

Beach Strategies Phase 1 Summary Report

Identifying Target Beaches to Restore and Protect

Estuary and Salmon Restoration Program Learning Project #14-2308

Prepared for the Estuary and Salmon Restoration Program
Prepared by Coastal Geologic Services, Inc.

**Contributors: Andrea MacLennan, Branden Rishel, Jim Johannessen, Alison Lubeck
and Lauren Øde**



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Table of Contents

Executive Summary.....	2
Background	3
Data and Revisions.....	3
Shore Armor	3
Existing Armor Mapping: Compilation and Assessment	4
Updated Armor Mapping.....	5
Armor Workshop	7
Historical Feeder Bluff Mapping	7
MODs to Shoretypes	9
Pocket Beaches	9
Fetch and Erosion Potential	10
Updated Net Shore-Drift Mapping	13
Revised Naming Convention	14
Divergence Zones.....	15
Net Shore-Drift Cell Linear Referencing.....	16
Shoreline Parcel Database	17
Euclidean Allocation.....	17
QA/QC	17
Attribution.....	17
Discussion of Data and Data Gaps	18
Shore Armor	18
Historical Feeder Bluffs	19
Modified (MOD) Shores to Shoretypes.....	20
Pocket Beaches	21
Fetch and Erosion Potential	23
Net Shore-Drift Cells and Divergence Zones.....	24
Shoreline Parcel Database	25
Nearshore Geospatial Framework	26
Integration with Existing Nearshore Datasets	27
Beach Strategies Workshops	28
Future Directions	29
Shore Armor Mapping	29
Historical Feeder Bluff Mapping	29
Bluff Crests and Bluff Structures.....	30
Data Maintenance.....	30
Appendices.....	31
Glossary.....	32
References	36

Executive Summary

This document describes significant updates to coastal data for the Puget Sound region. CGS has updated and refined historical and current records, including:

- ◆ New high-resolution shore armor mapping for 367 miles (15%) of Puget Sound shoreline, with elevation, condition, and material attributes (214 of these miles for Island County; CGS 2016c).
- ◆ A compilation of existing Sound-wide shore armor.
- ◆ Shore armor and shoretypes disentangled to answer the question of where historical feeder bluffs are located, using complimentary remote assessment and field-based methods.
- ◆ Comprehensive historical shoretype mapping for all other armored shores.
- ◆ Pocket beach mapping, updated at higher resolution using more recent aerial imagery.
- ◆ New measures of fetch (the over-water distance over which wind-generated waves form), to update erosion potential.
- ◆ Corrected net shore-drift cells and incorporated divergence zones, including renaming all drift cells in a consistent way.
- ◆ Drift cells were turned into *linear referencing* routes, which allow simple GIS queries to answer what is up-drift or down-drift of anything else.
- ◆ The Washington Department of Fish and Wildlife (WDFW) residential shoreline (real estate) parcel dataset was augmented to include all non-residential parcels.
- ◆ Land parcels adjacent to shore were extended waterward to connect with rich coastal data.

All components included in the *Beach Strategies Geodatabase* conform to the Washington Department of Natural Resources (WDNR) ShoreZone shoreline (2001), making this data compatible with many existing Washington State coastal datasets.

In combination with the data structures in the companion *Nearshore Geospatial Framework* project, these data will enable refined nearshore restoration and conservation planning. For example, the improved historical feeder bluff inventory, used in conjunction with armor mapping and net shore-drift cell data, could be readily applied to identify priority areas for shore armor removal restore critical sediment transport mechanisms and to promote forage fish spawning habitat restoration.

Future work will involve community stakeholder workshops to create an online mapping tool to apply these data to answer Sound-wide coastal restoration questions.

Funding for *Beach Strategies* comes from the Estuary and Salmon Restoration Program (ESRP) Learning Project, RCO #14-2308P. The Historical Feeder Bluff mapping amendment to *Beach Strategies* was funded by the Puget Sound Partnership. Island County boat-based armor mapping was funded by the Salmon Recovery Funding Board, the NOAA Pacific Coastal Salmon Recovery Fund, and the United States Environmental Protection Agency under Assistance Agreement [PC-00J90301] National Estuary Program funds. The associated *Nearshore Geospatial Framework* project was completed for the Puget Sound Partnership.

Background

The objective of *Beach Strategies* is to develop an integrated dataset representing best-available information that can be used by nearshore managers to assist decision-making and nearshore recovery. The project name “Beach Strategies” implies the overarching objective of these data, which is to inform management strategy development within beach systems in the Puget Sound region.

Approximately half of the shoreline length in the Puget Sound region consists of beach systems, which are defined as the shores in which beach sediment is transported by waves from eroding bluffs to barrier beaches and the many gradations in between (Cereghino et al. 2012; Shipman 2008; Simenstad et al. 2011). Prior to the development of these data, nearshore restoration and protection strategy development relied on several Sound-wide datasets, many of which required updates or improvements to support effective and efficient shore management (Cereghino et al. 2012).

The data developed as part of the *Beach Strategies* project improves upon previous data sets pertaining to shore armor, shoretypes, fetch and erosion potential, net shore-drift cells, and marine waterfront parcels — all used to assess nearshore geomorphic processes. However, these previous datasets were not readily integrated with existing data sources, and much of the information they contained was outdated, or was of a lower quality resolution. The updates applied to the *Beach Strategies* data sets will lead to improved understanding of the variable condition of nearshore processes in beach systems throughout the Puget Sound region. Beach formation and erosion, habitat availability for forage fish (a key food source for salmon), and identifying appropriate erosion control for coastal properties are all management concerns which depend upon access to these high-quality data.

Data and Revisions

Revisions made to extant nearshore data and the current condition of data included in the *Beach Strategies Geodatabase* are summarized below. For more information on data sources and methods applied to develop *Beach Strategies* data, refer to the *Beach Strategies GIS User’s Guide* (see Appendix A).

Shore Armor

Shore armor (structures placed on the shore to limit erosion, often referred to as bulkheads, revetments, and seawalls) present throughout the Puget Sound region adversely impacts nearshore processes, structures, and habitats (Dethier et al. 2016; Griggs 2005; Shipman et al. 2010). Armor alters patterns of erosion and deposition, and can sequester sediment inputs from adjacent eroding bluffs (Dethier et al. 2016; Johannessen and MacLennan 2007). Homeowners often build shore armor to prevent erosion and protect structures where sufficient setback from shore has not been maintained (Johannessen et al. 2014) or for other reasons such as landscaping.

Puget Sound armor mapping exists in various states of coverage, quality, age, and detail. CGS has worked to compile available data for analysis and to develop more consistent mapping approaches to improve data utility, using these methods in recent armor mapping projects throughout the Sound. The final *Beach Strategies* armor dataset consists of a compilation of best-available extant armor mapping data from the interim dataset (discussed below), and updated field- and remotely-mapped data.

Existing Armor Mapping: Compilation and Assessment

Initial armor quality assessment was conducted by a sub-group within the Puget Sound Ecosystem Monitoring Program — Nearshore Workgroup. This sub-group concluded that the Puget Sound Feeder Bluff Mapping database (MacLennan et al. 2013) contained the best-available records of armor mapped within net shore-drift cells (areas with appreciable drift patterns). Armor mapping from Simenstad et al. (2011) and Friends of the San Juans (2010) in San Juan County was preferred for areas of No Appreciable Drift (NAD) Sound-wide, and Accretion Shoreforms in Island and Whatcom Counties. These datasets were compiled from 23 different sources derived from field- and remote-based collection methods, spanning 16 years, to produce the interim dataset used to prioritize mapping updates for this project. Of the 2,461.7 miles of shore data included, the majority (2,023.1 miles) were mapped in the field, with the remaining 438.6 miles mapped remotely.

Four regions representing a combined 247.5 miles of Puget Sound shore were deemed Very High priority for conducting armor mapping updates, including most of Clallam County and parts of Kitsap, Mason, and Pierce Counties. An additional 278.8 miles were High priority in the interim dataset, including Discovery Bay to Port Townsend, the Great Bend of Hood Canal, and Whatcom County (Figure 1, left frame; CGS 2016b). High priority areas within NAD shores included portions of Hood Canal, sites between Pt. Defiance and the Nisqually River Delta, and areas within Snohomish and Skagit Counties. See the *Puget Sound Shore Armor Assessment Memo* in Appendix F for more details.

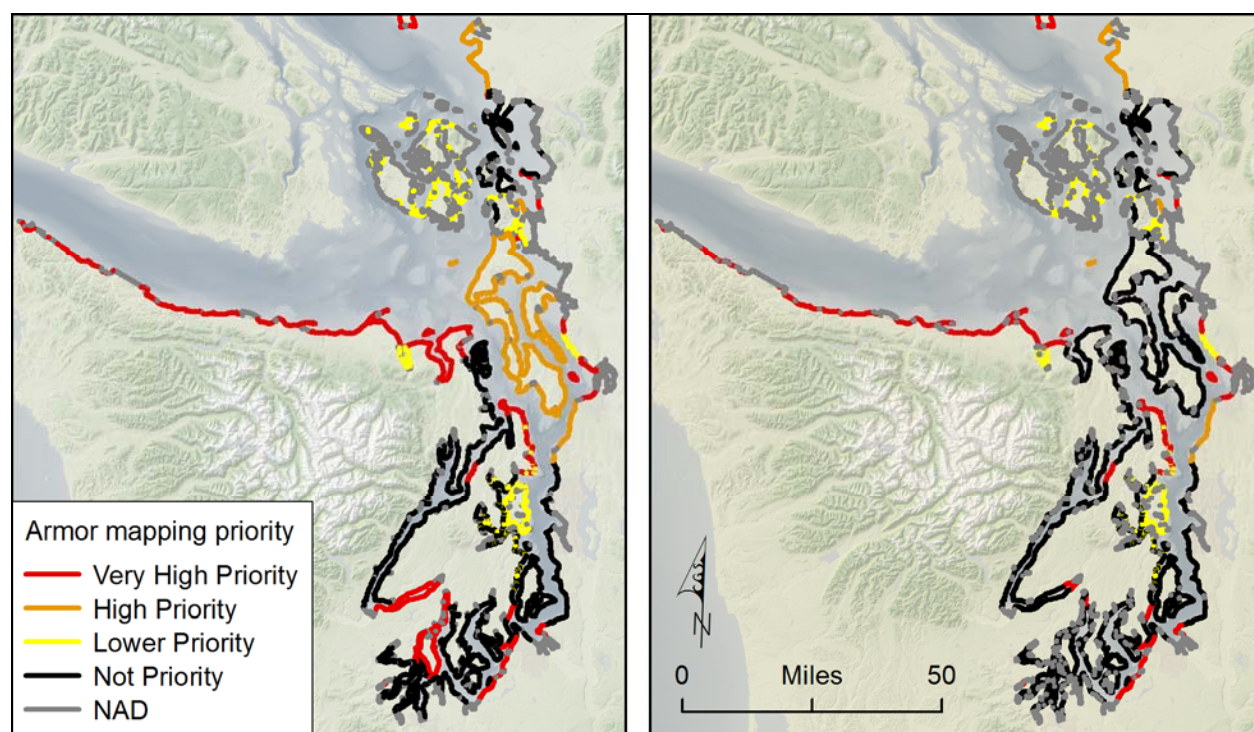


Figure 1. Map showing priority areas for armor mapping updates after the compilation of the interim dataset (left) and after recent updates were applied (right).

Updated Armor Mapping

New boat-based armor mapping using a Trimble GPS and laser rangefinder was completed by CGS in May and June of 2016. This mapping covered 153 miles of marine shoreline in Discovery Bay, the Port Townsend area, the Great Bend of southern Hood Canal, western Case Inlet, and Hartstene Island. Additionally, all of Island County's 214 miles of marine shoreline was mapped by CGS during this time for a separate project (CGS 2016c). The results of that mapping are included in the *Beach Strategies Geodatabase*.

Armor mapped in both of these efforts included the following attributes:

- ◆ Armor condition: OK, Functional but Failing, or Derelict
- ◆ Armor material: Rock, Concrete, Wood, Creosoted Wood, or Other
- ◆ Tidal elevation of armor toe: Below Mean Sea Level, Below Mean Higher High Water (and above MSL), Below the Ordinary High Water Mark (and above MHHW), in the Dunegrass, or farther Upland
- ◆ Historical feeder bluff status: Yes, No, or Unknown

As armor condition and elevation attributes were determined quickly at a distance, these values should be regarded as informational estimates, and not as engineering assessments.

Additional armor mapping updates were conducted for regions within the study area that were impossible to map by boat, such as shallow embayments, marinas, and sloughs, using remote mapping methods based on aerial photography (Figure 2). A lower confidence in remotely-mapped data than field-collected data was indicated in GIS attributes, as it is difficult to determine armor condition and material using these methods.

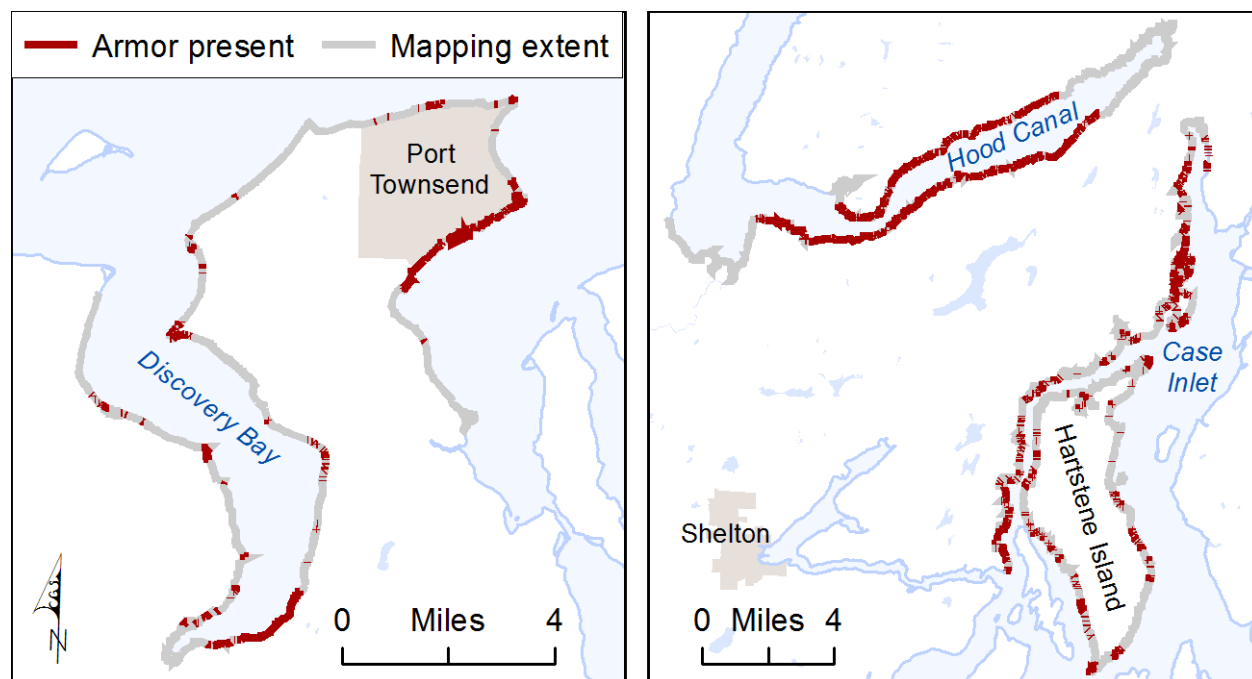


Figure 2. Extent of armor mapping for this project, and where armor was found. Shown are portions of Jefferson County (left) and Mason County (right).

Field and remote mapping data were aligned with the Washington State DNR ShoreZone Shoreline (WDNR 2001) such that the lines were topologically coincident. This process can sometimes cause small shifts in the data; original line lengths were preserved in a separate attribute field. Figure 3 shows an example of how recorded points are translated to the ShoreZone shoreline and attributed with relevant field data. The minimum mapping unit for shore armor was 20 feet (FT), though the minimum mapping unit for other source data varied widely. Very short (<20 FT) armor segments and changes in armor attributes were not recorded.

Field and processing notes were recorded for each armor segment, including historical armor mapping notes and comments. Updated armor mapping may contain notes about unusual materials, anchored logs, structures, fill, and whether geometry was modified from field data. A four-digit number or range of numbers indicates the file number associated with a field photograph.

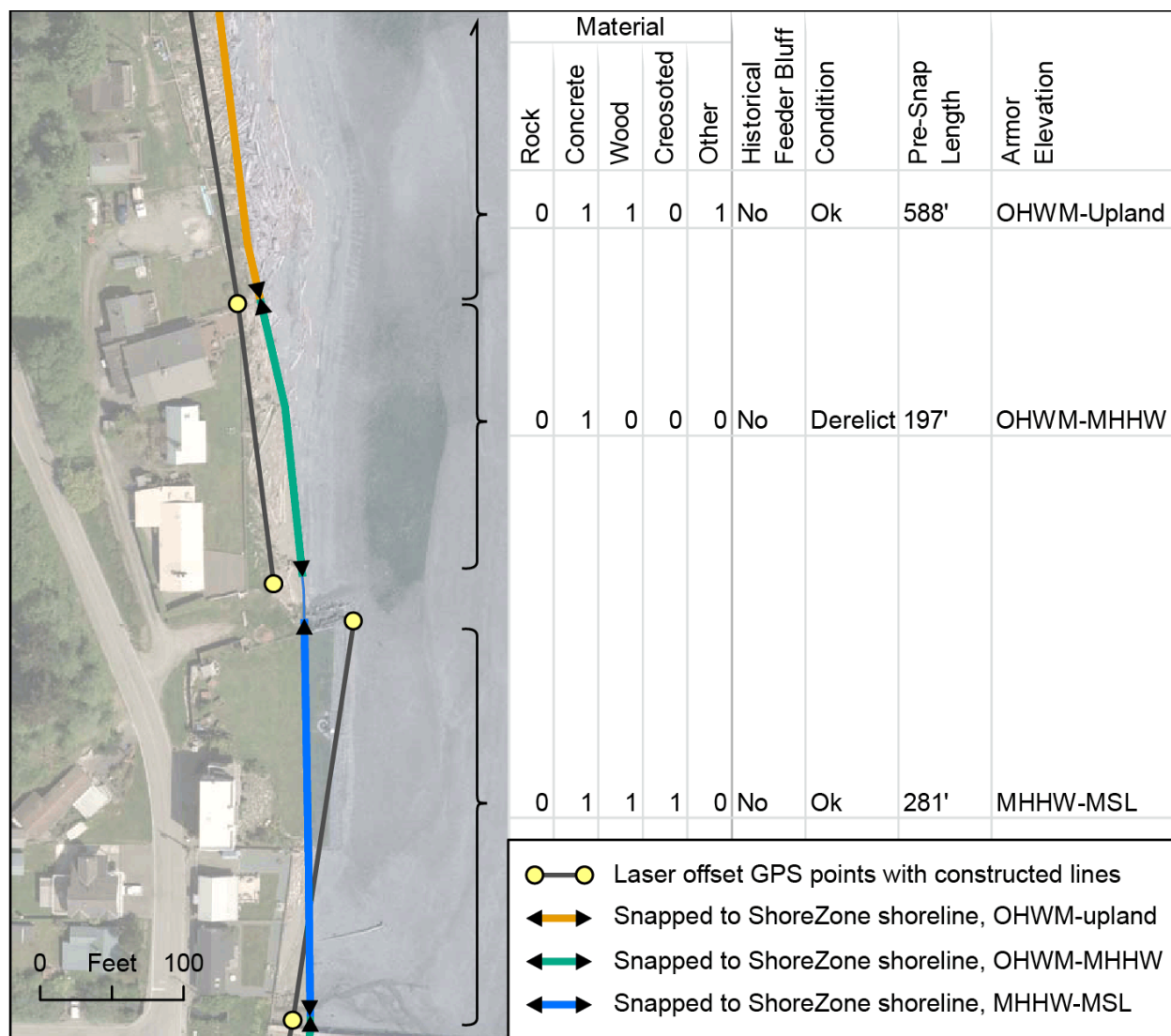


Figure 3. Schematic, fictionalized example of how armor GPS points are attributed and moved to the ShoreZone shoreline.

Armor Workshop

Local collaboration on armor mapping has led to the development of a data collection and management protocol to increase consistency and reliability between past and future armor mapping projects, increasing the utility and value of these data over time. The Puget Sound Partnership, in support of the Puget Sound Vital Signs project, convened a workshop that was held on May 18th, 2017 at the University of Washington campus where key members in the ongoing armor discussion voiced their concerns and goals for existing and future armor mapping datasets. The workshop discussed the following key points:

- ◆ Current definitions and assumptions
- ◆ Past and present GIS data sources and data gaps
- ◆ Armor attribute data and mapping methods
- ◆ Historical (armored) feeder bluff mapping within drift cells
- ◆ Methods for tracking temporal change
- ◆ Data management best practices
- ◆ Communication and outreach to develop strategies for planning and restoration

The workshop reviewed the current understanding of armor mapping data and its importance in Sound-wide strategic planning. Several key conclusions were reached in the discussions.

- ◆ Targeting removal or soft shore protection projects should focus on a larger context of land use and geomorphological issues, not just specific types of armor. Data collection should focus on shared goals and associated attributes.
- ◆ Current efforts are tracking the *extent* of armor, not change over time, as many older datasets are incomplete.
- ◆ The most important armor attributes for salmon recovery are tidal elevation, condition, shoretype. For example, low armor elevation may prevent nearshore ecosystem functions and derelict armor may be a candidate for removal.
- ◆ Due to rising seas, over-topping of armor, and increased precipitation rates due to climate change, some areas mapped as transport zones may become more erosive and transition to feeder bluffs.
- ◆ Possible methods to track temporal change include comprehensive surveys, project-level data analyses, HPA permitting data, crowd-sourced data, and survey/observed comparisons.
- ◆ Proposed armor mapping projects that use a regional data collection protocol will be prioritized over ones that do not.

Discussions are set to continue in the *Tool Development Workshop*, planned for October 2017. The full report of the May 18th workshop is included in the appendices.

Historical Feeder Bluff Mapping

The term *feeder bluff* is used in the Puget Sound region to describe bluffs that provide a significant volume of sediment to the beach (Bauer 1974; Johannessen 2010). Beaches, sustained by the ongoing supply of sand and gravel from feeder bluffs, are a key element in the Puget Sound nearshore ecosystem. Many bluff property owners in the Puget Sound region construct erosion control structures (armor/ bulkheads) to try to prevent bluff erosion and landslides. When feeder bluffs become modified by the addition of armor and no longer provide this valuable “beach feeding” function, they are referred to as *historical feeder bluffs* (HFBs).

As with updating armor mapping in Puget Sound, mapping HFBs began with compiling existing data in order to determine where additional historical feeder bluff mapping was necessary. Existing HFB mapping data consisted of multiple datasets using the Historical Sediment Source Index (HSSI) analysis (Johannessen et al. 2005), and refined with field-based mapping observations (MacLennan et al. 2013). For more detail pertaining to source data, refer to the *Beach Strategies GIS User's Guide* (Appendix A). For more information regarding HSSI methodology and calibration, refer to *Puget Sound Feeder Bluffs: Completing Sound-Wide Historical Feeder Bluff Mapping* (CGS 2016a; Appendix C).

Areas identified as requiring additional HFB mapping were first subjected to an automated assessment. The automated assessment was designed to screen for the most clear-cut cases and followed by a more detailed review of shores that were most difficult to assign a shoretype. For example, bluffs with considerable documentation of repeated erosion were very likely to be HFBs, and shores without bluffs were clearly never feeder bluffs. The combined criteria (Table 1, columns 1–3) were used to identify shore segments that were most likely feeder bluffs and did not require additional high resolution assessment (column 4). Additionally, shores that were evaluated and mapped as potential feeder bluffs (PFB) in previous CGS assessments were flagged as having a low level of certainty and did not receive additional historical assessment.

Table 1. Level of certainty of historical feeder bluff mapping of armored bluff-backed beaches with various levels of exposure, documented landslides, and adjacent feeder bluffs used in the preliminary automated assessment of historical feeder bluffs. Exposure refers to ShoreZone shoreline mapping categories.

Calculated Exposure (From ShoreZone Shoreline)	Documented Landslides	Adjacent Feeder Bluffs	Certainty of Historical Feeder Bluff Mapping
Semi-protected or greater	Yes	Yes	Very high
Semi-protected or greater	No	Yes	High
Protected	Yes	Yes	High
Semi-protected or greater	No	No	Moderate
Protected	No	Yes	Moderate
Protected	No	No	Low
Very protected	Yes	Yes	None
Very protected	No	Yes	None

Following the preliminary automated assessment, a more detailed secondary assessment was conducted on remaining shore segments for which time and funding were available, using visual remote assessment of aerial photos. Each reach of shore was evaluated for feeder bluff characteristics common to the standard feeder bluff mapping typology (Johannessen and Chase 2005; MacLennan et al. 2013). Supporting datasets included landslide mapping (Qwg Applied Geology et al. 2012; WDNR, DGER 2009, 2016a, 2016b; WDOE 1979), LiDAR DEMs (PSLC n.d.), and historical shoretype data from the Puget Sound Change Analysis (Simenstad et al. 2011). Where erosion was documented in the historical imagery, it was noted the GIS attribute table as supporting documentation that the unit was a feeder bluff, and the level of certainty associated with that reach being an HFB was qualified accordingly (Low, Moderate, High). Figure 4 includes examples of erosion occurring along historical feeder bluffs.



Figure 4. 1997 oblique imagery of feeder bluffs in central Case Inlet showing jackstrawed trees (left) and landslide scarps (right; CGS 2016a).

HFB mapping included in the *Beach Strategies Geodatabase* incorporates and augments all previously completed mapping (HSSI, field-based mapping) with updated methods and shoretypes. The results of these efforts and more detailed methods are addressed in the *Beach Strategies Secondary Assessment of Historical Puget Sound Feeder Bluffs: Final Results Summary* (CGS 2017; Appendix E).

MODs to Shoretypes

The “MOD” (modified or armored) shoretype segments in MacLennan et al. (2013) that were *not* found to be feeder bluffs were also assigned a shoretype. Where encountered during the HFB assessment, a shoretype was assigned based on PSNERP shoretype, aerial imagery, and geomorphological interpretation. Elsewhere, coasts corresponding to PSNERP bluff-backed beaches (BLB) were attributed as transport zones and barrier beaches (BAB) became accretion shoreforms. Small slivers resulting from GIS processes (e.g., from armor ends or snapping) were assigned by adjacent shoretype. Other cases were individually interpreted as above.

Pocket Beaches

Pocket beaches are typically small beaches that are contained between (bedrock) headlands, in which there is commonly no sediment exchange between the pocket beach and the adjacent shores. Pocket beaches were comprehensively mapped throughout the Puget Sound region as part of the *Puget Sound Change Analysis* (Simenstad et al. 2011), but that mapping occurred at a coarse resolution (30 meter minimum mapping unit) and erroneously included many beaches that were mapped within net shore-drift cells. CGS also developed and applied a pocket beach mapping method in San Juan County, the county in which pocket beaches are most abundant, in 2011 (Whitman et al. 2012). The *Beach Strategies* project compiles and augments these existing pocket beach data to more accurately reflect the occurrence of pocket beaches throughout the Puget Sound region.

Pocket beaches that were erroneously mapped within drift cells in the Puget Sound Change Analysis were identified and flagged for removal. Shoretype mapping in these areas was replaced with higher resolution mapping from the Puget Sound Feeder Bluff geodatabase (MacLennan et al. 2013). Pocket beaches mapped by CGS in San Juan County were merged with the remaining pocket beaches in the edited *Puget Sound Change Analysis* dataset. CGS pocket beach mapping was applied at a finer resolution, with a 50 FT minimum mapping unit. The dataset was then augmented Sound-wide by an

experienced coastal geomorphologist conducting visual surveys using Ecology oblique and vertical imagery of the shoreline in GIS. All potential pocket beach locations within bedrock (NAD-B) and artificial shores (NAD-AR) were reviewed at 1:1,500 scale, and less in-depth surveys were conducted on low-energy (NAD-LE) and deltaic (NAD-D) shores. See Figure 5 for examples of new pocket beach mapping.



Figure 5. Newly mapped pocket beaches on Vendovi Island in Skagit County (left; only the northwest cove was previously mapped), and artificial pocket beaches (PB-AR) in West Seattle (right).

All mapped pocket beaches were swash-aligned, located outside mapped net shore-drift cells, and did not exhibit substantial littoral drift. Pocket beaches with very small backshore width (approximately 10 FT) were not included in the mapping effort. Most pocket beaches were identified within bedrock shores, although some were also mapped within deltas, low energy shores, and artificial shores.

A separate shore classification was developed to encompass pocket beaches associated with artificial shores (PB-AR). Pocket beaches associated with artificial shores can be contained by engineered structures such as revetments and groins or fill areas, as well as bedrock exposures, or a combination of natural and anthropogenic features. Fully engineered shores, as in the case of a beach nourishment project along an urbanized shore, can also be classified as pocket beaches. Such artificial pocket beaches are unique as they did not develop naturally, but they are relevant to nearshore management as habitat features with associated, unique shoreline management issues. Artificial pocket beaches can also form from the natural deposition of beach sediment adjacent to engineered structures, though these beaches must accumulate sufficient sediment to meet the width criteria for mapping enumerated above.

Fetch and Erosion Potential

Fetch is defined as the unobstructed over-water distance over which wind-generated waves form. In the Puget Sound region, most waves are fetch limited, so fetch can be used as a proxy for wave height where no wave modelling data is available (USACE 1984). Older coastal data, such as the Feeder Bluff Mapping dataset, relied upon calculations of effective fetch at large intervals along the ShoreZone shoreline (MacLennan et al. 2013). This included shore-normal (perpendicular) fetch, fetch 45 degrees to either side, and a weighted average of these values (modified effective fetch).

Obvious conflicts arise with respect to fetch when using the ShoreZone shoreline for several reasons. Effective fetch is sampled from only three directions, allowing for smaller obstructions to easily skew the value, which is potentially not representative of actual conditions. Figure 6 shows an example of where this method describes wave climate better than the ShoreZone effective fetch.

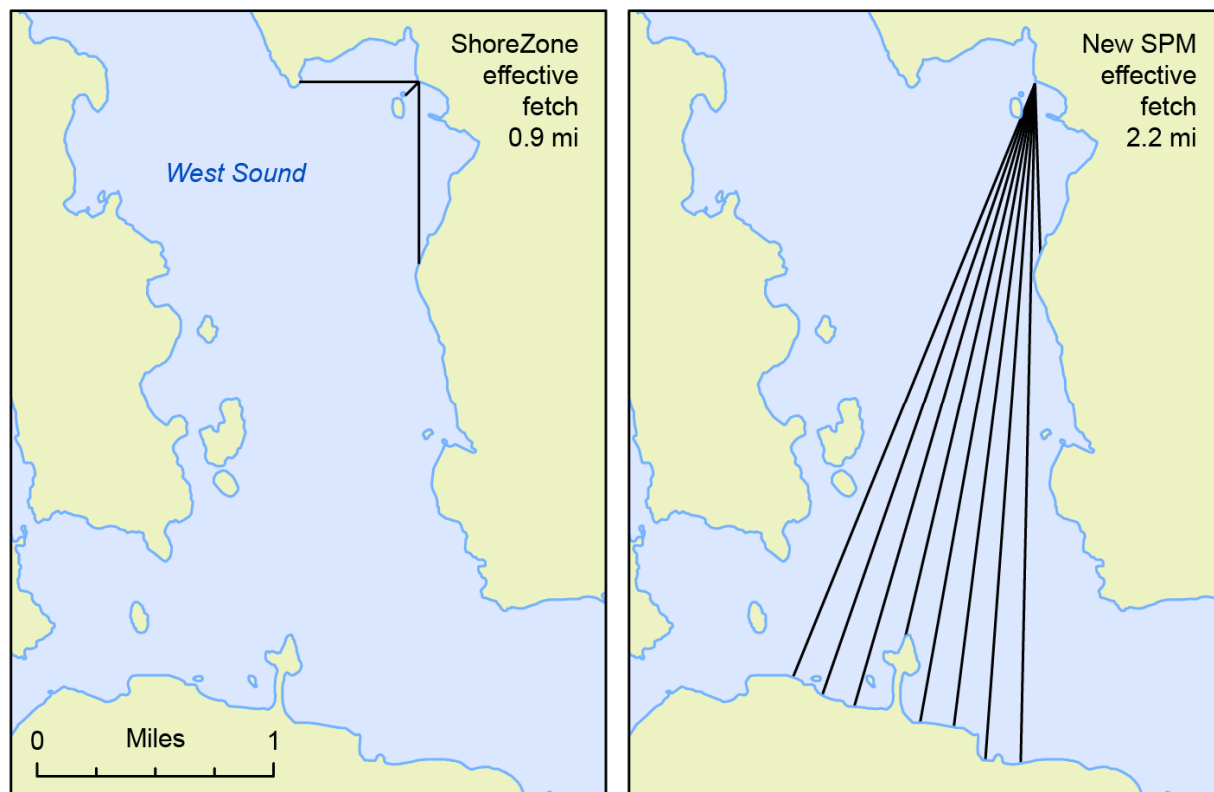


Figure 6. A comparison between ShoreZone effective fetch (left) and the improved SPM method (right) for a shoreline segment on Orcas Island.

Additionally, ShoreZone fetch measures are assigned to long segments of shoreline, some of which extend around a point and thus are subjected to different wave exposures. This new method applies a much higher sample spacing, with a minimum spacing of 250 FT alongshore.

In 2005, David Finlayson developed a script for calculating effective fetch following guidelines laid out in the Shore Protection Manual (USACE 1984). Since then, these methods have been adapted for use in many habitat restoration and rehabilitation projects (Rohweder et al. 2012). For this project, a series of more detailed fetch calculations were performed using this model, and attributed to the *Beach Strategies Geodatabase* for each possible wind direction at 2-degree intervals. For each of those possibilities, fetch was averaged at 3-degree intervals over a 24-degree swath. Final maximum averaged fetch values were attributed to each shoretype segment. Unlike some fetch calculations, fetch to the south was not doubled. An example of results for the San Juan Islands is shown in Figure 7.

A few locations in Clallam County and on Whidbey Island have fetches which extend far beyond the extent calculated — up to at least 7,200 miles. These few large fetch measures were not calculated due to processing constraints; therefore, measures of fetch over approximately 60 miles are not representative and should be used with caution.

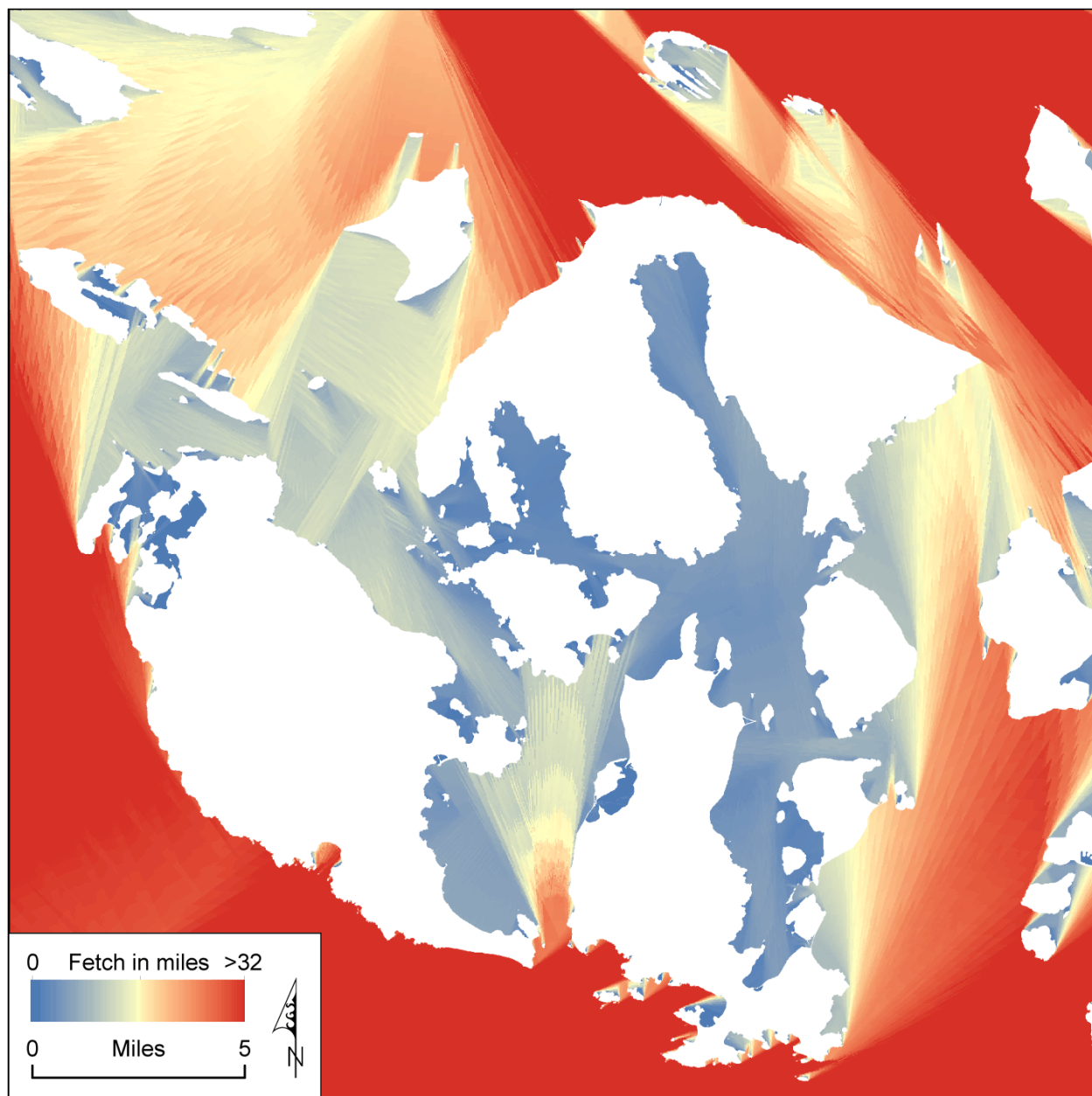


Figure 7. Example of calculated maximum fetch for the San Juan Islands.

Fetch distance, when combined with additional data, is useful for evaluating other aspects of nearshore management. Different shoretypes, for example, are variably susceptible to wind and wave erosion. The WDFW Marine Shoreline Design Guidelines (MSDG) includes protocols for jointly evaluating fetch and shoretype to assign relative *erosion potential* to a site; this value can be coupled with infrastructure data to evaluate a site's estimated *cumulative risk* (Johannessen et al. 2014). The cumulative risk at a site is valuable for identifying appropriate shoreline management designs or approaches. Calculated effective fetch was sorted into bins and assigned a point total based on sorting. The maximum value was 4. Similarly, shoretype designations were assigned a point value based on their relative ability to erode. The highest value was 4, given to feeder bluff exceptional shoretypes. Refer to Table 2 for more information on how point values were assigned.

Table 2. Erosion potential was calculated based on a combination of relative erosive tendencies of shores and wave exposure. The maximum value is 8, for FBE shores with fetch greater than 15 miles. From WDFW *Marine Shore Design Guidelines — Cumulative Risk Model* (Johannessen et al. 2014).

EROSION POTENTIAL			
Shoretype	Score	Maximum Fetch	Score
No Appreciable Drift (NAD)-Bedrock/Low Energy	0	0–1 mile	1
Modified, Accretion Shoreform, NAD-Delta	1		
NAD-Artificial, Transport Zone, Pocket Beach	2	1–5 miles	2
Feeder Bluff	3	5–15 miles	3
Feeder Bluff Exceptional	4	15+ miles	4
Erosion Potential Score = Shoretype Score + Fetch Score			

Calculating relative erosion potential in this manner inherently introduces some error, as higher resolution data is placed into lower resolution bins (i.e. fetch values of 1–4 and shoretype values of 0–4). This metric assumes shorelines have more or less fixed geomorphic shoretypes that are subject to a consistent amount of wave exposure. Real-life behavior of the erosive qualities of a shore reach is difficult to quantify in this way, but a general estimated *potential* based on known characteristics gives a baseline from which analysis and restoration priorities may stem.

Updated Net Shore-Drift Mapping

Drift cells have been mapped for the Puget Sound region over several decades by multiple mappers, most of whom were students of the late Western Washington University coastal geology professor Maurice (Maury) Schwartz. The various mapping efforts, originally conducted using paper maps, were later digitized by WDOE, which entailed considerable challenges in translating endpoints in coarse resolution into the higher resolution GIS workspace. The subjectivity required to interpret the original mapping and the original digitizing methods, combined with inconsistencies across several original mappers over decades, introduced numerous errors. CGS principal geologist Jim Johannessen, the last of the original mappers, mapped over 500 miles of shore including all of San Juan County and parts of Jefferson, Island, and Snohomish Counties (Johannessen 1992).

Many revisions were identified and applied to the WDOE data by CGS to the CGS in-house net shore-drift data. These revisions occurred over many years, resulting from several mapping efforts and characterizations to support Shoreline Master Program updates. The CGS in-house revisions formed the foundation for many more hundreds of revisions applied by CGS to the Sound-wide net shore-drift cell dataset in 2007 in support of the Puget Sound Change Analysis (Simenstad et al. 2011). Many additional revisions were identified and applied as part of the Puget Sound Feeder Bluff mapping (MacLennan et al. 2013). Still, divergence zones (DZs), critical areas where drift splits and is transported in both directions alongshore, needed to be updated to be compatible with the new drift cell corrections. These were individually assessed and hand-corrected, where errors existed, using ArcGIS Editor tools.

Following new armor mapping, several segments across Puget Sound were found to be in error and were updated using the best available information from previous mapping efforts. For example, a large net shore-drift cell (approximately 4,600 FT in length) on the Mason County mainland near Hartstene Island that had been formerly classified as exhibiting left to right (L to R) net shore-drift was reclassified as several smaller drift cells with alternating L to R and right to left (R to L) drift. Other similar cells of varying sizes were split and reclassified in all other counties. Long, adjacent NAD areas were merged in Whatcom, Skagit, and Snohomish Counties.

Revised Naming Convention

Upon updating drift cell mapping for the Sound, a new naming convention was developed to increase clarity in the dataset. The existing net shore-drift cell naming convention was often unclear and inconsistent. The updated renaming scheme addresses these issues by using fixed-length, non-hyphenated name fields to identify different drift cell segments by county, associated landform, and individual drift cell number.

The first two characters of the updated naming scheme identify the county to which each drift cell segment belongs. Each code is derived from the first two letters of the county name, with the exception of Kitsap (KS) and San Juan (SJ) Counties, following previous convention. Drift cells falling completely within a county were automatically assigned the associated county code, and those belonging to two counties were manually assigned to the county they originated in.

The second set of characters distinguishes between the landforms associated with each drift cell segment. Segments belonging to islands with an area greater than 0.5 square kilometers (km²), and segments belonging to islands with an area less than 0.5 km² that exhibited net shore-drift, were assigned a unique two-letter code derived from the island name. Segments belonging to islands with an area less than 0.5 km² and that exhibited no appreciable drift were assigned the code "IS." All non-island segments belonging to the mainland were assigned the code "MA". Polygons derived from the original ShoreZone Shoreline dataset were used to select islands of different size categories, which allowed for automation of code assignment to mainland drift cell segments, and to islands of <0.5 km² with no appreciable drift. Codes for islands larger than 0.5 km², and/or islands with appreciable drift, were assigned manually.

The third set of characters is a manually-assigned, three-digit numeric code which serves as a unique identifier for each drift cell within each county-island or county-mainland subset. Drift cells associated with county mainland were assigned numbers in ascending order beginning at 001, such that the first mainland drift cell in Skagit County would receive the code SKMA001. See Figure 8 for more information on how numbering was assigned for each county.

Areas of no appreciable drift (NAD) were coded similarly, by county and landform. If following or occurring within a drift cell, they inherit the three-digit number of that drift cell. All NAD areas follow this with an "N" and a one-digit ID number. For example, a NAD area just south of SKMA001 in Skagit County would be identified as SKMA001N1.

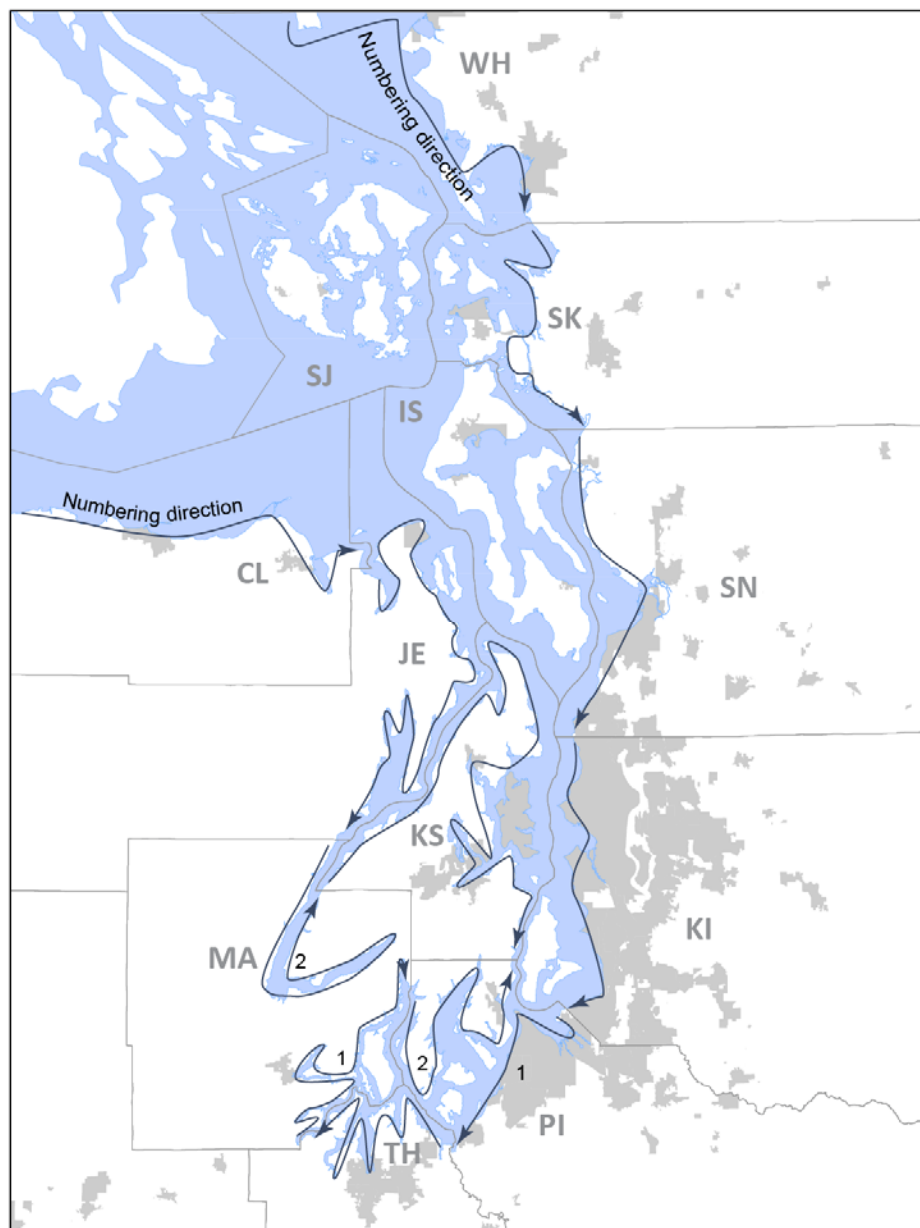


Figure 8. Direction of net shore-drift cell naming along mainland parcels. For Pierce and Mason Counties, areas labeled 1 were numbered before areas labeled 2.

Updated drift cell names can be found alongside their original names within the *Beach Strategies* dataset. Information on integrating newer data with older versions is outlined below in *Integration with Existing Nearshore Datasets*.

Divergence Zones

Divergence zones (DZs) typically encompass the origins of two diverging net shore-drift cells, in which littoral drift may occur in either opposing direction. Therefore sediment eroded from within drift cells has the potential to supply sediment to considerable lengths of down-drift shore. Divergence zone mapping was beyond the scope of the net shore-drift updates recently applied by MacLennan et al. (2013), so the most up-to-date net shore-drift mapping lacked divergence zones. Revisions made to the

drift cell mapping required that DZ mapping be revisited to reflect these changes and revisions to net shore-drift mapping made for this project.

Previously unmapped DZs were located and added to the dataset, and unnecessary DZs were flagged for review. All changes to the divergence zone dataset were checked by an experienced coastal geomorphologist and engineering geologist.

The resulting divergence zones are presence-absence line attributes. All mapped divergence zones are also within net shore-drift cells (Figure 9). Note that GIS precision greatly overstates the precision of these “fuzzy” features. Actual divergence of sediment transport varies over time due to subtle differences in wind and waves associated with each storm event. Divergence zone mapping is meant to capture the long-term average position of these areas (Jacobsen and Schwartz 1981).

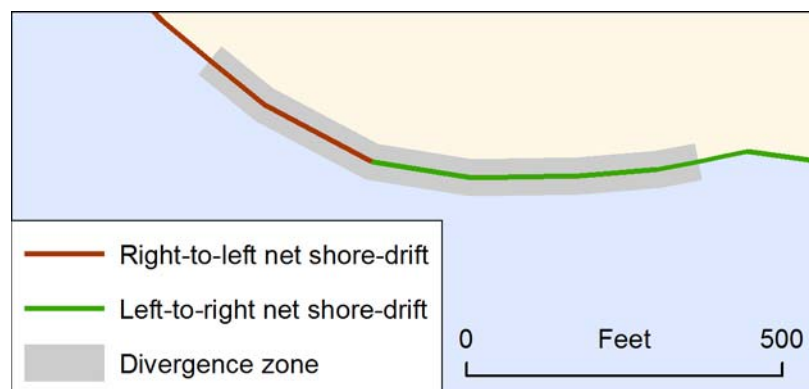


Figure 9. Divergence zones overlap net shore-drift cells.

Net Shore-Drift Cell Linear Referencing

Linear referencing of net shore-drift cells was completed Sound-wide, following completion of updated net shore-drift mapping. Linear referencing enables analyses of relationships between features along a common line; GIS users can query point, line, or polygon data that are up-drift or down-drift of an area of interest and analyze the relationships between them.

Analysis of historical sediment contribution with respect to a linear sediment transport network can provide data for drift cell management, a concept that has been discussed for decades in this region. For example, when using these new data it is now possible to explore options for restoration of sediment-starved reaches in relation to the removal of armor from historical feeder bluffs, or to investigate the potential down-drift impacts from proposed armor construction. It is also possible to quantify HFB sediment input that is impounded behind shore armor in drift cells, and compare to the historical extent of sediment input.

Net shore-drift cell linear referencing does not apply to NAD areas, such as bedrock shore or marinas and embayments, as there is an absence of littoral drift in these areas. When performing analysis over a large area, NAD areas and areas with drift must be treated separately.

The shoreline parcel database (described below) includes the results of linearly referencing the shoreline-intersecting parcels, for those parcels within net shore-drift cells. These include the lowest and highest addresses, and the names of intersecting drift cells.

Shoreline Parcel Database

In 2014, CGS completed a Sound-wide residential parcel geodatabase for site restoration prioritization and outreach efforts (CGS 2014). This parcel information was used in subsequent projects and studies along with other Sound-wide datasets (net shore-drift, forage fish habitat, etc.) to highlight high-benefit sites for armor removal (CGS 2015; CGS and NWSF 2017). High-benefit refers to the relative potential for restoring natural conditions, especially forage fish spawning habitat and feeder bluff sediment supply. For the *Beach Strategies Geodatabase*, this dataset was updated to include non-residential parcels for comprehensive coverage of ownership and management of Puget Sound shores.

Euclidean Allocation

Parcel polygons were obtained from the Washington Statewide Parcel Database, a project initiated by the University of Washington College of the Environment (Rogers and Cooke 2012). Original parcel geometry did not initially intersect the state-wide ShoreZone shoreline, so it was difficult or impossible to query attributes from the ShoreZone shoreline. To make this information transferrable to the parcel database, the Euclidean Allocation tool was used in ArcGIS to extend the parcels waterward to ensure they came into contact with the ShoreZone shoreline.

QA/QC

In some cases, automatic processing errors in Euclidean Allocation produced parcels that overlapped, did not extend far enough waterward, or otherwise contained data gaps. Each of the 93,236 parcel polygons was checked and often hand-edited in ArcGIS, using topology relationships to maintain data interconnectivity and ensure coincident borders and prevent parcel overlap. This task was completed for the residential parcels first and later incorporated non-residential parcels for comprehensive coverage using the same methods.

Attribution

All extended and edited parcels were intersected with the collected shoreline data, and the results were summarized for each parcel.

The original parcel identifier (PolyID) was used to join this same information back to the original assessors' parcel geometry. Parcel ID numbers were also transferred to the shoreline. *Beach Strategies* shoreline data (e.g., shoretype and net shore-drift attributes) were transferred to adjacent parcels, and these data were summarized for each parcel.

Parcels modified through Euclidean Allocation were not included in the final project deliverables, in order to avoid confusion with actual parcel geometry. The *Beach Strategies Geodatabase* contains original parcel polygons with new attributes from the comprehensive shoreline dataset. Detailed assessor data on property ownership is not included with the database, due to data use restrictions to protect landowners' privacy, and to allow the data to be shared among the nearshore community.

Despite extensive work to ensure parcels appropriately coincided with the ShoreZone shoreline, problems with data integrity of the source parcel geodatabase remain. It is apparent that many houses cross recorded property lines, suggesting that the original parcel extents are in need of review and some are likely in error. Although the parcel database represents the best-available GIS data for this purpose, there are known problems that arise when working on small regions. Parcel data and assessment of associated shore attributes is best applied over larger areas of interest.

Discussion of Data and Data Gaps

Complete editions of updated mapping of shore armor, shoretypes, fetch and erosion potential, net shore-drift, parcels, and linear referencing results were incorporated into a final, integrated feature class in the *Beach Strategies Geodatabase*. The updates to the *Beach Strategies Geodatabase* are intended to equip the user with current, high-quality datasets for shoreline restoration and other inquiries on a regional scale. The elements included in this dataset are intended to represent best-available information, and the work conducted by CGS to improve these datasets has been largely successful (though limited in resolution and extent where funding and time did not allow for more extensive updates). CGS has addressed uncertainty associated with previous and updated mapping efforts throughout. A discussion of important results follows in the same order as the preceding sections.

Shore Armor

New armor mapping data were included in over 367 miles of priority armor mapping areas in Jefferson, Mason, and Island Counties (see full-page maps in Appendix G). The Island County portion was mapped through the *Island County Armor Mapping Project* for the Island County Department of Natural Resources (CGS 2016c). New boat-based field mapping methods piloted by CGS in Island County yielded far more accurate data than had been collected by previous remote or field-based mapping efforts, and armor mapping updated through remote imagery was performed using more recent, higher resolution imagery than had been applied in previous efforts. An additional 159.3 miles of Puget Sound shore remains a priority area for mapping. Table 3 and Figure 10 show updated armor length totals by county.

King County has the greatest percent of armored shore (55% armored), as compared to other counties, followed by Pierce County (53%) and Kitsap County (48%). The least percent of armor was documented in San Juan, Jefferson, and Clallam Counties.

Table 3. Updated armor lengths by county, in miles and as a percent of shore length. Differences in totals, when compared to earlier mapping efforts, may be a result of increased mapping resolution and a more accurate field-based approach (rather than mapping with aerial photos). Note that armor mapping is still incomplete and almost certainly understates the extent of shore armor, especially in areas mapped remotely or not recently mapped. See the *Puget Sound Shore Armor Assessment Memo* (Appendix F) for more discussion.

County	Unarmored, miles	Armored, miles	Total, miles	Percent Armored
Clallam	128	31	159	20
Island	163	54	217	25
Jefferson	173	28	202	14
King	56	67	123	55
Kitsap	132	122	254	48
Mason	158	74	232	32
Pierce	114	127	240	53
San Juan	382	26	408	6
Skagit	155	74	229	32
Snohomish	96	37	133	28
Thurston	71	45	116	39
Whatcom	115	31	146	21
Sound-wide	1745	715	2,460	29

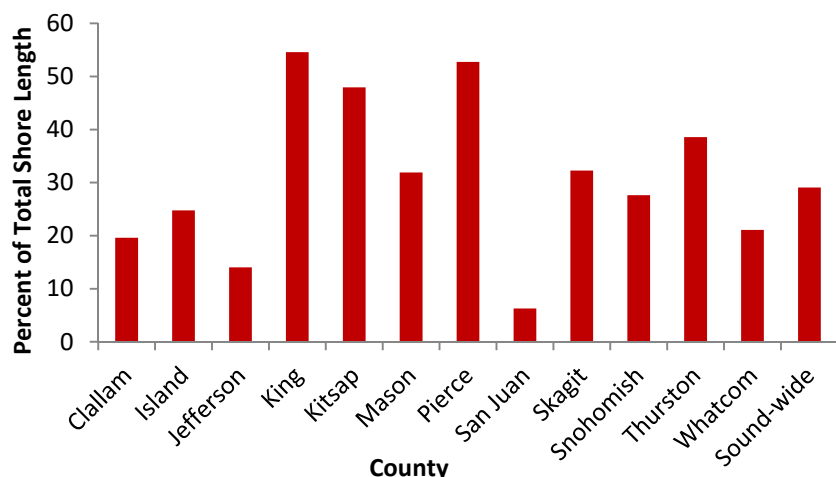


Figure 10. Shore armor length by county, as a percent of shore length.

A comparison between shore armor documented in previous years and armor mapped in 2016 is possible. However, because of differences across historical records and processing artifacts resulting from “snapping” (aligning) previous armor mapping to the ShoreZone shoreline, these results should be interpreted with caution. Some instances where armor was apparently *added* in the new mapping efforts may not have been recorded in previous years, especially where such armor was obscured by drift logs during high tides (CGS 2016c). Similarly, instances where armor was apparently *removed* from previous mapping efforts often represents armor that was incorrectly mapped in historical mapping. Areas where armor records were *maintained* from historical records may contain transposition errors resulting from snapping to the ShoreZone shoreline.

Historical Feeder Bluffs

Updated shoretype mapping for armored shores has significantly increased the level of insight into the extent of armored feeder bluffs in the Puget Sound region. The mapping of historical feeder bluffs and other armored shoretypes occurred in two parts: an automated preliminary analysis and an in-depth secondary analysis. The preliminary and secondary analyses combined assigned shoretypes to approximately 490 miles of armored shores in the Puget Sound region. Table 4 describes results by county. Key findings include:

- ◆ 656.6 miles of feeder bluffs in the Puget Sound region
- ◆ 223.0 miles of these are armored feeder bluffs
- ◆ 34% of feeder bluffs in the Puget Sound region are armored

Snohomish and King Counties had the greatest percent of historical feeder bluffs lost to shore armor, followed closely by Thurston County. The greatest lengths of armored feeder bluff were found in Pierce, Kitsap and King Counties. Greatest lengths of intact feeder bluffs are found in Island and Jefferson Counties. A more detailed review of results can be found in the *Secondary Assessment of Historical Puget Sound Feeder Bluffs: Final Results Summary* (CGS 2017; Appendix E).

When using these data it should be noted that accuracy of identifying HFBs by the remote automated assessment is dependent upon the quality and coincidence of datasets pertaining to erosive potential, and these datasets are not always of uniform quality and certainty Sound-wide.

Table 4. Tabulated summary of all updated shoretype results with percent of armored feeder bluffs by county. This data reflects the comprehensive updated shoretype dataset, with previously mapped shoretypes of non-armored shores and newly mapped armored shoretypes via this effort and others.

County	FB Intact, miles	FB Armored, miles	FB Total, miles	Percent FB Armored
Clallam	33.6	7.8	41.3	18.8
Island	72.9	21.3	94.2	22.6
Jefferson	72.0	9.1	81.1	11.2
King	21.1	32.4	53.5	60.5
Kitsap	50.0	33.9	83.8	40.4
Mason	42.8	22.2	65.0	34.2
Pierce	47.8	43.1	90.8	47.4
San Juan	22.4	7.6	30.0	25.3
Skagit	21.0	9.2	30.2	30.5
Snohomish	7.5	14.9	22.4	66.6
Thurston	16.0	18.3	34.3	53.4
Whatcom	23.9	6.0	29.8	20.1
Sound-wide	430.9	225.7	656.6	34.4

A secondary visual assessment was applied to areas where automated methods yielded lower certainties. The overall certainty field is intended to characterize the relative confidence in the shoretype assessment and serves to characterize these data inconsistencies. As time and funding allowed, the secondary assessment was designed to achieve Sound-wide HFB and shoretype mapping with lesser detail than a more intensive approach; therefore, more work may remain to achieve higher levels of historical shoretype certainty where needed.

Modified (MOD) Shores to Shoretypes

After all remaining armored areas were assigned a shoretype, the resulting shoretypes are as described in Table 5 and Figure 11. Key results include:

- ◆ Island, Jefferson, and King Counties have feeder bluff shores (FB, FBE, FB-T) along over 40% of their shoreline. Island, Kitsap, and Pierce Counties contain the most miles of feeder bluffs (including unarmored feeder bluffs and historical feeder bluffs).
- ◆ San Juan County has 27% of the NAD areas in the region, and by far the most pocket beaches. Whatcom County has more artificial pocket beaches than any other county.
- ◆ Considerably more NAD shore is found in the counties that encompass the large river deltas (Skagit, Snohomish, and Whatcom Counties).
- ◆ Greater lengths of accretion shoreforms are found in northern counties (such as Clallam, Island, and Jefferson Counties), where generally higher wave energy and lesser tidal range focuses wave energy on the upper range of tidal elevations, promoting development of these features.
- ◆ Clallam, San Juan, and Skagit Counties all have a low percentage of feeder bluff shoreline.
- ◆ Feeder bluff talus shores are most frequently found in Clallam and Jefferson Counties.
- ◆ Transport zones were prevalent across most counties but more abundant in the southern Puget Sound (such as Mason, Kitsap, and Pierce Counties), where wave energy is limited due to the complex nature of the shore.

Table 5. Shoretype lengths by county (including historical shoretype where armored). Units are in miles.

County	FB Excep- tional	Feeder Bluff	FB, Talus	Transport Zone	Accretion Shoreform	NAD (all)	Pocket Beach	PB Artificial	Total miles
Clallam	10	19	12	23	45	48	1	0	159
Island	15	79	0	29	65	28	0	0	217
Jefferson	9	69	4	29	42	48	2	0	202
King	4	50	0	23	12	33	0	0	123
Kitsap	1	82	0	68	37	64	1	0	254
Mason	0	65	0	71	32	63	0	0	232
Pierce	4	87	0	54	20	75	0	0	240
San Juan	3	26	1	35	25	270	49	0	408
Skagit	2	27	1	18	17	158	6	0	229
Snohomish	1	22	0	6	6	98	0	0	133
Thurston	0	34	0	24	6	52	0	0	116
Whatcom	2	26	2	12	30	71	3	1	146
Sound-wide	51	585	20	393	337	1,008	62	2	2,460

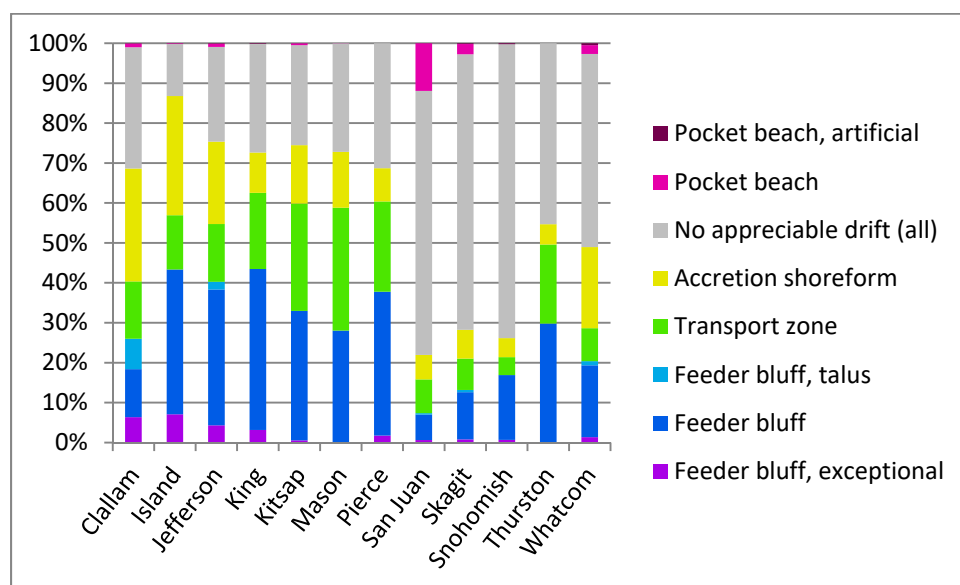


Figure 11. Percent of shoretype by county (including historical shoretype where armored).

Pocket Beaches

Updated pocket beach mapping was conducted for all of Puget Sound by an experienced coastal geologist and coastal geomorphologist. Fifty-four (54) pocket beaches that were previously mapped (Simenstad et al. 2011) in drift cells were removed from the data set. The data was then augmented to include pocket beaches at a finer resolution, with a minimum mapping unit of 50 FT in shoreline length (at high tide). Note that many pocket beaches likely exist in the region that are smaller than 50 FT in length. Mid-resolution (1:12,000) vertical air photos along with WDOE oblique air photos were used to verify the presence of pocket beaches. Future field-based mapping of shore armor and historical feeder

bluffs could potentially include verification of remotely-mapped pocket beaches identified in the *Beach Strategies* dataset. Field verification would be most valuable in Clallam County, where there are long lengths of bedrock shore and available imagery was of a coarse resolution. Tables 6 and 7 provide a breakdown of results by county.

Table 6. Pocket beach total lengths by county.

County	New PB, mi	New PB-AR, mi	Total New, mi	Total PB, mi	Total PB-AR, mi	Total PB & PB-AR, mi	% New Mapping
Clallam	0.7	0.1	0.8	1.5	0.1	1.6	50.4
Island	0.2	0.1	0.3	0.3	0.1	0.4	65.8
Jefferson	0.1	0.2	0.4	1.6	0.2	1.8	19.0
King		0.2	0.2		0.2	0.2	100.0
Kitsap		0.1	0.1	1.1	0.1	1.2	4.7
Mason				0.1		0.1	0.0
San Juan				48.7	0.1	48.7	0.0
Skagit	0.7	0.4	1.2	5.8	0.4	6.3	18.5
Snohomish		0.3	0.3		0.3	0.3	100.0
Whatcom	0.3	0.7	1.0	3.3	0.7	3.9	24.4
Totals	2.0	2.1	4.1	62.4	2.2	64.6	6.4

Table 7: New mapped pocket beaches, total by count.

County	New PB	New PB-AR	Total New	Total PB	Total PB-AR	Total PB & PB-AR	% New Mapping
Clallam	10	3	13	17	3	20	65.0
Island	4	4	8	5	4	9	88.9
Jefferson	8	9	17	25	9	34	50.0
King		6	6		6	6	100.0
Kitsap		1	1	19	1	20	5.0
Mason			0	2		2	0.0
San Juan			0	946	3	949	0.0
Skagit	24	3	27	96	3	99	27.3
Snohomish		2	2		2	2	100.0
Whatcom	13	17	30	54	17	71	42.3
Total	59	45	104	1,164	48	1,212	8.6

Because pocket beaches are exclusively found within bedrock shores with no appreciable drift, they are limited in distribution. San Juan County has more bedrock shore than any other county, so their prevalence there is unsurprising. Following San Juan County, the greatest lengths of pocket beach shores were found in Skagit and Whatcom Counties. Fewer numbers of pocket beaches are found in Jefferson, Clallam, and Kitsap Counties. Artificial pocket beaches most commonly occur in urbanized or heavily altered shores, such as long the BNSF causeway in Whatcom, Jefferson, and King Counties.

Fetch and Erosion Potential

Fetch distances included in this dataset represent a substantial improvement over previous estimates, applying a weighted average over 3° intervals instead of 45° intervals. Additionally, fetch was applied to individual shoretype segments, which are much smaller and more site-specific than segments in the state ShoreZone shoreline, which often exhibited a static fetch measure for a shoreline with a significantly varied orientation.

Increased accuracy of maximum fetch distances for a site subsequently improve the erosion potential rating, and understanding of relative risk. As noted in the MSDG, erosion and mass wasting do not pose a risk unless there is a threat to infrastructure (Johannessen et al. 2014). However, understanding a site's relative erosion potential also pertains to other elements of nearshore management, including assessing the likelihood of historical feeder bluff presence, assessing appropriate erosion control measures, and identifying important sediment sources for habitat maintenance.

Fetch mapping results highlighted the well documented gradient of exposure throughout the Puget Sound region. Shores exposed to 15+ miles occur along over 16% of the Puget Sound shore (Table 8). The greatest fetch is in the Northwest Straits, including Clallam County, followed by Whatcom, San Juan, and Island Counties. Region-wide, shores have more moderate fetch, with 36% ranging from 5–15 miles of fetch, and 35% with 1–5 miles of fetch. Shores with less than 1 mile of fetch occur along 13% of all shores.

Table 8. Fetch category by county.

County	0–1 Miles		1–5 Miles		5–15 Miles		15+ Miles	
	Miles	Percent	Miles	Percent	Miles	Percent	Miles	Percent
Clallam	7	4	15	9	12	7	126	79
Island	12	6	20	9	138	63	47	21
Jefferson	24	12	68	34	88	44	22	11
King	19	15	26	21	67	55	11	9
Kitsap	34	13	125	49	87	34	9	3
Mason	39	17	155	67	37	16	0	0
Pierce	41	17	92	38	108	45	0	0
San Juan	29	7	147	36	132	32	100	24
Skagit	50	22	61	27	84	37	34	15
Snohomish	31	23	47	35	43	32	12	9
Thurston	28	25	63	54	25	22	0	0
Whatcom	3	2	29	20	67	46	47	32
Total	318	13	849	35	887	36	406	17

Similar to fetch, the highest erosion potential occurs in the Northwest Straits counties (Table 9; Clallam, Jefferson, Island Counties). The bulk of the Puget Sound region has more moderate erosion potential. The least erosion potential is found in San Juan, Snohomish and Skagit Counties.

Table 9. Erosion potential by county. Values of “0” indicate units less than 0.5 that were rounded to no decimal places. Values of “-” indicate there were no recorded values for the given criteria.

County	EP=1		EP=2		EP=3		EP=4		EP=5		EP=6		EP=7		EP=8	
	Mi.	%	Mi.	%	Mi.	%	Mi.	%	Mi.	%	Mi.	%	Mi.	%	Mi.	%
Clallam	7	4	6	4	5	3	32	20	43	27	31	19	27	17	9	6
Island	7	3	6	3	13	6	54	25	47	22	62	29	19	9	10	4
Jefferson	19	10	16	8	23	11	39	19	46	23	39	19	14	7	5	3
King	1	1	0	0	21	17	21	17	32	26	39	32	9	7	0	0
Kitsap	27	10	19	8	28	11	70	27	63	25	43	17	4	2	0	0
Mason	27	11	19	8	45	20	68	29	57	24	16	7	0	0	-	-
Pierce	17	7	18	7	33	14	44	18	75	31	52	22	2	1	-	-
San Juan	17	4	92	23	105	26	116	28	47	12	23	6	6	1	2	0
Skagit	13	6	54	24	40	17	61	27	29	13	24	11	7	3	1	0
Snohomish	-	-	31	23	49	37	6	4	19	14	22	16	6	5	-	-
Thurston	27	23	12	10	6	5	27	24	37	31	7	6	-	-	-	-
Whatcom	2	1	11	7	22	15	36	25	37	26	22	15	16	11	1	1
Total	163	7	286	12	389	16	572	23	532	22	380	15	109	4	29	1

Net Shore-Drift Cells and Divergence Zones

Updated mapping of net shore-drift cells and divergence zones addressed previous incomplete mapping, resolved conflicts between previous mapping efforts, and addressed erroneous data. Best-available data from previous mapping efforts were assessed and used to check newer mapping. Where drift cell directions and extents were altered, a cardinality attribute was applied, indicating whether drift cell names in the *Beach Strategies* dataset represented a “1 to 1”, “1 to Many”, “Many to 1”, or “Many to Many” relationship with the PSNERP dataset (Cereghino et al. 2012; Schlenger et al. 2011). Users should pay special attention to drift cells with other than “1 to 1” cardinality when attempting to compare *Beach Strategies* net shore-drift cells with previous data editions. Note that net shore-drift cells mapped within the Puget Sound Change Analysis (Simenstad et al. 2011) represented historical drift patterns; changes to historical littoral drift are typically due to major alterations such as large breakwaters and jetties.

There are total of 945 net shore-drift cells distributed across 1,382.1 miles or 56.2% of the shoreline length in the Puget Sound region (Table 10). The longer drift cells are found in the northern counties, where there is greater fetch and less shoreline complexity. Far more cells are found in southern Puget Sound, where there is the greatest tidal range and shoreline complexity (such as Pierce and Mason Counties).

Table 10. Summary of current net shore-drift cells by their county of origin.

County of Origin	Net shore-drift cell count	Length of drift cells in miles	Shore length in miles	Shore % in drift cells (not NAD)
Clallam	40	110.1	159.0	69
Island	52	186.6	217.3	86
Jefferson	71	148.0	201.5	73
King	55	85.7	123.0	70
Kitsap	107	189.9	254.3	75
Mason	151	169.4	231.6	73
Pierce	155	164.5	240.5	68
San Juan	128	89.8	408.2	22
Skagit	59	64.8	229.2	28
Snohomish	11	39.0	132.7	29
Thurston	79	63.8	116.1	55
Whatcom	31	71.6	146.3	49
Total	939	1,383.0	2,459.7	56

Shoreline Parcel Database

Coastal parcels immediately adjacent to the Puget Sound shore were carefully checked and hand-edited using topology rules prior to applying associated *Beach Strategies* attributes, allowing for a more comprehensive analysis involving residential and commercial ownership (Table 11). Data users can now enjoy more complete parcel coverage and thus streamline any outreach efforts related to restoration and conservation planning efforts.

Table 11. Parcels by county. Parcels split between counties are double-counted.

County	Residential		Nonresidential		Parcel density
	Parcel Count	Shore Length, mi	Parcel Count	Shore Length, mi	Parcels per mile
Clallam	1,032	47	400	112	9
Island	5,861	137	957	77	32
Jefferson	3,299	118	411	83	18
King	3,297	68	553	52	32
Kitsap	7,789	200	740	54	34
Mason	5,534	155	733	77	27
Pierce	5,037	139	912	84	27
San Juan	4,584	280	385	124	12
Skagit	2,044	63	1,047	164	14
Snohomish	1,694	40	508	90	17
Thurston	2,627	81	211	35	24
Whatcom	2,202	58	763	77	22
Total	45,000	1,386	7,620	1,030	22

Similar to other *Beach Strategies* datasets that build off of or reference older data, errors with the source parcel dataset exist. Many parcels represent developed land with clear ownership, while others occur as smaller slivers of roads, dikes, right-of-ways, community owned trails or otherwise fragmented, non-specific areas with absent or unclear ownership data. Some stretches of shoreline have no associated parcel data as the state-wide parcel dataset did not include a feature. Extra caution should be used when addressing parcels adjacent to a railroad, as in many cases no railroad parcel exists but ownership still applies.

Parcel data should be used to inform general context, applying caution on larger scales, as it is not meant to replace results from high-quality site-specific surveys completed by a professional. Future updates to the *Beach Strategies* integrated parcel dataset would benefit from a state-wide update in parcel boundaries, including the creation of a railroad parcel(s). Additionally, an assessment of tidelands parcels would be extremely valuable as ownership can change from onshore to intertidal parcels, and more insight here may help to develop a better understanding of tidelands parcel owner responsibility and effects. Use of the current parcel information is best applied over large areas as current parcel attributes may inaccurately represent real property boundaries.

Updated parcel mapping revealed a cumulative total 52,578 shoreline parcels, including both residential and non-residential ownership on Puget Sound. Residential parcels encompassed 1,385 miles of shoreline or 56% of the Puget Sound. Non-residential parcels accounted for 1,030 miles or 42% of Puget Sound shore. The remaining 44 miles of shoreline (representing under 2% of the Puget Sound shoreline) either did not have ownership data or were absent from the source dataset. The greatest length of residential shore is found in San Juan, Kitsap, and Mason Counties. The most residential parcels are found within Kitsap, Island, Mason and Pierce Counties. The most non-residential parcels are found in Skagit, Island and Pierce Counties. It is not surprising that the counties with the greatest parcel density include Kitsap, King and Island Counties. In contrast the lowest parcel densities are found in Clallam, San Juan and Skagit Counties.

Nearshore Geospatial Framework

The Nearshore Geospatial Framework (NGF) was a project funded by the Puget Sound Partnership to develop an integrated dataset of aquatic and inland data to assist Chinook salmon recovery planning (CGS and WWU Spatial Institute 2017). The NGF was structured on a network of polygons generated from the *Beach Strategies Geodatabase*, conforming to the ShoreZone shoreline. Two sets of polygons – one with breaks defined by *Beach Strategies* shoretypes, and the other by *Beach Strategies* drift cells – extend from the ShoreZone shoreline to a depth of 10 m in the aquatic nearshore, and at overlapping ranges of 100, 200, and 400 FT, and 200 m onshore. *Beach Strategies* drift cell data was also used to develop pseudo-hydrologic basins for delineating onshore drainage adjacent to each net shore-drift cell.

Hydrologic Unit Code (HUC) 12 polygons from the Washington Department of Ecology were intersected with the ShoreZone shoreline, appending a summary of *Beach Strategies Geodatabase* attributes to each HUC 12 polygon. The *Beach Strategies Geodatabase* also includes the HUC12 and HUC 10 identifiers, which may be used to aggregate or summarize data by watersheds.

Other datasets were moved to the ShoreZone shoreline or summarized by intersecting NGF polygon, including:

- ◆ Stream mouths from the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP)
- ◆ WDNR eelgrass monitoring plots
- ◆ WDFW sand lance and surf smelt documented spawning areas
- ◆ WDFW herring holding and spawning areas

These NGF data can enable additional linkages between new *Beach Strategies* datasets and other nearshore datasets of value to nearshore restoration planning within beach systems, such as recently developed overwater structure mapping (NOAA in prep.) and other upland, offshore and polygon data from the *Puget Sound Change Analysis*.

Integration with Existing Nearshore Datasets

The *Beach Strategies Geodatabase* is designed to interact easily with existing datasets that are coincident with the ShoreZone shoreline (WDNR 2001). This includes much of the previous nearshore mapping work performed for the PSNERP Change Analysis (Cereghino et al. 2012; Simenstad et al. 2011), as well as other data used for Salmon Recovery by the Tribes and NOAA. When comparing data on the ShoreZone shoreline, topological checks frequently reveal important data characteristics. Ideas for integration with existing data include:

- ◆ **Shore Armor:** Old and updated armor datasets are readily comparable across the ShoreZone shoreline. Updated mapping was completed in Island County and parts of east Jefferson and Mason Counties. Where older armor mapping was carried forward from other shorelines, slight changes in line length and position may have occurred.
- ◆ **Historical Feeder Bluffs:** The presence of historical feeder bluffs was not complete in the Puget Sound Feeder Bluff dataset (MacLennan et al. 2013), and was partially derived from field-based mapping and analytical assessment of shore conditions as described above.
- ◆ **Pocket Beaches:** The updated dataset can be compared with the PSNERP mapping relatively easily, as both datasets conform to the ShoreZone Shoreline. Considerable differences are expected to exist between the PSNERP and *Beach Strategies* pocket beach mapping datasets, as they rely on very different minimum mapping unit lengths (30 m versus 50 FT) and *Beach Strategies* data does not consider pocket beaches within net shore-drift cells, as the applied mapping criteria excludes those areas. Pocket beach mapping can be linked with other data at the local level to fine focus salmon recovery efforts. Most notable are the linkages between forage fish spawning areas, as both of these data are of documented importance to salmonids that utilize the nearshore (Beamer and Fresh 2012). In addition, it should be noted that pocket beaches were not previously included in previous restoration and conservation strategy work (Cereghino et al. 2012), so there are several opportunities to link this mapping product with other data to elucidate new priorities and strategies.
- ◆ **Fetch and Erosion Potential:** Existing fetch values included in the ShoreZone Shoreline are very easily comparable with new fetch calculations included in the *Beach Strategies Geodatabase*. In the *Beach Strategies* dataset, fetch was calculated at 250-foot intervals along the ShoreZone shoreline and sampled for each shoretype segment with which they intersected.

- ♦ **Net Shore-Drift:** Net shore-drift was originally mapped for the Net Shore-Drift of Washington State (Schwartz et al. 1991) along the Department of Ecology mean high water (MHW) line, and has been reinterpreted by CGS numerous times. It is possible to “snap” the *Beach Strategies* net shore-drift cell data to the Ecology MHW line to compare these products, although care should be taken to best maintain spatial alignment. Original net shore-drift cell names were preserved in the *Beach Strategies* data with an additional cardinality attribute to signify the way they relate to the new names.

Drift cell mapping in the PSNERP database reflects historical drift conditions, while *Beach Strategies* data represents many additional corrections and interpretations of current drift. Note that the net shore-drift cells in the PSNERP data set overlap within divergence zones, whereas in the *Beach Strategies* data drift cells do not overlap, but divergence zones overlap with drift cells. Convergence zones were not mapped separately in the *Beach Strategies* Geodatabase.

- ♦ **Parcels:** Parcel data included in the PSNERP Change Analysis dataset included residential parcels only. Newer, public and commercially-owned parcels are now incorporated with this existing dataset using the same methods, spatially overlapping the ShoreZone shoreline. Onshore parcels can be easily populated with data from the *Beach Strategies* shoreline. If a more general approach is desired, it is possible to experiment with cluster tolerances to locate nearby parcels that do not intersect the ShoreZone Shoreline but are still a part of the coastal zone and may be of interest.

In addition to onshore parcels, the PSNERP Change Analysis dataset includes nearshore parcels extending to a depth of 10 m Sound-wide. This same extent was applied to aquatic nearshore polygons in the *Nearshore Geospatial Framework* and will serve as a valuable link between existing data iterations and the *Beach Strategies* Geodatabase.

Beach Strategies Workshops

Next steps for the *Beach Strategies* project entail working with nearshore managers to develop ways in which the *Beach Strategies* data can be used to meet strategic objectives for restoration, conservation and improved management in the nearshore. A preliminary presentation of the data and planning session for the stakeholder outreach workshops is scheduled for late July, 2017. Outreach efforts will commence with an online survey of nearshore managers to document the range of values and objectives driving nearshore strategy development across disciplines and stakeholders. Survey content will form the foundation for the *Beach Strategies Tool Development Workshop* (formerly referred to as the *Straw Dog Workshop*, as part of the Phase 1 *Beach Strategies* scope of work), which is planned for October 2017.

The objective of the *Tool Development Workshop* is to gain input on ways in which to use and expand upon the *Beach Strategy* data to meet the needs of local user groups. The workshop will begin with an introduction to the *Beach Strategies* geodatabase and related data including the *Nearshore Geospatial Framework* and the ways in which these data improve upon past data used in nearshore planning and management. Participants will be invited to share their data needs, and the challenges they experience trying to meet their restoration and management goals and objectives. An inventory of potential data queries and questions to ask the collective data will be developed based on the input from meeting

participants, which will form the basis for later tool development and forthcoming *Beach Strategies Workshop*. CGS and the WDFW will develop an online interactive mapping tool for this data.

Following the *Tool Development Workshop*, a data gaps assessment will also be conducted to identify ways in which new data linkages should be focused.

In phase 2 of the *Beach Strategies* project, continued stakeholder outreach will include additional workshops throughout the region. These efforts will include a discussion session at the up-coming 2018 Salish Sea Ecosystem Conference, with similar objectives of facilitating discussion and gathering input from nearshore restoration planners in the region. Results of the outreach workshops will be used to refine and apply the dataset to develop a science-based prioritization approach that will guide future protection and restoration efforts on beaches throughout the region.

Collectively, this second phase of *Beach Strategies* will result in the development of spatial analyses that will be used to prioritize nearshore management work. Additionally, a training curriculum will be developed to educate users on how to access and best use data and analytical outputs from the web-based tool. Final products from these stages will be transferred to the long-term data steward.

Future Directions

These datasets are ready to use for purposes not conceived of in upcoming planned work. For example, they could be used to identify or prioritize marsh restoration opportunities and for targeted outreach. Adjacency queries could identify parcels near currently preserved habitat or groups of adjacent parcels that could be restored together. Tideland and intertidal parcels could be combined with parcel and shoreline data. Parcels subject to tribal jurisdiction could easily be identified.

Shore Armor Mapping

During the recent Armor Workshop (May 18, 2017) the new armor mapping protocol developed and piloted by this project was reviewed and consensus was reached that while some parts of the protocol were more important than others, there was no need for major changes. Now that a mapping protocol has been proven satisfactory, completing the remaining 511 miles of armor mapping identified in the *Armor Assessment* (Appendix F) is the highest priority, followed by developing a program of rolling annual updates to maintain a high-quality, Sound-wide armor dataset. Through continued mapping with this new protocol, rolling updates will eventually ensure complete mapping of armor elevation, condition, and materials for the remaining 1,601 miles of shore in the Puget Sound region. For more details of how this could happen, see the *Shoreline Armor Indicators Workshop Report and Recommendations* and *Completing and Maintaining Sound-wide Armor Mapping*.

For reasons discussed in the *Armor Assessment* report, older sources of armor mapping contain additional attributes (e.g., tidal elevation) and a higher spatial resolution. These data could be incorporated in a new Sound-wide armor compilation.

Historical Feeder Bluff Mapping

Future efforts could increase the certainty of historical shoretype mapping, especially as better aerial imagery becomes available. The effort could also be expanded to identify exceptional feeder bluffs (FB-E shoretype) using geology mapping and LiDAR digital elevation models.

Bluff Crests and Bluff Structures

Erosion rate data from the ESRP Bluff Measures project has increased the utility of digitizing a Sound-wide bluff crest. A semi-automated method for delineating these bluff crests was developed during the *Nearshore Geospatial Framework* project, and is ready to be used for all bluffs in the region. These data can be combined with bluff structure digitization and bluff setback distances to enable regional characterization using the cumulative risk model in the MSDG.

Data Maintenance

Future updates to mapping of shore armor, historical feeder bluffs, bluff crests, and structures may easily be incorporated into future editions of the *Beach Strategies Geodatabase*. To facilitate clear use, current versions of these GIS feature classes are clearly labeled “Version 1”.

Any other data that are compatible with the ShoreZone shoreline can also be compared to *Beach Strategies* data products through normal GIS operations. By extension, many nearshore spatial datasets can be used with this project’s data via the *Nearshore Geospatial Framework*. See the *GIS User’s Guide* (Appendix A) and GIS feature class metadata for more details.

Appendices

Appendix A. *Beach Strategies GIS User's Guide* (October 25, 2017)

A detailed description of data modifications and caveats for GIS data users.

Appendix B. *Geodatabase Refinements Summary* (October 25, 2017)

Quick reference guide describing updates to each feature class.

Appendix C. *Puget Sound Feeder Bluffs: Completing Sound-wide Historical Feeder Bluff Mapping* (August 11, 2016)

Context for the HFB efforts, before recent work described in this document.

Appendix D. *Secondary Assessment of Historical Puget Sound Feeder Bluffs: Pilot Methods and Results Summary* (May 11, 2017)

Initial results of recent work performed for the HFB amendment to *Beach Strategies*.

Appendix E. *Secondary Assessment of Historical Puget Sound Feeder Bluffs: Final Results Summary* (June 28, 2017)

Final results of recent work performed for the HFB amendment to *Beach Strategies*.

Appendix F. *Puget Sound Shore Armor Assessment Memo* (March 25, 2016)

Description of the state of shore armor mapping before work described in this document.

Appendix G. Full-page maps of armor mapping results

Armor condition and elevation in portions of Jefferson and Mason Counties.

Glossary

Accretion: The gradual addition of sediment to a beach or to marsh surface as a result of deposition by flowing water or air (Shipman 2008). Accretion is the opposite of erosion.

Accretion shoreform (AS): Sediment sinks or depositional shores. Areas of the marine shoreline where sediment is deposited either currently or has done so in the past.

Adjacent shores: Generally considered the immediate vicinity of the project site from the project boundary to approximately 100–200 FT alongshore to either side. The length of adjacent shore should extend beyond the area of apparent impacts from the project.

Anchored: Characteristic describing large wood placement utilizing an artificial method of holding attachment such as chain or cable.

Armor: Rigid, permanent design techniques used to stabilize shorelines and prevent erosion.

Assessment: Processes that involve analyzing and evaluating the state of scientific knowledge and, in interaction with users, developing information applicable to a particular set of issues or decisions.

Backshore: The upper zone of a beach beyond the reach of normal waves and tides, landward of the beachface. Width is measured cross-shore from the waterward extent of the backshore to the waterward extent of upland vegetation or anthropogenic modifications.

Barrier beach (BAB): A linear ridge of sand or gravel extending above high tide, built by wave action and sediment deposition seaward of the original coastline (Shipman 2008).

Beach: The gently-sloping zone of unconsolidated sediment along the shore that is moved by waves, wind, and tidal currents. Width is measured cross-shore from the break in slope between the upper beach and the low-tide terrace and the waterward extent of the backshore.

Bluff crest: The highest point of a bluff or bank from which the slope levels off as part of the uplands.

Bluff: A steep slope rising from the shore. “Bluff” is typically used in the Pacific Northwest for a steep sea cliff composed of unconsolidated glacial or fluvial sediments that has no to moderate amounts of vegetation. This shoreform may also be referred to as a bank.

BNSF: Burlington Northern Santa Fe. A large railroad system within the study area.

Bulkhead: A hard armor technique, usually vertical, that maintains soil and abates erosion from waves and currents using rigid material.

Divergence Zone (DZ): An area where drift splits into two or more directions alongshore.

Down-drift: In the direction of the net longshore transport.

Drift [littoral] cell: A coastal compartment that contains a complete cycle of sedimentation including sources, transport paths, and sinks. See Johannessen and MacLennan (2007) for further description of drift cells.

Embayment: An indentation of the shore larger in size than a cove but smaller than a gulf.

Erosion: The wearing away of land by the action of natural or anthropogenic forces. Pertaining to a beach, the carrying away of beach material by wave action, tidal currents, littoral currents, or deflation (wind action). Erosion is the opposite of accretion.

ESRP: Estuary and Salmon Restoration Program.

Feeder bluff (FB): Coastal bluff with active erosion and/or mass wasting which periodically supplies moderate volumes of sediment to the nearshore with a longer recurrence interval than feeder bluff exceptional segments. The bluff face typically has vegetation indicative of disturbance with evidence of landslides and toe erosion (MacLennan et al 2013).

Feeder bluff exceptional (FBE): Coastal bluff with active erosion and/or mass wasting which periodically supplies substantial volumes of sediment to the nearshore in greater quantities with a shorter recurrence interval than feeder bluffs. The bluff face typically has little to no vegetation with active landslides and toe erosion, and may include colluvium and toppled large woody debris (MacLennan et al 2013).

Fetch: Open water distance over which a wind can blow unimpeded and form waves.

Historical Feeder Bluff (HFB): Refers to a bluff that has been armored.

Historical Sediment Source Index (HSSI): A remote method developed by Johannessen and Chase (2005) to determine the likelihood that a certain reach of shore was a feeder bluff prior to being armored.

HUC: Hydrologic Unit Code, developed by the US Geological Survey.

Infrastructure: Anthropogenic upland primary and secondary structures/improvements.

Landslides: A general term covering a large variety of mass wasting and processes involving the downslope transport of soil, sediment, or rock.

Littoral: Relating to the shore or a region along the shore.

Longshore transport: Transport of sediment parallel to the shore by waves and currents, also called littoral drift and alongshore drift.

Mass wasting: A general term for the downslope movement of soil and rock debris.

Mean higher high water (MHHW): The arithmetic mean of the elevations of the *higher* high waters of a mixed tide (as in Washington) over a specific 18.6-year period.

Mean lower low water (MLLW): The arithmetic mean of the elevations of the *lower* low waters of a mixed tide over a specific 18.6-year period.

Mean High Water (MHW): The arithmetic mean of the elevations of all the high waters of a mixed tide over a specific 18.6-year period.

MSDG: Marine Shoreline Design Guidelines (Johannessen et al 2014).

Nearshore: As defined by the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP), this includes the area from the deepest part of the photic zone (approximately 10 meters below Mean Lower Low Water [MLLW]) landward to the top of coastal bluffs, or in estuaries upstream to the head of tidal influence (Clancy et al. 2009).

Net shore-drift (NSD): The long-term, net effect of littoral or longshore drift along a particular coastal sector.

Net shore-drift cell: A net shore-drift sector from sediment source to deposition area along a particular coastal sector. A net shore-drift cell incorporates sediment inputs (sediment sources, locally referred to as feeder bluffs), throughputs (neutral shores or transport zones), and sediment sinks or depositional shores (accretion shoreforms).

NGF: Nearshore Geospatial Framework

No appreciable drift (NAD): Areas in which no appreciable littoral drift occurs.

NOAA: National Oceanographic and Atmospheric Administration

NWSF: Northwest Straits Foundation

Ordinary high water mark (OHWM): In Washington state: That mark that will be found by examining the bed and banks and ascertaining where the presence and action of waters are so common and usual, and so long continued in all ordinary years, as to mark upon the soil a character distinct from that of the abutting upland, in respect to vegetation as that condition exists on June 1, 1971, as it may naturally change thereafter, or as it may change thereafter in accordance with permits issued by a local government or department (RCW 90.58.030).

Pocket beach (PB): A beach that is contained between two bedrock headlands that essentially functions as a closed system in terms of littoral sediment transport.

Protection: Safeguarding ecosystems or ecosystem components from harm caused by human actions.

PSP: Puget Sound Partnership

QA/QC: Quality Assurance and Quality Control

Restoration: Returning an ecosystem to a close approximation of its pre-disturbance state in terms of structure and function (NRC 1992). This includes measures needed to protect and preserve restored systems in perpetuity.

Revetment: A hard armor technique using stone placed on a sloping bank to protect against waves or currents.

Risk: The relative need for the given infrastructure in terms of setback distance, infrastructure type and estimated erosion rate. Erosion rates estimated from maximum measured fetch and shoreform type.

Sediment input: Delivery of sediment from bluff, stream, and marine sources into the nearshore. Sediment input interacts with sediment transport to control the structure of beaches.

Sediment transport: Bedload and suspended transport of sediments and other matter by water and wind along (longshore) and across (cross-shore) the beach. The continuity of sediment transport strongly influences the longshore structure of beaches.

Setback: Distance of the nearest major infrastructure element (primary or secondary structure) from the coast, measured from bluff crest landward where present, or from OHWM for no-bank sites.

Shoreform: A term often used in Puget Sound to describe a coastal landform. The term is generally used to describe landscape features on the scale of hundreds to thousands of meters, such as coastal bluffs, estuaries, barrier beaches, or river deltas.

Shoretype: The Shipman typology classification for the project area (Shipman 2008). BLB=Bluff backed beach, BAB=Barrier Beach, BE=Barrier estuary, BL=Barrier lagoon, OCI=Open coastal inlet, CLM=Closed lagoon/salt marsh, PB=Pocket Beach, RP=Rocky platform, PL=Plunging rocky shore. The CGS typology classification for the project area (MacLennan 2013). FBE (feeder bluff exceptional), FB (feeder bluff), FB-T (feeder bluff — talus), TZ (transport zone), AS (accretion shoreform), MOD (modified), NAD-B (no appreciable drift — bedrock), NAD-LE (no appreciable drift — low energy), NAD-D (no appreciable drift — delta), NAD-AR (no appreciable drift — artificial). Added as part of *Beach Strategies* are PB (pocket beach) and PB-AR (pocket beach — artificial).

Soft shore protection: shore protection design which entails the use of indigenous materials such as gravel, sand, logs, and root masses in designs that mimic natural processes.

Transport zone (TZ): A bluff or bank which supplies minimal but not appreciable sediment input to the nearshore from erosion/mass wasting, and does not have an accretion shoreform present. The bluff face typically has considerable coniferous vegetation with few signs of disturbance from landslide activity or is of very low relief such that sediment input is very limited.

USACE: United States Army Corps of Engineers

Waterward: A description meaning towards the water.

WDFW: Washington Department of Fish and Wildlife

WDNR: Washington Department of Natural Resources

WDOE: Washington Department of Ecology

WWU: Western Washington University

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