*SALMON AND STEELHEAD HABITAT INVENTORY AND ASSESSMENT PROGRAM*

# QUALITY ASSURANCE METHODOLOGY FOR MAPPING MARINE SHORELINE GEOMORPHOLOGY

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## 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.

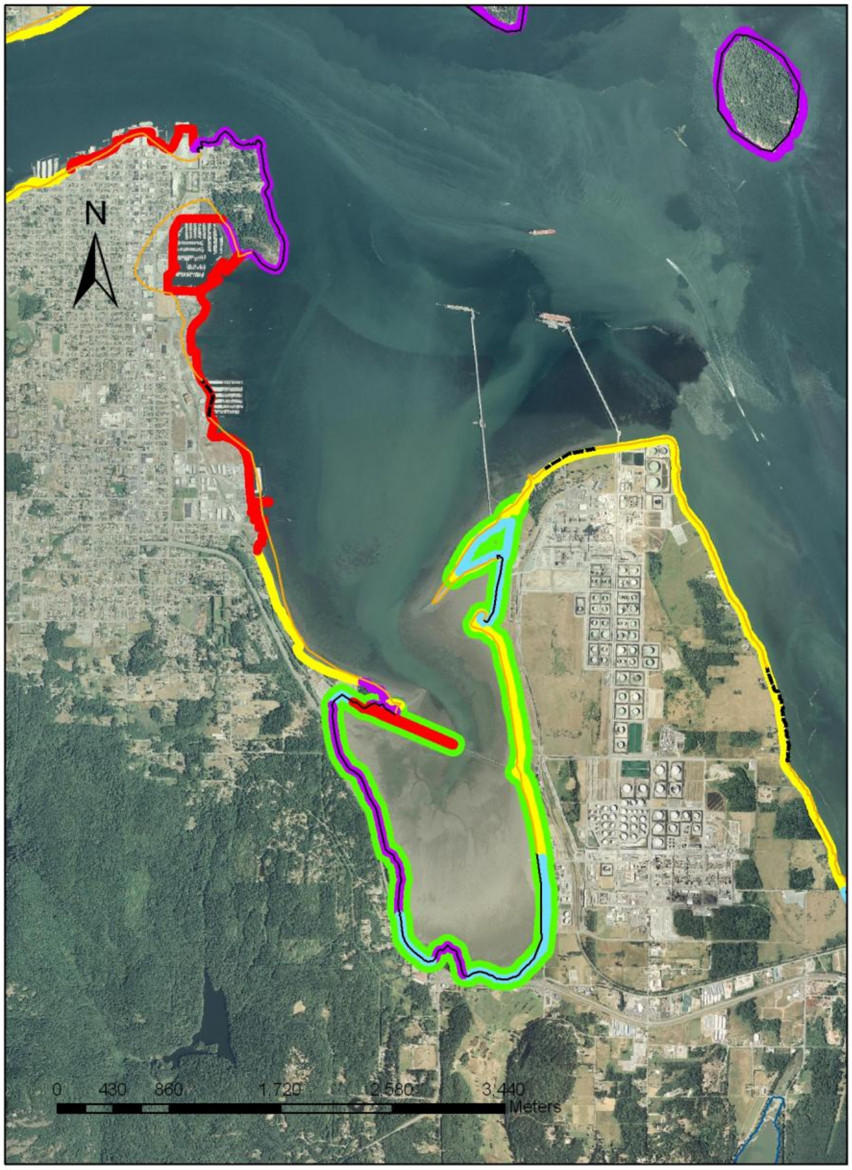


**Figure 1. Fidalgo Bay, an example of a *tidal channel lagoon* Complex Embayment located in the San Juan sub-basin. The broad green-colored band of shoreline marks the extent of the complex. Different colors within the complex indicate the various geomorphic unit types, including sediment source, barrier 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)*

<u>Geology</u>
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).

<u>Topography</u>
Any slope (flat for *barrier beach* and some *depositional beach* units)

<u>Dominant Processes</u>
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.

<u>Air Photos</u>
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)**

<u>Geology</u>
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).**

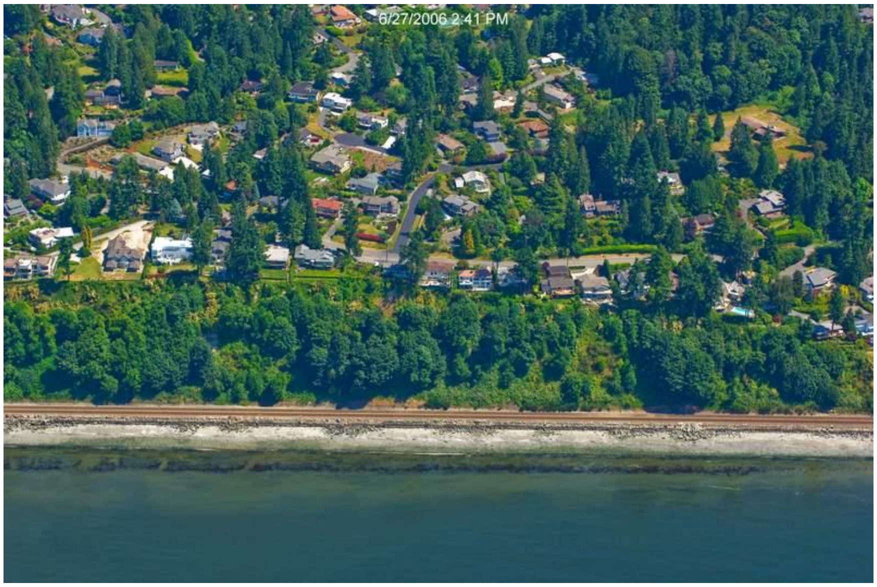


**Figure 3. Example of a *sediment source beach* (modified by a railroad grade built at the toe of the bluff) located just north of downtown Edmonds, South Central sub-basin (photo from Washington Department of Ecology).**

**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)**

<u>Geology</u>
Qb (beach deposit) or Cohesive material (see file: gunit_lu_REV)

<u>Slope</u>
Flat (< 3 degrees, landward of the WDNR Shorezone line)
See Special Rule above in *Depositional Beaches*

<u>Dominant Processes</u>
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)**

<u>Geology</u>
Qb and/or Qp (peat) or Cohesive material (see file: gunit_lu_REV)

<u>Slope</u>
Flat (< 3 degrees, landward of the WDNR ShoreZone line), valley is U-shaped.
Spit located seaward of tidal wetlands

<u>Dominant Processes</u>
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)**

<u>Geology</u>
Qa (alluvium), Qp (peat), or Cohesive material (see file: gunit_lu_REV)

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

<u>Dominant Processes</u>
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)**

<u>Geology</u>
Qa, Qp, and/or Qb, or Cohesive material (see file: gunit_lu_REV)

<u>Slope</u>
Flat (< 3 degrees, landward of the WDNR ShoreZone line), valley is U or V-shaped.
Spit located seaward of stream inlet

<u>Dominant Processes</u>
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)**

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

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

<u>Dominant Processes</u>
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)**

<u>Geology</u>
Qb + / - Qp, or Cohesive material (see file: gunit_lu_REV)

<u>Slope</u>
Flat (< 3 degrees, landward of the WDNR ShoreZone line), but no valley.
Spit located seaward of wetlands

<u>Dominant Processes</u>
Drift is directional (LtoR, RtoL) or convergent (CZ)
Persistent surface tidal connection lacking in current and historical datasets, and in air photos.

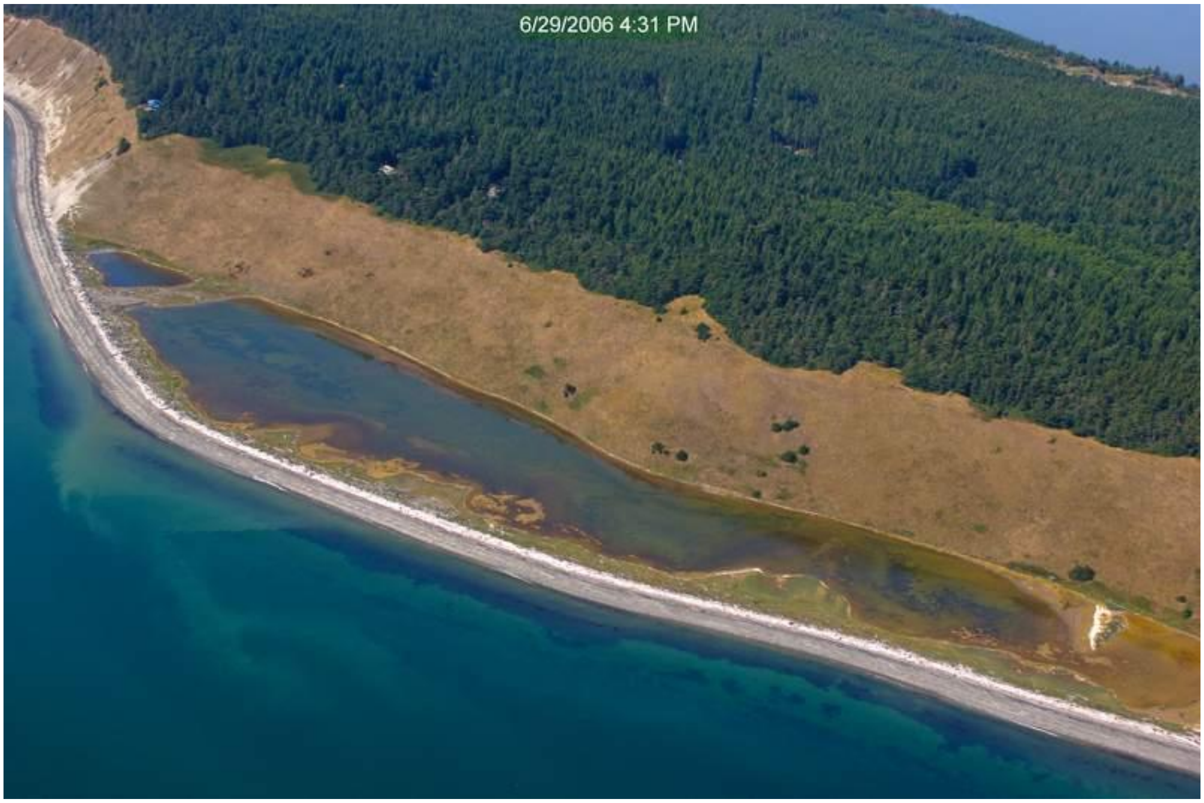


**Figure 17. Example of a *barrier beach* and an associated "offline" *closed lagoon/marsh*, Perego Lagoon, Whidbey Island, North Central sub-basin. A *sediment source beach* occurs in the upper left corner (photo from Washington Department of Ecology).**

***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)

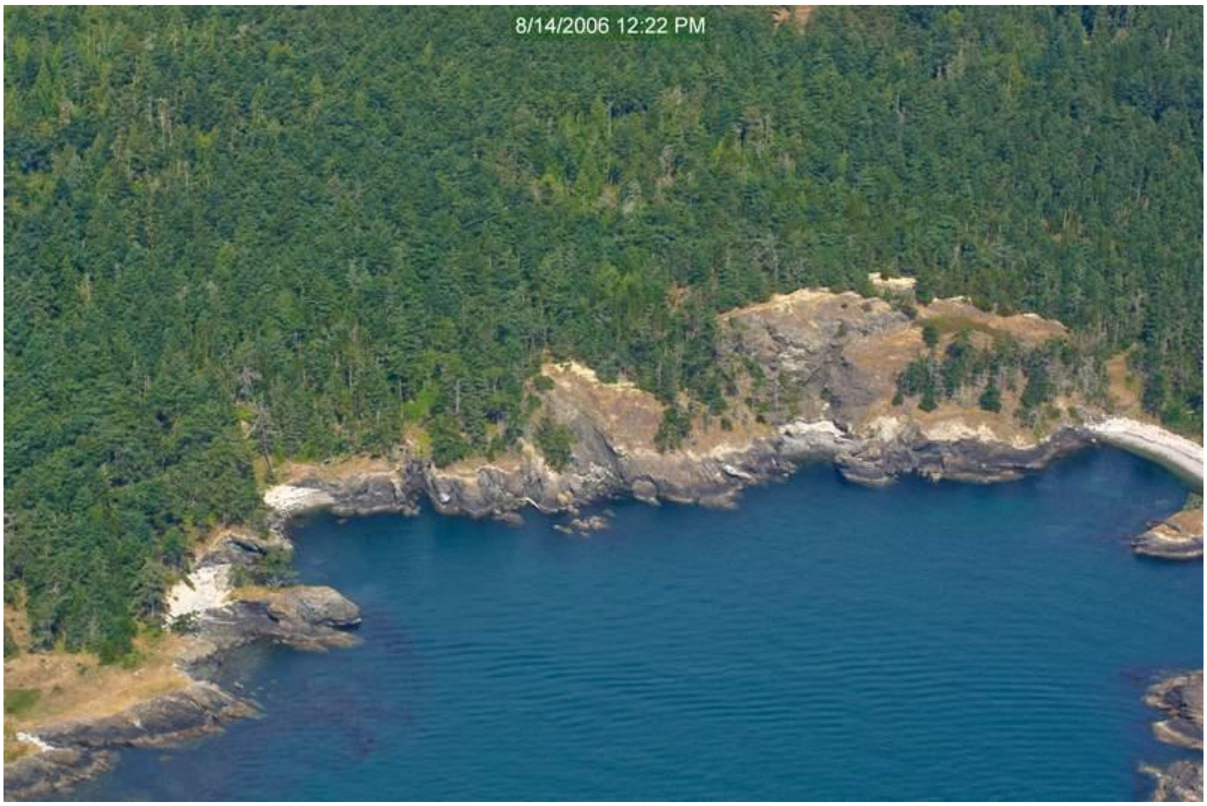


**Figure 19. Example of a *plunging rocky shoreline* (near center of image), south shore of Lopez Island, San Juan sub-basin. A small *pocket beach* occurs at far right. (photo from Washington Department of Ecology).**

**Veneered Rock Platform (Figure 20)**

<u>Geology</u>
Bedrock (see file: gunit_lu_REV)

<u>Slope</u>
Any slope

<u>Dominant Processes</u>
Drift directional (LtoR, RtoL), divergent (DZ), or convergent (CZ); and beach development evident in air photos.

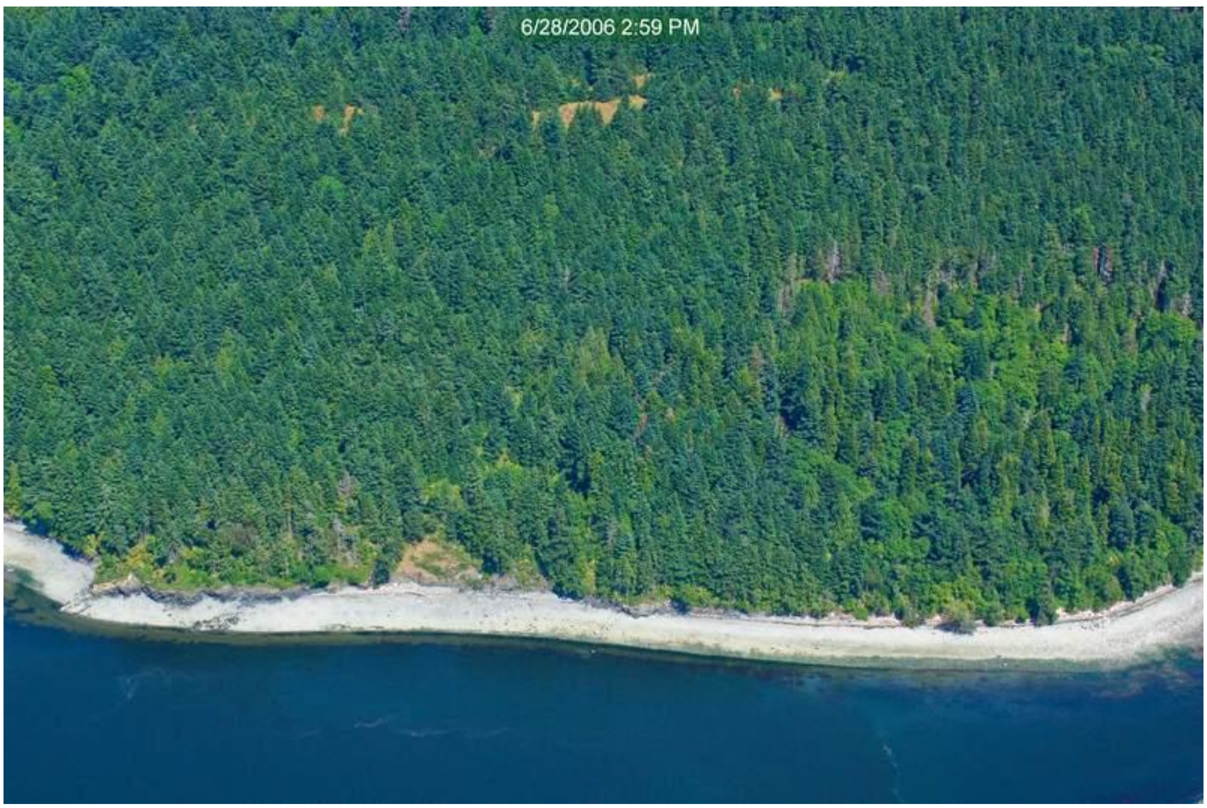


**Figure 20. Example of a *veneered rock platform*, west shore of Lummi Island, San Juan sub-basin (photo from Washington Department of Ecology).**

***Pocket Beaches (General Criteria)***

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

Topography:
Any slope

<u>Dominant Processes</u>
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

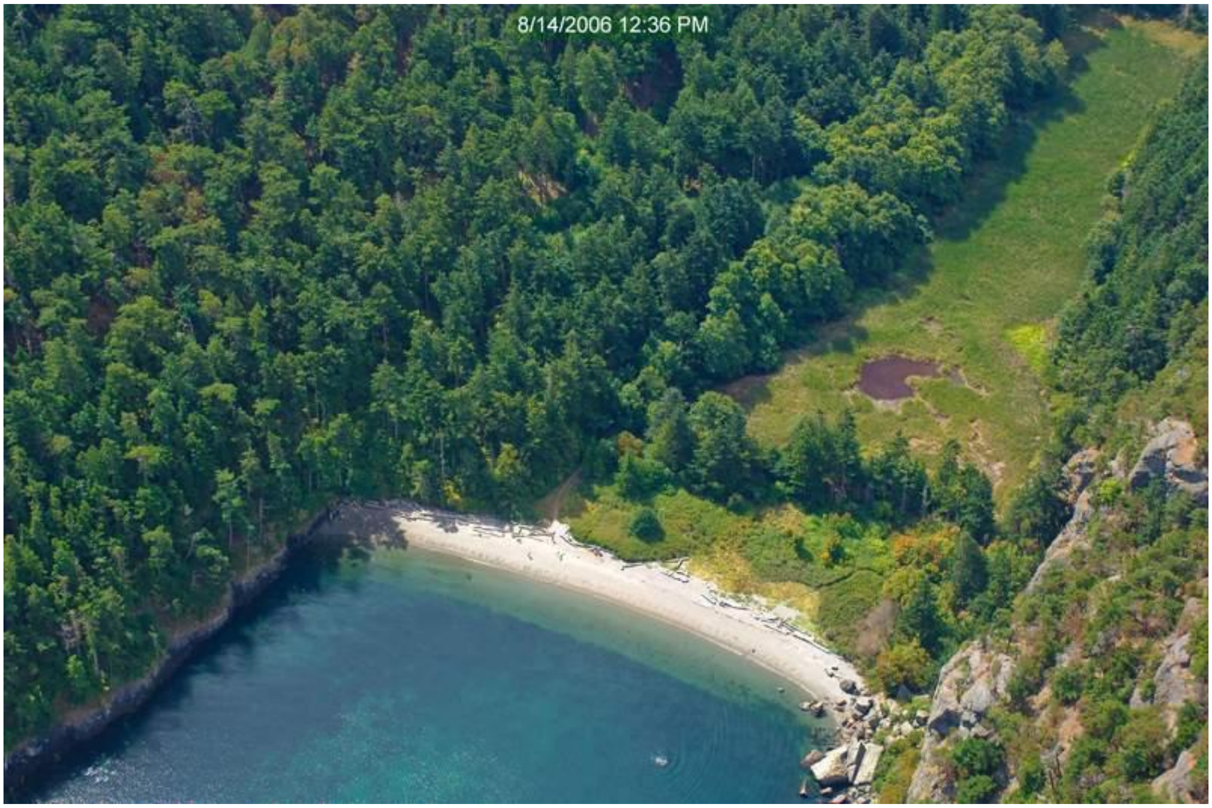

**Figure 23. Example of a *pocket beach closed lagoon/marsh*, Watmough Bay, Lopez Island, San Juan sub-basin (photo from Washington Department of Ecology).**

***Modified* (note: this is <u>not</u> a geomorphic unit type)(Figure 24)**

<u>Geology</u>
Geology typically obscured and indicated as Qf (fill)

<u>Slope</u>
Any slope

<u>Dominant Processes</u>
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, <u>not</u> 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).**

## References

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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 |
|---|---|
| *Tidal Channel Estuary* | *Tidal Channel Marsh** |
| *Tidal Channel Lagoon* | *Tidal Channel Lagoon* |
| *Drowned Channel* | *Drowned Channel* |
| *Drowned Channel Lagoon* | *Drowned Channel Lagoon* |
| | *Tidal Delta*** |
| | *Tidal Delta Lagoon*** |
| *Delta* | *Delta* |
| *Delta Lagoon* | *Delta Lagoon* |
| | *Pocket Beach Estuary*** |
| | *Pocket Beach Lagoon*** |
| | *Pocket Beach Closed Lagoon/Marsh*** |
| | *Pocket Beach*** |
| | *Closed Lagoon/Marsh*** |
| *Longshore Lagoon* | *Longshore Lagoon* |
| | *Beach Seep*** |
| *Depositional Beach* | *Depositional Beach* |
| *Sediment Source Beach* | *Sediment Source Beach* |
| *Transport Beach**** | *Transport Beach now combined with Sediment Source Beach* |
| *Spit Beach* | *Barrier Beach** |
| | *Plunging Sediment Bluff*** |
| *Deepwater Embayment**** | |
| *Rock Platform* | *Rocky Shoreline** |
| *Plunging Rock Cliff* | *Plunging Rocky Shoreline** |
| *Veneered Rock Platform* | *Veneered Rock Platform* |
| *Artificial* | *Modified* |