ISLAND COUNTY SEA LEVEL RISE MONITORING PLAN

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and

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DRAFT
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Note:
Some pages in this document have been purposely skipped or blank pages inserted so that this document will print correctly when duplexed.

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Introduction

The Island County Planning and Community Development Department (Island County PCDD) retained The Watershed Company and Herrera Environmental Consultants, Inc. (Herrera) to analyze existing monitoring programs and data sources to verify their overall effectiveness and ability to provide accurate long-term data within two specific advisory areas: Historic Beaches and Canal Communities. Each of these advisory areas are considered sub-designations within the Shoreline Residential shoreline environmental designation. There is additional interest in monitoring on coastal bluffs with denser development (particularly near the bluff crest). Monitoring data will be used to assess if the existing buffers and setback distances are adequate for changing conditions associated with sea level rise.

Project Goals and Objectives

Data sources were analyzed for redundancies and gaps to ensure that an efficient and thorough monitoring program is created. These sources will then be uses to describe and quantify baseline conditions and data points. The same sources will be used to develop a programmatic framework that monitors the effects of sea level rise as it relates to advisory zones. This monitoring program will be created with the goal of providing the County with sufficient data to evaluate planning strategies based on expected risks for the range of nearshore conditions across the County.

Inventory of Existing Monitoring Programs

Numerous local monitoring efforts are taking place throughout Island County. There are data collection efforts being applied at various scales by different organizations, ranging from Federal and State Agencies, consultants, volunteers and Home Owners' Associations (HOAs). The data developed by these different entities is described further below. The ways in which the different monitoring data can be used to effectively monitor physical changes to the shores of Island County will be described later in this document.

Washington Department of Ecology Mapping

Washington State Department of Ecology's Coastal Monitoring and Analysis Program (CMAP) has conducted a series of boat-based LiDAR surveys over 135 miles of shoreline between 2013 and 2018 (Figure 1, Weiner et a. 2018). This critical work produces 0.5-meter digital elevation models that can be used to inventory and characterize the shoreline landscape, including feeder bluff activity, beach slope and width. Data is available for the following areas in Island County: intermittent coverage along the west shore of Whidbey Island from south of Swantown to near Useless Bay and along a limited stretch of southwest Camano Island near Elger Bay (Table 1).

The area from West Beach County Park to Point Partridge was surveyed both in 2015 and again 2018. The digital elevation models (DEMs) produced from these mapping efforts have not yet been compared by WDOE, but profiles could easily be extracted and shoreline proxies compared to generate change rates in this area.

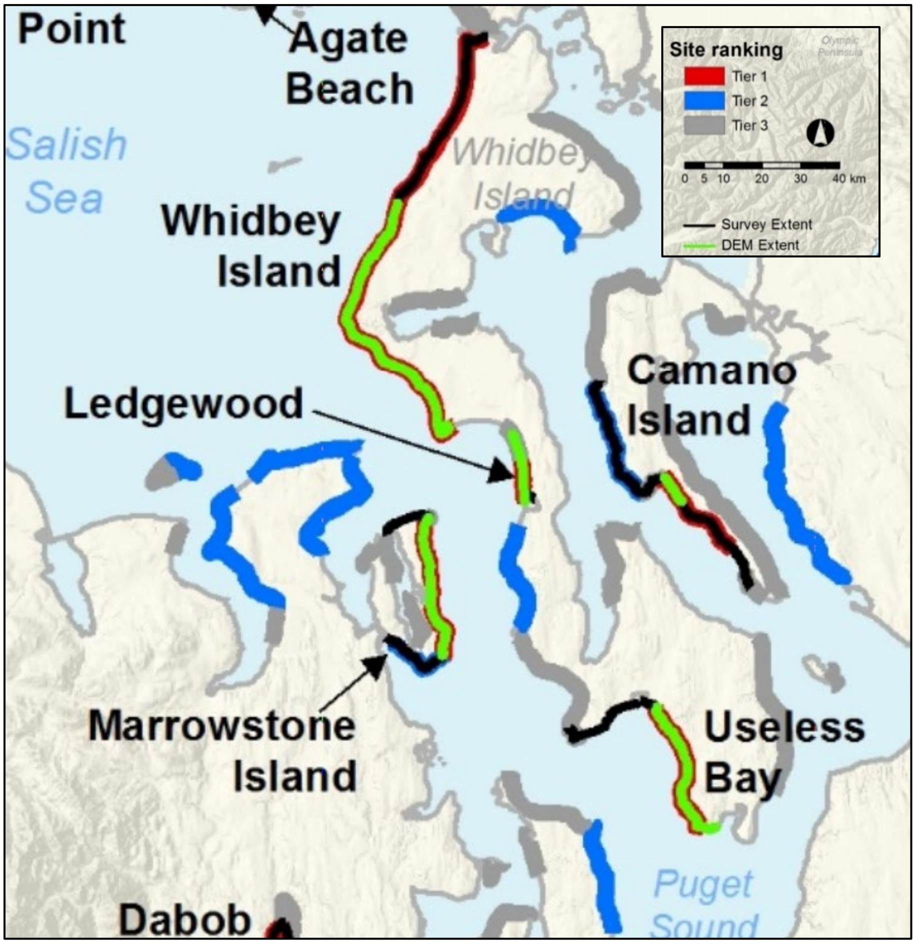

Figure 1. Spatial Extent of Surveyed Shoreline Versus Processed Data and DEM Development (Weiner et al. 2018).

Funding was awarded to repeat this high-resolution mapping in 2019, however the data may not be available until 2021. Additional project delays have taken place due to COVID-19, including the identification of the new survey areas (beyond repeating the northwest Whidbey survey). The best use of this data will be in measuring short-term bluff and beach change with a very high level of accuracy.

Table 1. WDOE Boat-Based LiDAR.				
Year	Areas Mapped	Sub-Designations Addressed	Data Format	Resolution
2016	West Whidbey from West Beach to Fort Casey, Ledgewood, and Useless Bay and southwest Camano Island.	Historic Beach Communities and Coastal Bluffs	0.5-meter digital elevation models. ESRI SSCII grid (.asc), NAVD88 (meters)	H, 9cn: V, 2 cm
2018	West Beach to Point Partridge	Historic Beach Communities and Coastal Bluffs	0.5-meter digital elevation models. ESRI SSCII grid (.asc), NAVD88 (meters)	H, 9cn: V, 2 cm
2021	To Be Determined			

Washington Department of Fish and Wildlife Monitoring (WDFW)

Hannah Faulkner, nearshore biologist with WDFW, monitors several armor removal sites in Island County. She monitors the beach using both the 2-stick method (described further in the Northwest Straits Foundation monitoring data) and a photogrammetry data collection process in which overlapping convergent imagery (and a series of ground control points) were used to create DEMs of the beach surface. These surfaces (DEMs) can be compared to calculate change rates over time in CAD or GIS.

The sites that she monitors are all located along the eastern shoreline of Whidbey Island and include Maylor Point, near Oak Harbor; Seahorse Siesta and Waterman, which are located north and south of the town of Langley, respectively. Each site was monitored before and after armor removal.

National Geodetic Survey Benchmarks and Reference Points

The National Ocean and Atmospheric Administration's (NOAA) National Geodetic Survey Data Explorer includes the locations of monuments or benchmark sheets with known vertical and horizontal coordinates in Island County (and the rest of the Nation). In many cases, these monuments (benchmark sheets) include references and measurements to notable features near the monument, which can be repeated to develop change rates. For example, the survey monument could be located on top of a large boulder on the beach with measured distances to the bluff toe (Figure 2). Alternatively, the survey monument could be located on top of a boulder at the top of a bluff with measurements recorded to the bluff crest. Additional notes can be found in the Station Recovery sections of the benchmark sheets and in some cases there are multiple measurements from different years that can also be used to determine change rates across different time periods (e.g., station recovery report from 1960 and station recovery report from 1970, etc., Figure 2). Rates should be annualized to provide a consistent, comparable metric and evaluated across time with sea level rise data. This method of measuring bluff recession and beach change is highly accurate.

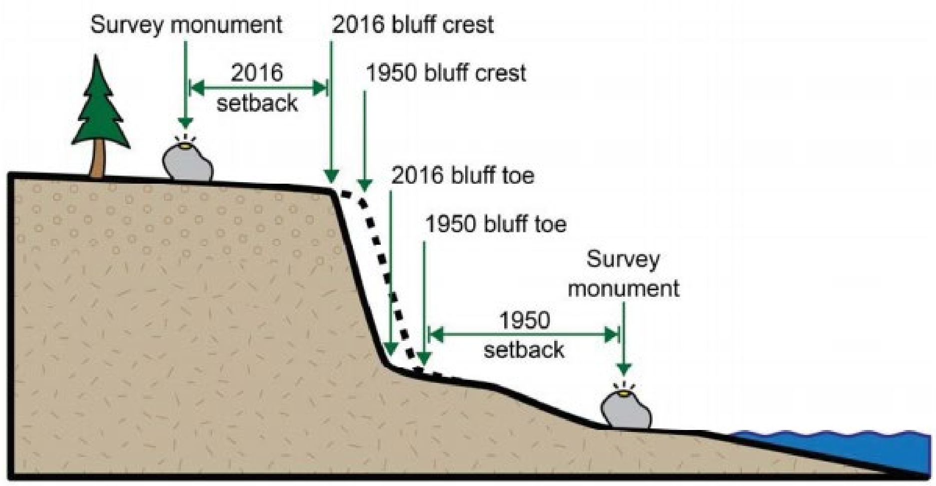

Figure 2. Bluff Profile Depicting Bluff Features and Survey Monuments Used to Measure Change Rates.

Local Monitoring Efforts

Consultants

Strawberry Point Monitoring

Herrera Environmental Consultants developed a habitat protection monitoring plan for Island County Planning and Community Development Department for Strawberry Point, which is located on northeastern Whidbey Island, Washington near Skagit Bay. Strawberry Point has been identified as a very high priority site for protection of forage fish species and a high priority site for protection of juvenile salmonids. The goal of this project was to protect and maintain the nearshore processes and aquatic habitats at Strawberry Point for the benefit of both salmonids and forage fish species.

Nearshore conditions are described in the document but no quantitative data appropriate for physical monitoring is included.

Long-Term Bluff Recession Rates in Puget Sound

Coastal Geological Services measured and compiled long-term bluff recession rates in the Puget Sound region using two different methods; historical aerial photographs in GIS (method 1) and NGS monuments (method 2, see above). Measurement locations are shown in Figure 3 and the measurement methods shown in Figure 4. There are 38 long-term bluff recession rates that were documented in Island County (Table 2, Figure 3). Figure 4 shows the methods that were used to measure bluff recession rates at each site. Bluff recession rates could be repeated to measure contemporary bluff recession rates and compared to long-term rates using the methods described in the Coastal Geologic Services 2018 report <https://secure.rco.wa.gov/prism/search/ProjectSnapshotAttachmentData.aspx?id=332187>.

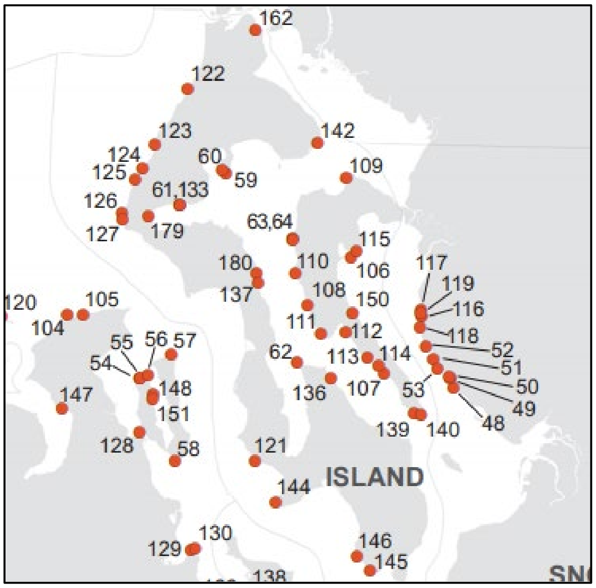

Figure 3. Bluff Recession Measurement Locations.

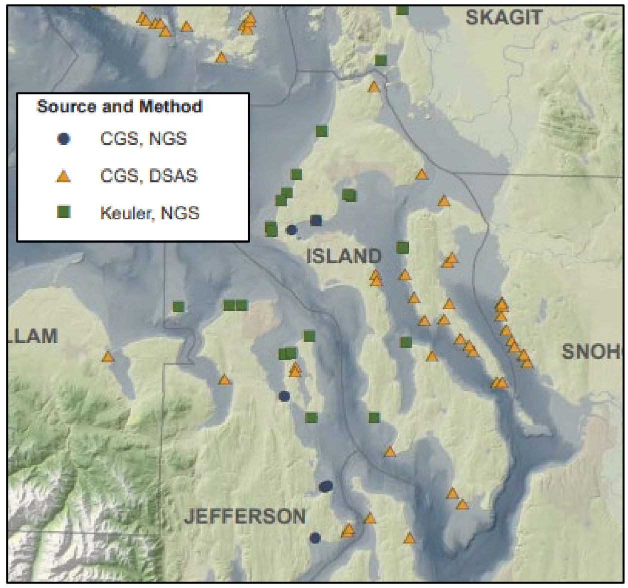

Figure 4. Bluff Recession Measurement Methods.

A multivariate analysis of the bluff recession rates was conducted to explore variables of influence to bluff recession rates across the region. Fetch was found to have the most direct relationship with bluff recession rates, while tidal range had an inverse relationship with bluff recession rates (Coastal Geologic Services 2018). Some of the highest bluff recession rates documented in the region occur on the west shore of Whidbey Island and along the more exposed shores of Jefferson County (Figure 5). Bluff recession rates are negative numbers (Figure 5, Table 2), therefore the lower values correspond with more rapid rates of bluff retreat.

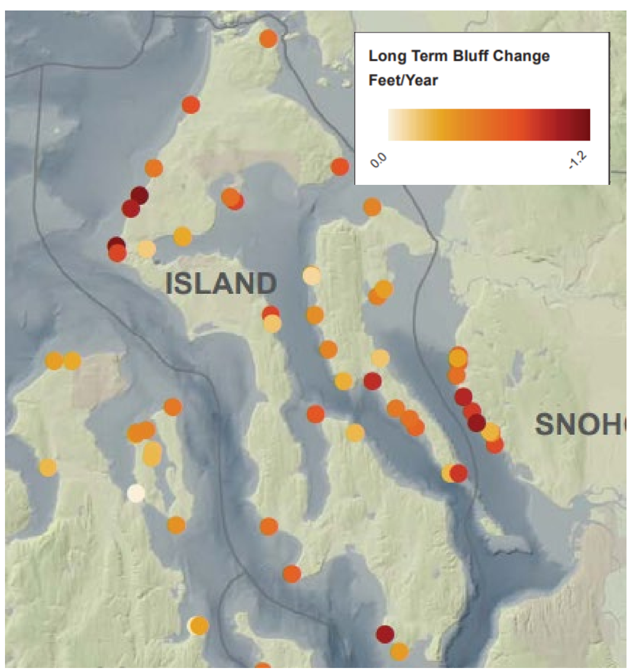

Figure 5. Long-Term Bluff Recession Rates in Island County (CGS 2018).

Table 2. WDOE Boat-Based LiDAR.					
West Whidbey		East Whidbey		Camano	
Site ID	Rate (ft/yr)	Site ID	Rate (ft/yr)	Site ID	Rate (ft/yr)
122	-0.46	162	-0.36	109	-0.3
123	-0.33	136	-0.17	63	-0.23
124	-1.05	139	-0.17	64	-0.10
125	-0.72	62	-0.43	110	-0.27
126	-1.12	137	-0.49	111	-0.19
121	-0.36	180	-0.14	112	-0.64
127	-0.49	179	-0.13	113	-0.33
144	-0.40	61	-0.40	114	-0.36
145	-0.24	133	-0.20	108	-0.30
146	-0.75	59	-0.49	107	-0.39
		60	-0.36	108	-0.30
		142	-0.44	139	-0.17
				140	-0.53
				150	-0.77
				106	-0.31
				115	-0.23

Diking District No. 1 Sunlight Beach Dike Monitoring

Aerial Whidbey has been monitoring the marine shoreline, including the Sunlight Beach Dike (from Kohles Road to west of the drainage outfall pipes), the mouth of Deer Lagoon, and a large area labeled “Henny Spit and Lagoon” for Diking District No. 1. The objective of the monitoring is to document recent erosion of Sunlight Beach to justify erosion control and potential compensatory mitigation for future engineering to reduce beach erosion and prevent a breach of the dike during a winter storm (at high tide). Aerial Whidbey is in Year-2 of this 6-year monitoring effort. Drone mapping has been used to develop surface models (DEMs), which are used to document and compare change rates between monitoring events. Early monitoring data has shown extensive progradation of Henny Spit and infilling at the mouth of Deer Lagoon.

Canal Communities Dredge Permit Monitoring

There are three main Canal Communities in Island County: Sandy Hook, located on south Whidbey Island; Lagoon Point, located on southwest Whidbey Island and Mariner’s Cove, located on east shore of Oak Harbor on Whidbey Island. These unique shoreline communities were historically barrier estuaries (embayments) but are now largely reconfigured by heavy development, land clearing, filling and dredging. Dredging within the Canal Communities is typically required to maintain adequate depths for boat moorage and navigation every few years (5–10 years). Dredge permitting is often facilitated and managed by the local HOAs within the Canal Communities. The dredge design and permitting process often entails bathymetric (survey-grade) mapping and comparison of past elevations to calculate sedimentation rates and dredge volumes necessary for permitting. This data is included with permit applications and could likely be requested from the Canal Community HOAs.

Canal Community HOAs could also provide information on frequently flooded areas, local elevation benchmarks, and could help to set up local monitoring stations within the community. In addition, local engagement with the HOAs could help to develop new monitoring data collection.

Citizen Science

Sound Water Stewards of Island County

Once per year, the Sound Water Stewards conduct intertidal monitoring of 12 beaches on Camano and Whidbey Islands (for a total of 24 monitoring locations: Table 3). Monitoring entails documenting elevations and (dominant) substrate over 10 feet along a profile from a fixed starting point in the backshore (of known elevation). Three one-quarter quadrats are used to document the species observed at the terminal or waterward end of the transect. These data have been collected since 2003, all with the help of local volunteers. The presence of shoreline armor within the surveyed profiles has not been explored, but should be, before monitoring sites are selected to use in this application.

Monitoring was cancelled for 2020 due to COVID and the vulnerability of the volunteer community, which largely consists of retired persons. Data can be requested from Dave Brubaker, whose contact information is listed on the Sound Water Stewards of Island County website.

Table 3. Beaches on Whidbey and Camano Islands Monitored by Sound Water Stewards.

Whidbey Island	Camano Island
Ala Spit	Utsalady
Clinton	English Boom
Cornet Bay	Iverson Spit
Coupeville Town Park	Cavalero
Double Bluff	Tillicum
Lagoon Point	Pebble Beach
Langley	Mabana (road)
Ledgewood	Elger Bay
Partridge Point	Camano Island State Park
Possession Beach	Cama Beach State Park
Trail’s End Road (Greenbank)	Onamac Point
Hastey Lake Road/County Park	Madrona Beach

MyCoast: Washington (application)

The MyCoast: Washington is a project of the Washington State Department of Natural Resources in collaboration with US Geological Survey, Washington SeaGrant, the Snohomish County Marine Resources Committee and the Northwest Straits Initiative. This application (app) facilitates citizen science data collection (via cell phones) that can be used to characterize and document beach change, the impacts of nearshore hazards (storm surge/coastal flooding), marine debris, king tides and storm surge elevations using photos. Data can be downloaded and viewed via maps online. Users can take photos of beaches from a specific location or vantage and compare images and beach conditions across time. There are several Island County beaches with documented conditions in the My Coast app database, including, the Utsalady Boat Ramp. This method of data collection is useful, easy to access, and a great way to facilitate crowd-sourced data.

Northwest Straits Foundation

Then Northwest Straits Foundation (NWSF) conducts beach monitoring at their restoration sites using the methods described in the Puget Sound Shoreline Monitoring Toolbox <https://sites.google.com/a/uw.edu/toolbox/home>. The monitoring toolbox is largely focused on monitoring ecological conditions and habitats rather than beach morphology and other physical conditions of the beach.

NWSF is currently collecting monitoring data from the beaches near the Oak Harbor marina to inform baseline conditions for an upcoming restoration project. This monitoring includes some topographic mapping of the beach. They are documenting conditions using the following protocols:

- Site Photos: Site photos are used to document changes in physical habitat over time. Photo point locations, camera directions, and angles will be determined based on visibility of key habitat characteristics.

- Beach Profiles: The objective of the profile data is to determine potential sediment accretion, erosion, and other changes in sediment distribution and the spatial extent and condition of available forage fish spawning habitat. A 50 meter transect parallel to shore is established within each survey area. Beach profiles extend from the upland/toe of bank from three points along the transect at 0 m, 25 m, and 50 m. For each profile, a transect tape will start at the upland toe and run perpendicular to the shoreline extending down to mean lower low water (MLLW), or mean low water (MLW), if the substrate is not suitable for walking out to MLLW. Any key elevation or transition areas will be marked with wire flags to document obvious changes in beach profile, which should be measured. A laser-level and stadia rod are preferred for this monitoring; but the “two stick method” is also a suitable option.

Some additional information is provided on the monitoring approach here:

> <https://docs.google.com/viewer?a=v&pid=sites&srcid=dXcuZWR1fHRvb2xib3h8Z3g6Y2ZjNzJlNTg2NzU3MmZl>.

Contrasting Nearshore Conditions Relevant to Monitoring

The following section provides an overview of the geologic and geomorphic conditions across the marine shorelines of Island County and the relevance of these conditions to monitoring beach change in the context of sea level rise. Several factors influence the character of the nearshore environment in Island County. Some factors, such as climate and geology, have more consistent influence throughout the county, while other factors are more variable. These factors with greater variability should be taken into consideration in the development of a monitoring plan aimed at measuring changes to physical processes along the marine shorelines.

The shores of western Whidbey Island are distinct from those of eastern Whidbey and Camano Island due to oceanography, wave energy (exposure), topography/bathymetry and other characteristics. These contrasting physical conditions are important to be mindful of when developing a monitoring program as they result in differing mechanisms driving change and differing rates of change.

Geology

Most Island County surficial geology consists of glacial and non-glacial fluvial deposits from multiple continental advances and interglacial periods of the Cordilleran Ice Sheet during the Quaternary (Easterbrook et al. 1968, Easterbrook 1992). A limited extent of bedrock shores are found west of Cornet Bay, near Deception Pass. Both the modern topography and bathymetry were carved by advancing and retreating glaciers, which left behind an extensive outwash plain elevated up to 300 feet above present sea level. This outwash plain was carved into the modern north-south trending trough that make up the Puget Lowlands by sub-glacial water flows (Booth 1994). The topography was then reworked as sea levels rose to resemble current levels (over the last approximately 5000 years) and over-steepened bluffs collapsed and reached new equilibrium. Surface runoff caused rills and gullies to form on the bluff faces, some of which have developed into proper streams and rivers (Finlayson 2006).

Regional tectonic forces have also affected nearshore conditions in Island County. Thrust faults and more abundant high angle faults account for this structurally complex area (Dragovich et al. 2005). Catastrophic vertical displacements of the marine platform have occurred at a number of these east-west striking faults. The most dramatic is a 5- to 7-meter vertical displacement, dated to around 1090 and 1120 years ago (Finlayson 2006). Other displacements of this fault on Whidbey Island within past 3,500 years were between one and two meters.

Swell, Waves, and Fetch

Most marine shorelines in the Puget Sound region are isolated from the Pacific Ocean. However, the west shore of Whidbey Island (north of Admiralty Bay) is an exception, and one of the most dynamic and energetic shorelines in the region as a result. This wave-dominated environment is exposed to ocean swell propagated from the northeastern Pacific Ocean. Ocean swells travel east through the Strait of Juan de Fuca, driven by intense westerly winds that also drives aeolian sediment transport and deposition, an uncommon occurrence in the Puget Sound region. Significant wave heights exhibit spatial and seasonal distribution patterns through the Straits.

The sill that delineates the main Puget Sound oceanographic basin is located at the north end of Admiralty Inlet between the north Quimper Peninsula (near Port Townsend) and just north of Admiralty Bay on Whidbey Island. South of the sill the shore is largely protected from ocean swell and waves are generated by local winds. This is also the case for east Whidbey and Camano Islands. In addition, subtle changes in orientation and relatively minor crenulations of the shoreline limits the fetch (the overwater distance over which waves can develop) of many beaches and bluffs in eastern Whidbey and Camano Island(s). Consequently, the waves have very little energy and are tightly coupled with local wind patterns (Finlayson 2006).

The shores of Puget Sound are commonly described as a fetch-limited environment, due to the lack of substantial wave energy to support sediment transport (Finlayson 2006). Beach and bluff change rates are typically very slow and are often linked with large storm events that occur at high water, referred to as “change events”. Puget Sound beaches and bluffs are often described as being part of an event-driven systems, in which considerable change occurs in association with storm events, followed by periods of general stability. The frequency of change events is not well documented and can be as long as 15 to 20 years, therefore long-term monitoring is often preferred over short-term monitoring to assure that the measured change is bracketing the full cycle of change and stability, rather than just minor change within a period of overall stability.

The direction of prevailing winds in the region are from south or southwest during the winter and northwest during the summer. The strongest winds are southerlies resulting from winter storms moving inlands from the eastern Pacific. Periodically during the winter, strong northerly winds are forced down the Fraser River valley and through the mountain passes (Finlayson 2006).

Maximum measured fetch is often used as an analogue for wave energy in the region. Shores with greater fetch, have greater wave energy available to transport sediment across and alongshore. Therefore, the rates of change observed on a beach or bluff are directly related to the maximum measured fetch (CGS 2018). The combined effects of exposure to ocean swell and considerable fetch to both the north and south, contributes to the faster rates of change on the west shore of Whidbey Island, relative to the rest of the shores in the County.

Seasonality

Beaches in the Puget Sound region are well known for their contrasting conditions during the winter versus the summer (Downing 1983, Johannessen and MacLennan 2007). The winter beach profile is known for being steeper, due to the larger waves pulling finer sediment offshore and pushing larger sediment higher on the beach. Substrate composition of the upper foreshore is typically coarser in winter when there is also typically less driftwood and backshore vegetation. In contrast the summer beach profile has often built to higher elevations, with new finer sediment deposited. Driftwood deposits are typically wider and upper beach vegetation typically consists of several species of perennial halophytes.

Timing is critical to effectively monitoring the beach, particularly when monitoring objectives to detect long-term change. Seasonality has the potential to be a confounding factor in beach profile monitoring, therefore beach profiles monitoring data should be compared within seasons and across years. For example, beach elevation data should be compared across winters or summers. Comparing the winter to summer profiles will likely only highlight seasonal dynamics.

Littoral Drift and Sediment Supply

Shore orientation relative to the predominant and prevailing winds (and waves) determines the net direction of littoral transport, or *net shore-drift*. When waves approach the shore at an oblique angle, an alongshore current is generated resulting in sediment transport. All the shores of Washington have been delineated into discrete sediment sub-systems, referred to as net shore-drift cells. Each drift cell exhibits a dominant direction of sediment transport. Short term changes in the direction of sediment transport can occur due to variability in winds, however the direction of sediment transport noted in the drift cell mapping represents the (long-term) *net* direction of transport, which influences long-term changes, such as landform development over time. Shores exposed to the south exhibit northward drift and conversely, those exposed to the north typically exhibit southward sediment transport.

Within a drift cell there is typically a gradient of more erosion occurring near the drift cell origin, where wave energy is greater, with more neutral shores in the center of the cell, and low-lying depositional shores found near the cell's terminus. The beaches waterward of eroding bluffs commonly consist of a relatively narrow band of mixed sand and gravel (sometimes coarser) with waterward sandy tidal flats. Sediment eroded from bluffs is deposited on the backshore and upper beach is gradually transported and deposited down-drift by waves to depositional shores or barrier beaches. The sediment composition found on the beach becomes finer moving down-drift as wave energy diminished along that same gradient (Jacobson and Schwartz 1981). Coastal embayments are often found landward of barrier beaches. These unique features are low in elevation, vulnerable to flooding, and are often associated with coastal wetlands. Many embayments on Whidbey Island have been dredged and are now considered Canal Communities, such as Lagoon Point or Mariner's Cove. The inner shores of embayments have no appreciable net shore-drift and the beaches are narrow, finer-grained (consisting of sand and muddy-sand), covered with halophytic vegetation, and sometimes associated with stream mouths and other sources of freshwater (seeps or springs).

Coastal bluffs are the primary source of sediment for most Puget Sound beaches (Johannessen and MacLennan 2007, Downing 1983). Mass wasting (landslides) and bluff toe erosion deliver sediment to the beach in large quantities. The sediment composition of the beach is influenced by the geology of the bluff. Throughout much of Island County, bluff geology consists of glacial till, advance outwash, and glaciomarine drift peat (Easterbrook 1968). Bluff stratigraphy is often comprised of a combination of permeable layers over impermeable glacial lake deposits, which greatly increases landslide susceptibility, particularly during periods of heavy precipitation (Gerstel et al. 1997, Shipman 2006). Local hydrology (groundwater and surface water) also contribute to mass wasting processes and bluff recession rates.

Landslides are most likely to occur in areas where there is a landslide history or where the lower bluff strata is comprised of unconsolidated, permeable layer (sand), overlain by a (more) consolidated impermeable layer (such as dense silt or clay; Gerstel et al. 1997). Change rates measured from within landslide areas should not be compared with bluff recession rates outside landslide areas and should only be compared with existing monitoring data for that same site, due to the site-specific nature of landslide drivers.

Vertical Land Movement and Relative Sea Level Rise

Vertical land movement (VLM) was measured throughout the marine shores of Island County as part of the Washington Coastal Resilience Project, in which relative sea level rise projections were calculated for the states' marine shorelines. There is a general trend of increasing rates of subduction (negative VLM) across Island County from north to south, therefore relative sea level rise will be greater on southern Whidbey and Camano Islands, compared with the northern shore of Whidbey Island (Table 4). Vertical land movement has been estimated at -0.4 foot per century (+/- 0.2 foot per century) at Possession Head and -0.1 foot per century (+/- at Cornet Bay. Table 4 displays recently developed relative sea level rise projections for different planning horizons and designations in Island County.

Table 4. Relative Sea Level Rise Projections for Island County.

Year	99 Percent Probability of Exceedance	50 Percent Probability of Exceedance	1 Percent Probability of Exceedance
2050	0.3 (0.1)	0.6 (0.7)	1.5 (1.4)
2100	0.9 (0.6)	2.4 (2.1)	5.2 (4.9)

Geomorphic Response of Different Shoreforms to Sea Level Rise

Sea level rise will produce a range of impacts from increased erosion of coastal bluffs, the inundation of low-lying coastal areas, and the landward translation of beach profiles, among other impacts (Huppert et al. 2009). The shores of Island County are comprised of a range of geomorphic shoretypes (also referred to as coastal landform types or shoretypes), which respond to the rise in sea level in different ways. Certain shoretypes are more vulnerable to erosion, others to inundation, and some are vulnerable to both. Shores exposed to ocean swell are likely to incur greater change rates due to increased wave heights (Ruggerio 2013). A change in the El Nino—Southern Oscillation (ENSO) cycle may have additional impacts on the frequency and magnitude of storms and duration of high water events.

Bedrock shores are less likely to incur considerable impacts outside of a vertical rise in the mean highwater mark. The geomorphic response of each of the shoretypes found in Island County are included below.

Barrier Beaches/Accretion Shoreforms

These shores include low lying depositional beaches and spits that are often associated with landward coastal wetlands. They are also the most likely location of Historic Beach Communities. The natural response of these shores is to build additional elevation and translate landward through repeated overwash during high water events. These areas are vulnerable to coastal flooding, beach erosion, loss of dune and backshore habitats, and landward wetland loss.

Coastal Bluffs/Feeder Bluffs

Coastal bluffs, commonly described regionally as feeder bluffs, contribute most of the sediment found on Puget Sound beaches. Bluff recession rates and mass wasting are expected to accelerate due to sea level rise and increased precipitation, for which there is a documented threshold for when Puget Sound landslides are known to occur (Chleborad et al. 2006). The combined results of the added erosion are likely to contribute additional sediment to littoral drift cells, which will enable down-drift shores to naturally adapt or translate landward.

Embayments

There are several small stream mouths and embayments located within Island County. In many cases, these areas include a waterward spit or shoal, and landward coastal wetlands, estuaries, and lagoons. Sea level rise will affect stream mouths and embayments by expanding their tidal prism and the landward extent of inundation. This expansion is likely to result in additional changes in riparian conditions such as adjacent flood areas, coastal wetlands, mortality of less salt tolerant marine riparian vegetation, bank toe erosion, and additional mass wasting. Mass wasting of adjacent hillslopes is likely to be further exacerbated by increased precipitation due to climate change.

Armored and Artificial Shores

Armored shores are any kind of shore with shoreline armor, including riprap, bulkheads, seawalls and other similar structures designed to mitigate wave-induced coastal erosion. Artificial shores include shoreline armor as well as considerable fill that likely entails changes to landward elevations. These altered shores represent static shorelines in which the natural geomorphic response of the shoreline is precluded. When sea levels rise along a static shoreline, beaches and the habitats found therein, narrow in a process referred to as the 'coastal squeeze', as deep water is found closer to shore. Along artificial shores the coastal squeeze will continue as sea levels rise until intertidal areas are entirely inundated and the rise and fall of the tide is observed as only vertical change along the face of the structure.

In most cases, armored and artificial shores are engineered for current sea levels and sea level rise results in their frequent inundation or overtopping, which can lead to structure failure. Many filled, armored shores do not include sufficient drainage to effectively drain water during overtopping, which can lead to additional problems. In most areas, for the fill and armor to persist the rise in sea level, additional elevation or "freeboard" needs to be added to existing coastal structures. Inundated fill can contribute to additional issues such as settling, scour, sink holes and subsidence, particularly where fill is placed over historical salt marshes, such as in Canal Communities and other barrier beaches in Historic Beach Communities with substantial fill.

Shore armor is well understood to result in adverse impacts to nearshore processes and ecological habitats found on the beaches of Puget Sound. Recent research has documented that the greater that armor infringes on the beach (where the structure extends waterward extent of the structure is), then the greater the impacts to nearshore habitats (Dethier et al. 2018).

Some of the impacts that shoreline armor has on physical characteristics of the beach could be amplified and confounded by the impacts that sea level rise can have on the beach along an armored shore.

These impacts include:

- Narrowing of the upper beach
- Coarsening of upper beach sediment
- The development of a scour trough waterward of armor
- Undermined toe of the structure
- End effects, erosion hotspot along the adjacent shoreline
- Reduced sediment supply from landward eroding coastal bluffs
- Loss of backshore beach and habitats due to structure footprint
- Armor overtopping

As a result, it is recommended that unarmored shores should be the focus of this monitoring program.

Sea Level Rise Monitoring Framework

The following recommendations for a sea level rise monitoring program are intended to provide a foundation for additional monitoring program development. Critical decisions relevant to the final monitoring approach, include:

- If and how much funding is available to support this monitoring,
- The spatial extent of the monitoring program – more locations could be monitored if additional funding is available,
- If the effort would be totally supported and completed by Island County staff, or via a consultant.

Much of the monitoring data collection and analysis could be conducted by Island County professionals. Collaborations between data scientists and GIS professionals in the Departments of Public Works and Natural Resources could benefit this program. In-house effort could be augmented with limited consultant time to reduce costs.

Mapping Signs of Sea Level Rise

A new monitoring program is recommended for mapping signs of sea level rise throughout the County. Data collection could be conducted by Island County staff using a phone-based application called Survey-1-2-3 (created by ESRI), in which users identify the location, type of sea level rise impact (e.g. coastal erosion (wave scour), coastal flooding, and coastal landslides), then take a photo. The observations would be prompted with data entry fields and dropdown menus to guide the observer, enable consistency, and efficiency. Data points populate a geodatabase and associated webmaps that can be viewed and analyzed by multiple users within the County. The tool could be developed by in-house GIS staff and the data could be evaluated continually by Planning staff. This tool could help to identify areas with the County that are increasingly vulnerable to sea level rise impacts and document the frequency at which these impacts occur.

This program could be initiated with an email or brief presentation describing the types of sea level rise impacts of interest, the data collection process, and the importance of the data set. Public Works road crews regularly explore and assess road conditions throughout the County and are particularly knowledgeable about locations in which there is regular damage from storms, floods, and landslides. Similarly Island County Department of Natural Resources staff are often doing field work and could provide additional observations of on the ground conditions. Other County staff could be asked to take a few minutes to learn about the program and note the locations of observed erosion. Existing data that has not been digitized could be added to the database to make it more comprehensive, such as past FEMA claims, landslide locations, or road damage records from Public Works. It is important for the County to identify specific geographic locations that are vulnerable to sea level rise impacts and this type of crowd-sourced monitoring effort is the best way to achieve this goal within a very limited budget.

Building on Existing Data

When building a data set that was established in the past, it is important to begin by acquiring an in-depth understanding of the data collection process and necessary instrumentation. Data collection methods typically include specifics on quality assurance and control and detailed methods so that data collection can be effectively repeated, and other basic scientific standards are met.

- The makes and models of instruments used in data collection should be noted and equipment should be calibrated and well-maintained.
- References to local monitoring monuments or benchmarks should be documented. Accuracy and precision of the data collection process should be quantified where possible.
- Error will be greater if data collection is conducted by multiple people, so when selecting data sources, choose the data that has been collected with the most consistency.
- Maintain back-ups of all field data and original field forms.
- When using the 2-stick method (used by NWSF and Sound Water Shore Stewards), identify location/elevation of a known reference point, from which elevations can be corrected.
- Alternatively, note the water level elevation (on the stick) and time, and adjust elevations to the observed water level (for the time) at the nearest Tide gauge. Correct all elevation data to be in a consistent vertical datum prior to analysis.

Data Compilation and Analysis

Monitoring data should be compiled in a single master database. Monitoring locations should have unique identifying numbers, with associated dates of data collection, abbreviated methods (e.g., 2-stick versus LiDAR or other) of data collection, and the entity responsible for the data collection. Some data augmentation or measuring of additional background change rates may be necessary to allow data comparisons across additional time periods. For example, historical or background change rates can be calculated from aerial photographs or new profiles can be extracted from LiDAR data to facilitate comparison with modern change rate data.

The analysis of monitoring data should be conducted by a professional data analyst and interpreted by a trained coastal geomorphologist or engineer. Beach change is complex and there are often several variables at work driving observed changes on the beaches and bluffs of the region (Johannessen and MacLennan 2007). Data should be compiled annually and analyzed every two years. As part of analysis, new erosion rate data should be compared to past erosion rate data. The data should be subjected to an appropriate test of significance for the data, this could be a T-test or an analysis of variance, depending on how many measurements exist for the site.

Erosion rate data should be paired with sea level rise data from the Seattle NOAA tide gauge. First data recent SLR rates should be integrated into the project database in association with the erosion rate data, the trends of which will be analyzed when there are enough data to detect a relationship. A simple statistical test, such as a T-test could be used to measure if there is a significant difference in the rate of sea level rise, between the current and previous monitoring period.

Where there is a significant change in the erosion rates, it should be noted and the station should be flagged for high change. When there has been two or more monitoring periods with significant increases in erosion rates, then the setback distances sh

Comparisons of boat-based LiDAR and airborne LiDAR may result in error at the bluff crest and bluff toe due to averaging point data across this area with considerable elevation changes. Change rates should note this additional source of error, which should be addressed when interpreting results.

New change rates developed from this monitoring data should be compared with background change rates (long-term or short-term change trends) at each individual monitoring location. Change rates should be calculated to reflect annualized change rates that can be compared across different monitoring periods. Care should be taken to identify the influence of seasonal beach changes, and beach profile data should only be compared from the same season and not across seasons (e.g., compare profiles from winter to winter, rather than winter to summer). Rates of change should also be compared across different monitoring locations from within the same shoretypes (e.g., feeder bluffs).

Differing change rates (across time) at a given monitoring location should be explored to identify local to drift-cell-wide changes associated with other potential drives of change, such as recently installed or removed structures.

Change rates should also be paired with known “change events” or storms that occurred during high water. The number of change events and sea level change should be noted within each monitoring period. Change event data can be acquired from USGS coastal geologist Eric Grossman.

Differing change rates (across time) should also be compared with local changes in sea level rise as documented at the nearest NOAA tide gauge. Additional sources of changes in local water levels (e.g., El Nino) should be considered when interpreting annual changes in sea level.

What Data to Use Where?

Different monitoring data is available and more appropriate for meeting project objectives in some environments. Tables 5 through 7 below, shows the preferred monitoring data sources (or the available data sources listed above) for each of the different shoreline environments.

Canal Communities

Canal communities are likely to incur the slowest rates of change and are likely to only be affected by increased water surface elevations and localized erosion of fill material. These shores are largely considered to be depositional and were developed as a result of long-term sediment accretion and past fill. Fill areas commonly erode more rapidly than native soils, as fill is less consolidated. Very limited data is currently available on physical conditions of the beaches within canal communities. The best data to determine and document change in these areas can be extracted or interpreted from bathymetric and nearshore surveys to facilitate dredge design and planning. Elevations and different shoreline proxies within the canal community could be compared over time, such as the location of mean higher high water (MHHW) or mean sea level. These data could include additional LiDAR analysis. This type of analysis would likely require hiring a consultant to document and interpret change in surface elevation models. The frequency of analysis would depend on when new surface models are available, which is largely associated with the frequency that the communities are dredged.

Island County's internal FEMA claims could also be documented and perhaps mapped to allow comparison across years. Other documentation of flood damage and flood observations could be compiled from outreach efforts to local property owners. Active engagement with Canal Community Home Owners' Associations (HOAs) will be necessary to acquire these data.

Table 5. Monitoring Targets, Areas Mapped, and Data for Canal Communities.

Monitoring Target	Areas Mapped	Data Source	Data Format	Data to Compare
Canal Communities	Lagoon Point, Sandy Hook, Mariner's Cove	Puget Sound LiDAR consortium	LiDAR data, 0.5-meter DEMs	Compare tidal prism area over time. Extract profiles in problem locations and compare.
		HOAs' dredge design and permit records	Sedimentation rates, profiles, elevations	Explore changing locations of different shoreline proxies (e.g., MSL, MHHW, EHW)
		Island County Emergency Management Department	FEMA claims	Interpreted water levels from claims from different years

Coastal Bluff Communities

The objective of coastal bluff monitoring is to document changes in the rate of bluff recession and beach conditions relative to rates of sea level rise. Although additional bluff sites have been monitored, monitoring data that is focused only on beach conditions using the 2-stick method, will not capture changes to the bluff.

Considerable monitoring data is available for comparing the physical conditions of coastal bluffs in Island County, however, there is no comprehensive data source or methodology. Therefore, comparisons across different data collection methods is necessary, for many locations. The following recommendations consider data availability and nearshore conditions for the shores of Island County. The frequency of this bluff recession monitoring is annually for monitoring from

NGS monuments (following the winter storm season) or (if using digital data) depends on data availability. Repeating bluff recession rates measured (by Keuler and CGS) from NGS monuments would be the most accurate and cost effective method of measuring bluff recession. The amount of available funding will determine the number of locations that can be monitored.

Weiner et al.'s (2018) boat-based LiDAR mapping for Washington State Department of Ecology (Ecology) is the most accurate data available throughout much of the study area and is appropriate for detecting short-term changes in beach and bluff conditions. However, in more slowly eroding areas, such as along the shores of east Whidbey and west Camano Islands, there are less data available. Compensating for this is that longer-term change measurements may be more appropriate. For areas where there is no Ecology mapping available, profiles can be extracted and compared from available (airborn) LiDAR data from 2014 and 2006. Bluff recession rates can be measured from multiple profiles or wholesale comparison of their surfaces. Using a surface comparison, the position of the bluff crest and bluff toe should be compared across both surfaces using a digital shoreline analysis system (DSAS: Theiler et al. 2009). DSAS will generate short-term change rates that can be compared with long-term bluff recession rates (CGS 2018), where they are available. Long-term bluff recession rates are available from several sites on the east shore of Whidbey Island and the shores of Camano Island. Long-term bluff recession rates measured using the NGS monuments can be repeated and have a very high level of accuracy (Coastal Geologic Services 2018).

Ledgewood change rates will be influenced by the large deep-seated landslide that occurred in 2013. Profiles extracted from unarmored bluffs greater than 1,500 feet from slide could be informative and appropriate for the objectives of this project, though they may reflect regional geologic changes unrelated to climate change.

Monitoring of restoration sites conducted by the NWSF at Maylor Point and the Whidbey and Camano Land Trust's Waterman property should be used with caution, if at all. Physical changes to the beach at these locations will be faster and more dramatic in the years following armor removal, as the bluff and beach adjust to unarmored conditions and reach a new equilibrium. Change rates from these sites are therefore not ideal for the objectives of this monitoring effort due to this complicating factor.

Monitoring Target	Areas Mapped	Data Source	Data Format	Data to Compare
West Whidbey Bluffs	West Beach to Point Partridge	WDOE, Weiner et al. (2015, 2018)	LiDAR and 0.5-meter DEMs	Compare profiles or proxies between 2015 and 2018 WDOE DEMS with 2006 LiDAR data.
South Whidbey Bluffs	Ledgewood and Useless Bay	WDOE, Weiner et al. (2015, 2018)	LiDAR and 0.5-meter DEMs	Compare profiles or proxies from WDOE DEMs with 2006 LiDAR.
East Whidbey Bluffs	Maylor Point, Penn Cove, Rocky Point	NGS Monuments	Background bluff recession rates	Repeat monument measurements in field, compare to historical rates by CGS.
East Whidbey Bluffs	Maylor Point, Oak Harbor and WCLT's Waterman Property	WDFW Before and After armor removal	DEMs	Compare with future monitoring data only.
West Camano Bluffs	Sunset Drive, Northwest Camano	NGS monument benchmark sheets, reference notes	Background bluff recession rates	Measure and compare monument and references locations.
	South of Elger Bay, Southwest Camano	WDOE, Weiner et al. (2015, 2018)	LiDAR and 0.5-meter DEMs	Compare profiles or proxies with 2006 LiDAR.
East Camano Bluffs	Barnum Point, Bluffs off Highland Drive	GIS points with historical bluff recession rates	Background bluff recession rates	Repeat monument measurements in field, compare to historical rates by CGS.

Table 6. Monitoring Targets, Areas Mapped, and Data for Coastal Bluffs.

Historic Beach Communities

Several different data sets are available to monitor Historic Beach Communities (HBCs) throughout Island County. Ecology's mapping is the preferred data set for the west shore of Whidbey Island. Beach profiles from the west Whidbey shore can be extracted from WDOE DEMs and compared with LiDAR DEMs from previous years (2014 or 2006), where repeated survey data is not available. Analysis and interpretation of monitoring data should be carefully conducted due to the dynamic nature of the west shore of Whidbey Island (see *Data Compilation and Analysis,* above). The frequency of the monitoring will depend on data availability.

Elsewhere in the County, beach monitoring data from Sound Water Stewards of Island County could be used to documented changes in (relative) elevations and substrate composition. This beach profile data was collected using the "two-stick" method, in which a profile is drawn perpendicular to the shore from a noted upland reference point. Considerable profile data exists for these beaches, some of which have been monitored for more than 20 years. As previously noted, the explicit location of profiles should be evaluated to exclude sites with shoreline armor. Unfortunately, there will not be monitoring data from 2020 due to COVID-19.

Like bluff monitoring, beach profile data should be compared with either LiDAR elevations or repeated in the future using the same control points for reference. As described previously, the Sound Water Stewards data is collected during summer conditions, and therefore should not be compared with data collected during or following the winter storm season. Physical monitoring should be conducted annually following the winter storm season, or at the time of year that past monitoring was conducted.

Table 7. Monitoring Targets, Areas Mapped, and Data for Historic Beach Communities.

Monitoring Target	Areas Mapped	Data Source	Data Format	Data to compare
West Whidbey HBCs	Swantown, Hastie Lake County Park, West Beach County Park	WDOE, Weiner et al. (2015, 2018)	LiDAR and 0.5-meter DEMs	Compare profiles or proxies with 2006 LiDAR
Southwest Whidbey HBCs	Useless Bay, Sunlight Shores	WDOE DEMs, Aerial Whidbey DEMs, LiDAR	0.5-m DEMs	Compare profiles or proxies from recent DEMs with 2006 LiDAR
East Whidbey HBCs	Langley Clinton, Trail's End Road (nearr Greenbank), Possession Beach	Sound Water Stewards	Beach Profiles	Compare profiles or proxies with 2006 LiDAR
West Camano Island	Utsalady, Madrona Beach, Onemac Point, Mabana Road, Pebble Beach	Sound Water Stewards	Beach Profiles	Compare profiles or proxies with 2006 LiDAR
East Camano Island	Tillicum	Sound Water Stewards	Beach Profiles	Compare profiles or proxies with 2006 LiDAR

Damage to Shoreline Armor

Additional data collection on damage to shoreline armor should be documented through the County. This could be added to the Survey-1-2-3 data collected by the County. Considerable shoreline armor occurs within Historic Beach Communities, which could present a challenge to traditional monitoring and the objectives of this monitoring effort. Shoreline structures are engineered to meet current conditions, and in many cases are not engineered for higher water levels and the additional wave impact from waves breaking against them. Additionally, there are many stretches of shoreline in Island County, that were armored around the same period, such as prior to the shoreline management act (early 1970s) and again in the 1980s. It is likely that new spatial patterns will emerge where shoreline armor commonly fails in association with high water events. The following potential data sources for failed armor structures should be considered and compiled if data sharing is permitted.

- Monitor emergency requests for erosion control
- Monitor location and frequency of FEMA claims
- Partner with Public Works Department to map damage to roads and other infrastructure.

REFERENCES

Booth, D.B. 1994. Glaciofluvial Infilling and Scour of the Puget Lowland, Washington, During Ice-Sheet Glaciation. Geology 22.

Chleborad, A.F., R.L. Baum, and J.W. Godt. 2006. Rainfall Thresholds for Forecasting Landslides in the Seattle, Washington, Area—Exceedance And Probability: US Geological Survey Open-File Report 2006–1064. Accessed June 21, 2016. <http://pubs.usgs.gov/of/2006/1064/>.

Coastal Geologic Services. 2018. Long-Term Bluff Recession Rates in Puget Sound: Implications for the Prioritization and Design of Restoration Projects. Prepared for the Estuary and Salmon Restoration Program—Learning Program.

Dethier, M., W. Raymond, A. McBride, J. Toft, J. Cordell, A. Ogston, S. Heerhartz, and H. Berry. 2016. Multiscale Impacts of Armoring on Salish Sea Shorelines: Evidence for Cumulative and Threshold Effects. Estuarine, Coastal and Shelf Science 175.

Downing, J. 1983. The Coast of Puget Sound—Its Processes and Development, 1st edition, A Washington SeaGrant Publication. University of Washington Press. Seattle, Washington.

Dragovich, J.D., G.T. Petro, G.W. Thorsen, S.L. Larson, G.R. Foster, and D.K. Norman. 2005. Geologic Map Of The Oak Harbor, Crescent Harbor, and Part of the Smith Island 7.5-Minute Quadrangles, Island County, Washington: Washington Division Of Geology and Earth Resources Geologic Map GM-59, 3 sheets, scale 1:24,000.

Easterbrook, D.J. 1968. Pleistocene Stratigraphy of Island County, Water Supply Bulletin No. 25, State of Washington Department of Water Resources

Easterbrook, D.J. 1969. Pleistocene Chronology of the Puget Lowland and the San Juan Islands, Washington. Geological Society of America Bulletin 80.

Easterbrook, D.J. 1992. Advance and Retreat of Cordilleron Ice Sheets in Washington, USA. Geographie Physique et Quaternaire 46(1).

Finlayson, D. 2006. The Geomorphology of Puget Sound Beaches. PhD Thesis. University of Washington. Seattle, Washington.

Gerstel, W.J., M.J. Brunengo, W.S. Lingley Jr., R.L. Logan, H.S. Shipman, and T.J. Walsh. 1997. Puget Sound bluffs: The Where, Why, and When of Landslides Following the Holiday 1996/97 Storms. Washington Geology 25(1). March.

Huppert, D.D., A. Moore, and K. Dyson. 2009. Impacts of Climate Change on the Coasts of Washington State. Chapter 8 in The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate. Climate Impacts Group, University of Washington. Seattle, Washington.

Jacobson, E.E., and M.L. Schwartz, 1981. The Use of Geomorphic Indicators to Determine the Direction of Net Shore-Drift. Shore and Beach 49.

Johannessen, J., and A. MacLennan. 2007. The Beaches and Bluffs of Puget Sound. Puget Sound Nearshore Partnership Report 2007-04. Valued Ecosystem Components. Washington SeaGrant Program, University of Washington. Seattle, Washington.

Keuler, R.F. 1988. Map Showing Coastal Erosion, Sediment Supply, and Longshore Transport in the Port Townsend 30- by 60- minute quadrangle, Puget Sound Region, Washington. <https://pubs.usgs.gov/imap/1198e/plate-1.pdf>.

Miller, I.M., H. Morgan, G. Mauger, T. Newton, R. Weldon, D. Schmidt, M. Welch, and E. Grossman. 2018. Projected Sea Level Rise for Washington State—A 2018 Assessment. A Collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, Oregon State University, University of Washington, and US Geological Survey. Prepared for the Washington Coastal Resilience Project.

Ruggerio, P. 2013. Is the Intensifying Wave Climate of the US Pacific Northwest Increasing Flooding and Erosion Risk Faster Than Sea Level Rise? American Society of Civil Engineers. DOI: 10.1061/(ASCE)WW.1943-5460.0000172.

Shipman, H. 2004. Coastal Bluffs and Sea Cliffs on Puget Sound, Washington. Pages 81–94 in M.A. Hampton and G.B. Griggs (eds.), Formation, Evolution, and Stability of Coastal Cliffs—Status and Trends. Professional Paper 1693. US Geological Survey.

Theiler, E.R., E. Himmelstoss, J. Zichichi, and A. Ergul. 2008. The Digital Shoreline Analysis System (DSAS) Version 4.0—An ArcGIS Extension for Calculating Shoreline Change. US Geological Survey Open File Report 2008-1278.

Weiner, H., G. Kaminsky, and M. Gostic, 2018. Mapping Bluffs and Beaches of Puget Sound to Quantify Sediment Supply, Estuary and Salmon Restoration Learning Project Final Report, Appendix A: Lessons Learned. Shorelands and Environmental Assistance Program, Washington Department of Ecology. Olympia, Washington, Publication #18-06-008.