Iverson Preserve and Livingston Bay: Sedimentation, Groundwater Data Collection & Synthesis

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Introduction and Purpose

Coastal Geologic Services (CGS) was contracted by the Island County Department of Natural Resources to provide consultant services using institutional knowledge of nearshore mapping data to characterize conditions at Iverson Spit Preserve, located on Camano Island. CGS aims to augment understanding and design efficient field data collection and processing to:

- Characterize sedimentation patterns to evaluate the effects on current drainage from the field, ditches, and natural tidal channels to Livingston Bay and, to the best extent possible, predict future effects on drainage.
- Characterize the groundwater behavior and response to tides to determine the extent of tidal forcing.

Sediment coring was completed to help quantify the character and rate of sedimentation within the salt marsh, the tidal flats, and east of the spit. Grain size analysis and dating of the core samples was completed to describe the character and age of various sediment deposits. Additional analysis into historical shoreline and bathymetric change was used to characterize conditions at the Preserve. Groundwater behavior was analyzed by Skillings Connolly and is provided as an Appendix to this report.

Site Conditions

Iverson Spit Preserve is located on the eastern side of Camano Island, in Island County, Washington. The site consists of approximately 300 acres of County-owned land, much of which is wooded uplands and is not considered in this analysis. The remaining areas have been converted to agricultural use with the addition of a tide gate and dike, and private homes have been constructed along Long Beach adjacent to the Preserve.

Geology

Geology of the site was mapped at 1:24,000-scale by the DNR Division of Geology and Earth Resources (Schasse et al., 2009). The geology of the spit was mapped as having marsh deposits (Qm) in the large area now contained by the dike landward of the houses, which are shown to be constructed on artificial fill (af). Marsh and beach deposits (Qb) form the main components of the spit. The marsh deposits are described as:

> "Mostly soft to stiff, olive gray to gray silt and silty clay and bluish gray clay, commonly with lenses and layers of peat, muck, and other organic material; deposited in a saltwater or brackish marsh (estuarine or lagoonal) environment; deposits occur near highest tide levels and are covered with salt-tolerant vegetation or floated logs (particularly at Elger Bay). Many of these deposits (at the north end of Port Susan) have been converted to agricultural use by construction of levees" (Schasse et al., 2009).

The high bluffs bordering the western extent of the study area and south of the spit are mapped as Vashon advance outwash sand ($Qgas_v$). Advance outwash sands are described as:

> "Mostly lacustrine sand with layers of silt; well-stratified; gray; thick exposures display well-developed crossbedding and cut-and-fill structures that are typical of this unit; locally coarsens upward into gravel; thickness is typically 80 ft; thick and extensive in

subsurface, with maximum estimated thickness of approximately 200 ft; commonly forms angle-of-repose slopes along drainages and coastal bluffs" (Schasse et al., 2009).

The bluffs adjacent to the study area were mapped as having Intermediate stability, with no historical landslides mapped within the project bounds during the 1979 mapping (WDOE, 1979a). Historical recession rates measured from bluffs to the south of the site—mapped as Unstable—range from 0.23–0.31 FT/year (CGS 2015). These are moderate to high erosion rates for the Salish Sea region, largely due to the unconsolidated bluff geology combined with the considerable exposure to the south-southeast (11-19 miles), which is the origin of both the prevailing and predominant winds and waves.

The spit is mapped as mostly beach and marsh deposits, much of which is influenced by the sediment from the Stillaguamish River. Much of this sediment is believed to have been deposited relatively recently. Coastal processes acting on the site are discussed in more detail below.

Coastal Processes

The site is located within net shore-drift cell CAM-10, which exhibits northward drift beginning southwest of the site and terminating at the beach in northern Livingston Bay (Keuler, 1988). A net shore-drift cell is an area with long-term littoral sediment transport in a particular direction. A drift cell typically originates at a sediment source, such as a feeder bluff, and extends to an area of deposition (Johannessen and MacLennan, 2007). These high-elevation bluffs are found at the origin of this drift cell near Barnum Point. Feeder bluffs are the primary source of sediment for nearby beaches and intertidal habitats in the Sound (MacLennan et al., 2013). Feeder bluff exceptional shores, so named because they are exceptional contributors of sediment to the drift cell, are present southwest of the Preserve.

Moving northeast, the shore transitions between feeder bluffs and transport zones, eventually ending in the accretion shoreform that includes Iverson Spit Preserve and Livingston Bay. A transport zone is a reach of shore that is neither eroding nor accreting. Accretion shoreforms are characterized by long-term sediment deposition, although many accretion shoreform segments are no longer depositional. Sediment supplied from the feeder bluffs to the south, or up-drift of the Preserve, sustains the accretion shoreform upon which the houses abutting the Preserve are built.

The most frequent large wave activity approaches the Preserve from the southeast, with much smaller waves occurring less frequently approaching from the northeast (PWA, 2001; WDOE, 1979b). The tide gate at the north end of the site is mostly sheltered from the prevailing winds and waves due to the characteristic inward curve of Camano Island at the north end of Port Susan.

Flooding is an important part of the sediment deposition and vegetation colonization in coastal marshes. The dike was constructed to prevent saltwater intrusion and is expected to protect the homes and agricultural land up to the 10-year flood elevation (PWA, 2001).

A variety of saltmarsh vegetation communities were identified at the Preserve, but a significant amount has been lost due to agricultural development (Sheldon & Associates, Inc., 2001). Vegetation communities and wildlife uses of the area are discussed in extensive detail as part of the restoration feasibility efforts completed by PWA and Sheldon & Associates, Inc.

Methods

The methods for this work include four main components, described in detail below. For the project components, horizontal and vertical control was collected via the following: On August 17 and 29, 2016, CGS performed a ground survey with a high accuracy total station (Leica TCR-1105) and direct rod measurement. Survey monuments were set along Iverson Road, the dike, and the spit for future reference. Horizontal control was based on GPS observations using a mapping-grade Trimble GeoHX unit, post-processed with data from WSRN base station COUP. The vertical datum used was NAVD88 based on RTK observation by Eric Grossman, double-checked against LiDAR flown by WSI in 2014 on behalf of Island County Public Works and obtained through the Puget Sound LiDAR Consortium (PSLC).

Shore Change

The historical shoreline and drainage channel location at the Iverson Spit Preserve was examined from the best available data sets (Table 1). The US Coast and Geodetic Survey T-Sheet was obtained from the River History Project as a georeferenced image, and was heads-up digitized to yield lines, polygons, and points (Crowell et al., 1991, Fletcher et al., 2003, Moore, 2000). The 1954 shoreline was heads-up digitized from the USGS topographic quads, but was later replaced by higher-quality aerial image heads-up digitization. Shore changed mapping methods followed will establish methods used for this type of work (Crowell et al., 1991)

LiDAR data was obtained from the PSLC as LAS-format categorized all-returns points. The location of the main drainage channel from the tide gate out through the marsh and low tide terrace was heads-up digitized from aerial photography. These were overlain for a comparison of the location and overall length of drainage.

Table 1. Historical shore change data sources and collection method.

Year	Source	Method
1886	USCGS T-Sheet #1755	Survey
1954	Island County	Aerial Photography
1990	USGS DOQQ	Aerial Photography
2014	Island County	Aerial Photography
2014	Island County Public Works Topographic/bathymetric LiDAR	LiDAR
2016	CGS	Field-mapped (GPS)
2017	CGS	Field-mapped (GPS)

Additional change mapping of current conditions was completed during 2016 and 2017 field reconnaissance and mapping efforts. These shoreline features were determined by walking the approximate mean high water (MHW) line on the beach using a Trimble mapping-grade, differential GPS. This included walking the approximate mean high water (MHW) line using recent recorded and predicted high tides and small offset distances from the visible wet-dry traces on the beach. This work focused on the spit shores in the vicinity of the preserve and further north to the tip of the spit, at the end of the Northwest limb of the spit. Selected additional features were also mapped by GPS.

Bathymetric Change

An analysis of nearshore bathymetric change was undertaken using the best available sources of sea floor mapping (Table 2). Historical hydrographic surveys (H-sheets) were obtained through the National Oceanic and Atmospheric Administration's bathymetric data viewer online (NOAA 1886, NOAA 1962).

The earliest bathymetric data obtained was H-sheet #H08701, mapped in 1886 and available as a scanned image. The map was georeferenced to monuments shown on the T-sheet obtained from the UW River History Project (Puget Sound River History Project, 2005) and to the reference grid sketched on the map in NAD27. The sounding points and bathymetric contours were then heads-up digitized from the georeferenced image. The 1962 H-sheet image was also georeferenced to the map grid and contours heads-up digitized, but the soundings were obtained as digital data.

Table 2. Historical bathymetric change data sources.

Year	Source	Method
1886	USCGS H-sheet #H01730	Lead-line
1954	USCGS H-sheet #H08701	Lead-line
2014	Island County Public Works Topobathy LiDAR	LiDAR

The soundings and contours were used to generate a bathymetric surface model in AutoCAD Civil 3D 2016. Surfaces from each year were then compared to the others to generate an overall volume change surface for analysis of bathymetric change.

Surface Sediment

Sediment samples were collected from the inner low tide terrace, between 70 – 100 FT waterward of the sloping, gravel-dominated high tide beach. In all, 14 different locations were sampled for surface sediment starting near the south-central section of the spit and moving north to the tip of the spit, and then southwards towards the marsh channel landward of the tide gate (map is in *Results* section). Samples were collected at a depth range of 0.0–0.3 FT (10 cm) below the surface. The sediment samples were bagged and labeled, the positon was mapped by GPS, and later the elevation NAVD88 was determined from the 2014 Island County Public Works LiDAR.

Grain size and other relevant beach characteristics were recorded at the time of collection. Particle size gradations used followed the Wentworth Scale (Wentworth, 1922). All surface sediment and core grain size lab analysis was performed by the USGS sediment lab.

Sediment Coring

Five sediment cores were collected from the site using a vibracore system with 10-foot lengths of 3-inch aluminum irrigation pipe with an inner diameter of 3 inches (7.4 cm). Core sampling site selection was intended to sample from a variety of areas within the Iverson preserve and adjacent intertidal zone. The coring sites are shown on the location map in the *Results* section.

Cores were driven into the ground to refusal or until 9 FT of pipe had been inserted. Measurements were then recorded for length of pipe above ground and depth to soil surface inside the pipe, for use in calculation of soil compaction. The cores were then capped and removed from the ground using a manual jack. Excess pipe was cut away and the ends were capped and sealed for transport.

Each of four cores were cut open and separated into two halves, retaining one-half for Pb-210 analysis and the other for sediment grain size and radiocarbon analysis, such that the total cross-sectional area of each sample was 21.5 cm^2. The halves were then photographed, measured, and the various sediment horizons described. The cores were then sliced into 2 cm sections and bagged. Compaction measurements from the field were used to convert the compacted soil measurements to feet below ground surface (FT BGS). Core locations were mapped by GPS, and the ground surface elevation was taken from the 2014 Island County Public Works LiDAR.

Results

Shore Change

Mean High Water

The Mean High Water (MHW) line was the determined to be the most reliable shoreline with which to track long-term change. Much of these locations are approximate where the source is a georeferenced image, and are most useful in demonstrating overall general change.

The area was already diked by 1924, as mentioned in the description for the National Geodetic Survey's station HAY (PID TR1003), which was located near the southern end of Iverson Road, at what is now 169 Iverson Rd. The station had been destroyed in 1946 during reconstruction of the dike in preparation for a beach plat subdivision. The dike and a number of houses can be seen in the USGS Quad (Figure 1). This explains the dramatic changes between the 1886 T-sheet shoreline and the 1954 quad shoreline to the south of Iverson Spit. These changes were especially apparent in the disappearance of the small channel extending into the marsh (Figures 2 and 3).

Iverson Spit has continued to prograde northward over the entire 130-year mapping record (Figures 3 and 4). The tip of the spit prograded approximately 1,240 FT between 1886 and 2001, equivalent to an average rate of 10.7 FT/YR. The northern end of the spit has become narrower and more elongated since 2001. The In the last 16 years, the waterward MHW line has gradually moved inland just along the northern extent while the tip has moved approximately 130 FT to the northwest, accreting approximately 8.1 FT/YR. The northern portion of the spit was mapped one additional time in late June 2017 to determine if the progradation rate was changing. Between 2014 and 2017, the tip of the spit prograded approximately 93 FT to the northwest, which was a rate of 31 FT/YR.

A smaller lobe has begun to form on the base of the northwest limb of the spit on the eastern side (in the Preserve), and has similarly lengthened in more recent years. The area just north of this smaller spit has transitioned landward (westward) over the entire 130-year record. This appears to be one of the most dynamic areas in recent years, seen especially with the formation of the smaller lobe.

The "bend" in the spit, near the base of the northwest limb of the spit in front of the northernmost house/structure has transitioned waterward approximately 171 FT since 1886 to 2014, or about 1.3 FT/YR. This area has a very broad beach and backshore zone with extensive drift logs.

Intertidal Drainage Channel

The intertidal drainage channel outside the tide gate has changed with the spit progradation outlined immediately above. The intertidal channel has consistently run northward from the tide gate and then turned roughly eastward around the tip of the spit, to finally reach a large drainage channel extending south and southeast form Livingston Bay to deeper water of Port Susan. The intertidal drainage channel across the tide flats has lengthened considerably since the first aerial photo of reasonable quality from 1941, when the spit was considerably shorter (Figure 5). The spit continued to prograde between 1941 and 1956 through the accretion of narrow and recurved spit limbs. By 1990, the spit was straightened and further extended, and the intertidal channel length measured from the 1990 aerial photograph was only slightly longer than in the previous period. (3,535 FT; Table 3). By 2014 the channel spit extended further, the intertidal channel migrated northward, and the path of the channel was extended significantly, to 4,353 FT long, an overall increase of 58% as compared to the 1941 channel length.

Table 3. Intertidal drainage channel length across the tide flats, measured from the tide gate to deep water (see Figure 5).

Year	Length (FT)	% Length Increase	Rate of Increase (FT/YR)
1941	2,763	-	-
1958	3,364	21.8	35.4
1990	3,535	5.1	5.3
2014	4,353	23.1	34.1

Northwestward progradation of the spit into the former location of the intertidal channel was a driving factor of this lengthening, and continued sedimentation on the tide flats was likely also a causal factor (see the following sections).

The intertidal drainage channel appears to have remained open across all referenced historical documentation, despite the restrictions on tidal influence by the tide gate when closed. This channel drains a substantial area north of the dike that contains the tide gate (1,052,443 SF; 24.2 acres, in the area north of the dike to an east-west line from the tip of the spit), in addition to the field area when the tide gate is open (4,351,450 SF; 99.9 acres).

Topography Change

The best and most current topography for the study area is from the Island County Public Works LiDAR flown in 2014 (Figure 6). LiDAR data is collected from radar sensors in a plane along with highly accurate GPS sensors for location information. These data extend at least 400 – 600 FT north of the spit and cover the area between the dike and the spit and extend to below mean lower low water on the east shore. Where present, vegetation landward of the dike alters the accuracy, and sharp changes in slope are not captured well in LiDAR data.

The majority of the field inside the dike was at elevation 6 to 8 FT NAVD88 in 2014, well below the local mean higher high water (MHHW, which is at 9.10 FT NAVD88). The 2014 LiDAR data mapped MHHW at or near the landward side of houses with ground just landward of the beach and around the houses higher. The tide flats north of the dike were mostly at higher elevations than the field (Figure 6), and gently sloped to the northeast towards the north end of the spit.

The two different LiDAR data sets (2001 and 2014) were used to: compare the elevation of the northern portion of the field with the area north of the dike and tide gate and north of the spit; to see change over time; and to examine trends in sedimentation and erosion in these areas and others. Due to accuracy issues near sharp slope breaks, such as those present along channels and borrow ditches in the tide flat north of the dike and in the well-vegetated area just south of the dike, erosion may be indicated in areas that are not likely experiencing erosion. However, in flatter areas that are largely devoid of shrubs and trees, the accuracy of these two data sets should be fairly well matched.

This fact that the majority of the field south of the dike is lower than the tide flats just north of the dike is attributed to the lack of sediment input into the field, and likely some amount of settling of the fine grain and compressible sediments of the field. The tide flats between the dike and the spit have likely experienced continued sedimentation due to daily tidal circulation of often-sediment-laden water, along with likely some amount of sediment transport caused by southeasterly waves. As the dike has been present since the early 20th century, small change rates in sedimentation rates can result in the difference in elevation across the dike.

Surface change between 2001 to 2014 (Figure 7) over the broad, non-vegetated areas reveals that the majority of the area north of the dike and south of the spit accreted, with considerable areas experiencing 0.5 – 1.0 FT of elevation gain. Elevation gain exceeded 1 foot in several small areas north of the dike, with more accretion in the more protected eastern area. Some adjustments near the tip of the spit are apparent in the surface comparison, with progradation of the waterward side of the north end of the spit and some lowering of the landward side of the north end of the spit, likely due to shifting of the drainage channels and erosion due to scour along the margin of this channel during ebbing tides (see upper photo in Figure 10). The only other areas that appeared to show erosion were along the channels slopes where measurement error likely occurred.

Two long profiles were cut through the 2001 and 2014 LiDAR data sets, and are shown in large-format (Figure 8). Examination of both profiles A and B graphically display how much lower the northern portion of the field is as compared to the tide flats north of the dike, with general elevation differences in the neighborhood of 1.5 – 2.0 FT. These areas were likely the same elevation when the dike was first installed, and the result of long-term isolation and settling of the field area is apparent.

The elevation of the dike is not thought to have changed, however the crest was likely better resolved in the 2014 LiDAR (Figure 8). In 2001, the deeper areas to the north held water that interrupted the LiDAR signal during data collection. As a result, the lower areas are not well-represented in that data set. Some areas closer to the south side of the spit also appear to be higher in in 2014 along profile B. Spit progradation in profile A is noticeable with approximately 3 FT of vertical accretion in this area. No surface change data is available further waterward due to complications with the 2001 data picking up the water level at approximately 8 FT elevation.

Tide Flat Bathymetry Change

Historical bathymetric data from 1962 was present for the area well east of the houses and the Preserve but did not extend to the intertidal beach. These 1962 data started approximately 400 FT or more waterward of the houses. The main beach area closer to the shore is not included in the analysis, as there were not enough overlapping datasets from which to derive change. Repeated bathymetry mapping (by boat) was a low priority of the government surveyors as the area was well away from ports and commercial navigation routes. These 1962 data were compared to 2014 data from LiDAR.

The lower tide flat area has lowered in elevation since 1962 by as much as 8.39 FT (red areas in Figure 9). The area further east has increased in elevation by as much as 6.90 FT, with the most abrupt change occurring just offshore of the approximate midpoint of Iverson Road (see contour lines in Figure 9). This appears to be a result of the westward translation of the deep channel (this channel drains Livingston Bay area tidal waters southward to the deeper portions of Port Susan) in this area.

Further north, considerable sedimentation occurred east of the Preserve in the one area of data overlap (Figure 9). Total sedimentation in this narrow area was up to approximately 4 FT between 1962 and 2014. This clear trend of shoaling and apparent sedimentation north of the Preserve agree with the LiDAR data presented in Figures 6—8, and appears to show that this sedimentation and shoaling waterward of the dike is a longer term trend.

Sediment Analysis

Surface Sediment

Surface sediments were described in groups based on location on the beach profile and are described by below. Sediment size classes are described using bins of median grain diameter defined in Table 4 based on the Wentworth classification (Wentworth, 1922). See the attached Figure 10 for sample locations and accompanying ground photos. Tabular data is in Appendix A.

The upper intertidal portion of the beach, also referred to as the high tide beach was dominated by highly variable quantities of gravel and coarse sand. This gravel-sand portion of the beach tapers out at the south end of the Preserve, with almost no gravel found further north. The Low Tide Terrace (LTT), defined as the very gently sloping area waterward and below the steeper and gravel-dominated high tide beach, is where the majority of littoral sediment transport is thought to occurred, as this are is far wider (much more surface area) than the high tide beach, and fine sediment is more easily mobilized. With this in mind, and as gravel is not a part of the intertidal beach on either side of the north end of the spit, sediment sampling and analysis was focused on the LTT and the area closer to the tide gate.

Two sets of duplicates sediment samples were analyzed in the lab for quality control, with one set from the surface sediment grab samples and one set from the cores. The data from the duplicates were all in agreement, with differences all within 1% or less in each grain size fraction.

Table 4. Sorting criteria for sediment grain size analysis.

Lab Fraction Names	Fractions	Size Bins	Bin Name
Fines	Clay	<4um	8–12
Fines	Silt	63um->4um	4–8
Fines	Mud (Silt + Clay)	<63um	4+
Intermediate	Sand	63um->2mm	-1 to 4
Coarse	Gravel/Pebble	>2mm	-4 to -1

For the Upper LTT surface sediment sample locations 1, 2, 3 and 6 contained high percentages (>90%) of sand in the 0.063–2.00 mm range, while more northerly locations 7, 8, and 13 consisted of more silts and clays (Figure 10 and Appendix A). Figure 11 shows the cumulative percent frequency of the upper LTT samples, with curves to the left showing more coarse sediment size distributions. Sample 5, located waterward of the northern end of the houses, had the highest percentage of sediment greater than 2 mm in diameter out of the Upper LTT samples. This marked the north end of gravel transport on the LTT. Sample 12 contained a more variable mix of sands, silts and clays. The samples with the finest sediment were located along the northern limb of the spit, and the single most fine-grained sediment was just north of the tide gate. Overall there was a clear trend of less gravel and sand moving north on the upper LTT, along with increased percentages of fines.

For the Mid LTT, the area waterward of the north-central house area (sample 4) and along the south portion of the Preserve (sample 6) both had high percentages (> 90%) of sands (Figure 12 and Appendix A). Sediment from waterward of the northern limb of the spit (sample 9) had minor sand with silt dominant. Sediment continued to fine moving away from open Port Susan, with silt with clay present at samples 11 and 13. It appears there was insufficient wave energy to transport sand into this sheltered location inside of the spit, with only fines deposited in the area north of the tide gate. There is a very clear trend of increasing fines to the north along the mid LTT. Sample 14 was collected inside of the diked area behind the tide gate and consisted mostly of mud (99.9% silts and clays).

Core Sediment Grain Size

A total of five cores were sampled from locations along the spit and in the marsh area on both sides of the tide gate (Figure 10). Core 1 was collected in the field, approximately 750 FT west of the northern-most houses along Iverson Road. Core 2 was collected approximately 30 FT outside the toe of the dike in the saltmarsh protected by the spit. Core 3 was collected from approximately 115 FT southwest of the dike and tide gate, in an area not currently used for agriculture. Core 4 was collected from the tide flat northeast of the Preserve and spit. Core 5 was collected at the toe of the high tide beach just west of the tip of the spit. All cores samples, with the exception of Core 2, were collected below the mean higher high water (MHHW) line.

Figure 10 shows the core sampling locations, and photographs of the split cores are shown in Figure 13. Cores 1, 2, and 3 were predominantly comprised of sandy silt and sandy, silty clay with a layer of medium-coarse silty sand appearing at a depth of 2—3 FT BGS. Core 4, which was taken in the tide flats, was mostly comprised of silty sand throughout, with some embedded shell and wood fragments. Core 5 was not analyzed, as it was not possible to collect a sample of adequate depth. Sediment, grain size, and other features of the deposits in the core are described further in Appendices A and B.

Sediment in the upper portions (0.6—1.3 FT BGS) of cores 1—4 were very fine (silt and clay), except where medium sand dominated core 4 on the lower LTT (Figures 14-17). This shows that fine-grained sedimentation dominated the area in the recent period. Cores 2 and 3, located on either side of the dike, consistently showed this fining upwards trend, indicating that the wave and current energy levels decreased over time here, consistent with a pre-spit development environment that evolved into a sheltered lagoon environment landward of the prograding spit over time. Sediment grain size was somewhat to significantly coarser in the mid-upper elevation of the cores as compared to the upper portions (Figures 16 and 15), with pebble and sand more common.

The mid-lower core sediment samples (2.5—4.7 FT BGS) were fairly similar in terms of grain size with all cores except core 4 (from the far northeast) completely dominated by coarse sand (Figure 16). Core 4 was dominated by fine sand, still much less fine than the upper samples described immediately above. This indicates that the entire area may have been depositional tide flats prior to spits developing. Lower core samples (4.8—6.0 FT BGS) were available only from cores 3 and 4, which were dominated by medium to coarse sand with minor pebble (Figure 17). Core 4 on the northeast tide flats had more medium to coarse sand in the lower portion (Figures 13—17), along with several pebble clasts, indicating that the energy level was highest when the lower portion of the core sediment was deposited, consistent with the understanding of progressive shoaling and potentially fining of source sediment over time.

Core Dating

As described in the *Methods* section above, cores were split lengthwise into two halves. One-half of each of the four cores was sent to MyCore Scientific lab in Ontario, Canada and analyzed for PB-210 concentrations to determine the age of the sample. Results are shown in Table 5 and data reports are in Appendix C. There was no Pb-210 in excess of the background concentration in cores from the central field (core 1) and from the lower LTT northeast of the Preserve (core 4). This suggests that sedimentation was rapid, or that the sediment may have been very disturbed by repeated plowing or ditching in the field (core 1) or by intertidal drainage channel movement, which appears to have occurred near core 4 (see *Intertidal Drainage Channel* section above).

Table 5. Sedimentation rates based on Pb-210 analysis of cores taken from Iverson Spit in August of 2016. Data provided for cores 2 and 3; there was no Pb-210 in excess of the background concentration in cores 1 and 4.

Core	Depth of Section (CM)	Depth of Section (FT)	Sedimentation Rate (CM/YR)	Sedimentation Rate (IN/YR)	Time Period
2	0-2	0-0-0.07	0.261	0.10	2009-2016
	2-4	0.07-0.13	0.263	0.10	2001-2009
	4-6	0.13-0.2	0.240	0.09	1993-2001
	6-8	0.2-0.26	0.189	0.07	1983-1993
	8-10	0.26-0.33	0.095	0.04	1962-1983
	10-12	0.33-0.39	4.000	1.57	1962-1962
	12-14	0.39-0.43	0.272	0.11	1954-1962
	14-16	0.43-0.46	0.068	0.03	1925-1954
3	0-2	0-0-0.07	0.143	0.06	2003-2016
	2-4	0.07-0.13	0.090	0.04	1981-2003
	4-6	0.13-0.2	0.114	0.04	1963-1981
	6-8	0.2-0.26	0.076	0.03	1937-1963

The second half of three of the cores was subsampled for organic material suitable for radiocarbon analysis of select wood fragments found within the sediment by Direct AMS, as described in the *Methods* section above. Wood deposits were used for dating wherever present in adequate quantity. Twelve sediment samples were identified by core and depth. Sample locations were selected to best characterize thick deposits and transition areas in the cores. Results from the radiocarbon dating analysis are shown in Table 6, with original reports in Appendix D. Note that the age of wood in the marine environment may vary greatly from the age of the sediment in which it was deposited. Overall, radiocarbon dating was found to be somewhat inconsistent and uncertain, and the PB-210 dating information appears more reliable. However, the radiocarbon data extends farther back in time and is included in the analysis with lower confidence and importance.

The slowest sedimentation rate measured with Pb-210 in the study was located just south of the present-day location of the dike and tide gate at core 3. Pb-210 ages here extended back to an approximate age of 91 years in 2016, having been deposited around 1937, at a depth of 0.2—0.26 FT (6—8 CM; Table 5). The sedimentation rate at this location was generally 0.03 inch per year (IN/YR) starting in approximately 1937 and slightly faster very recently (Table 5). Radiocarbon dating for this location south of the tide gate had numerous dates around the year 1100 for the middle elevation of the core (Table 6). This equates to a slower sedimentation rates over the long-term, on the order of 0.05 IN/YR, similar to the more recent rates here.

Table 6. Radiocarbon dating of wood samples collected from sediment cores taken from Iverson Spit in August of 2016. RC Age determined in relation to reference year of 1950 (e.g. 169 years is approximately the year 1781).

Core	Depth (cm)	Depth (FT)	RC Age	Year	Sed. Rate to Present (IN/YR)	RC 1σ error
2	85	2.8	169	1781	0.14	30
3	49	1.6	246	1704	0.06	27
	98	3.2	935	1015	0.04	24
	116	3.8	809	1141	0.05	37
	130	4.25	810	1140	0.06	28
	149	4.9	825	1125	0.07	29
	158	5.2	790	1160	0.01	22
4	61	2.0	modern	-	(high)	
	110	3.6	173	1777	0.18	23
	113	3.7	132	1818	0.22	26
	137	4.5	121	1829	0.29	32
	146	4.8	54	1896	0.48	34

Pb-210 data from just north of the present dike and tide gate at core 2 revealed a consistently accelerating sedimentation rate since approximately 1925, with rate of 0.03 increasing to 0.10 IN/YR (Table 5). Rapid sedimentation at core 2 appeared to occur around 1962 but was much slower between approximately 1925 and 1954. Farther back in time (since 1781) at this location, the radiocarbon data showed a long-term rate similar to the most recent rate (Table 6). It appears that the area north of the present dike has continued to get sedimentation at moderate rates, with increases in recent decades.

Radiocarbon dating for this location north of the tide gate had dates around the year 1100 for the deeper portions of the core (Table 6). These slower sedimentation rates averaged about 0.06 IN/YR over the long-term, approximately half of the more recent rate here.

The dike was in place since at least 1924 (described on page 6 of this report). Comparison of the core sample dating on both sides of the dike suggests that the dike has significantly reduced the sedimentation rate in the north end of the enclosed area since it was constructed, as marine sedimentation is precluded by the dike. Data shows that the sedimentation rate continues north of the dike at rates similar to pre-development.

Pb-210 dating was not available for the lower LTT/tide flat northeast of the Preserve and north spit at core 4, which was perhaps due to disturbance here or a rapid sedimentation rate. As previously mentioned, this area likely experienced some reworking of sediment and change due to the intertidal drainage channel from Livingston Bay. Radiocarbon data, although inconsistent, suggests that sedimentation has been very high most recently with a modern age date at 2.0 FT BGS (Table 6) and sedimentation rates a little more than double those north of the dike and four times those of south of the dike. Sediment in this area has included a high percentage of fines

Groundwater Monitoring Report Conclusions

See Appendix E for the full *Groundwater Monitoring Report*, produced by Skillings and Connolly (2017). The *Conclusions* section is included here in its entirety:

Groundwater levels for Iverson Preserve are shown to fluctuate with seasonal and tidal influence. The inland monitoring wells were found to have a smaller fluctuation in high and low differences compared to the marine shoreline portion, which showed tidally influenced water levels. At no time during the study period did groundwater reach the existing ground levels. Surface flooding, in the form of extensive ponding was observed during the monitoring period. However, groundwater levels did not exceed the surface elevation. It was determined that shallow ponding was a result of precipitation rather than high groundwater levels. Surface ponding was determined to be due reduced infiltration rates associated with agricultural use of Iverson Preserve. The high clay content observed, combined with soil compaction associated with agricultural use has reduced the infiltration rate within the Preserve, creating surface ponding.

With respect to the western boundary, slope conditions did not influence groundwater levels due to heavy/dense vegetation and the conveyance ditch at toe of slope. Soil conditions vary from west to east within the project boundary. The western extent exhibited a thick layer of clay. Sand predominated through the soil matrix in the eastern extent. Groundwater will move freely through less dense materials thus leading to the assumption that higher levels of pressure influenced by daily tidal fluctuations from Iverson Bay affect groundwater levels at the MW-4 location the most. Evaluation of surface water data indicates that the ditch network throughout the study area likely receives hydrology from high groundwater levels. During the wet season and winter high tides, groundwater remains relatively shallow, being restricted by hydrostatic pressure caused by close proximity to marine waters. During the dry season and lower high tides, groundwater collected within the ditch network is discharged via a single culvert that conveys flows through the protective dike. During high tide, a tide gate on the culvert restricts flows, impounding surface water within the ditch system and maintaining higher groundwater levels. Due to the fact that the average tidal elevation is higher in winter, the tide gate remains closed for longer periods of time, further restricting the existing drainage system. At the very beginning of the study, the tide gate was obstructed, which would have allowed tidal flushing within the ditch system. However, the obstruction was cleared within a few weeks of well installation.

Based on soil type and the slow response time seen in groundwater fluctuations, it can be concluded that while tidal fluctuations have an impact on groundwater levels, it does not appear that the groundwater elevation responds as quickly as observed tidal fluctuations. The use of a tide gate on the discharge culvert likely limits the level of high groundwater within the study area by limiting tidal inundation. The size of the culvert and tide gate also likely limit the volume of surface water discharged from the study area during low tide, based on hydraulic sizing.

Summary and Conclusions

Historical shore change analysis revealed significant changes in the position and elevation of the spit, surrounding nearshore area, and in development of spit features. These changes have significantly altered processes surrounding the spit and marsh, including sediment deposition and erosion, and water flow and circulation. Drainage of the pre-development back-barrier lagoon (and later the developed field area) was also likely affected.

Major physical changes and their effects, which were detailed in the *Results* section above and in the attached figures, are summarized below:

Coastal Geomorphic/Sedimentation Trends

Much data on sedimentation were collected with multiple analysis methods, as outlined in the body of the report above. These data are summarized briefly here:

- The study area is located in a short drift cell and therefore has limited littoral sediment input.
- Spit progradation (lengthening) has consistently occurred over time, but at increased rates in recent decades.
- The intertidal drainage channel running northward then eastward from the dike and tide gate to deep water has increased in length substantially in the past century.
- The elevation of the fields is generally 2 – 3 FT below the level of MHHW, and is now generally 1.5-2 FT lower than the tide flat present between the dike and the spit.
- The presence of the dike has prevented the sedimentation that is occurring on the tide flats north of the dike from occurring south of the dike.
- The fields and other area south of the dike have likely subsided some due to the presence of fine grain, compressible sediments and the lack of sedimentation coming from marine waters.
- Intertidal sediment became progressively finer grained spatially, moving northwest from the residential area.
- Intertidal sediment became finer grained temporally in most location, as the spit prograded northward and decreased the water depth and/or protected increasing amounts of the study are from wave energy.
- Increase in sedimentation rates were observed on the tide flats north of the tide gate and spit up to the present.
- Sediment accretion rates outside of the dike have increased over time at many locations.
- The most rapid sedimentation appears to be occurring in the area northeast of the Preserve and north end of the spit, with sedimentation rates roughly double those north of the dike and more than four times those of south of the dike. Sediment in this area has included a high percentage of fines.
- More rapid sedimentation northeast of the Preserve may be related to deposition of fine grain sediment from high sediment load discharge from the Silliguamish River following the Oso landslide in 2014, along with sediment from feeder bluffs to the south and from the more-distant Snohomish River.

All of these observed changes have functioned to decrease the ability of the tide gate and the northern intertidal channel to drain water from the marsh. As the elevation of the intertidal surface north of the tide gate has increased, the length of time during which it has been possible for the tide gate to open has decreased. Consequently, the tide gate has likely been backed up and unable to drain water for longer periods of time in recent years, decreasing the ability to drain precipitation and other water from the field area. Compounding this problem is the small size of the tide gate and the fact that beaver activity and the current design results in the gate becoming clogged periodically.

The low elevation of the field area appears to be a function of the former intertidal nature of this portion of the site. This has been exacerbated by the dike, which has isolated the field from marine sedimentation. Presently, the elevation of the field is likely settling due to compression of fine-grained sediment and subsidence of the marsh area, which is also being affected by sea level rise.

The 2001 study on restoration alternatives (Williams et al., 2001) assumed a 2-inch per decade sedimentation rate in what is now the field area if the dike were setback or removed. Elevations behind the current dike could be expected to increase by one foot in approximately 60 years at this rate, with tidal inundation and sediment delivery restored.

Groundwater and Surface Water Monitoring

- Elevation of the field is below elevation of normal high tides, with large areas of the northern fields with a very shallow water table.
- Groundwater in field area is influenced by tides, especially in close proximity to the beach
- Groundwater did not cause flooding of the ground surface during the 2016-2017 study, but precipitation did cause flooding once in late winter.
- Poorly draining, fine-grained soils caused surficial flooding following precipitation in spring 2017.

Findings of the forthcoming USGS study report on oceanographic flux should be considered in context of the sedimentation and groundwater findings addressed above.

Sea Level Rise

An additional compounding factor of drainage, coastal inundation, and precipitation-caused flooding at the site is projected sea level rise. Projections vary between different sources, as does the interpretation of published projections. Recent work by the University of Washington—Sea Grant team working on coastal resilience in Washington, with funding by NOAA (Miller et al., 2016), chose to use the intermediate projections for sea level rise from work by the National Academy of Sciences (National Research Council, 2012). This team also looked at vertical land motion of selected areas of Island County, including at Iverson spit, and came up with the probabilities of sea level rise exceeding certain values by the years 2050 and 2100 (Miller et al., 2016; National Research Council, 2012). These data suggest that 0.8 FT of sea level rise is likely at the 50% confidence interval by 2050, and 1.4 FT of sea level rise is likely at the 1% Confidence interval. By 2100, 2.2 FT of sea level rise is likely at the 50% confidence interval, and 4.9 FT is likely at the 1% confidence interval. Under this intermediate projection model, the study placed the probability of daily inundation of Iverson Preserve at high tide in the range of 1—5%, and Iverson Spit in excess of 50% probability by 2050. The entirety of the Iverson Preserve area, including Iverson Spit and the associated dike and houses, fell within projected annual extreme storm flooded areas by 2050 in excess of 50% probability.

Other groups have chosen to use the high sea level rise scenario from the National Academy of Sciences (National Research Council, 2012) work for planning into the future, including the State of California, the City of Olympia, and San Juan County Public Works. One reason for a number of authors and managers to anticipate higher sea level rise projections are the occurrence of significant ice melt from Greenland and Antarctica, along with potential rapid loss of portions of floating ice sheets near Antarctica, which were not generally included in previous projections due to incomplete understanding in work to date (Sweet et al., 2017). In the absence of vertical land motion, the magnitude of the high scenario for sea level rise in the Seattle to North Puget Sound region is 1.24 to 4.69 FT by 2100, relative to the year 2000 (National Research Council, 2012).

One foot of sea level rise would have dramatic effects on flooding in drainage at the Iverson Preserve area, not to mention coastal erosion or potential damage to the road and houses. Two feet of sea level rise would bring extreme changes in these parameters. Increasing water levels due to sea level rise from the marine side would result in significantly shorter periods for the tide gate to drain, as well as likely increased infiltration through the current tide gate into the field due to the longer times of inundation. This could be compounded by projected increases in frequency of heavy or extreme precipitation events due to climate change in the future (Sweet et al., 2017). SLR clearly is a critical factor to be considered in any future planning work, and adds urgency to working on the existing problems.

Preliminary Implications

The tide gate and surrounding channels appear undersized to allow for proper drainage of the field, and generally prohibit the exchange of marine waters southward across the dike. The fact that the field is well below the elevation of mean high water, and that the ground here is likely settling/subsiding, results in an increasing amount of water volume above the level of the tides that attempts to drain through the tide gate when open. This compounds the progressively worsening drainage across the tide flats due to both the longer intertidal drainage channel and the natural sedimentation occurring north of the dike.

Addressing implications and management of the area was beyond the scope of this effort, but preliminary implications are mentioned here to aid in planning. In the absence of changes to the system, current trends of spit progradation, apparent continued sedimentation in the intertidal, and occasional flooding are likely to continue, and impacts will likely increase in severity. Projected sea level rise with continued storm wave forcing will likely make the severity and frequency of storm damage and coastal flooding worse over time, in the absence of substantial changes to the system. As the geologic deposits beneath the spit and field are sedimentary and likely contain some fine-grained and compressible sediment, the area may also be experiencing settlement/subsidence. These factors could contribute to increased terrestrial and coastal flooding, as well as storm damage.

Recommendations for Determining Management Options

These recommendations are informed by review of major findings and recommendations from the *Iverson Farm Restoration Feasibility* study (Sheldon & Associates, Inc., 2001) and the *Flood Study to Determine Alternatives for Restoration and Enhancement* (Williams et al., 2001). It is important to note that these two studies did not have the benefit of extensive data collection specific to those studies, and that the science and engineering of these types of projects has advanced since these two studies were written. Although the scope of the current study was limited to data collection and documentation, the following general recommendations are provided to assist Island County in determining the next steps for the site.

The following additional work is recommended to better understand processes and allow for evaluation and potential design of adaptation approaches, as they may be feasible:

- Complete leveling studies to determine if settling/subsidence of the Preserve and developed area is occurring
- Monitor surface elevation changes in the intertidal flats north and northeast of the tide gate and dike and shore change trends over time

- Monitor net oceanographic flux (as completed by the USGS in parallel to this study) into the future to characterize variability during different tidal and wind conditions and to see if a change can be detected over time.
- Consider continued groundwater level monitoring in established locations (from this study)
- Install instrumentation to monitor the opening and closing of the existing tide gate to help determine its function and to assist with potential hydraulic modeling
- Carefully record maintenance events at and surrounding the tide gate area
- Complete field measurements of flow from the tide gate, and hydraulic modeling of the area, to determine how much of a limitation the current tide gate is on draining the field and surrounding area
- Evaluate in more detail, including developing a new hydraulic model, different scenarios for management including:
    - replacement of the tide gate with a larger gate
    - dike setback to reduce the volume of impounded water to drain allow for sedimentation in a broader area, and facilitate habitat enhancement
    - projections of future conditions
- Perform conceptual design work using current and new data, hydraulic modeling, and planning level cost estimates for different alternatives.
- The general goal of reducing the area that needs to be drained while also providing for some amount of nearshore marsh and pocket estuary restoration will aid in acquiring funding.
- Qualitatively (and potentially quantitatively) evaluate likely nearshore habitat benefits of conceptual alternatives outlined immediately above.
- Evaluate the feasibility of adapting the road access, tide gate, and drainage network for projected sea level rise and site evolution.

Limitations of This Report

This report was prepared for the specific conditions present at the subject property to meet the needs of specific individuals. No one other than the client and their agents should apply this report for any purposes other than that originally contemplated without first conferring with the geologist that prepared this report. The findings and recommendations presented in this report were reached based on a series of focused field visits. The report does not reflect a complete examination of sub-surface conditions present at the site, or drainage system designs, which are not known to exist. It is based on examination of surface features, bank exposures, sediment characteristics, gross vegetation characteristics, and coastal processes. In addition, conditions may change at the site due to human influences, floods, groundwater regime changes, or other factors. This report may not be all that is required to carry out recommended actions. More detailed design specifications may be needed for proper implementation of a habitat enhancement project.

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ATTACHMENTS:

Figure 1. Location and net shore-drift (completed)

Figure 2. Historical T-Sheet map with comparison to 2014 LiDAR MHW (completed)

Figure 3. Shore change from 1886–2014 (Completed)

Figure 4. Shore change from 2001–2017 (completed)

Figure 5. Channel change from 1941–2014 (completed)

Figure 6. Topography using 2014 LiDAR (completed)

Figure 7. Surface change from 2001–2014 (completed)

Figure 8. LiDAR cross sections (completed)

Figure 9. Bathymetry change from 1962 NOAA H-Sheet and 2014 LiDAR.

Figure 10. Surface sediment and core sample locations

Figure 11. Surface sediment grab sample (upper LTT) cumulative percent frequency results by phi size

Figure 12. Surface sediment grab sample (mid LTT) cumulative percent frequency results by phi size

Figure 13. Split sediment core sample photographs

Figure 14. Core sample cumulative percent frequency results by phi size, upper depths

Figure 15. Core sample cumulative percent frequency results by phi size, mid-upper depths

Figure 16. Core sample cumulative percent frequency results by phi size, mid-lower depths

Figure 17. Core sample cumulative percent frequency results by phi size, lower depths

Figure 18. Grain size analysis cumulative percent frequency results by phi size, Core 1, field

Figure 19. Grain size analysis cumulative percent frequency results by phi size, Core 2, inside tide gate

Figure 20. Grain size analysis cumulative percent frequency results by phi size, Core 3, outside tide gate

Figure 21. Grain size analysis cumulative percent frequency results by phi size, Core 4, tide flat

Appendix A. Sediment grain size tables

Appendix B. Sediment core descriptions

Appendix C. pb-210 Analysis, MyCore scientific report

Appendix D. Direct AMS radiocarbon dating report

Appendix E. Groundwater Monitoring Report, Skillings Connolly Inc.