et al. 2009, Appendix B) and applied that method across all Washington State shorelines (Figure 2) according to the decision tree in Figure 3.

A second phase of collaboration was initiated by the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP), a partnership of the United States Army Corp of Engineers and the Washington State Department of Fish and Wildlife. PSNERP expressed an interest in using the dataset developed by SRSC and SSHIAP as part of their Puget Sound Nearshore Change Analysis. Through the PSNERP project SSHIAP checked and refined the first draft mapping product, developing it into a final product (Todd et al. 2009 in Appendix B).

Table 1: Geomorphic Classification of Puget Sound Shorelines. Field heading definitions follow on the next page.

<i>Shore Shape</i>	<i>Shoreline Material</i>	<i>Shoreline Topography</i>	<i>Dominant Process/es</i>	<i>Freshwater Input</i>	<i>Geomorphic Unit</i>	<i>Mid Scale Unit (Complex or Major River System)</i>
Embayments & Estuaries	nearshore +/- peat deposits	U-shaped valley	tidal erosion	unknown	Tidal Channel Marsh	Tidal Channel Marsh
	beach, nearshore and/or peat deposits	U-shaped valley + coastal landform seaward of area below MHHW	tidal erosion & wave deposition where tidal $\approx$ wave	unknown	Tidal Channel Lagoon	Tidal Channel Lagoon
	fluvial and nearshore deposits	v-shaped valley +/- nearshore and/or peat deposits	tidal erosion and fluvial deposition where tidal > fluvial	yes	Drowned Channel	Drowned Channel
	beach, fluvial, and nearshore deposits	v-shaped valley and nearshore deposits +/- peat deposits	tidal erosion wave deposition, and fluvial deposition where tidal $\approx$ wave and tidal > fluvial	yes or unknown	Drowned Channel Lagoon	Drowned Channel Lagoon
	fluvial +/- nearshore or peat deposits	Valley (U-shaped or V-shaped)	tidal erosion & fluvial deposition where tidal $\approx$ fluvial	yes or unknown	Tidal Delta	Tidal Delta
	fluvial + beach +/- nearshore or peat deposits	Valley and coastal landform seaward of area below MHHW	wave deposition, tidal erosion, fluvial deposition where tidal $\approx$ fluvial $\approx$ wave	yes or unknown	Tidal Delta Lagoon	Tidal Delta Lagoon
	fluvial deposits	V-shaped valley, fan shape in the intertidal and backshore	fluvial deposition where fluvial > wave and fluvial > tidal	yes or unknown	Delta	Delta
	fluvial + beach +/- nearshore or peat deposits	V-shaped valley, fan, and coastal landform seaward of area below MHHW	fluvial & wave deposition where fluvial $\approx$ wave	yes or unknown	Delta Lagoon	Delta Lagoon
	beach deposits, nearshore/marsh deposits	coastal landform seaward of area below MHHW, flat to steep upland	wave deposition and tidal erosion	unknown	Longshore Lagoon	Longshore Lagoon
	beach deposits, nearshore/marsh deposits	coastal landform seaward of area below MHHW, flat to steep upland	wave deposition with no tidal processes; marsh impoundment	yes, no, or unknown	Closed Lagoon/Marsh	Not Applicable
	cohesive or beach deposits +/- nearshore deposits, surrounded by bedrock	coastal landform seaward of area below MHHW, flat to steep upland	NAD; onshore wave erosion (no adjacent sediment source) + tidal erosion	yes, no, or unknown	Pocket Beach Lagoon	Not Applicable
	cohesive or beach deposits +/- upland peat deposits, surrounded by bedrock	flat to gentle	NAD; onshore wave erosion (no adjacent sediment source) without tidal erosion	yes, no, or unknown	Pocket Closed Lagoon/Marsh	Not Applicable
	cohesive, beach +/- fluvial deposits surrounded by bedrock	flat to gentle	NAD; onshore wave erosion (no adjacent sediment source); fluvial deposition +/- lagoon/marsh	yes	Pocket Beach Estuary	Not Applicable
Open Shoreline	cohesive or beach deposits surrounded by bedrock	Gentle to steep	NAD; onshore wave erosion (no adjacent sediment source)	no	Pocket Beach	Not Applicable
	fluvial deposits and/or beach deposits, or cohesive sediments +/- fluvial deposits	Gentle to steep	fluvial deposition (minor variation along a wave dominated shoreline)	yes	Beach Seep	Not Applicable
	cohesive sediments and beach deposits	Gentle to steep	wave deposition	no	Depositional Beach	Not Applicable
	cohesive sediments	Gentle to steep	wave erosion	no	Sediment Source Beach	Not Applicable
	beach deposits	coastal landform (spit, tombolo, cusp)	wave deposition	no	Barrier Beach	Not Applicable
	cohesive sediments	Gentle to steep	glacial remnant, no evidence of other processes, no beach development	no	Plunging Sediment Bluff ⁶	Not Applicable
	Bedrock	flat to gentle	NAD; little or no evidence of coastal or tidal erosion, no fluvial processes. no beach development	no	Rocky Shoreline	Not Applicable
	Bedrock	Steep	NAD; little or no evidence of coastal or tidal erosion, no fluvial processes. no beach development	no	Plunging Rocky Shoreline	Not Applicable
	bedrock + beach development	any slope	wave deposition or transport; evidence of beach development	no	Veneered Rock Platform	Not Applicable

Table 1 Definitions

The following definitions apply to Table 1 column headings:

- Shore Shape—embayments and estuaries that are partially enclosed or interfingering vs. open, straight shorelines.
- Shoreline Material—geologic material mapped along the shoreline and immediately upland from the shoreline classified by erodability (resistant, cohesive, and loose) and, in the case of loose sediments, by mode of deposition (beach deposits, fluvial deposits, marsh deposits).
- Shoreline Topography—shape and relief of the backshore zone classified as flat (slope <3 degrees), gentle (slope 3-7 degrees), or steep (slope >7 degrees). Slope was further classified into v-shaped valley or u-shaped valley as an indicator of process.
- Dominant Process/es—geomorphic processes acting (now or in the past) along a stretch of shoreline. Because geomorphic processes are not directly observable, these are identified using geologic signatures, hydrologic data layers, net shore drift data layers, and current and historic geomorphic signatures observable in maps and photos. (NAD in the table means areas of no appreciable drift.)
- Freshwater Input—mapped freshwater input to a segment of shoreline (yes or no). This field was not part of the geomorphic unit determination, but was used as supplemental information for determining dominant process.
- Geomorphic Unit—classification name applied to a segment of shoreline that is uniquely defined by the geomorphic processes acting there, and the geologic and topographic setting.
- Mid-scale Unit or Major River System—a Geomorphic Unit that contains smaller scale geomorphic units nested within it. The geomorphic unit types in this model occur at multiple and nested scales (Figure 5). The Mid-Scale Unit column of the table identifies the encompassing geomorphic unit. Major river estuaries are also mid scale features. River Estuaries are classified according to the same ternary continuum that applies to smaller estuaries. Smaller scale geomorphic units may be nested within these larger scale estuaries as well.

SSHIAP Shoreline Geomorphology: Puget Sound Sub-Basins and Outer Washington Coast

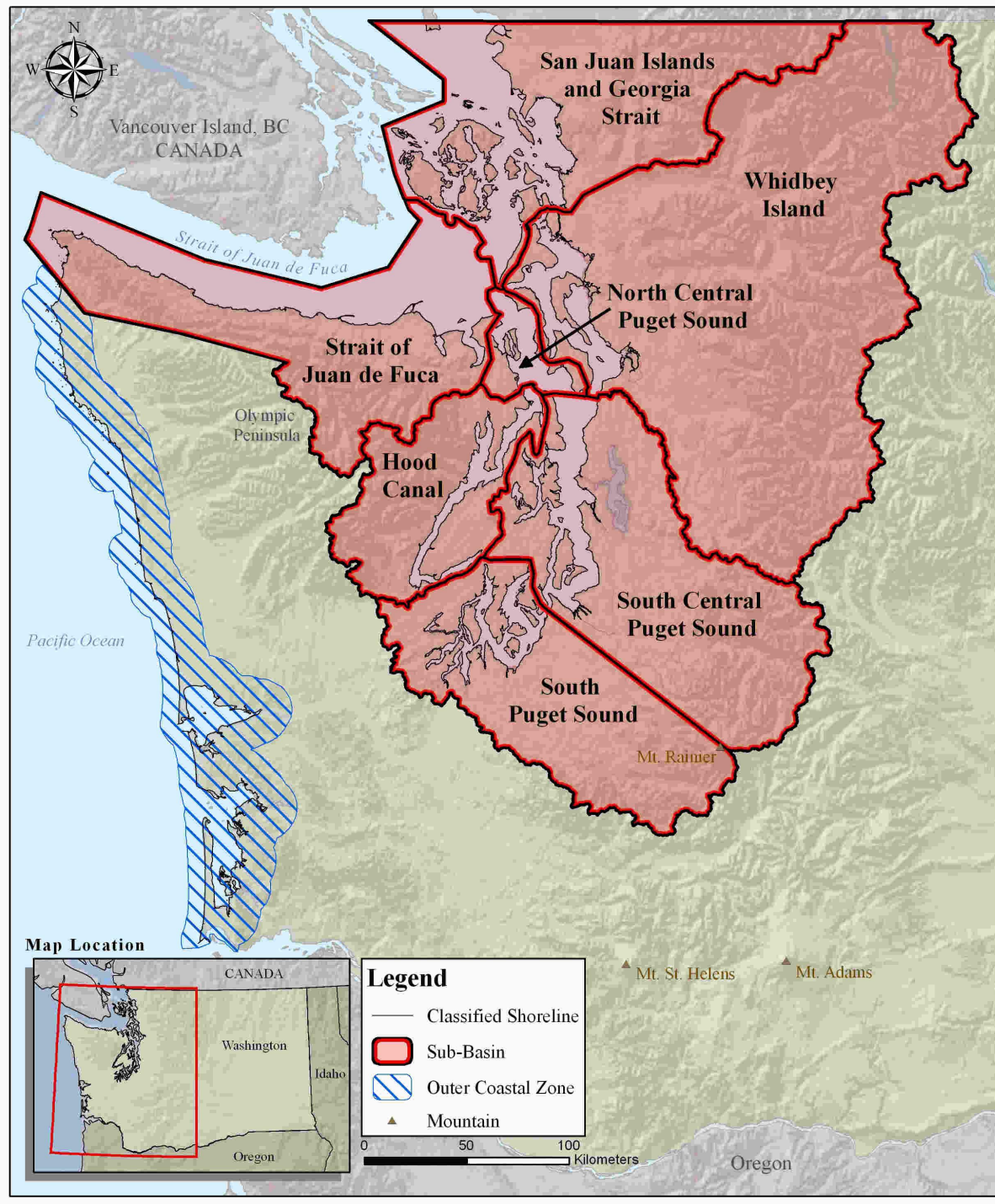


Figure 2: Shoreline geomorphology classified by SSHIAP in 2007-08 included the Puget Sound sub-basins and the outer Washington Coast to the mouth of the Columbia River estuary.

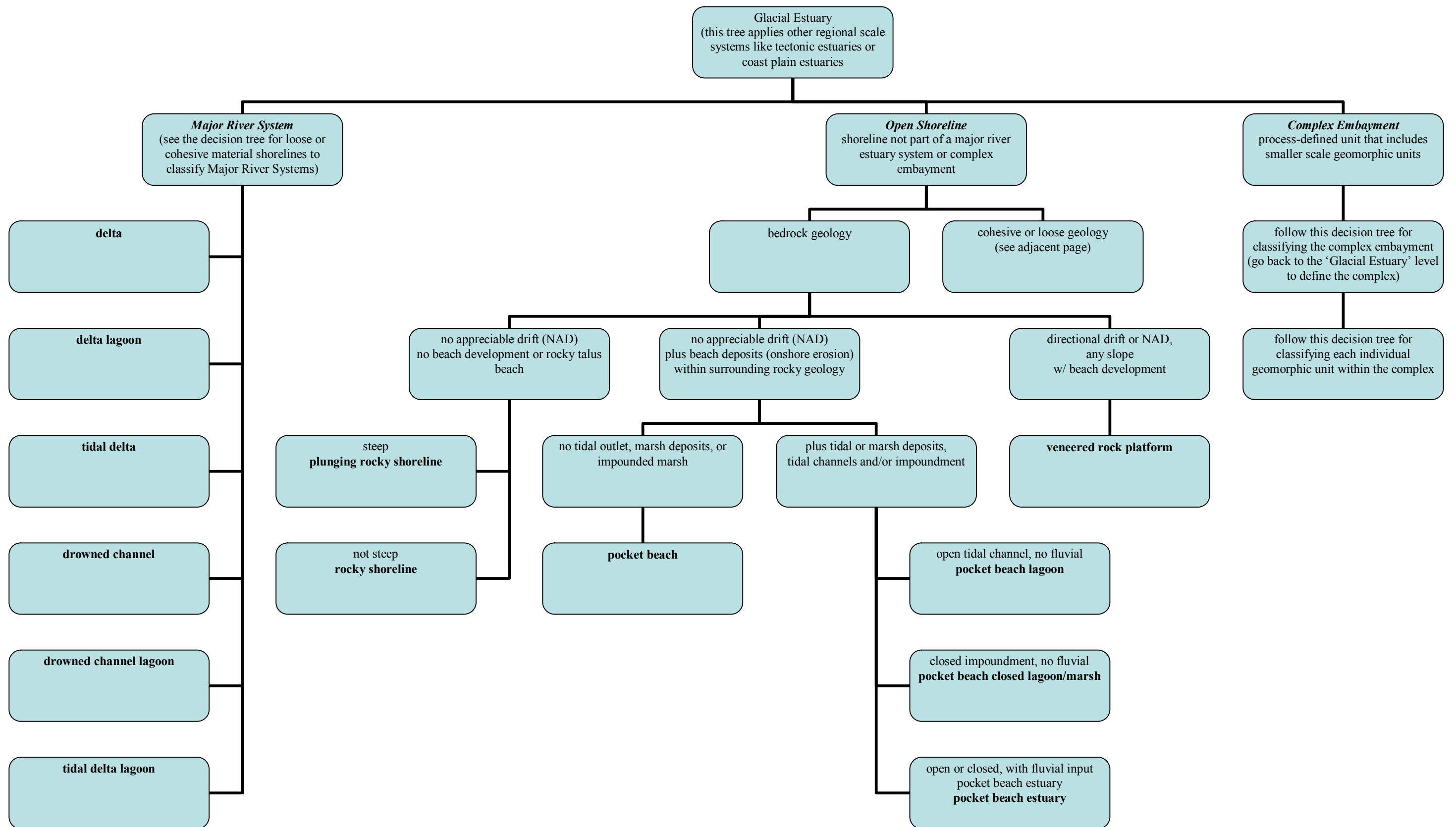


Figure 3: Decision diagram for classifying the Salish Sea nearshore into geomorphic units.

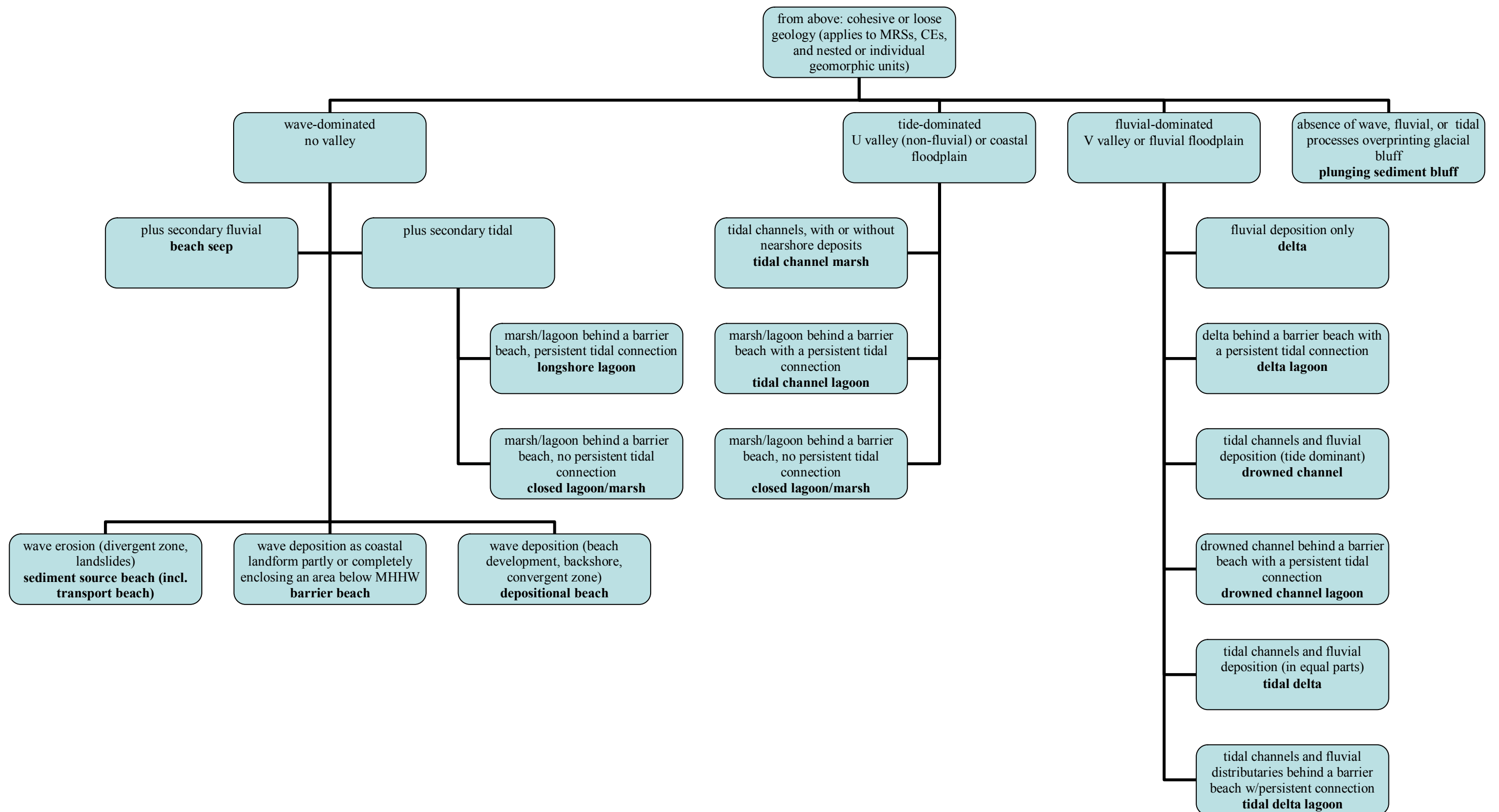


Figure 3 continued: Decision diagram for classifying the Salish Sea nearshore into geomorphic units.

Methods for Developing the Theoretical Model

The model for classifying nearshore habitats is $a + b + c = \text{geomorphic unit}$. Model variables were chosen after detailed field mapping showed up themes in habitat characteristics and landscape processes and structures. The variables used to describe the geomorphic scenarios are: *dominant process* as evidenced in fluvial, tidal, and coastal geomorphic signatures; *shoreline material*; and *shoreline topography*. Topography and geologic material define the geologic canvas upon which landscape processes act in the nearshore environment. The geologic canvas brackets what kinds of habitats the landscape processes may create.

Rationale for Choosing the Model Variables

The *shoreline material* variable reflects the susceptibility to erosion for a segment of shoreline. For example, wave erosion acting on a sediment bluff will result in beach development, whereas wave erosion acting on a bedrock shoreline will generally not result in beach development considering the relatively low energy environment of Puget Sound. This variable limits how landscape processes may shape the shoreline (i.e., waves and tides having little impact on resistant bedrock, waves carving the base of bluffs, or tides carving channels in loose sediments). The ‘Shoreline Material’ variable, when considered with topography, is a surrogate for the cumulative geologic history of a segment of shoreline upon which wave, tidal, and fluvial processes are acting.

Shoreline topography is a function of past regional scale processes (i.e., plate tectonics and glaciation). This landscape characteristic determines the width of the interface between upland and coastal processes. Different degrees of intermingling between coastal and upland processes create different geomorphic scenarios. For example, tidal channels and marshes are likely to develop along flat shorelines. Steep shorelines only develop tidal marshes when beach accretion creates flat topography below the bluff and then tidal processes encroach on the accretion landform. Shoreline topography is also a principal indicator of landscape processes. Coastal landforms can be identified by their low topography and shape, and fluvial processes can be identified by the v-shaped valleys they carve.

The *dominant process* variable refers to the local scale processes acting on a segment of shoreline. The dominant process or combination of processes acting on a segment of shoreline can be determined by geomorphic signatures of those processes (including topographic relief) and/or previously mapped longshore drift. These processes may be interfered with by anthropogenic change to the shoreline or upland. However, the climate, weather, shore orientation, aspect, fetch, geology, and hydrology that drive natural landscape processes persist. Determination of the dominant process may require investigating historic conditions in cases where anthropogenic change has obscured process signatures. Defining the dominant process variable for the model requires weighing interacting and overlapping processes that shape that landscape along a continuum (Figure 4).

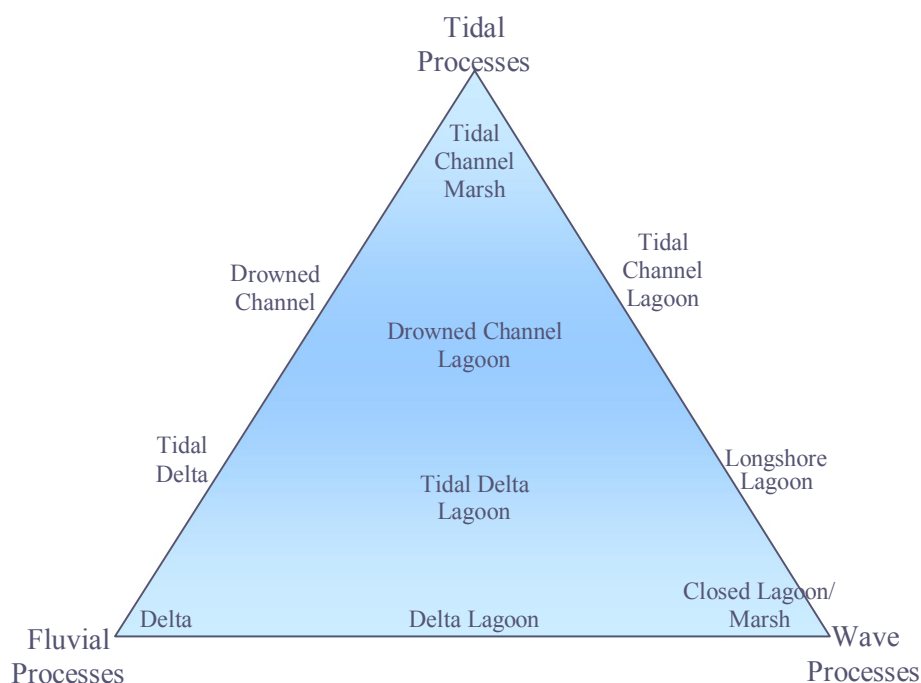
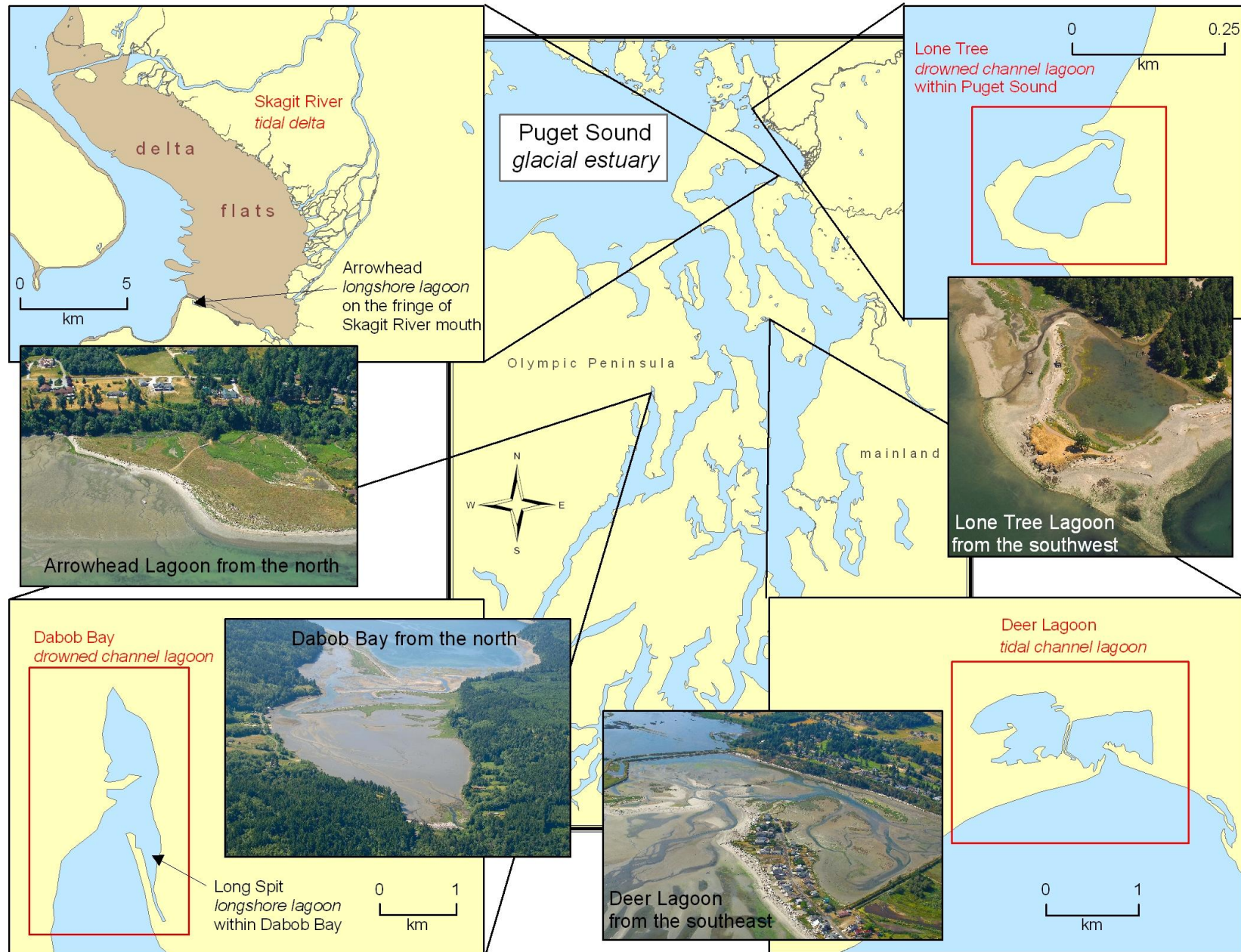


Figure 4: This diagram defines geomorphic units by the relative importance of fluvial, tidal, and wave processes. Processes interact along a continuum. Geomorphic unit names are ‘stopping points’ along the continuum. More or fewer divisions (stopping points) could have been chosen. We opted for the most commonly used estuary names and those commonly present in the Salish Sea. (After Galloway 1975)

Nested Scales

There are many cases in Puget Sound where geomorphic units are nested within larger scale geomorphic units and even nested again within the regional geomorphic unit (Figure 5). We term the mid-scale nested systems ‘*Complex Embayments*’. The classification model works (i.e., $a + b + c$ are almost exactly the same) at multiple scales (Figure 3). The same unit names apply at all three scales: regional scale (Puget Sound), mid-scale *Complex Embayments and Major River Systems*, and small scale geomorphic units (Figure 5). We classify nested geomorphic units because habitat conditions are impacted by processes at each of the overlapping scales. A large embayment crossed by a spit may contain smaller lagoons or streams. If the spit crossing the embayment is removed, the shoreline within the embayment will be exposed to more wave energy and habitats will change. Therefore the outer unit impacts the inner units. Some ambiguity exists in defining the threshold at which complex embayments are separated as discrete entities. For the purposes of this mapping effort, a landform that does not include any smaller scale units is not considered a complex embayment (i.e., if no other $a + b + c$ scenarios can be called out within the mid-scale lagoon, it is not called a complex embayment).

Figure 5: Nested scales of geomorphic units. The regional scale Puget Sound glacial estuary contains the mid scale Skagit Delta and mid scale complex embayment Dabob Bay. It also contains small scale Lone Tree Lagoon and Deer Lagoon. Skagit Bay includes the small scale unit Arrowhead Lagoon along the margins of the delta flats. Dabob Bay includes Long Spit and lagoon. Deer Lagoon is similar in size to Dabob Bay, but is not a complex because it does not contain any overprinting geomorphic signatures within the lagoon. Note different map scales.



Model Limitations

The landscape is continuously evolving in response to natural forces. Characterizing the Puget Sound nearshore environments based on geomorphic processes requires identifying active physical forces that can often only be observed by the ‘signatures’ they leave on the landscape. These signatures have an inherent time scale and spatial scale resolution. Also, the nearly unlimited variability of shoreline geology and geomorphology at the small scale means our geologic calls are only a general summary of reality. These limitations determine our mapping resolution.

Temporal Resolution

The process signature we observe in the landscape is a snapshot in time—past time. We observe the results of landscape processes that have already acted on the shoreline. We are looking at the recent past (decades to centuries) and assuming it is the present and will be the near-term future. In basing a habitat characterization on this observable snapshot, we are assuming that the processes that left their signature on the landscape most recently are the same processes that continue to act and form habitats in the nearshore. This assumption could be wrong, especially with respect to sea level changes. However, the orientation of the shoreline relative to prevailing winds (and thus wave processes) is unlikely to have changed over a time scale of the last few thousand years and is likely to remain unchanged into the future centuries. We can observe freshwater inputs active in the present and safely assume they will remain active barring strange circumstances (like a road rerouting the stream into a storm ditch that drains outside the watershed). We need to account for sea level rise and climate change, but otherwise we can assume the past is the key to the future. This gives us enough confidence in the snapshot being meaningful for restoration in practical terms (i.e., there will be measurable ecological benefit for many decades). We can therefore estimate the temporal resolution to be about 100 years. Obviously this is somewhat arbitrary.

Spatial Resolution

The geomorphic model uses imperfect datasets as inputs: resolution varies from one data set to another, inputs contain inaccuracies, and varying degrees of accuracy across a data set. The model outputs inherit all the imperfections in the input datasets. We attempt to address the input dataset problems and the inconsistencies within and between input datasets by cross checking with other datasets that can corroborate or modify our interpretation of the input data. Unfortunately the cross-check data sets were not available everywhere or were not usable as automated mapping inputs. The goal in this approach is to arrive at a more accurate output than any of the individual inputs, where the whole is greater than the sum of the parts. Based on field verification of the model at a few points, we think we have achieved this goal.

Results

Composition of Puget Sound Shoreline and its Sub-Basins

Results of the SSHIAP geomorphic mapping are presented for Puget Sound and individual sub-basins in Table 3 and in Figures 6 through 8.

The most common geomorphic unit type across the Puget Sound region was *sediment source beach* (24.6% of the units), followed by *plunging rocky shoreline* (15.4% of the units) (Table 3). Interestingly, *plunging rocky shoreline* was prevalent in just two (San Juan and Strait of Juan de Fuca) of the seven Puget Sound sub-basins. By far the most common “offline” geomorphic unit types were *longshore lagoon* (105 units) and *closed lagoon/marsh* (71 units). The most rare geomorphic unit type was the *plunging sediment bluff* (9 units).

Table 3: Summary of occurrence of geomorphic unit types and offline unit types for Puget Sound shorelines.

Geomorphic Unit Type	Number of Units	Percent of Shoreline Composition*	Number of Offline Units	Percent of Offline Shoreline Composition*
<i>Sediment Source Beach</i>	1,193	24.64	0	0
<i>Plunging Rocky Shoreline</i>	746	15.41	0	0
<i>Barrier Beach</i>	596	12.31	4	2.02
<i>Depositional Beach</i>	458	9.46	0	0
<i>Pocket Beach</i>	302	6.24	0	0
<i>Delta</i>	261	5.39	0	0
<i>Rocky Shoreline</i>	222	4.58	0	0
<i>Veneered Rock Platform</i>	219	4.52	0	0
<i>Modified/Artificial</i>	147	3.04	0	0
<i>Beach Seep</i>	109	2.25	0	0
<i>Drowned Channel Lagoon</i>	107	2.21	9	4.55
<i>Longshore Lagoon</i>	95	1.96	105	53.03
<i>Drowned Channel</i>	92	1.90	2	1.01
<i>Delta Lagoon</i>	79	1.63	2	1.01
<i>Tidal Delta</i>	50	1.03	0	0
<i>Tidal Channel Lagoon</i>	40	0.83	2	1.01
<i>Pocket Beach Estuary</i>	27	0.56	0	0
<i>Tidal Delta Lagoon</i>	25	0.52	3	1.52
<i>Tidal Channel Marsh</i>	24	0.50	0	0
<i>Pocket Beach Lagoon</i>	21	0.43	0	0
<i>Pocket Closed Lagoon/Marsh</i>	16	0.33	0	0
<i>Plunging Sediment Bluff</i>	9	0.19	0	0
<i>Closed Lagoon/Marsh</i>	4	0.08	71	35.86

*By occurrence, not length.

The relative occurrence of geomorphic unit types is fairly consistent with the overall composition (in length) of the shorelines by geomorphic class (Figure 7), geomorphic unit types (Figure 7), and offline unit types (Figure 8).

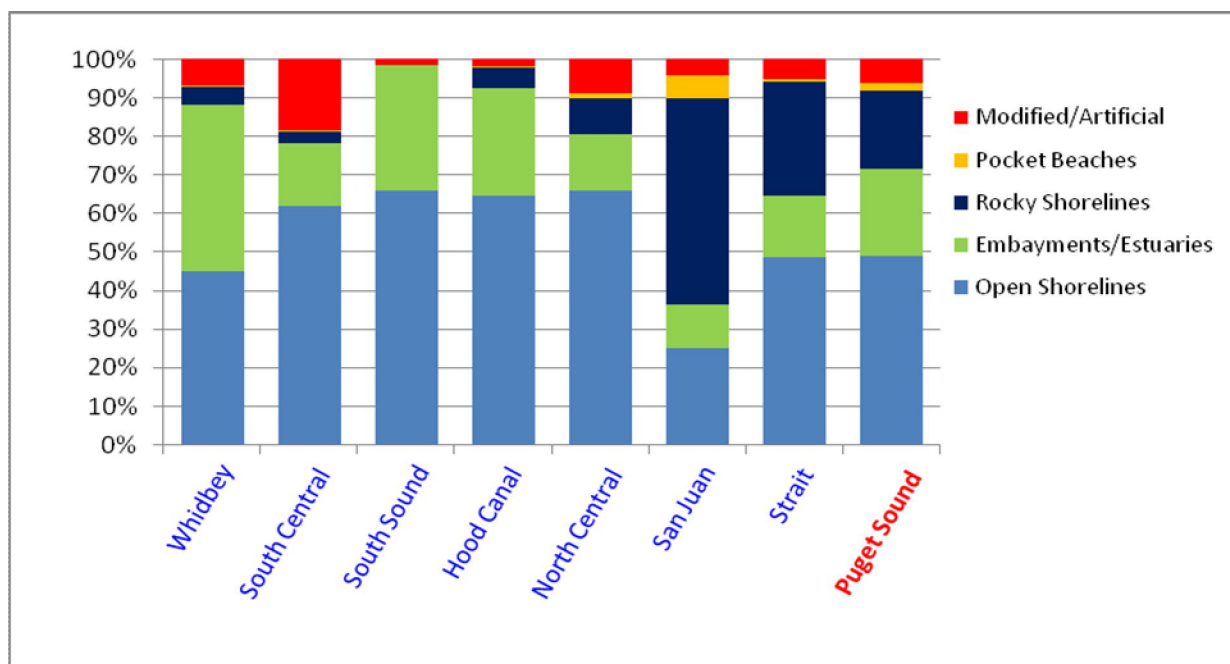


Figure 6: Geomorphic class composition of Puget Sound and individual sub-basin shorelines, by percentage of shoreline length. Note: geomorphic classes are not exactly the same as shore shape as depicted in Table 1. The embayment/estuary class may be under-represented by this graphic because “offline” feature lengths are not included, and most “offline” features are of the embayment/estuary class (e.g., *closed lagoon/marsh* geomorphic units) (see Mapping Methodology in Appendix for description of “offline” feature).

Puget Sound-wide, Open Shorelines (which comprise the geomorphic unit types: *sediment source beach*, *depositional beach*, *barrier beach*, *beach seep*, and *plunging sediment bluff*) make up about half (49%) of the shoreline length. Embayments and Estuaries (which comprise the geomorphic unit types: *tidal channel marsh*, *tidal channel lagoon*, *drowned channel*, *drowned channel lagoon*, *tidal delta*, *tidal delta lagoon*, *delta*, *delta lagoon*, *longshore lagoon*, and *closed lagoon/marsh*) occupy 22.6% of the Puget Sound shoreline. Rocky Shorelines (which comprise the geomorphic unit types: *rocky shoreline*, *plunging rocky shoreline*, and *veneered rock platform*) occur along 20% of the shoreline length. Pocket Beaches (which comprise the geomorphic unit types: *pocket beach*, *pocket beach estuary*, *pocket beach lagoon*, and *pocket closed lagoon/marsh*) make up just 1.9% of the shoreline. Modified/Artificial (M/A) shorelines occur along 6.4% of the Puget Sound shoreline. Recall that M/A is not a geomorphic class but rather a category that captures any shoreline area that has been so heavily modified so as to obscure its original geomorphology, or a completely artificial structure such as a jetty. We did not identify a section of shoreline as M/A if we could determine what the geomorphic unit type was historically, using the input datasets and air photos.

The Puget Sound sub-basin that most closely resembles the overall composition of Puget Sound shorelines is the Strait of Juan de Fuca sub-basin, which is located along the most northwestern part of the Puget Sound region (Figure 2). The sub-basins that compositionally depart most from the Puget Sound region as a whole are the San Juan and the South Sound sub-basins, though these two sub-basins could scarcely be more different from each other in many ways. The San Juan sub-basin is made up primarily of Rocky Shorelines (53.3%), followed by Open Shorelines

(25.3%), Embayments/Estuaries (11.2%), Pocket Beaches (5.9%), and Modified/Artificial (4.3%). The South Sound sub-basin has no Rocky Shorelines or Pocket Beaches, and Modified/Artificial shorelines comprise less of the sub-basin (1.6%) than any other sub-basin. Open Shorelines make up 65.8% and Embayments/Estuaries 32.7% of the South Sound sub-basin shoreline.

The composition of shoreline geomorphology across the Puget Sound region is shown in Figure 7. *Sediment source beaches* make up more (34.8%) of the Puget Sound shoreline length than any other geomorphic unit type, followed by *plunging rocky shorelines* (15.3%), and *barrier beaches* (9%), which are geomorphic types typically associated with wetlands that occur landward of the barrier or spit. The geomorphic unit types that are influenced by fluvial processes (i.e., *delta*, *tidal delta*, and *drowned channel* (and their respective lagoon variations, e.g., *delta lagoon*) in combination comprise 19.1% of the Puget Sound shoreline length.

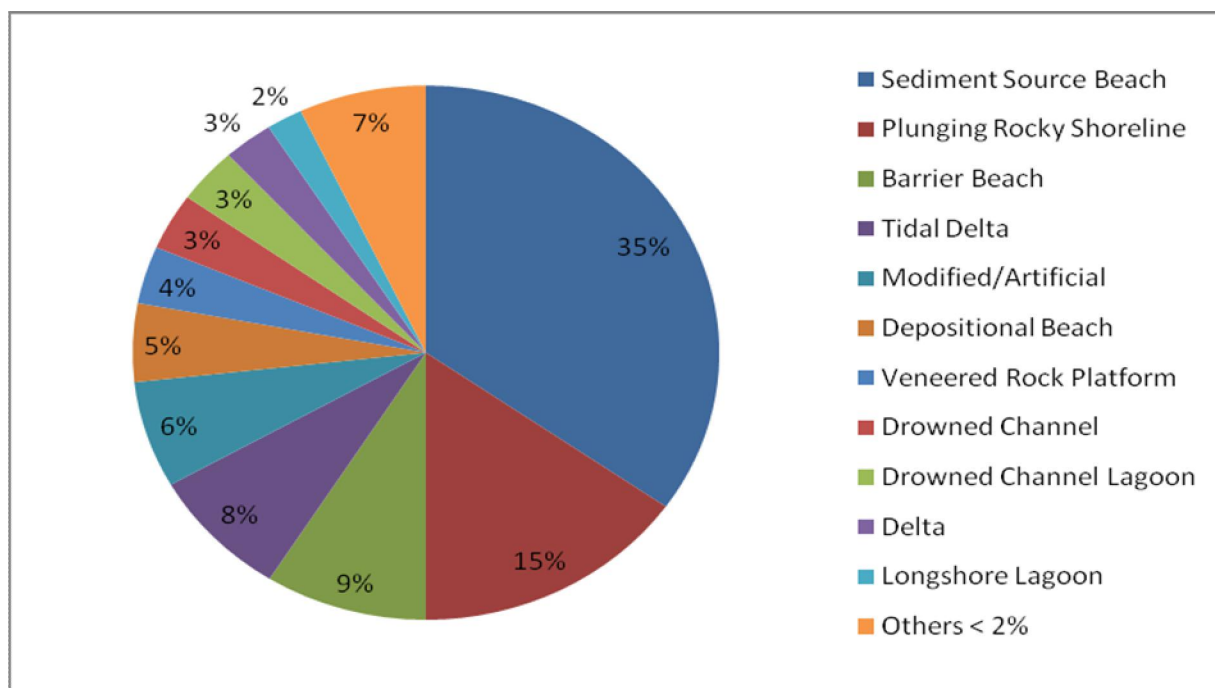


Figure 7: Geomorphic unit composition of Puget Sound, by percentage of shoreline length. These lengths do not include “offline” features such as *closed lagoon/marsh* units, which would be under-represented by this graphic.

“Offline” Geomorphic Features

“Offline” geomorphic units are features that were not spatially represented by the shoreline GIS line-work, as depicted by the WDNR Shorezone, but they were of interest to map primarily because of their potential ecological importance (e.g., presence of wetlands). The vast majority of these offline features occur immediately landward of the shoreline, which in the case of offline features, the shoreline itself is often represented as a *barrier beach* geomorphic unit type. Though we did not have a shoreline to attribute as “offline”, we did identify which specific shoreline units have associated offline features, and the type of offline geomorphic unit. *Longshore lagoons* made up 46% and *closed lagoon/marsh* 45% of the length of offline geomorphic units (Figure 8).

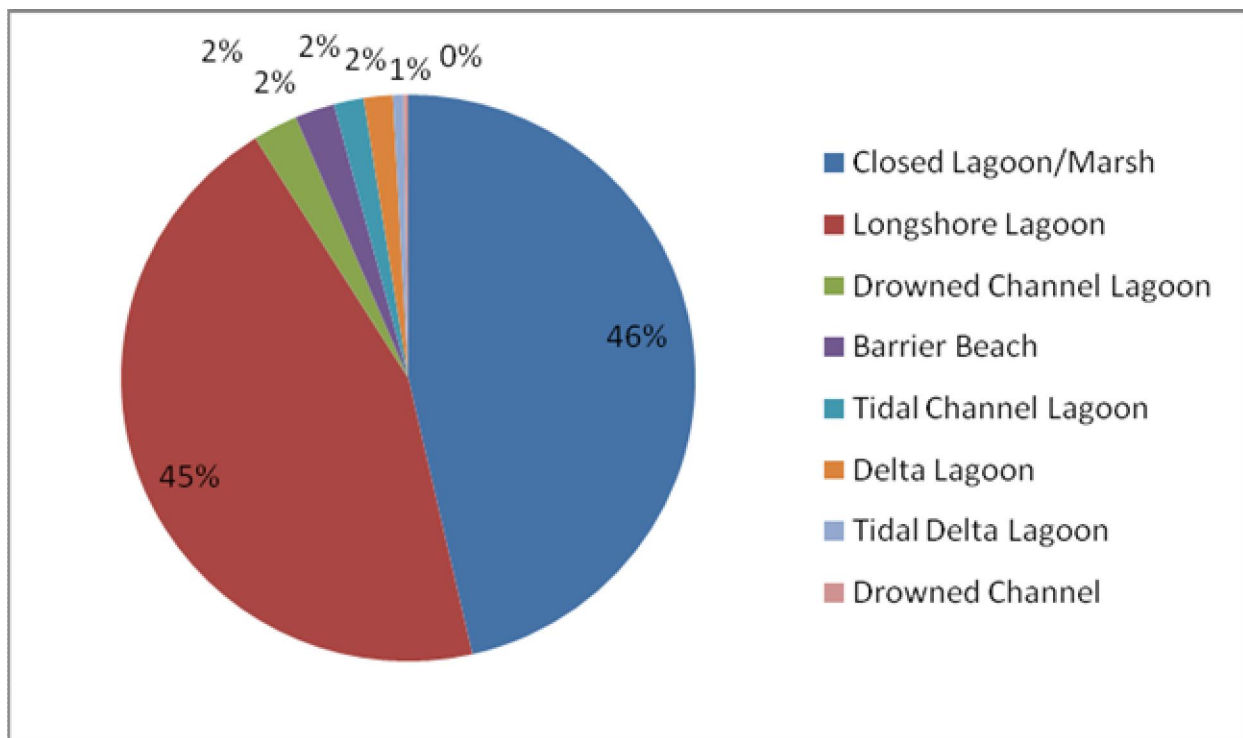


Figure 8: Composition of geomorphic units that occur “offline” of the WDNR Shorezone shoreline for Puget Sound shorelines, by percentage of offline shoreline length. Note: the lengths are not of the offline feature, rather the geomorphic unit associated with the offline feature.

Discussion

Developing this model for shoreline classification has applications for ecosystem based nearshore habitat restoration and for further refinement of habitat classification systems.

Considerations for Future Mapping

As SSHIAP looks ahead to refining the Puget Sound and outer Washington Coast geomorphic mapping in future phases, several lessons learned from the QA/QC mapping effort can be applied with the primary intent to increase the accuracy and repeatability of the mapping as new information is gained and methodologies are improved.

Polygonal Representation of Geomorphic Units

The current SSHIAP geomorphic dataset includes only linear representation of the shoreline, which is useful in making comparisons across sub-basins and the Puget Sound region as a whole, but lacks the dimension to more fully assess the relationships among various nearshore datasets. A polygonal representation of geomorphic features, particularly in the Embayment/Estuary geomorphic unit types, would not only provide a more accurate spatial representation of these features, but polygons would allow one to nest various habitat-related or biological components within the polygons. We could then evaluate relationships among land use patterns and shoreline stressors (e.g., area of fill or diked wetland) and the status and trends in habitat and other environmental parameters (e.g., locations of forage fish spawning, eelgrass beds, water

temperature). SSHIAP will therefore develop polygons in addition to the existing line-work to represent the geomorphic units, with a priority for the Embayment/Estuary geomorphic types.

Complex Embayments

The purpose of delineating Complex Embayments (larger scale geomorphic units that house multiple geomorphic unit types) is to recognize the importance in understanding physical processes acting across different spatial scales. This is particularly relevant when one is considering habitat restoration and protection alternatives. The method used to identify where Complex Embayments occur and the type of complex present was subject to more interpretation than other aspects of the geomorphic mapping methodology. In considering future mapping, SSHIAP, ideally working with Aundrea McBride of SRSC, will need to develop a more rigorous and repeatable means of identifying the Complex Embayments.

Stream Inputs

Considerable interest among researchers and restoration practitioners lies in better understanding, protecting, and restoring the numerous small streams and estuaries that empty into Puget Sound waters. Some of this interest is aimed at not just the stream input itself but in knowing how streams and other freshwater inputs (including groundwater seeps) might influence the ecological processes, structures, and functions along the nearshore. In future geomorphic mapping, SSHIAP will likely employ a “multiple lines of evidence” approach to more accurately and precisely identify the location of small stream inputs along the Puget Sound and outer Washington Coast shorelines. This approach will involve the integrated use of all input datasets used in the QA/QC methods, including the best available geology, topography, and hydrography GIS datasets, as well as air photos and field verification.

Revisiting Heavily Modified Shorelines

SSHIAP will consider revisiting the shorelines that are most heavily modified by human development. Many of these were identified as Modified/Artificial (M/A), while others were once tidally accessible and are now closed off by a road, dike or fill. We often made special notes of these locations and it would be valuable to be able to more accurately and systematically describe what is likely responsible for modifying and often fundamentally changing these parts of the shoreline. Other datasets (e.g., tidal barriers, fill, etc.) might aid in this effort.

GIS Representation of “Offline” Geomorphic Features

We devised the “offline” geomorphic unit because the WDNr Shorezone shoreline that was used as the base layer for our mapping lacked any spatial representation of these offline features though we felt they were important geomorphic features along the nearshore. It would be of interest to SSHIAP, and an advantage to data users, to revisit these offline geomorphic units and digitize their actual presence. Perhaps a re-visit of the delineation of the shoreline on a regional scale (i.e., Puget Sound or all of Western Washington) could help in identifying many or most of these “offline” features. We make a call below for a revised delineation of the shoreline on a regional or Statewide basis.

Improved GIS Representation of the “Shoreline”

SSHIAP used the WDNr Shorezone “shoreline” as the base layer for mapping shoreline geomorphology in Puget Sound. Though the Shorezone shoreline is generally accepted across

the region and was typically adequate for our mapping purposes, we did encounter instances where a more spatially accurate representation of the shoreline might have provided a better quality product. For example, we used the Shorezone shoreline as the reference point for determining the upland topography immediately adjacent to the shoreline. Therefore, when this shoreline was inaccurately depicted, i.e., either seaward or landward of its actual location, it potentially resulted in an incorrect determination of topography, which could have led to incorrect identification of geomorphic types. Recall that topography was one of the primary data inputs used in the mapping. With our use of air photo verification in the QA/QC methodology, it is believed that we identified and corrected the vast majority of these potential errors in topography, errors that were rooted in an inaccurate representation of the shoreline. Another example of how a potentially inaccurate shoreline affected the geomorphic mapping is related to the identification of offline features. In some instances, the Shorezone shoreline simply “missed” a spit (common in South Puget Sound where spits tend to be lower in elevation than in more wave exposed parts of Puget Sound, such as the Strait or Whidbey sub-basins) or the shoreline failed capture the presence of a tidal lagoon (e.g., *longshore lagoon*) that was of interest in the mapping. We dealt with these circumstances by employing the “offline” feature. As mentioned above, SSHIAP has an interest in being able to map the offline features and potentially habitat and other components that make up an offline feature.

SSHIAP would like to take this opportunity to appeal to the PSNERP and Puget Sound Partnership for an updated and improved GIS data layer that represents the Puget Sound and outer Washington Coast “shoreline”. This shoreline might represent the mean higher high water (MHHW) or the ordinary high water (OHW) line, or another “line” that has ecological significance.

Model Applications

By linking geomorphic types to biota and examining the landscape scale distribution of geomorphic units, we can understand ecological impacts and habitat protection and restoration priorities for the biota of concern. SRSC has used the model to describe historical changes in pocket estuary abundance and distribution within the Whidbey sub-basin of Puget Sound and to evaluate the implications of changes for juvenile Chinook salmon (Beamer et al. 2005). Pocket estuaries are a subset of the geomorphic types. They are embayments at stream valley mouths, lagoons behind spits, and stream channel mouths, including the following geomorphic units: tidal channel marsh, tidal channel lagoon, drowned channel, drowned channel lagoon, tidal delta, tidal delta lagoon, delta, delta lagoon, longshore lagoon, pocket beach lagoon, pocket beach estuary, and beach seep. Juvenile Chinook salmon use pocket estuaries as predation refuges and feeding sites during their migration from larger natal streams and deltas to the ocean (Beamer et al. 2003).

We identified 107 historical and current pocket estuaries within the Whidbey Basin using the model (Figure 10). Field reconnaissance, geologic and topographic map data, historical maps, and remote sensing by current and historic air photo interpretation were used to verify the modeled pocket estuaries. Approximately 68% of the pocket estuaries mapped are no longer accessible to fish (completely filled in or diked off). Most of the remaining sites have been partially modified by dredging, filling, shoreline hardening, and diking.

The complete loss of many individual pocket estuaries within the Whidbey Basin has also further fragmented these habitats, decreasing the opportunity for juvenile salmon and other fish to find pocket estuaries during their nearshore migrations. Juvenile Chinook salmon leaving their natal rivers (The Skagit, Stillaguamish, and Snohomish rivers are within the Whidbey Basin) must now travel farther to reach a pocket estuary. The number of pocket estuaries within 10 km of the Skagit and Stillaguamish River mouths (the two largest salmon-bearing rivers in the basin) has declined by 50% and 77%, respectively. Likewise the average distance between pocket estuaries has increased 70% from 1.8 km historically to 3.9 km today. This habitat loss and fragmentation has likely had significant impacts on juvenile Chinook salmon migration success and on other nearshore fish using these habitats. Similar types of analyses can make use of model results. Additionally, power can be added to model results by establishing finer scale correlations between habitat conditions and geomorphic types. This work is underway.

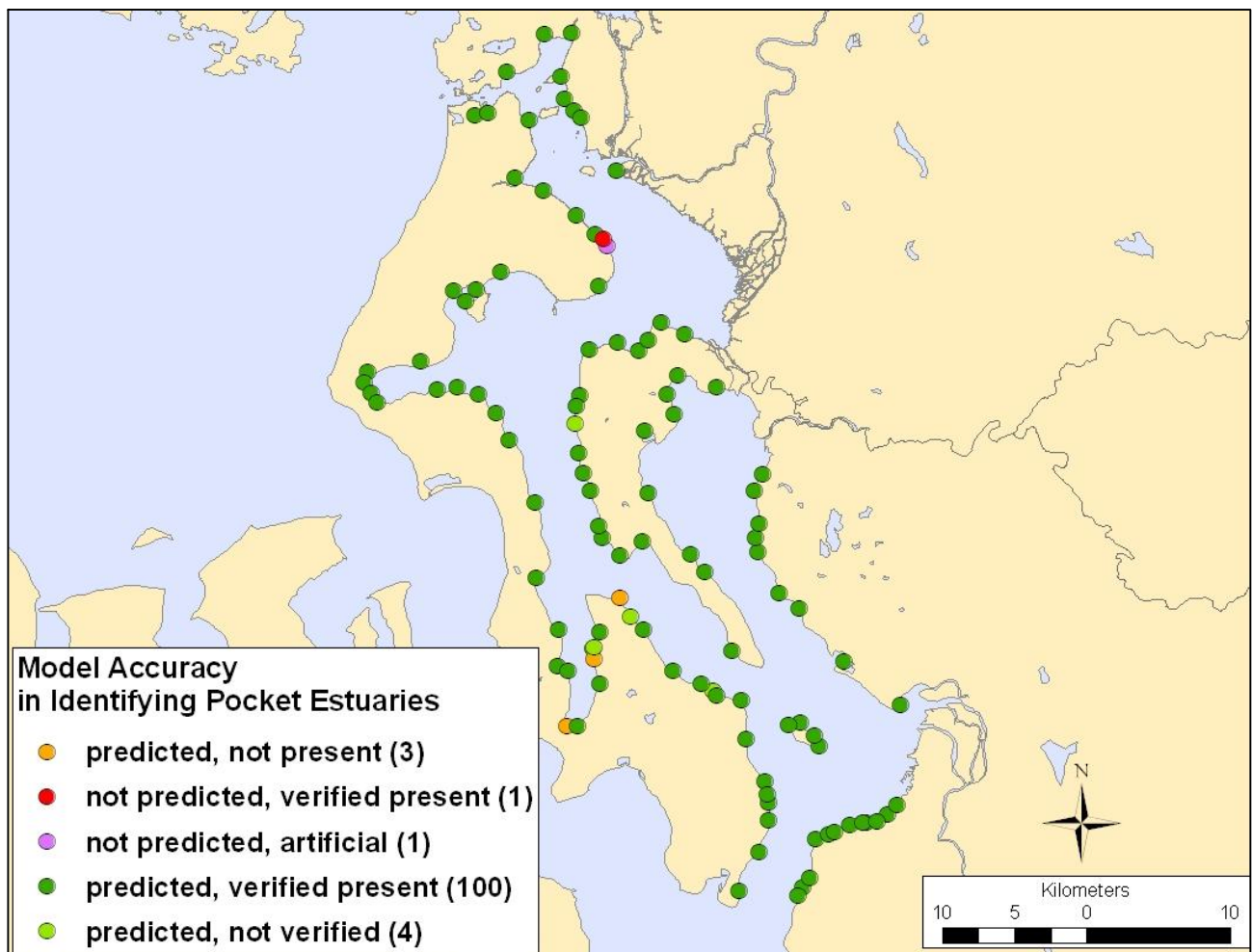


Figure 9: Model accuracy in predicting the location of pocket estuaries. 80% of these sites have been field checked. One site was artificially created and thus not detected by the model.

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Appendix A:

Crosswalk between Shipman Typology (Shipman 2008) and McBride Model.

Shipman Typology Classes	McBride Model Classes	Shipman Typology Shoreform	McBride Model Geomorphic Units
Rocky Shores/Bedrock	Open Shorelines	Plunging	Plunging rocky shoreline
		Platform and ramp	Rocky shoreline
			Veneered rock platform
	Embayments	Pocket beach and barriers	Pocket beach
			Pocket beach lagoon
			Pocket closed lagoon and marsh
			Pocket beach estuary
Beaches	Open Shorelines	Bluff-backed beaches	Depositional beach
			Sediment source beach
		Barrier beaches	Barrier beach
		not specified	Plunging sediment bluff (no beach)
		not specified	Beech seep
Estuaries and deltas	Embayments	Open coastal inlet	these are divided into geomorphic units (below) and nested sub-units as applicable
		Barrier estuary	Delta lagoon
			Tidal delta lagoon
			Drowned channel lagoon
		Barrier lagoon	Longshore lagoon
			Tidal channel lagoon
		Closed lagoon and marsh	Closed lagoon and marsh
		River dominated delta	Tidal delta
		Fan delta	Delta
		Wave dominated delta	Delta lagoon (duplicated)
		Tide dominated delta	Drowned channel
		not specified	Tidal channel marsh

Appendix B

Quality assurance methodology for mapping marine shoreline geomorphology

SALMON AND STEELHEAD HABITAT INVENTORY AND ASSESSMENT PROGRAM

QUALITY ASSURANCE METHODOLOGY FOR MAPPING MARINE SHORELINE GEOMORPHOLOGY

Updated: February 19, 2009

Prepared by: Steve Todd, Point No Point Treaty Council
Osa Odum and Marilu Koschak, Northwest Indian Fisheries Commission
Aundrea McBride, Skagit River System Cooperative

Background

The Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP) developed and applied a methodology (Fitzpatrick 2007) for mapping marine shoreline geomorphology in a GIS according to a model developed by McBride (McBride et al. 2005). Following completion of an initial draft dataset for all of Puget Sound and outer Washington coastal shorelines, SSHIAP collaborated with McBride and others to complete a quality assurance (QA) mapping phase of the initial draft, incorporating air photo verification and supplemental datasets not used in the initial draft. In addition to incorporating additional input data to support the QA phase, we revised some of the mapping rules applied in the initial draft and in the way geomorphic units are hierarchically organized (see Table 1 in the Appendix for a comparison of pre- and post-QA geomorphic unit types). This document focuses on the revisions to mapping methodology and how data inputs were applied in the mapping process.

The main intent of the QA mapping phase was to produce a “current day” shoreline geomorphology dataset for the Puget Sound region that would complement a “historic” geomorphology/typology dataset being developed by the Puget Sound Nearshore Ecosystem Restoration Program (PSNERP) Nearshore Science Team (NST). It should be noted that in order to map current day geomorphology it was necessary to understand the historic characteristics of the shoreline (i.e., prior to significant human modification of the shoreline), as this historic information provides a basis for the current day geomorphology and it informs our understanding of the potential for nearshore restoration. This was the primary reason for including historical wetland datasets as supplementary information for this QA mapping phase. At a later time SSHIAP intends to employ these same QA methods to map geomorphology along the outer Washington Coast, which was not included in this QA mapping phase.

Input Datasets

The initial draft SSHIAP geomorphology mapping used WDNR 1:100,000 geology, 10 meter digital elevation model (DEM), Ecology drift cell, and WDNR 1:24,000 hydrography datasets to segment the existing WDNR ShoreZone line. This QA mapping protocol relied on a systematic evaluation of recently available air photos (Washington State Department of Ecology 2006-07 oblique air photos) and the incorporation of a revised drift cell dataset (Johannessen 2007) to verify and make corrections to the initial draft SSHIAP shoreline geomorphology. We also consulted finer scale WDNR 1:24,000 geology digital data where it was available and the 1970s Washington Coastal Atlas when the 100k geology was called into question. Where shorelines have been modified by human development, particularly in places where tidal wetlands have likely existed (i.e., in flat topographic settings), we consulted a digital dataset developed by the University of Washington River History Project [UWRHP] that represents historic and current tidal wetlands. Under some circumstances we also reviewed recent vertical color ortho-photos (National Agriculture Imagery Program [NAIP], 2006).

Mapping Organization and Scales

Since the initial SSHIAP geomorphology dataset was completed, we made some revisions to the way we organize and scale shoreline geomorphology landforms (See McBride et al. 2009).

Nested Scales

The revised QA geomorphic mapping includes a scaled hierarchical system for the mapping of shoreline segments where units are nested according to the following scales, moving from large to small scale with *italics* indicating the geomorphic unit type:

1. Regional (e.g., Puget Sound/Georgia Basin – *Glacial Estuary*)
2. Complex Embayment (e.g., Skagit River - *Tidal Delta*, within the *Glacial Estuary*)
3. Geomorphic Unit (e.g., Arrowhead Lagoon within Skagit River Complex Embayment that is, in turn, within the Puget Sound/Georgia Basin).

All geomorphic units (Scale 3), except for those along the outer Pacific Coast, are nested within the Regional scale (Scale 1) of Puget Sound/Georgia Basin, a *Glacial Estuary*. Within the Puget Sound/Georgia Basin, geomorphic units may also be nested within individual Complex Embayments (Scale 2). Most geomorphic units, and particularly those along open exposed shorelines, are not associated with any Complex Embayment (see Figure 1 in Appendix for examples of nested scales).

The initial draft SSHIAP geomorphology dataset included “Nearshore Cell” categories grouped into the following classes: Estuaries, Littoral Drift Cells, and Bedrock. The revised classification system generally replaces Estuaries with *Embayments/Estuaries*, Littoral Drift Cells with *Open Shorelines*, and Bedrock with *Rocky Shorelines*. A fourth class, *Pocket Beaches*, has been added (See Applied Table in the Appendix). Nested within each of these

Geomorphic Classes are the Geomorphic Unit Types. Glacial Estuaries and Tectonic Estuaries are all now considered types of Regional Scale Landforms.

Complex Embayments

A complex embayment is a process-defined unit that includes smaller scale geomorphic units as described in the Nested Scales section above. A complex embayment typically includes a spit that partially encloses the embayment, and a combination of shorelines with net shore drift (i.e., LtoR, RtoL, DZ) and shorelines of no appreciable drift (NAD), and possibly localized fluvial inputs occurring inside of the spit (see Figure 1 for example of complex embayment). Other complex embayments include the deltaic and estuarine portions of the larger river systems in Puget Sound. These are large enough systems to have localized processes occurring within a larger scale process context (e.g., wave deposition along the margins of a larger fluvial/tidal system such as in the Skagit tidal delta system).

Some ambiguity exists in defining the threshold at which complex embayments are separated as discrete units. For the purposes of this mapping effort, a mid-scale landform that does not include any small scale units will not be considered a complex embayment. For example, an embayment crossed by a spit that creates a lower energy environment behind the spit was considered a discrete complex embayment when it contains smaller scale units (e.g., deltas) as described above. When no overprinting small scale units were identified within the mid-scale landform at the mapping resolution, it was simply identified as a larger version of the geomorphic units (i.e., not a complex embayment). Other scenarios for calling out complex embayments were evaluated on a case-by-case basis to determine whether the structure of the mid-scale landform is truly creating a distinct environment.

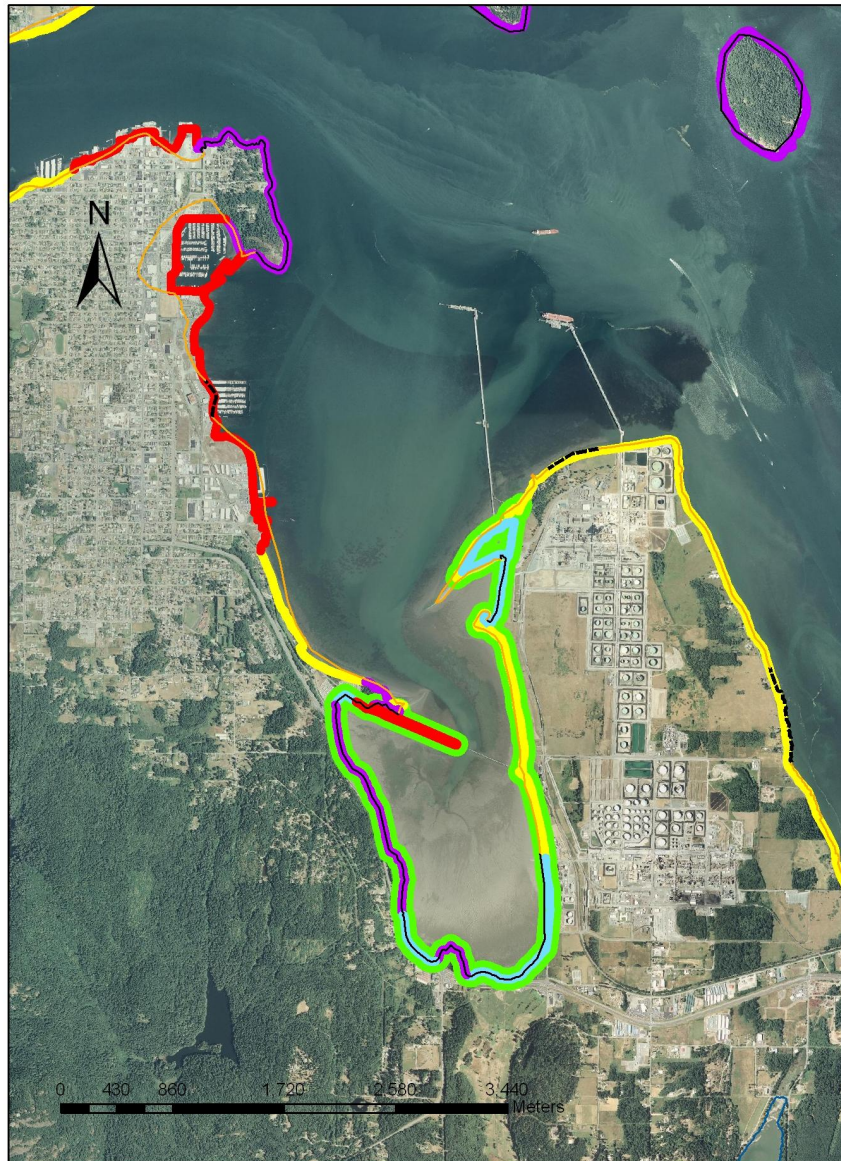


Figure 1. Fidalgo Bay, an example of a *tidal channel lagoon* Complex Embayment located in the San Juan sub-basin. The broad green-colored band of shoreline marks the extent of the complex. Different colors within the complex indicate the various geomorphic unit types, including sediment source, barrier beach, rocky shorelines, and tidal channel lagoon units. The narrowest colored lines indicate net shore drift (air photo is from NAIP 2006).

Mapping Rule Revisions

In addition to changes in the way the geomorphology mapping is hierarchically organized and nested, important revisions were made to the mapping rules since the initial SSHIAP geomorphology dataset was completed (See McBride et al. 2009). The following is a summary of these map rule revisions. Additional details are found later in this Mapping Methodology document.

- We used 2006-07 Ecology oblique air photos, updated drift cell dataset, and the UW River History Project (RHP) historical and current datasets, to strengthen and validate the SSHIAP initial draft geomorphology dataset (e.g., use of historic datasets and air photos allowed us to better distinguish *closed lagoon/marsh* from *longshore lagoon* geomorphic unit types).
- We added nine new geomorphic unit types (e.g., 4 pocket beach types, *closed lagoon/marsh*, etc.), deletion of *deepwater embayment*, revisions to geomorphic unit names (e.g., *spit beach* is now *barrier beach*), and changes in the criteria for some geomorphic unit types (See Table 1 in Appendix).
- We added a mid-scale unit, *complex embayment* (CE). A CE is a process-defined unit that includes smaller scale geomorphic units.
- We identified “offline” shoreline features that are not a part of the WDNR ShoreZone dataset that the SSHIAP shoreline geomorphology mapping is based upon. In this QA phase SSHIAP did not actually map these “offline” features, but identified where they occur and with which geomorphic unit the “offline” feature is associated (see example in Figure 5).
- We added a field in the GIS dataset that captures the presence or absence of freshwater inputs, either *yes*, *no*, or *unknown*.
- We classified lagoons as either *longshore lagoon* or *closed lagoon/marsh* depending on whether a surface tidal connection was identified in the input or supplemental datasets (e.g., RHP historic/current wetlands, T Sheets, air photos, etc.).
- We used a “modified” category (not a geomorphic unit type) to generally replace the “artificial” used in the SSHIAP initial draft geomorphology dataset. We restricted modified for shorelines that have been extensively filled and/or dredged and little/no indication of the historic geomorphology remains.
- We added a field in the GIS dataset that captures whether a geomorphic unit is modified by human development, either *yes* (presence of shoreline armoring, fill, dredging, many overwater structures, or removal of riparian vegetation, etc.) or *unknown* (absence of these structures/actions). This field is not to be confused with assigning a section of shoreline as “modified” (as described above) in the GeoUnitCode and GeoUnit fields.

Overview of QA Mapping/Editing Procedure

Before proceeding with the QA mapping process, we made a copy of the initial draft geomorph_line feature class, and then performed the QA using the copy version (e.g., “Whidbey_geomorph_lineQA”). In order to track the QA process in the GIS and document the basis for making revisions to the initial draft geomorphic classification, several new fields

were added to the “Whidbey_geomorph_lineQA” feature class within the SSHIAPMarine geodatabase (consult metadata for actual file names).

With all input and geomorphic datasets loaded and in the same data projection in ArcMap, we began the QA mapping process for a given geographical area (e.g., Whidbey sub-basin) by reviewing each mapped geomorphic unit (or groups of similar units) for geology, slope, and dominant processes to verify whether the appropriate material class, slope class, and dominant processes are represented in the geomorphic units. In addition, we applied the revised drift cell dataset and reviewed the UW River History Project (RHP) historic and current wetland datasets for these geomorphic units. To validate what we observed in these various datasets, we viewed the 2006-07 Ecology oblique air photos for each section along the shoreline. We made edits to the geomorph_lineQA according the Applied Table (see Final Report) and the Decision Diagram (see Final Report). To prevent accidental movement of the arcs during editing, we set the “sticky move tolerance” at 100 pixels.

Data Input Limitations

Geology

The 1:100,000 WDNR geology is the finest scale surface geology dataset available digitally across western Washington, but it has limitations and inconsistencies. Notably, the 100k geology fails to show locations of alluvium (Qa) associated with many deltas and other fluvial features that we are interested in mapping. Similarly, it does not show beach deposits (Qb) for many spits (*barrier beaches*) or Qp for many tidal marshes. Though somewhat less common, the 100k geology sometimes indicates Qa, Qb, or Qp, or other geologic types, in unlikely locations (e.g., Qa in steep topography and not associated with a valley, or Qb associated with steep bluff shorelines). Some of these inaccuracies stem from inconsistencies in mapping methodology from one geologist to another.

In order to identify these streams, *barrier beaches*, and marshes, we used other datasets, namely the topography and hydrography, and particularly the air photos. In highly impaired shorelines, we also consulted the historical T sheets. For example, even if the 100k geology fails to show a Qa indicative of a fluvial feature, the presence of flat (<3 degree) topography and a distinctive valley, a stream represented in the 1:24k hydrography, and a stream (particularly deltaic deposits) observable in the air photos is conclusive evidence of a fluvial feature (e.g., *delta*). Likewise, a *barrier beach* was sometimes not evident in the 100k geology. However, flat topography and the observation of a spit feature in the air photos is adequate evidence to map the feature as a *barrier beach* (assuming that tidal wetland features are/or were historically present landward of the *barrier beach*, criteria that must be met to be identified as a *barrier beach*).

Topography

We used the 10m DEM to determine the upland slope immediately landward of the shoreline (represented by the WDNR ShoreZone line [SZ line]). Because we used the SZ line as the

reference line for determining upland slope, inaccuracies in the SZ line sometimes resulted in an inaccurate identification of slope during the initial draft of the geomorphic mapping (See ***Shoreline*** below). For example, if the SZ line was delineated seaward of its actual location (i.e., somewhere within the intertidal zone), then we may have incorrectly identified the slope of the beach rather than the adjacent upland. The 2006 NAIP ortho-photos and Ecology oblique air photos were used to help us identify and correct these potential sources of slope error that may have occurred in the initial draft SSHIAP mapping.

Dominant Processes

Wave Processes (Drift Cell):

There are some sections of the shoreline that are not mapped according to net shore drift, even in the newly revised drift cell dataset. Many of these are smaller lagoons and/or marshes located behind (i.e., landward of) spits and some are typically open to the tides (e.g., longshore lagoons), while others are normally closed to the tides (e.g., closed lagoon and marsh). For our purposes, these areas behind spits that are not mapped in the drift cell datasets were assumed to be areas of no appreciable drift (NAD), and they were treated as such.

Fluvial Processes (Hydrography):

Not all streams are identified in the 1:24,000 hydrography. Some additional streams were identified using air photos and where the topography indicates valleys and deltaic deposits (e.g., deltas, etc.). *Beach seeps* may or may not be identified in the 24k hydrography, and their identification was marked primarily by steeper upland (slope > 3 degrees) and by the presence of a stream input evidenced by deltaic deposits in the air photos. Valley development is usually less obvious with *beach seeps* than with *deltas* and other fluvial features.

Tidal Processes (Drift Cell):

Tidal erosion was typically identified by the presence of NAD in the revised drift cell dataset. Tidal erosion was also recognized in the air photos by the presence of tidal channels, particularly those that are not of fluvial origin.

Shoreline

We used the WDNR ShoreZone shoreline (SZ line) to represent the line used for segmenting the shoreline into individual geomorphic units. There are instances where the SZ line is not spatially accurate (e.g., the line occurs somewhere on the beach or in the upland) and this could have affected our interpretation of shoreline slope (see ***Topography*** above). We did not correct the SZ line itself during this QA mapping phase; however we did correct our interpretation of slope if we judged that an inaccurate SZ line affected our slope interpretation in the initial draft dataset. Of additional importance is that the SZ line does not include many smaller features such as small embayments (e.g., *longshore lagoons and closed lagoon/marshes*). These features not captured by the SZ line would then be considered “offline” features (see immediately below).

“Offline” Features:

Offline features are features that we are interested in mapping but are not well represented by the existing WDNR ShoreZone line. We used the following criteria to identify potential “offline” features (all criteria must be met to be considered “offline”):

- 1) The presence of wetlands of any of the following classes: estuarine mixing, oligohaline transition, or tidal freshwater, in the RHP current wetland dataset.
- 2) The wetlands are not spatially represented by the WDNR ShoreZone line. And,
- 3) The wetlands make up a distinctive geomorphic unit from the *barrier beach* unit that encloses or partially encloses the wetlands (see Figure 5 for example).

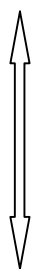
For example, tidal wetlands may exist (as shown in the RHP current wetland dataset and in air photos) landward of a *barrier beach*, but the WDNR ShoreZone does not show a line representing these tidal wetlands; instead, the WDNR ShoreZone line only represents the *barrier beach* unit. We include a field in the GIS feature class for referencing this “offline” feature (e.g., *longshore lagoon*)(consult metadata).

In addition to the RHP current wetland dataset, the Ecology oblique air photos were used to help identify “offline” features.

Input Data Conflicts

Where input data conflicts occur (e.g., geology and slope appear to contradict one another) we consulted additional available data sources, and applied a hierarchy of data reliability to guide our decision. The more reliable datasets, including air photos, governed our conclusion about typing the shoreline.

Most reliable



Air photos (2006-07 Ecology obliques and 2006 NAIP)
Revised 2007 Ecology Drift Cells
10 m DEM topography*
24k hydrography
Historical T Sheets
RHP wetlands data
24k geology
100k geology

Least reliable

* In the initial draft mapping, the slope was interpreted as slope immediately landward of the WDNR ShoreZone line. The interpretation of shoreline slope can therefore be erroneous in cases where the WDNR ShoreZone line is spatially inaccurate. We attempted to correct for these gross errors in slope that were due to WDNR ShoreZone inaccuracy during the QA mapping process using primarily the 2006-07 Ecology oblique air photos and the 2006 NAIP ortho-photos.

The 100k geology was generally the least reliable of the input datasets used during the initial draft mapping (largely due to its coarse scale), and so many of the edits made during the QA mapping were based on the identification of incorrect 100k geology. The following describes how we addressed questionable 100k geology. If the material class that was derived from the 100k geology was judged to be in error for a specific location along the shoreline, and it affected the identification of a geomorphic unit, then we correctly identified the material class for the location. If available, we used the finer scale 24k geology dataset to substitute the 100k geology. Absent the 24k geology dataset, the QA reviewer evaluated additional datasets that are available (particularly the topography, hydrography, Ecology oblique air photos, and UWRHP wetlands datasets) to make the most informed interpretation in identifying the geology that actually occurs at the site. Note: we did not attempt to re-define the geology dataset, only reject the most obvious errors. If this reinterpretation could not be done, due to ambiguity, then the geomorphic unit(s) affected by this now unknown geology was flagged for future review. If at any point a decision could not be made regarding the typing of a shoreline, the geomorphic unit(s) was flagged (e.g., “further review needed”) so that the particular location could be revisited with assistance from other staff.

Mapping Guidelines and Criteria

The Applied Table and Decision Diagram located in the Appendix were used as a guide in the mapping process. Note: There were instances where the below criteria contradict one another and the mapping “rules” were subject to considerable interpretation. In these cases we applied the hierarchy of data reliability described above to govern our decision about shoreline geomorphology at a given location.

Open Shorelines (General Criteria)

Geology

Cohesive material (see file: gunit_lu_REV), Qls (for *sediment source beaches*), or Qb (for *barrier beach* and *depositional beaches*). Qa (alluvium) may occur indicating a *beach seep* along an otherwise gentle/steep wave-dominated shoreline.

Note: *Barrier beach* geomorphic units (often indicated as Qb in the 100k and 24k geology), though considered an “Open Shoreline” geomorphic class, are typically associated with Embayments. For example, in the case of a *longshore lagoon* geomorphic unit, the *barrier beach* geomorphic unit is represented by the outer (i.e., seaward) shoreline while the *longshore lagoon* would be the inner (i.e., landward) shoreline or the lagoon itself (see Figure 5 for example). Also, *barrier beaches* are typically associated with “offline” features (see above and Figure 5 for example).

Topography

Any slope (flat for *barrier beach* and some *depositional beach* units)

Dominant Processes

Open Shorelines are generally characterized by wave processes [i.e., divergent zone (DZ)], directional (LtoR, etc.), or convergent zone (CZ). A DZ almost always marks the presence of

a *sediment source beach* (as can directional drift when slope is > 3 degrees). Convergent zones are typically either *barrier beach* or *depositional beach* geomorphic units.

Fluvial deposition (24k hydro input and evident in air photos) in gentle/steep topography identifies the presence of a *beach seep* along an open shoreline. Fluvial deposition in flat topography with a distinctive valley identifies the presence of an embayment (e.g., *delta*) with fluvial processes recognized as at least one of the dominant processes.

Air Photos

The distinction between a *barrier beach* and a *depositional beach* is marked by the presence of wetlands that are below MHHW and occur landward of the spit in the case of *barrier beaches*. *Depositional beaches* do not have wetlands landward of the spit (in either RHP historic or current wetland datasets). Thus, *barrier beaches* were identifiable in air photos and/or in the RHP historic wetland dataset by the presence of a spit located seaward of wetlands that are below MHHW. There are many cases where the wetlands associated with the *barrier beach*, and sometimes the spit itself, have been filled and altered by human development. Even if all the wetlands that were historically present landward of the *barrier beach* have been lost to development, we still mapped these shorelines as *barrier beach*.

For *beach seep* geomorphic units, which are localized fluvial inputs along an open shoreline, fluvial inputs were evident in the form of deltaic deposits and typically (though not always) captured by the 24k hydrography dataset.

In practice, “unknown” was sometimes noted in the FW Input field even if the hydro layer shows a small stream. If we observed no evidence in air photos or in the topography, then FW = unknown. If two or more datasets or observations indicated FW input (e.g., hydro-layer and delta appears), then FW = yes.

Open Shorelines (Specific Criteria)

There are five different Open Shoreline geomorphic types:

- Sediment Source Beach
- Depositional Beach
- Barrier Beach
- Beach Seep
- Plunging Sediment Bluff

Data Input Criteria (with some noted exceptions, the geomorphic unit type was identified by meeting each of the following criteria for geology, slope, and dominant processes):

Sediment Source Beach (Figures 2 and 3)

Geology

Cohesive material (see file: gunit_lu_REV) or loose (Qls)(landslide), or more rarely Qb (beach deposits) when other datasets, namely topography and air photos, suggest steeper topography and *Sediment Source Beach* characteristics.

Slope

Gentle or Steep (> 3 degrees, landward of the WDNR ShoreZone line)

Dominant Processes

Drift is directional (LtoR, RtoL), divergent (DZ) or, rarely, convergent (CZ).

Stream inputs are insignificant in *Sediment Source Beach* (distinctive valley and deltaic deposits are lacking in topographic dataset and air photos, respectively).



Figure 2. Example of a *sediment source beach*, Quimper Peninsula, Strait of Juan de Fuca sub-basin (photo from Washington Department of Ecology).

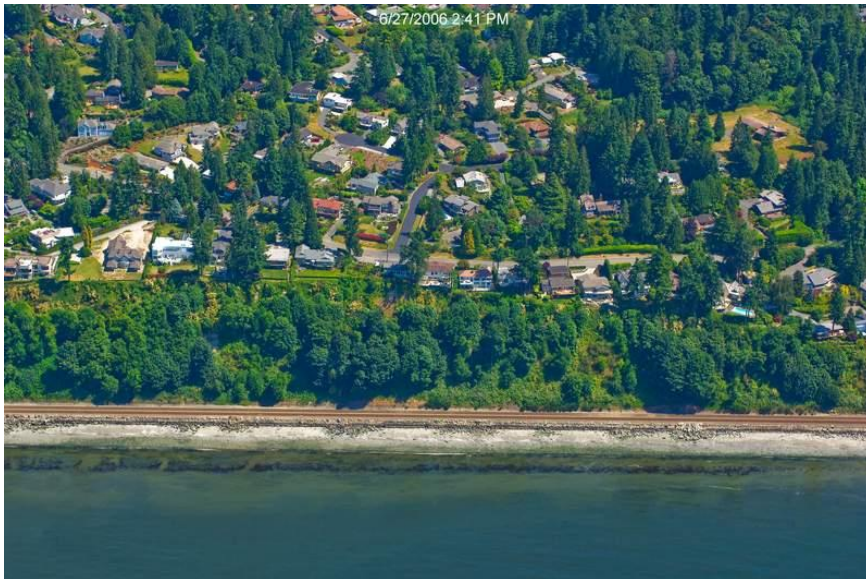


Figure 3. Example of a *sediment source beach* (modified by a railroad grade built at the toe of the bluff) located just north of downtown Edmonds, South Central sub-basin (photo from Washington Department of Ecology).

Depositional Beach (Figure 4)

Geology

Qb (beach deposit) or Cohesive material (see file: gunit_lu_REV)

Slope

Any slope (must have Qb if gentle/steep), though typically flat landward of the WDNR ShoreZone line

Note: The distinction between a *depositional beach* and a *barrier beach* was indicated in the case of *barrier beaches* by the presence of tidal wetlands in the RHP historic and/or current wetland datasets associated with the spit. *Depositional beaches* will not have tidal wetlands landward of the spit. Thus, *barrier beaches* should be identifiable in air photos and/or in the RHP historic or current wetland datasets by the presence of wetlands immediately landward of the spit. There are many cases where the wetlands associated with the *barrier beach*, and sometimes the spit itself, have been filled over and altered by human development. Even if all the wetlands that were present historically landward of the *barrier beach* have been lost to development, we still mapped these shorelines as *barrier beach* because of the historical presence (and potential for restoration) of these wetlands. Given this rule, if a slope is either gentle or steep, and geologic and dominant processes criteria for *depositional beach* are met, the shoreline in question is unlikely to be a *barrier beach* because a gentle/steep slope is not likely to accommodate tidal wetlands landward of the spit simply because the topography is not compatible.

Dominant Processes

Drift is directional (LtoR, RtoL) or convergent (CZ).

Stream inputs are insignificant (distinctive valley and deltaic deposits are lacking in topographic dataset and air photos, respectively).



Figure 4. Example of a *depositional beach*, Kitsap Peninsula, Hood Canal sub-basin. The topography is generally flat, but evidence of historic and/or current wetlands landward of the shoreline is lacking from the UWRHP datasets and air photos (photo from Washington Department of Ecology).

Barrier Beach (Figure 5)

Geology

Qb (beach deposit) or Cohesive material (see file: gunit_lu_REV)

Slope

Flat (< 3 degrees, landward of the WDNR Shorezone line)

See Special Rule above in *Depositional Beaches*

Dominant Processes

Drift is directional (LtoR, RtoL) or convergent (CZ).

Stream inputs are insignificant (distinctive valley and deltaic deposits are lacking in topographic dataset and air photos, respectively).

Note: Almost without exception, the presence of a *barrier beach* signals the presence of an Embayment of some kind (i.e., tidal channel lagoon, drowned channel lagoon, tidal delta lagoon, delta lagoon, longshore lagoon, closed lagoon/marsh, pocket beach lagoon, or pocket closed lagoon/marsh).



Figure 5. Example of a *barrier beach* associated with an “offline” *closed lagoon/marsh* geomorphic unit, Marrowstone Point on Marrowstone Island, North Central sub-basin (photo from Washington Department of Ecology).

Beach Seep (Figure 6)

Geology

Cohesive material (see file: gunit_lu_REV), Qls (landslide), or Qa (alluvium)

Slope

Gentle or Steep (> 3 degrees, landward of the WDNR ShoreZone line)

Dominant Processes

Drift is directional (LtoR, RtoL), divergent (DZ) or, more rarely, convergent (CZ). Stream input is localized (deltaic deposits are evident in topographic dataset and air photos, respectively).

Note: A *beach seep* is essentially a *sediment source beach* geomorphic unit (gentle/steep slope) that happens to have a stream(s) entering the shoreline that is observable by the presence of deltaic deposits on the beach. The distinction between *beach seep* and other fluvial geomorphic types that occur within the Embayment Class (e.g., *delta*, *delta lagoon*, *drowned channel*, etc.) is that the latter all occur within a flat topographic setting; whereas *beach seeps* occur along gentle/steep shorelines.



Figure 6. Example of a *beach seep* located near entrance of Totten Inlet, South Sound sub-basin (photo from Washington Department of Ecology).

Plunging Sediment Bluff (Figure 7)

Geology

Cohesive material (see file: gunit_lu_REV)

Slope

Gentle or Steep (> 3 degrees, landward of the WDNR ShoreZone line)

Dominant Processes

Drift is not appreciable (NAD)

Tidal processes are lacking

Beach development is lacking

Stream inputs are insignificant (distinctive valley and deltaic deposits are lacking in topographic dataset and air photos, respectively).

Note: *plunging sediment bluff* characterizes shorelines that meet the above criteria and are not subject to any other overprinting processes (i.e., they are glacial remnants with little/no fluvial, wave, or tidal processes detectable).



Figure 7. Example of a *plunging sediment bluff* (abrupt shoreline near center of image) in Hammersley Inlet, South Sound sub-basin. A small *delta* is at far left and a *beach seep* occurs near the top right of the image (photo from Washington Department of Ecology).

Embayments (General Criteria)

Geology

Qa (fluvial), Qb (wave), and/or Qp (tidal)(24k geology may show Qp as Qm or Qn).

Note: The 100k geology (and even the 24k geology) often fails to identify these geology units though they may exist on the ground (e.g., spits and many streams). In addition, the 100k geology polygons are often spatially inaccurate. In these instances, we typically used the 10 m DEM slope data (which we consider more reliable) as a surrogate to geology to define the extent of a geology polygon (e.g., where boundary between Qa and cohesive material occurs).

Topography

Flat (< 3 degree slope) (See Note below regarding *barrier beach* geomorphic units)

Distinctive valley (V or U shape)

Dominant Processes

Embayment shorelines are generally characterized as having no appreciable drift (NAD). However, net shore drift (LtoR, CZ, etc.) may be found along all or part of an Embayment shoreline. Examples are where fluvial deposition (flat topography, 24k hydro input and evident in air photos) occurs, and where spits occur (usually directional or CZ) that enclose or partially enclose embayments (e.g., *delta lagoon*, *longshore lagoon*, etc.). With embayments

involving spits (i.e., *barrier beaches*) and lagoons, NAD often occurs in the lee of the spit but net shore drift can occur on the windward (i.e., less protected) side of the spit.

Air Photos

Fluvial inputs should be evident in the form of deltaic deposits. Many embayments are identifiable in air photos by the presence of tidal marsh, channels, and in some cases a spit (*barrier beach*) that occurs seaward of wetlands that are below MHHW.

Embayments (Specific Criteria)

There are ten (10) different Embayment geomorphic types:

- Tidal Channel Marsh
- Tidal Channel Lagoon
- Drowned Channel
- Drowned Channel Lagoon
- Tidal Delta
- Tidal Delta Lagoon
- Delta
- Delta Lagoon
- Closed Lagoon/Marsh
- Longshore Lagoon

Data Input Criteria (with noted exceptions, the geomorphic unit type was identified by meeting each of the following criteria for geology, slope, and dominant processes):

Tidal Channel Marsh (Figure 8)

Geology

Qp (peat) or Cohesive material (see file: gunit_lu_REV)

Slope

Flat (< 3 degrees, landward of the WDNR ShoreZone line), valley is U-shaped.

Dominant Processes

Drift is not appreciable (NAD)

Tidal processes are dominant

Stream inputs are insignificant



Figure 8. Example of a *tidal channel marsh* located in Oyster Bay near Bremerton, South Central sub-basin (photo from Washington Department of Ecology).

Tidal Channel Lagoon (Figure 9)

Geology

Qb and/or Qp (peat) or Cohesive material (see file: gunit_lu_REV)

Slope

Flat (< 3 degrees, landward of the WDNR ShoreZone line), valley is U-shaped.

Spit located seaward of tidal wetlands

Dominant Processes

Drift is directional (LtoR, RtoL) or convergent (CZ) seaward or in front of the spit, and NAD landward or behind the spit (sometimes NAD is not shown in the drift cell dataset if the feature is small in scale and/or not subject to regular tidal inundation).

Tidal and wave processes (in forming the spit) are dominant.

Stream inputs are insignificant.



Figure 9. Example of a *tidal channel lagoon*, Triangle Cove on Camano Island, Whidbey sub-basin (photo from Washington Department of Ecology).

Drowned Channel (Figure 10)

Geology

Qa (alluvium) or Cohesive material (see file: gunit_lu_REV)

Slope

Flat (< 3 degrees, landward of the WDNR ShoreZone line), valley is V-shaped.

Dominant Processes

Drift is not appreciable (NAD)

Tidal and fluvial processes are dominant, with tidal $>$ fluvial



Figure 10. Example of a *drowned channel*, Woodward Creek in Henderson Inlet, South Sound sub-basin (photo from Washington Department of Ecology).

Drowned Channel Lagoon (Figure 11)

Geology

Qa and/or Qb, or Cohesive material (see file: gunit_lu_REV)

Slope

Flat (< 3 degrees, landward of the WDNR ShoreZone line), valley is V-shaped.

Spit located seaward of stream inlet

Dominant Processes

Drift is directional (LtoR, RtoL) or convergent (CZ) seaward or in front of the spit, and NAD landward or behind the spit (sometimes NAD is not shown in the drift cell dataset if the feature is small in scale and/or not subject to regular tidal inundation).

Tidal, fluvial, and wave processes (in forming the spit) are dominant, with tidal > fluvial.



Figure 11. Example of a *drowned channel lagoon*, (with road crossing) Clear Creek in Dyes Inlet, South Central sub-basin (photo from Washington Department of Ecology).

Tidal Delta (Figure 12)

Geology

Qa (alluvium), Qp (peat), or Cohesive material (see file: gunit_lu_REV)

Slope

Flat (< 3 degrees, landward of the WDNR ShoreZone line), valley is U or V-shaped.

Dominant Processes

Drift is not appreciable (NAD)

Tidal and fluvial processes are dominant, with tidal = fluvial.



Figure 12. Example of a *tidal delta*, Quilcene River in Quilcene Bay, Hood Canal sub-basin (photo from Washington Department of Ecology).

Tidal Delta Lagoon (Figure 13)

Geology

Qa, Qp, and/or Qb, or Cohesive material (see file: gunit_lu_REV)

Slope

Flat (< 3 degrees, landward of the WDNR ShoreZone line), valley is U or V-shaped.

Spit located seaward of stream inlet

Dominant Processes

Drift is directional (LtoR, RtoL) or convergent (CZ) seaward or in front of the spit, and NAD landward or behind the spit (sometimes NAD is not shown in the drift cell dataset if the feature is small in scale and/or not subject to regular tidal inundation).

Tidal, fluvial, and wave processes (in forming the spit) are dominant, with tidal = fluvial.



Figure 13. Example of a *tidal delta lagoon*, Pysht River, Strait of Juan de Fuca sub-basin (photo from Washington Department of Ecology).

Delta (Figure 14)

Geology

Qa (alluvium) or Cohesive material (see file: gunit_lu_REV)

Slope

Flat (< 3 degrees, landward of the WDNR ShoreZone line), valley is V-shaped.
Delta fan is evident in air photos.

Dominant Processes

Fluvial deposition

Drift is not appreciable (NAD) or directional (LtoR, RtoL), but spit is not present at stream mouth.



Figure 14. Example of a *delta*, Lyre River, Strait of Juan de Fuca sub-basin (photo from Washington Department of Ecology).

Delta Lagoon (Figure 15)

Geology

Qa (alluvium) and Qb (+ / - Qp), or Cohesive material (see file: gunit_lu_REV)

Slope

Flat (< 3 degrees, landward of the WDNR ShoreZone line), valley is V-shaped.

Dominant Processes

Fluvial deposition (delta fan evident in air photos)

Drift is directional (LtoR, RtoL) or convergent (CZ), with spit present at stream mouth.



Figure 15. Three distinctive geomorphic units occur along this short stretch of shoreline on Vashon Island, South Central sub-basin. At lower left is a *barrier beach* that had an associated historic lagoon that is now filled, and at far right is a *delta lagoon*. Between these features is a *sediment source beach* (photo from Washington Department of Ecology).

Longshore Lagoon (Figure 16)

Geology

Qb + / - Qp, or Cohesive material (see file: gunit_lu_REV)

Slope

Flat (< 3 degrees, landward of the WDNR ShoreZone line), but little/no valley.

Spit located seaward of estuarine/tidal wetlands

Dominant Processes

Drift is directional (LtoR, RtoL) or convergent (CZ)

Drift not appreciable (NAD) inside/behind spit (*drift cell data may be absent entirely landward of spit if feature is small and/or tidal connectivity is minimal)

Persistent surface tidal connection evident in current and/or historical datasets, or in air photos.



Figure 16. Example of a *longshore lagoon*, Crane Point on Indian Island, North Central sub-basin. As is typical, a *barrier beach* geomorphic feature encloses the lagoon (photo from Washington Department of Ecology).

Closed Lagoon/Marsh (Figure 17)

Geology

Qb + / - Qp, or Cohesive material (see file: gunit_lu_REV)

Slope

Flat (< 3 degrees, landward of the WDNR ShoreZone line), but no valley.

Spit located seaward of wetlands

Dominant Processes

Drift is directional (LtoR, RtoL) or convergent (CZ)

Persistent surface tidal connection lacking in current and historical datasets, and in air photos.

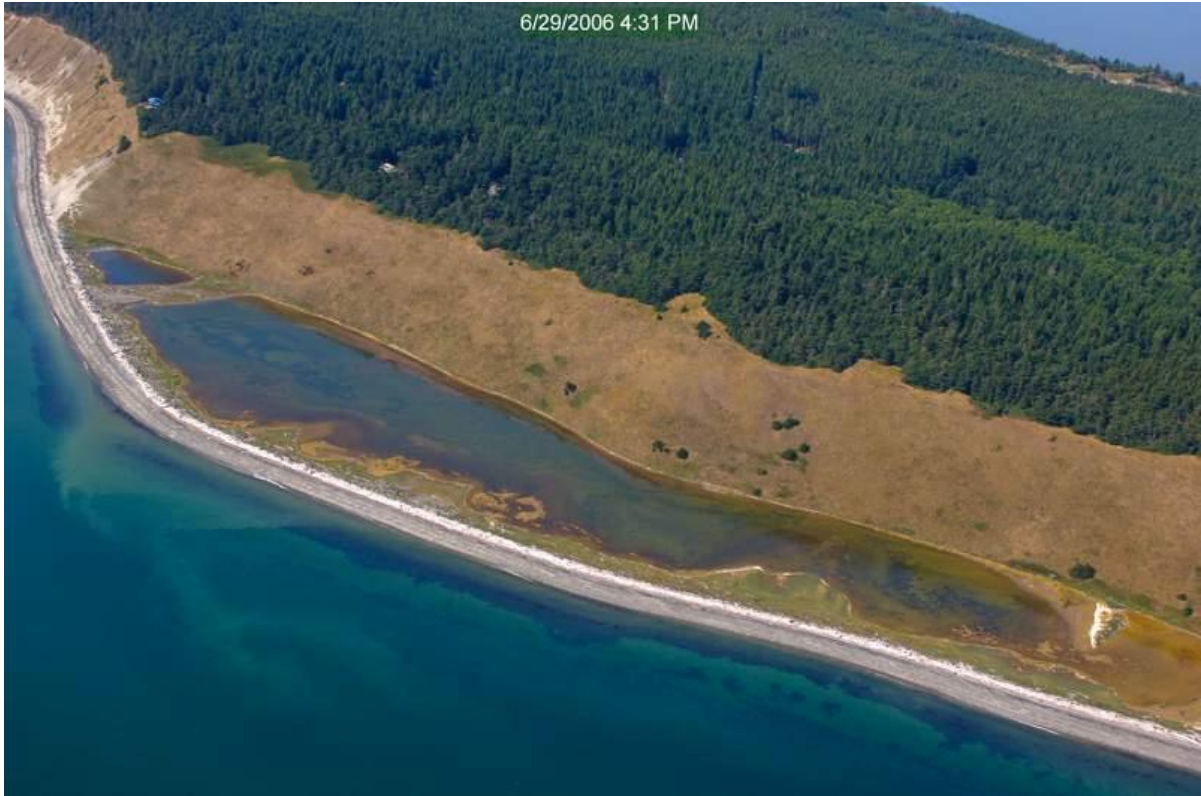


Figure 17. Example of a *barrier beach* and an associated “offline” *closed lagoon/marsh*, Perego Lagoon, Whidbey Island, North Central sub-basin. A *sediment source beach* occurs in the upper left corner (photo from Washington Department of Ecology).

Rocky Shorelines (General Criteria)

Geology

Bedrock materials (see file: gunit_lu_REV)

Topography

Any slope

Dominant Processes

Often no appreciable drift (NAD), but can have drift (in case of *veneered rock platform*)

Air Photos

Rocky shorelines are usually evident in Ecology oblique air photos as irregular and jagged-shaped shorelines, and often there is little/no beach development (*rocky shoreline* and *plunging rocky shoreline*).

Rocky Shorelines (Specific Criteria)

There are three different Rocky Shoreline geomorphic types:

- Rocky Shoreline
- Plunging Rocky Shoreline

- Veneered Rock Platform

Data Input Criteria (with noted exceptions, the geomorphic unit type was identified by meeting each of the following criteria for geology, slope, and dominant processes):

Rocky Shoreline (Figure 18)

Geology

Bedrock (see file: gunit_lu_REV)

Slope

Flat/gentle

Dominant Processes

No appreciable drift (NAD)



Figure 18. Example of a *rocky shoreline*, Rich Passage, South Central sub-basin (photo from Washington Department of Ecology).

Plunging Rocky Shoreline (Figure 19)

Geology

Bedrock (see file: gunit_lu_REV)

Slope

Steep

Dominant Processes

No appreciable drift (NAD)

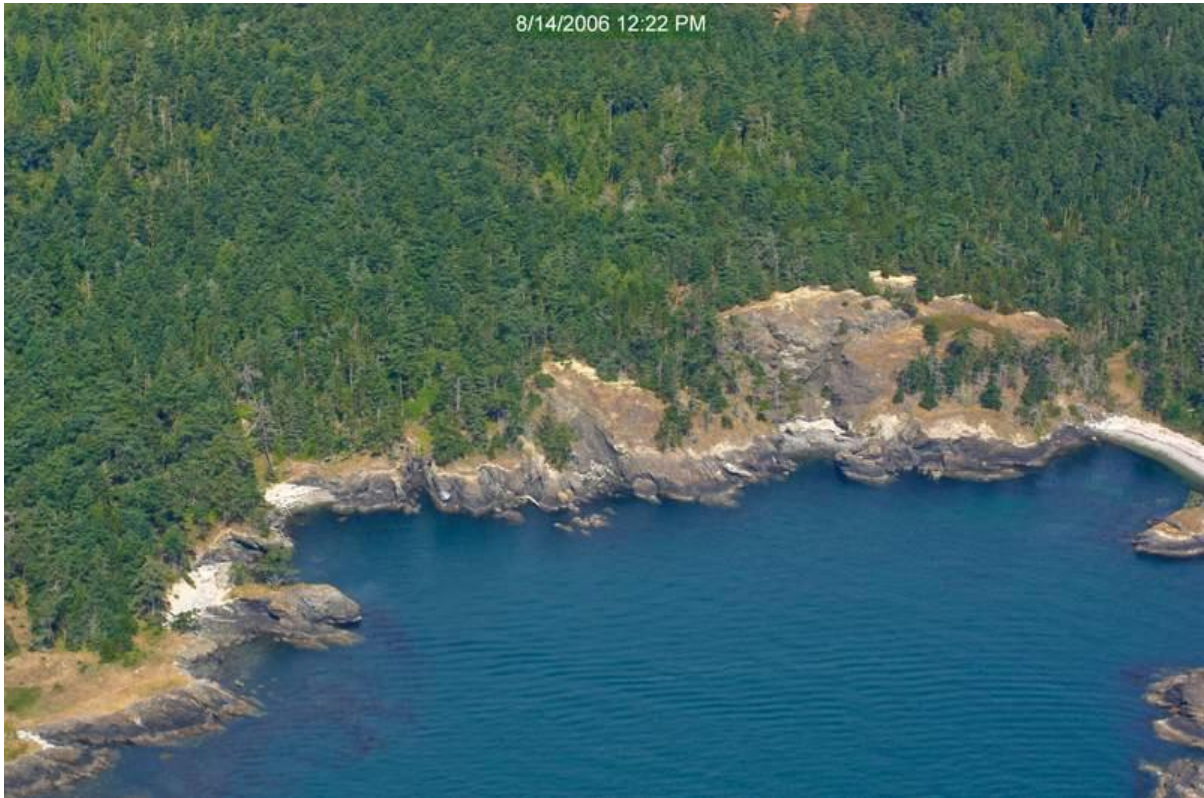


Figure 19. Example of a *plunging rocky shoreline* (near center of image), south shore of Lopez Island, San Juan sub-basin. A small *pocket beach* occurs at far right. (photo from Washington Department of Ecology).

Veneered Rock Platform (Figure 20)

Geology

Bedrock (see file: gunit_lu_REV)

Slope

Any slope

Dominant Processes

Drift directional (LtoR, RtoL), divergent (DZ), or convergent (CZ); and beach development evident in air photos.

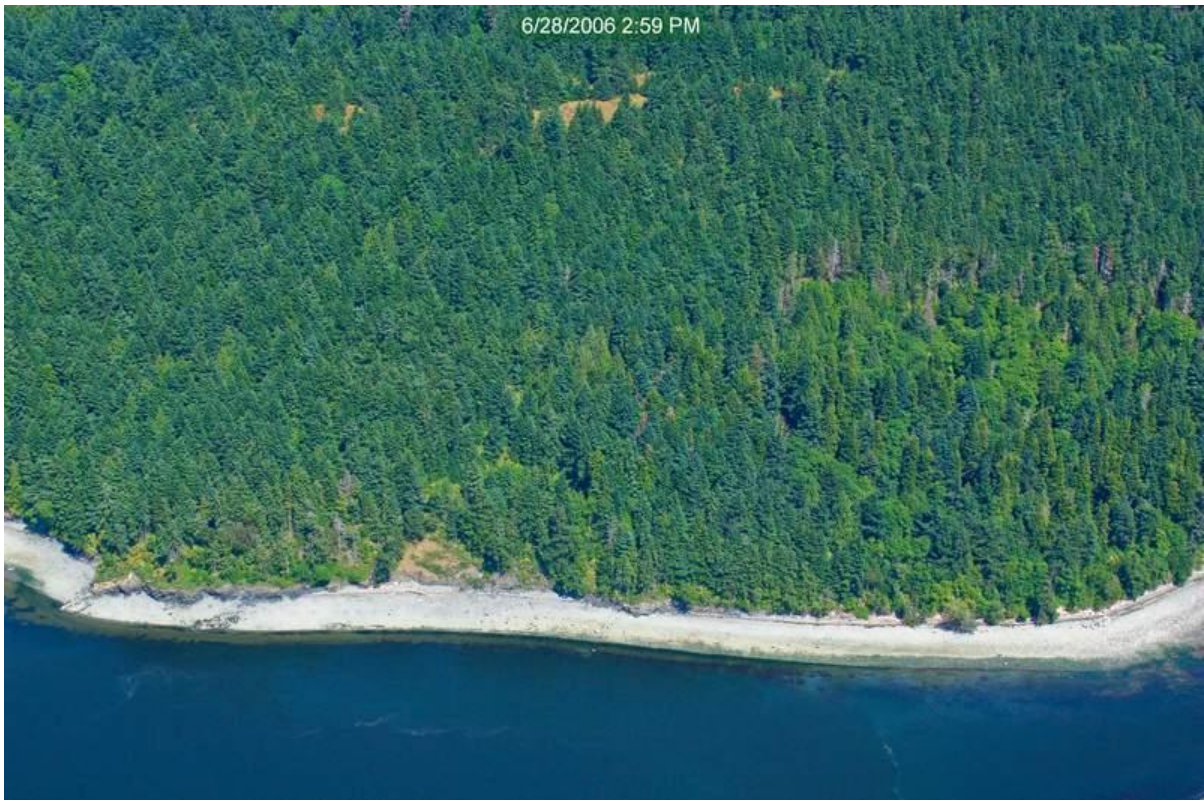


Figure 20. Example of a *veneered rock platform*, west shore of Lummi Island, San Juan sub-basin (photo from Washington Department of Ecology).

Pocket Beaches (General Criteria)

Geology

Cohesive and/or Qb, Qp, Qa surrounded by bedrock materials (see file: gunit_lu_REV)

Topography:

Any slope

Dominant Processes

No appreciable drift (NAD); onshore wave erosion with no adjacent sediment source

Air Photos

Pocket Beaches are evident in air photos as a beach surrounded by bedrock outcrops.

Pocket Beaches (Specific Criteria)

There are four different Pocket Beach geomorphic types:

- Pocket Beach
- Pocket Beach Estuary
- Pocket Beach Lagoon
- Pocket Beach Closed Lagoon/Marsh

Data Input Criteria (the geomorphic unit type was identified by meeting each of the following criteria for geology, slope, and dominant processes):

Pocket Beach (Figure 21)

Geology

Cohesive and/or Qb or Qp, surrounded by bedrock (see file: gunit_lu_REV)

Slope

Gentle/Steep

Dominant Processes

No appreciable drift (NAD); onshore wave erosion with no adjacent sediment source

Pocket Beach Estuary (Figure 21)

Geology

Qa, Qb and/or Qp, and/or cohesive, surrounded by bedrock (see file: gunit_lu_REV)

Slope

Flat

Dominant Processes

No appreciable drift (NAD); onshore wave erosion with no adjacent sediment source
Fluvial input (24k hydro, distinctive valley, and evident in air photos)



Figure 21. From left to right, a *pocket beach*, *rocky shoreline*, and *pocket beach estuary* (with road across creek mouth), near Port Orchard, South Central sub-basin (photo from Washington Department of Ecology).

Pocket Beach Lagoon (Figure 22)

Geology

Cohesive, Qb and/or Qp, surrounded by bedrock (see file: gunit_lu_REV)

Slope

Flat; spit located seaward of wetlands

Dominant Processes

No appreciable drift (NAD); onshore wave erosion with no adjacent sediment source
Persistent tidal connection



Figure 22. Example of a *pocket beach lagoon* (open to tidal exchange) and a *pocket beach closed lagoon/marsh* (closed to tidal exchange), Henry Island, San Juan sub-basin (photo from Washington Department of Ecology).

Pocket Beach Closed Lagoon/Marsh (Figures 22 and 23)

Geology

Cohesive, Qb and/or Qp, surrounded by bedrock (see file: gunit_lu_REV)

Slope

Flat; spit located seaward of wetlands

Dominant Processes

Drift not appreciable (NAD); onshore wave erosion with no adjacent sediment source

No persistent tidal connection

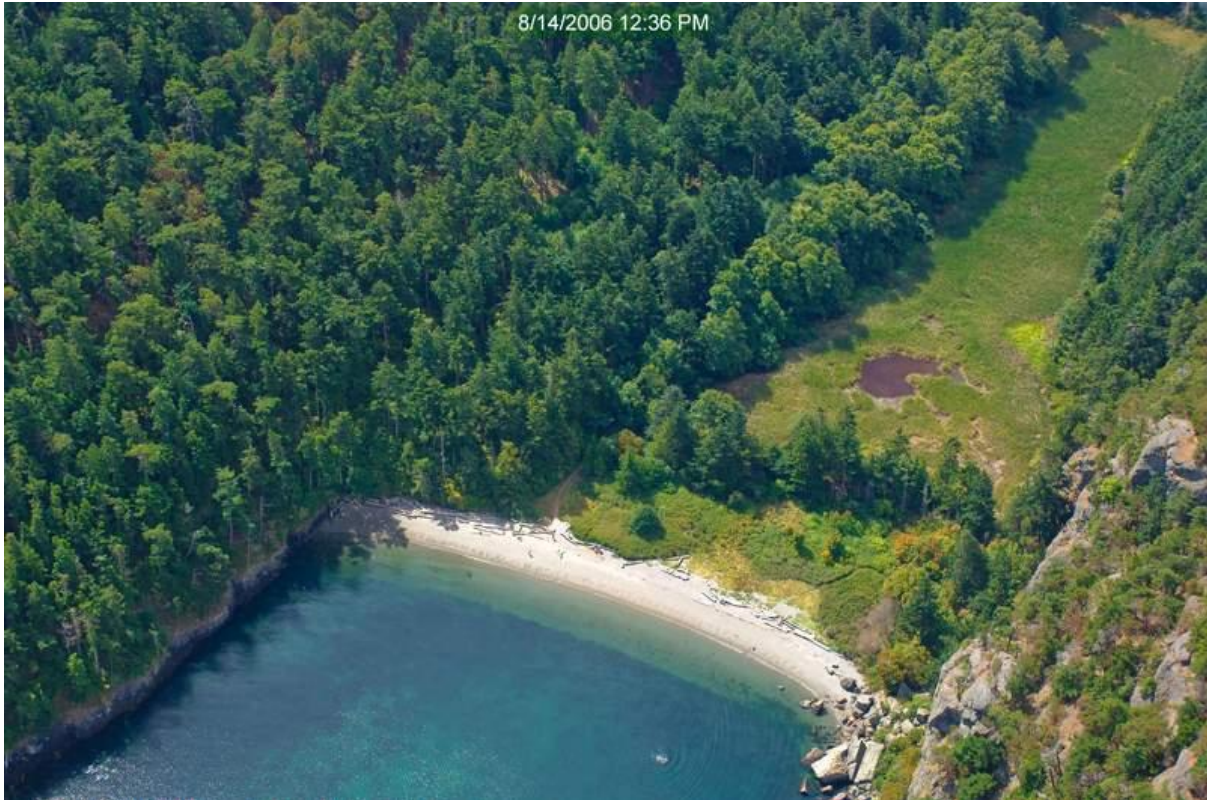


Figure 23. Example of a *pocket beach closed lagoon/marsh*, Watmough Bay, Lopez Island, San Juan sub-basin (photo from Washington Department of Ecology).

***Modified* (note: this is not a geomorphic unit type)(Figure 24)**

Geology

Geology typically obscured and indicated as Qf (fill)

Slope

Any slope

Dominant Processes

Processes highly impaired/obscured (intertidal largely filled or dredged)

Note: Though not a geomorphic unit type itself, we assigned to the GeoUnitCode and GeoUnit fields “modified” to shorelines that have been extensively filled and/or dredged and there is little/no indication of the historic geomorphology. Typically, this means the intertidal area has been largely eliminated. If the shoreline in question is a fluvial feature, however, and a stream and alluvial deposits are obvious in current air photos, then we did not likely identify this shoreline as “modified” because there is still an important indicator of process evident (e.g., fluvial deposition).

The “modified” type (again, not a geomorphic unit type) should not be confused with the field “ModShoreline” within the SSHIAP GIS database, although the two can be related. All shorelines that we identified in the GeoUnitCode (code 25) and GeoUnit field as “modified”

should also have “1” (which is code for “yes”) in the “ModShoreline” field. But not in all cases where we have indicated “1” in the “ModShoreline” field do we identify in GeoUnitCode and GeoUnit fields as “1” and “modified” (see Figure 25 for an example).

The field “ModShoreline” is used to indicate in general whether human modification (e.g., armoring, filling, dredging, overwater structures, excessive riparian vegetation removal, etc.) is evident within the shoreline unit, regardless of the geomorphic unit type. It is very common to have shoreline armoring, for example, but this does not fundamentally change the geomorphic unit type (e.g., *sediment source beach*). However, we would indicate “1” in the “ModShoreline” field for this *sediment source beach*. When shoreline modifications are not obvious from air photos, we indicated “0” (code for “unknown”) in the “ModShoreline” field.

Therefore, in the example above under “Note”, we would still identify this geomorphic unit as a *delta lagoon* or other fluvial geomorphic unit, but we would populate “1” in the GIS field “ModShoreline” to indicate that this geomorphic unit has been modified (see Figure 25).



Figure 24. Example of a *modified* shoreline unit, Shilshole, South Central sub-basin (photo from Washington Department of Ecology).



Figure 25. Example of a *delta lagoon* flanked on both sides by *sediment source beach* units. These geomorphic units are considered modified (code 1) in the “ModShoreline” field in the GIS database due to the road, armoring, and fill along the shoreline and wetlands associated with Eagle Creek, Hood Canal sub-basin (photo from Washington Department of Ecology).

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Appendix

Table 1. Comparison of Geomorphic Classification from SSHIAP Initial Draft and the Final QA mapping versions. In addition to additions or deletions of geomorphic unit types, in some cases revised criteria than that used in the Initial Draft dataset were applied in the identification of these geomorphic unit types.

* Indicates revised geomorphic unit name (e.g., *tidal channel estuary* changed to *tidal channel marsh*).

** Indicates new geomorphic unit type (e.g., *tidal delta* did not exist in Initial Draft).

*** Indicates geomorphic unit type that was used in the Initial Draft but not used in the Final QA geomorphology mapping (e.g., *transport beach*).

SSHIAP Initial Draft geomorphology	SSHIAP Final QA geomorphology
<i>Tidal Channel Estuary</i>	<i>Tidal Channel Marsh*</i>
<i>Tidal Channel Lagoon</i>	<i>Tidal Channel Lagoon</i>
<i>Drowned Channel</i>	<i>Drowned Channel</i>
<i>Drowned Channel Lagoon</i>	<i>Drowned Channel Lagoon</i>
	<i>Tidal Delta**</i>
	<i>Tidal Delta Lagoon**</i>
<i>Delta</i>	<i>Delta</i>
<i>Delta Lagoon</i>	<i>Delta Lagoon</i>
	<i>Pocket Beach Estuary**</i>
	<i>Pocket Beach Lagoon**</i>
	<i>Pocket Beach Closed Lagoon/Marsh**</i>
	<i>Pocket Beach**</i>
	<i>Closed Lagoon/Marsh**</i>
<i>Longshore Lagoon</i>	<i>Longshore Lagoon</i>
	<i>Beach Seep**</i>
<i>Depositional Beach</i>	<i>Depositional Beach</i>
<i>Sediment Source Beach</i>	<i>Sediment Source Beach</i>
<i>Transport Beach***</i>	<i>Transport Beach now combined with Sediment Source Beach</i>
<i>Spit Beach</i>	<i>Barrier Beach*</i>
	<i>Plunging Sediment Bluff**</i>
<i>Deepwater Embayment***</i>	
<i>Rock Platform</i>	<i>Rocky Shoreline*</i>
<i>Plunging Rock Cliff</i>	<i>Plunging Rocky Shoreline*</i>
<i>Veneered Rock Platform</i>	<i>Veneered Rock Platform</i>
<i>Artificial</i>	<i>Modified</i>

