BLUE COAST
ENGINEERING

To: David Palazzi (DNR)

CC: Kathy Ketteridge, P.E., PhD (Blue Coast Engineering)

From: Greg Curtiss, P.E. Jessica Côté, P.E.

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Re: Whiteman Cove – Coastal Processes Assessment

1. INTRODUCTION

A team of consultants led by Anchor QEA, including Blue Coast Engineering (Blue Coast), has been retained by the Washington State Department of Natural Resources (DNR) to provide analysis, design, permitting, and outreach support for the Whiteman Cove Restoration Architecture and Engineering Design Project (Project). The purpose of the Project is to re-establish anadromous fish passage between Whiteman Cove and Case Inlet in Puget Sound to meet the requirements of the 2013 federal court injunction for fish, which requires fish passage for "all species of salmon at all life stages at all flows where the fish would naturally seek passage (United States v. Washington, No. C70-9213, W.D. Wash. Mar. 29, 2013)."

Whiteman Cove is a historical barrier lagoon located on the southwestern shoreline of the Key Peninsula in Pierce County, Washington. It is separated from Case Inlet by a natural spit formed by net littoral drift to the north and feeder bluffs to the south, which has been closed off by a sheet pile wall and fill. The historical opening to the cove, located at the northern end of the spit, was artificially closed by the Washington Department of Fisheries (Née WDFW) in 1962 to create a perched brackish water lagoon that was intended for the rearing of juvenile salmon.

The impounded lagoon is approximately 25 acres in size. Two control structures maintain water surface elevations in the lagoon at an average of 13 feet mean lower low water (MLLW) or 9 feet North American Vertical Datum of 1988 (NAVD88). Minimal water exchange occurs through the control structures between the perched lagoon and Case Inlet resulting in a nearly static water surface elevation.

Fish passage is completely blocked by the control structures. The outlet of the north control structure is buried in beach sediment and is rated as a complete barrier (WDFW 2020c), and there is a large drop at the upstream end of the south control structure during all but the highest tides. Freshwater input to the cove comes primarily from a small intermittent stream (Whiteman Creek) at the eastern end of the cove that drains the approximately 1.7-square-mile upland watershed. The WDFW Salmonscape mapping indicates that there are several fish passage barriers on this stream (WDFW 2020).

Four options to provide fish passage to the Cove were considered and evaluated as part of a screening-level feasibility study conducted by the Anchor QEA team as part of this project. The results of that analysis are documented in the Feasibility Report for the Project (Anchor QEA et al., 2020). The screening analysis provided information regarding fish passage, permitting and site use challenges and opportunities for each of the proposed options. Following the screening analysis, all four options were moved forward into the feasibility study. This memorandum summarizes the results of the coastal processes and geomorphic analysis conducted for each proposed option described briefly below:

- Option 1: A new gated control structure at the current location of the DNR control structure
- Option 2: A new weir control structure at the historical opening to the north
- Option 3: An open channel at the historical opening of the Cove with a bridge crossing
- Option 4: An open channel at the historical opening of the Cove with road removal and rerouted access from the south.

2. PURPOSE

This memorandum provided by Blue Coast summarizes an evaluation of coastal sediment dynamics of Whiteman Cove and its adjacent nearshore if the cove were to be re-connected to Puget Sound with a functional control structure (Option 1), weir control structure (Option 2), or an open channel (Options 3 and 4). The scope of the evaluation included a combined analysis of geology and hydraulics to determine the existing geomorphology and sediment dynamics and to evaluate the potential impacts of Options 1 through 4 on these processes. Analysis will address the potential impacts to nearshore habitats updrift from the project site as well as the ability for a tidal channel to be self-sustaining under coastal processes at the site (Options 3 and 4 only).

This memo describes changes to some biological habitats because of coastal processes and sediment transport. However, the potential changes to the biological communities due to proposed options are described more comprehensively in the Habitat Memo for the project (Anchor 2020).

3. SITE OVERVIEW

Whiteman Cove is located along the eastern shoreline of Case Inlet. The lagoon is separated from Case Inlet by a barrier spit that extends from the south to the north with a historical inlet through a tidal channel on the north side of the lagoon. The spit formed from sediment transported from the south to the north, the direction of littoral drift due to predominant winds from the southwest. The lagoon inlet was filled as part of a roadway constructed on the spit in 1962.

The following aerial photographs, Light Detection and Ranging (LiDAR) datasets, ground-based topographic surveys, and bathymetric surveys are available for the site:

- 1876 topographic T-sheet
- Aerial photographs (USGS): 1951, 1957, 1968, 1969
- 2005 Puget Lowlands LiDAR
- 2011 Pierce County LiDAR
- 2014 bathymetry data (Anchor QEA 2015).

The topography sheet (T-sheet) from 1876 (Figure 1) shows the barrier spit fronting the lagoon extending to the north with the inlet opening to the north. No hydrographic data are available inside the cove, indicating it may have been too shallow and lacked a navigable channel deep enough to allow surveying. The delineation of the low tide line on the T-sheet shows an accumulation of sediment in a fan shape west of the lagoon tidal channel extending into the nearshore which is commonly referred to as an ebb tidal delta. The ebb tidal delta is formed as sediment being transported alongshore from south to north (littoral drift) is disrupted by the flow through the tidal channel and deposited in sand bars south of the tidal channel.

A 1951 aerial photograph (Figure 2) taken prior to the roadway construction shows the lagoon in a similar configuration as the T-sheet with the inlet opening to the north. The photograph shows an approximate 250-foot wide opening (measured from inside of barrier spit to shoreline at the location of the current roadway) with two low flow channels less than 50-feet wide within the opening. Inside the lagoon there is also a tidal delta which was formed by the asymmetry of tidal flows (stronger flood tide velocities) which transport and deposit sediment inside the lagoon near the opening as the currents decrease in magnitude. Outside of the lagoon, there is a braided network of smaller tidal channels which extend across the ebb tidal delta and into Case Inlet.

Department of Ecology (Ecology) oblique aerial photographs from 1977 and 2016 (Figure 3) show the closed off lagoon and growth of the barrier spit to the north fronting the historic tidal channel entrance. North of the roadway berm and outside of Whiteman Cove, a small lagoon formed behind the extension of the spit. In the 1977 photograph, the inlet from this smaller lagoon is parallel to the northern shoreline. Between 1977 and 2016 (Figure 3), the small lagoon has filled in (likely from a combination of overwash and runoff) and become salt marsh. In

2016, the primary inlet appears to be on the south end of the small lagoon and is nearly adjacent to the roadway berm. There is also increased vegetation visible on the outside of the barrier spit.

The elevation along the crest of the barrier spit outside of the smaller lagoon ranges in elevation from 16 to 17 feet Mean Lower Low Water (MLLW) (12 feet to 13 feet North American Vertical Datum of 1988 [NAVD88]) while the roadway berm is at an elevation of 20.5 feet to 21 feet MLLW (16.5 feet to 17.0 feet NAVD88). Slopes along the upper nearshore are in the range of 1:9 to 1:10 H:V (Horizontal to Vertical). A shellfish (geoduck) aquaculture lease is located on the low-sloping delta outside the proposed channel opening. Also located in this area of the nearshore are eelgrass beds planted as part of a DNR pilot project.

4. COASTAL SETTING

4.1 Geologic Setting

Whiteman Cove was historically a tidal barrier embayment, a lagoon or estuary which forms where the shoreline abruptly changes direction protecting the embayment from wave action and the depths are sufficiently shallow for sand bars to rapidly form into a barrier sand spit. These systems are protected from wave action inside the embayment by the sheltered configuration and the protective barrier spit. The term pocket estuary is often used to describe this system of geomorphic landforms in Puget Sound (Shipman 2008). As a barrier embayment, Whiteman Cove falls within the sub-category of a barrier lagoon as defined by Shipman (2008) as a "tidal inlet largely isolated by a barrier beach and without considerable input of freshwater from a stream or upland drainage." While there is a small intermittent (perennial) stream entering Whiteman Cove, Whiteman Creek is not significant enough of a water source to create an estuary at this location.

4.1.1 Geology

The geology at Whiteman Cove was mapped by the Washington Division of Geology and Earth Resources (Logan et al. 2003). The uplands north of the cove are mapped as Vashon Stade fine-grained sediments which are lacustrine in origin. South of the cove is mapped as Vashon Stade till, a compacted mixture of clay, silt, sand, and gravel and landslide deposits along the shoreline deposited by mass wasting. Sediments along the spit which separates the lagoon from Case Inlet are mapped as fill (which in includes engineered and non-engineered fills) and beach deposits of Holocene age which consist of mud, sand, and gravel deposited in the inter-tidal zone.

4.1.2 Geomorphology and Sediment Transport

Feeder bluffs located to the south of the spit (Figure 4) are the current source of sediment to the nearshore area, barrier beach, and barrier spit adjacent to Whiteman Cove. Recent slides have been mapped by Logan et al. (2003) immediately to the south of Whiteman Cove. Sediments from the feeder bluffs are introduced to the nearshore area through mass wasting (i.e. landslide events) and are transported through the nearshore by littoral drift. The littoral cell, which originates at Taylor Bay to the south, is approximately 2.5 miles in length and Whiteman Cove is on the terminal end of this cell.

The nearshore area adjacent to the proposed inlet opening is partially protected from the largest southwest wave events by the shallow bathymetry of the historic ebb delta which formed naturally and still somewhat persists because of the rapid change in the orientation in the shoreline . Aerial photos (Figure 5) show an area of coarser sediment (cobbles) on the more exposed beach to the northwest along Joemma State Park. The cobble suggests armoring of this stretch of shoreline which is more exposed to wave action from the southwest where the curvature of the shoreline changes.

No estimates of littoral cell drift rate are available for Whiteman Cove, however, a published estimate of littoral drift volume is available for Vaughn Bay spit, approximately 8 miles to the north of Whiteman Cove (Wallace 1988). Vaughn Bay spit is a close analog to Whiteman Cove with respect to fetch exposure and cell length. The site has a similar exposure along the eastern shoreline of Case Inlet, cell length (2.4 miles), and maximum fetch length (5.3 miles). The estimate of littoral drift at Vaughn Bay is 2,650 cubic yards (CY) per year. This is consistent with Keuler (1988) which reported most moderate and low energy drift cells in Puget Sound have net transport rates less than 4,000 CY/year.

An analysis of the shoreline change using the available LiDAR data (Figure 6) shows the recent evolution of the spit and the change in the opening from the smaller lagoon outside the roadway berm. The analysis shows the location of the Mean Higher High Water (MHHW) elevation based on the LiDAR datasets from 2005 and 2011. In addition to the shift in the small lagoon channel opening, the MHHW contour has moved waterward approximately 40 to 50 feet on the north side of the channel and 10 feet to 15 feet waterward immediately south of the small channel. This suggests deposition of sediment along the barrier spit has continued in recent years.

4.2 Water Levels

4.2.1 Tidal datums and extreme water levels

Water levels in Puget Sound are influenced by astronomical tides (mixed semi-diurnal), localized, short-term fluctuations due to meteorological conditions (storm surge), and long-term changes in mean sea level resulting from climatic variation and vertical land motion. The tidal datum elevations and extreme water levels and projections for sea level rise are provided in this section to understand the frequency and level of inundation along the shoreline at Whiteman Cove.

Characteristic tidal datum elevations are available from the National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) water level station #9446807 in Budd Inlet near Olympia, WA approximately 9 miles south of the project site. The tidal datum elevations are reproduced in Table 1 for the 1983 to 2001 tidal epoch relative to Mean Lower Low Water (MLLW) and NAVD88.

The Federal Emergency Management Agency (FEMA) and the National Flood Insurance Program (NFIP) provides a Flood Insurance Rate Map (FIRM) for Pierce County which includes the Whiteman Cove and is based on the preliminary Flood Insurance Study (FIS) for Snohomish County (FEMA FIS 2017). The FIRM gives a Base Flood Elevation (BFE) (subject to inundation by the 1% annual chance or 100-yr flood and includes wave run-up) of 20.1 feet MLLW (16 feet NAVD88) (FEMA FIRM 2017). The 1% annual chance stillwater flood elevation in Case Inlet is 17.3 feet MLLW (13.2 feet NAVD88). The 1% annual chance flood elevation inside Whiteman Cove is 17.1 feet MLLW (13 feet NAVD88) and is similar to the elevation in Case Inlet. Wave run-up and setup are not significant inside Whiteman Cove and therefore the stillwater elevation (which doesn't include wave run-up or setup) is most relevant within the Cove.

Table 1. Tidal Datums at Budd Inlet, Olympia, Washington (#9446807)

Tidal Datum	Elevation (feet MLLW)	Elevation (feet NAVD88)
Highest Astronomical Tide (HAT)	16.5	12.4
Mean Higher High Water (MHHW)	14.5	10.4
Mean High Water (MHW)	13.6	9.5
Mean Tide Level (MTL)	8.3	4.2
North American Vertical Datum of 1988 (NAVD88)	4.1	0.0
Mean Low Water (MLW)	3.1	-1.0
Mean Lower Low Water (MLLW)	0.0	-4.1

4.2.2 Sea level rise

The historical mean sea level trend based on a NOAA-NOS analysis of the Seattle station is an increase in mean sea level of 2.06 millimeters per year (0.08 inches/year) with a 95% confidence interval of 0.03 inches/year. This is equivalent to an increase in water level of 0.7 feet over the last 100 years.

Long-term mean sea level in Puget Sound is predicted to increase versus historical rates of sea level rise (SLR) because of climate change related impacts. Miller et al. (2018) provides projections of local SLR at coastal locations in Puget Sound and Washington for various planning horizons. The projections incorporate the latest assessments of global sea level rise due to different greenhouse gas scenarios and local estimates of vertical land motion. Table 2 provides projections for year 2050, 2070, and 2100 planning horizons for the coastal location nearest the Whiteman Cove project site for various exceedance probabilities.

Table 2. Projected average sea level rise for different time periods and greenhouse gas scenarios for the coastal area near Whiteman Cove (Miller et al 2018).

Year	Greenhouse Gas Scenario	Sea level rise magnitude (feet) Central estimate (50% probability exceedance)	Sea level rise magnitude (feet) Range of Estimates (83-17% probability exceedance)
2050	Low (RCP 4.5)	0.7	0.5 - 0.9
2050	High (RCP 8.5)	0.8	0.5 - 1
2070	Low (RCP 4.5)	1.1	0.8 – 1.5
2070	High (RCP 8.5)	1.3	0.9 – 1.6
2100	Low (RCP 4.5)	1.7	1.2 – 2.4
2100	High (RCP 8.5)	2.2	1.5 - 3

4.3 Hydrology

Freshwater input to Whiteman Cove is from a small intermittent stream that drains an approximately 1.7-square-mile watershed. The stream is not gaged, and hydrology was estimated using USGS StreamStats (USGS, 2016). Peak flows predicted using StreamStats are 45 cubic feet per second (cfs) for the 2-year flow, 145 cfs for the 100-year flow and about 160 cfs for the 200-year flow.

4.4 Wind-Waves and Wave Run-up

The nearshore area at Whiteman Cove is subject to wind-waves which are generated over fetches across Case Inlet. The interior of Whiteman Cove is generally sheltered from wave energy, but the barrier beach and historic barrier spit is exposed to wave energy from the northwest and southwest. The predominant wind direction in Puget Sound is from the south to southwest and typically occur during winter storm events.

A wind-wave hindcast was completed to estimate wave conditions at Whiteman Cove for the 10-year, 50-year, and 100-year return interval wind speed. Extreme wind speeds were estimated based on the historical record of hourly wind speeds at Olympia Municipal Airport (WBAN station I.D. 24227) as reported in Anchor QEA (2015) for the south and southwest (195° to 225°) and west and northwest (285° to 315°).

The wind-wave parameters near the Whiteman Cove shoreline were calculated using the Automated Coastal Engineering System (ACES) software (Leenknecht et al. 1992) developed by the United States Army Corps of Engineers (USACE) to estimate wind-wave growth in deep water. Wave run-up ($R_{2\%}$) on the barrier spit was calculated using the methods of Mase (1989) and Stockdon et al (2006) as reported in Melby et al. (2013). The calculation assumed an 11% beach slope (9 horizontal to 1 vertical) on the barrier spit based on measurements from the 2011 LiDAR dataset.

The estimated wind-wave parameters and wave run-up are presented in Table 3. Waves are largest from southwest, the direction of the longest fetch and greatest wind speeds. These wave events drive littoral drift along the shoreline from the south to the north. Wave run-up values range from 0.5 feet to 1.25 feet for waves arriving from the northwest and from 1.0 feet to 2.5 feet for waves arriving from the southwest. Wave run-up would be expected to be at or in exceedance of the beach crest for southwest waves during a high tide but are not large enough to exceed the elevation of the roadway berm.

Table 3. Wind-wave hindcast scenarios and results.

Wind Speed Return Interval (years)	Wind Direction	Wind Speed (mph)	Fetch (miles)	Significant Wave Height, H_s (feet)	Peak Wave period, T_p (seconds)	Wave run-up, R2% (feet) range of values
Southwest						
10	225	40.0	4.6	2.3	3.1	1.0to 1.5
50	225	52.6	4.6	3.3	3.4	1.5 to 2.0
100	225	58.0	4.6	3.7	3.6	1.5 to 2.5
Northwest						
10	315	25.9	3.8	1.3	2.4	0.5 to 1.0
50	315	32.1	3.8	1.6	2.6	0.75 to 1.0
100	315	34.7	3.8	1.8	2.7	0.75 to 1.25

4.5 Conceptual Model of Sediment Transport

A conceptual model of sediment transport has been developed for Whiteman Cove to understand the potential sediment transport patterns and pathways and to predict a stable channel opening width and depth.

The coastal processes and morphology at Whiteman Cove are most similar to a wave-dominated barrier estuary as described by Dalrymple et al. (1992 [Figure 7]) and embayment as described by Shipman (2008 [Figure 8]). Estuary is used by Dalrymple as a more general term and is replaced with embayment for application to Puget Sound. Wave-dominated embayments can be divided into three sections (outer, middle, and inner) representing three distinct zones of energy distribution and morphology. The relative energy within each zone controls sediment dynamics and morphology within the embayment. The sections are characterized as follows:

- The marine-dominated outer region is characterized by high wave energy, with some tidal influence.
- The middle region is mixed-energy and characterized by relatively low energy as the wave and tidal energy at the entrance is dissipated by the barrier and also by the effect of friction due to the presence of inter-tidal flats in the central basin. Also, fluvial energy has decreased as the drainage basin reaches the base level and the flow of freshwater decreases and the majority of sediment load have been released.
- The inner region in accordance with the definition is dominated by fluvial energy (if it exists) and the input of freshwater and inputs of terrestrial sediment from the fluvial catchment.

A simplified version of the conceptual model based on Shipman (2008) is applied to Whiteman Cove as shown in Figure 8. The existing conditions at Whiteman Cove include most of the active components except the ebb tidal delta and tidal inlet channel, which are dormant in the existing conditions.

The outer estuary at Whiteman Cove extends from the barrier spit to the ebb tidal delta and includes the former inlet/tidal channel. This is the highest energy portion of the system from both waves and tidal energy and will be subject to change if an open channel is reestablished. The existing bedforms in the historic ebb tidal delta were formed by wind-wave energy transporting sediment which accreted adjacent to the former tidal channel. The existing barrier beach has been maintained by the same processes, but the historic ebb tidal delta appears to have lost sediment and eroded in some areas in the absence of the larger tidal channel. A re-established tidal channel will be fronted by a barrier spit, maintained by accretion from littoral drift and the ebb tidal delta will be re-established.

The middle region encompasses the lagoon between the flood tidal delta and creek delta and is the lowest energy regime in the system. The middle region might be subject to locally generated wind-waves which are small because of the short fetch inside the lagoon, limited creek flow and limited tidal energy. The low energy regime results in an increased potential for sediment deposition, particularly of finer grained suspended sediment from the creek and marine environment. Flocculation of clay particles and increased deposition is enhanced in this region at the convergence of the generally low flow from the creek and marine waters which creates shallow mud flats.

The inner region includes the creek delta at the head of Whiteman Cove. The far western end of the lagoon may be fluvial-dominated where the creek enters the Cove. Due to the creeks influence, the western end of the lagoon may be higher energy regime than the middle portion. The fluvial forcing and sediment input in this region can vary seasonally with precipitation and discharge. Rain events increase the stream discharge which results in suspended sediment load entering the embayment. At Whiteman Cove the creek is perennial and only flows in the winter months during intervals of higher rainfall (Anchor QEA and Blue Coast 2020). It is important to note that sediment loads from Whiteman Creek is expected to be negligible because of its size.

5. EFFECTS OF OPTION 1 ON COASTAL PROCESSES

5.1 Effects on Tidal Prism and Flow Velocities

Option 1 will allow limited tidal flushing of water through a functional control structure at the location of the existing control structure. Whiteman Cove is currently a static lagoon (no tidal inlet) with a potential tidal prism of approximately 307,000 cubic yards (190 acre-feet) at MHHW if a tidal channel similar to the historic dimensions was re-established(see further discussion in Section 7.3). The lagoon is currently connected to Case Inlet by control structures (consisting of a culvert, intake/outlet valves, stop logs, and valve screens) which are not operating as designed to allow water exchange although they do maintain the design intent of the water surface elevation within the lagoon.

The new control structure would be designed to allow water to enter the lagoon above a certain elevation and also to close automatically or manually at extreme high-water elevations to limit high-water events in the lagoon, if desired. With proposed Option 1, the water level would not drop lower than 13 feet MLLW (9 feet NAVD88) inside Whiteman Cove (current water level in the lagoon). It is expected that the tidal exchange with Case Inlet for this option would be similar to the exchange modeled due to Option 2 of 122,000 cubic yards (75 acre-feet) of water on average each day, but slightly attenuated depending on the daily tidal range.

The control structure proposed for Option 1 will operate in a similar manner as the existing system and will therefore result in minimal changes to the near-bed velocity and shear stress near the outlet in the inter-tidal zone outside of Whiteman Cove and near the intake within the lagoon.

5.2 Effects on Wind-Waves and Wave Run-up

Options 1 will not change the magnitude of wind-waves inside or outside of Whiteman Cove. Because no significant changes to the barrier spit are expected to be associated with this option; wave run-up on the beach will also remain unchanged.

5.3 Effects on Geomorphology

Option 1 would allow water exchange at higher tidal elevations but will not allow sediment exchange, therefore changes to the barrier spit geomorphology are not expected to result from this option. Deposition or erosion of sediment should be expected to continue along the barrier spit at a rate comparable to recent years. Some minor localized wave and current scour patterns may develop around the new outlet of the control structure in the inter-tidal zone.

Inside the lagoon, the minor increase in tidal flushing resulting from Option 1 will likely increase salt marsh and/or mudflat around the fringe of the lagoon due to the change in water level. The increase in tidal flushing with these options will marginally improve water quality. There are no changes in sediment erosion or accretion expected to occur at the YMCA docks due to Option 1.

6. EFFECTS OF OPTION 2 ON COASTAL PROCESSES

6.1 Effects on Tidal Prism and Flow Velocities

Option 2 will allow limited tidal flushing of water and sediment exchange to occur through a weir structure at the historical opening to the north. The proposed option would construct a 40-foot opening in the berm at the former outlet at the north end of the spit. The opening would consist of a non-erodible bottom (i.e. armor rock or concrete sill) and a 40-foot single span bridge would be constructed over the opening to maintain vehicle access. For this option, the water levels would not drop lower than 13 feet MLLW (9 feet NAVD88) inside Whiteman Cove (current water level in the lagoon) and would result in an exchange of approximately 122,000 cubic yards (75 acre-feet) of water with Case Inlet on average each day.

Option 2 will increase near-bed velocities and shear stress across localized portions of the outer region of the system, including the flood tidal delta (interior delta), outer tidal delta and nearshore shellfish beds. Estimates of velocity and shear stress at the channel inlet from a two-dimensional (2-D) model developed by Anchor QEA and Blue Coast (2020) were used to assess changes related to Option 2 (weir structure). The velocity regime predicted for Option 2 is ebb tide-dominated (strongest tidal flows occur as the tide is flowing out of the estuary). The velocity regime of a barrier embayment is typically flood tide dominated and the velocity regime of Options 3 and 4 show stronger flood tide velocities.

The maximum depth-averaged velocities were obtained from a transect along the center of the tidal channel cut to connect Whiteman Cove to Case Inlet at an elevation of approximately 11 feet MLLW (7 feet NAVD88). The maximum velocities occur during a spring ebb tide (water leaving the lagoon) and range from 4 to 9 feet per second (fps) over approximately two hours. Velocities are highest (9 fps) where the flow passes over the weir control structure and lower approaching the nearshore. The weir control structure results in a logarithmic decay in velocity beginning during the ebb tide following the daily higher high tide (exceeding 13 feet MLLW [9 feet NAVD88]) and continuing through the following high tide as water exits Whiteman Cove.

The predicted ebb velocities are strong enough to erode fine to medium-sized gravel (pebble) based on critical velocities for sediment transport from work by Van Rijn (1993). This suggests gravel armoring (up to ½ inch diameter) would occur along portions of the channel bed within the inlet; small gravel-sized material and finer would be transported as bedload or suspended load out of the channel and deposited on the adjacent deltas as the tidal velocity decreases.

6.2 Effects on Wind-Waves and Wave Run-up

Option 2 will not change the magnitude of wind-waves inside or outside of Whiteman Cove. Because no significant changes to the barrier spit are expected to be associated with the option, wave run-up on the beach will also remain unchanged.

6.3 Effects on Geomorphology

Option 2, installation of a weir control structure at the historical opening to the north, will direct water through the small lagoon formed behind the extension of the spit. This will likely enlarge the small lagoon (currently flooded at high tides) and its outlet to Case Inlet towards the north, creating a network of small channels across the inter-tidal zone and causing some interruption to the littoral drift along the spit. The nature of the weir control structure at 13 feet MLLW (9 NAVD88) will alter the flow through the channel to an ebb tide-dominated velocity regime (Section 6.1). Depth-averaged velocities will be elevated for approximately 12 hours following daily higher high tide. This option will enhance the flow from Whiteman Cove into the small lagoon and subsequently into Case Inlet. The small lagoon outside of the weir may increase in size and become more dynamic and will provide refuge to fish in the smaller pools. The outer tidal-delta and nearshore shellfish beds will be altered by this asymmetry in flow and potentially lead to increased deposition of sediment across the nearshore shellfish beds.

Inside the lagoon, the minor increase in tidal flushing will create a zone of salt marsh and/or mudflat around the fringe of the lagoon due to the drop in water level. The increase in tidal flushing with these options will marginally improve water quality. There are no changes in sediment erosion or accretion expected to occur at the YMCA docks due to Option 2.

7. EFFECTS OF OPTIONS 3 AND 4 ON COASTAL PROCESSES

7.1 Effects on Tidal Prism and Flow Velocities

Options 3 and 4 will allow tidal flushing of water and sediment exchange to occur through the inlet between Whiteman Cove to Case Inlet. Whiteman Cove is currently a static lagoon (no tidal inlet) with a potential tidal prism of approximately 307,000 cubic yards (190 acre-feet) at MHHW if an open tidal channel was re-established (see further discussion in Section 7.3) The most significant changes to the lagoon due to options 3 and 4 will occur in the higher energy outer region along the barrier spit and outer ebb tidal delta as well as the interior flood tidal delta.

Under the existing conditions the near-bed velocity and shear stress in the inter-tidal zone outside of Whiteman Cove and within the lagoon are minimal. Outside of Whiteman Cove, the near-bed velocities are driven by tidal forcing in Case Inlet and wind-wave events. Flow from the small existing lagoon outside of the roadway berm dissipates across the inter-tidal zone and is generally too weak to erode sediment, as evidenced by the lack of a defined channel below MLLW in the aerial photographs.

Options 3 and 4 will increase near-bed velocities and shear stress across localized portions of the outer region of the system, including the flood tidal delta (interior delta), outer tidal delta and nearshore shellfish beds. Estimates of velocity and shear stress at the channel inlet from a two-dimensional (2-D) model developed by Anchor QEA and Blue Coast (2020) were used to estimate the potential for sediment mobilization and scour in the channel. Maximum depth-averaged velocity and near-bed shear stress were output from the model for two simulations

- Option 3: Northern alignment channel with bridge abutments and an 85-ft wide opening at MHHW, negligible freshwater input
- Option 4: Northern alignment channel with a 120-ft width at MHHW, negligible freshwater input

The maximum depth-averaged velocities were obtained from a transect along the center of the tidal channel cut to connect Whiteman Cove to Case Inlet at an elevation of approximately 7 feet MLLW (3 feet NAVD88). The maximum velocities occur during a spring flood tide (water entering the lagoon) and range from 4 to 6 fps over approximately an hour in both options. Velocities are higher for Option 3 because of the narrower channel width (85 feet as opposed to 120 feet). The predicted flood velocities are strong enough to erode fine to medium-sized gravel (pebble) based on critical velocities for sediment transport from work by Van Rijn (1993). This suggests gravel armoring (up to ½ inch diameter) would occur along portions of the channel bed within the inlet; small gravel-sized material and finer would be transported as bedload or suspended load into or out of the channel and deposited on the adjacent deltas as the tidal velocity decreases. Somewhat larger sediment can be transported by the velocities generated under Option 3 as compared to Option 4, but this is a localized increase in velocity under the bridge. A more detailed discussion of channel geomorphology under Option 3 and 4 is provided in Section 7.3. There are no changes in sediment erosion or accretion expected to occur at the YMCA docks due to Options 3 and 4.

The open tidal channel in both Options 3 and 4 will result in increased flow between the lagoon and Case inlet as compared to existing conditions. There are two areas of higher velocities as compared to existing conditions predicted during the ebb tide, where the tidal channel bisects the barrier beach and in small channels in the outer ebb tidal delta. The higher velocities at the intersection of the tidal channel with the barrier beach during ebb tide are associated with rapid change in depth and will occur over a short duration of the tidal cycle immediately after the inlet channel construction. These velocities will form a network of small tidal channels in the sand and gravel substrate on the beach within the first couple of months after construction and reach equilibrium within 1 to 2 years resulting in a condition similar to what existed at the site historically as observed in the 1951 photograph.

7.2 Effects on Wind-Waves and Wave Run-up

Options 3 and 4 will not change the magnitude of wind-waves inside or outside of Whiteman Cove. However, wave run-up (the landward excursion of water caused by wind-waves) will change if the slope of the beach or barrier spit is changed as a result of Options 3 and 4. Therefore, wave run-up calculated in Section 4.4 should be recalculated during future design phases based on the selected Option.

In addition, wind-waves generate alongshore sediment transport which can result in infilling of the tidal channel in Option 3 or 4. However, the balance between sediment transport under wind-waves and tidal currents generated through the tidal channel are dependent on several other factors such as channel slope, thalweg elevation, and shoreline orientation as compared to wave direction. The wind-wave information from Section 4.4 will be used in future design phases to compare sediment transport under wind-waves to sediment transport generated by tidal currents through the inlet to refine the tidal channel dimensions of the selected Option.

7.3 Effects on Geomorphology

Hydrodynamic modeling of Options 3 and 4 conducted by Anchor QEA and Blue Coast (2020) predict changes to tidal prism, velocities, and bed shear stress just after construction. However, the modeling effort does not provide specific information on how the tidal channel will migrate and change over time or if it will remain open or close-off in the future. A reference site comparison (Section 7.3.1) and evaluation of natural tidal channel geometry (Section 7.3.2) was conducted to evaluate the sustainability of Options 3 and 4.

7.3.1 Reference Site Comparison

Barrier embayment systems have complex geomorphology that is dependent on several feedback mechanisms. For example, wind-waves generate alongshore sediment transport which accumulates in the barrier spit and the nearshore where the shoreline abruptly changes orientation. Because of this sediment deposition creating shallower water depths, wind-waves are dissipated before reaching the inlet of most barrier embayments, and therefore the tidal flow generated by tides circulating in and out of the embayment can clear sediment and keep the tidal channel open. These complicated feedback mechanisms and sediment transport patterns are difficult to directly measure or model numerically, therefore evaluation of sites with similar geomorphology are used to understand these processes and to assist in design of barrier embayment systems.

An evaluation for the Estuary and Salmon Restoration Program (ESRP) of tidal estuaries and barrier embayments has shown that the tidal channel hydraulic geometry (cross-sectional area, width, and depth) are correlated with the embayment marsh area and tidal prism (Côté et al. 2018). Findings from the ESRP Tidal Channel Study specific to Puget Sound indicate:

- Intertidal volume of the embayment is the best predictor of sustainable tidal inlet cross-sectional area and cross-sectional width
- The tidal channel inlet depth is also correlated to intertidal volume, but not as strongly as the cross-sectional area or width as the depth appears to be influenced by other factors such as dominant habitat type (Marsh, Mud flat, or Lagoon).
- Sediment availability and habitat type (lagoon, marsh, or mud flat) are significant factors in the determination of tidal channel geometry and barrier lagoons may have some significant differences in their tidal channel geometry (potentially narrower and shallower) and tidal flushing as compared to systems that are dominated by marsh or mud flats.
- Barrier Lagoons typically have perched tidal channels where the invert elevation (lowest elevation in the tidal channel at the system inlet) is 9 feet MLLW (5 feet NAVD88) or higher and the smaller the lagoon the higher the tidal channel invert elevation.

Two reference barrier embayment sites that have similar wave conditions and geomorphology were evaluated to assist in characterizing potential for changes to the existing condition at Whiteman Cove and provide an understanding of evolution of the site after implementation on Options 3 and 4. Reference sites #1 and #2 (Figure 9, lower left panel) are both barrier lagoons located along the eastern shoreline of Case Inlet, 3.5 miles and 5.5 miles from Whiteman Cove, respectively. The reference sites are shallow coastal lagoons with similar characteristics to

Whiteman Cove although smaller in surface area. Both are located in littoral drift cells with south to north drift, have low inflow from upland streams, impound water at low tide, and are separated from Case Inlet by a barrier spit with an opening to the north. They have similar fetch lengths as Whiteman Cove (Figure 10) which result in similar wind-wave conditions (Table 4).

A scaled side-by-side comparison of the reference sites and Whiteman Cove (Figure 10) shows the similarities between the embayments, including the rapid change in shoreline orientation which protects the inlet tidal channel and terminal end of the barrier spit from wind-wave energy and results in the accretion of sediment in the ebb tidal delta. Aerial photos of the reference sites (Anchor QEA 2015) have shown the channel inlets tend to migrate slowly over the past 30 years, but the ebb tidal delta only exhibits minor changes with movement of the tidal channel. The channel inlet at reference site #1 migrated slowly northward while the size remained relatively stable over time. The channel inlet at reference site #2 is more dynamic but has also most recently migrated northward.

The primary tidal channel tends to be oriented west to east across the nearshore and across the terminal end of the barrier spit then abruptly turn south. The inlet channel splits into two smaller channels flowing southward inside the barrier spit and are separated by sediment accumulated in the flood tidal delta. One of the smaller channels tends to parallel the inside of the barrier spit and the second flows along the adjacent shoreline/vegetation line. This channel configuration was also visible in the 1951 photograph of Whiteman Cove.

Although the reference sites are smaller systems, the relevant design parameters for the systems scale based on size, which is discussed further in the next section.

Table 4. Wind-wave hindcast scenarios and results for 100-year wind-wave events.

Site	Direction	Fetch (miles)	Significant Wave Height, H_s (feet)	Peak Wave period, T_p (seconds)
WMC	SW, 225°	4.6	4.8	3.9
WMC	NW, 315°	3.8	2.2	2.9
REF#1	SW, 225°	1.8	3.1	2.9
REF#1	NW, 315°	4.6	2.4	3.1
REF#2	SW, 225°	4.8	4.9	4.0
REF#2	NW, 315°	3.3	2.1	2.8

7.3.2 Tidal Channel Geometry

The tidal channel of barrier lagoons is maintained by current velocity produced by the rising and falling of water levels from tides. These flows produce the force on the bottom and sides of the channel (shear stress) to mobilize and transport sediment which might be deposited within the channel as a result of longshore drift from wind-waves. Current velocity and discharge generated between the change in water levels from MLLW to MHHW through the tidal channels of barrier embayment systems in Puget Sound were measured as part of the ESRP Tidal Channel Project (Côté et al 2018). The tidal channel maximum depth, maximum width, cross-sectional area and tidal volume for water levels between MLLW and MHHW were also measured or calculated as part of the study. These parameters were used to conduct a preliminary regression analysis of the tidal channel geometry (cross-sectional area, channel width, and channel depth) regressed against tidal prism and surface area at MHHW.

The tidal channel hydraulic geometry at the reference sites were measured (Table 5) and used to test and validate the preliminary regression models. These reference sites were chosen because of their geomorphic similarities to Whiteman Cove. The surface area and tidal prism for Whiteman Cove were measured based on the more recent LiDAR and bathymetry data and then used to predict the channel cross-section area, width, and depth from the regression models (Table 5). The ESRP regression models are constructed around data from unaltered barrier embayments around Puget Sound and are still be validated for accuracy which is why a range of dimensions is provided for the predicted values for Whiteman Cove. In addition, the regression models utilize data from systems which are both smaller and larger than Whiteman Cove, not just the reference sites listed in Table 5.

Table 5. Tidal channel prediction.

Site	Cross-section area (ft^2)	Cross-section width (ft)	Average depth at MHHW (ft)	Tidal prism (cubic yards)	MHHW area (hectares)
Reference site #1	128	52	8	16,200	2
Reference site #2	172	63	9	36,470	4
Whiteman Cove (2011 LiDAR calculated MHHW area)	500 to 700[1]	120 to 160[1]	12[1]	307,120	13

[1] Predicted based on regression models

The predicted channel width for Whiteman Cove of 120 to 160 feet is at the location of hydraulic control which is through the inlet which crosses the terminal end of the barrier spit. The channel width of 85 feet for Option 3 and 120 feet for Option 4 are measured across the proposed bridge span and are further inside of the lagoon than the primary tidal channel. In general, the primary tidal channel of a barrier embayment is narrower than the opening just inside. However, as noted previously the primary tidal channel tends to bifurcate on the inside of the barrier spit with sediment deposition in a flood tidal delta. Based on the ESRP regression models and geomorphic understanding of barrier lagoons, the dimensions of the channel across the proposed bridge span at Whiteman Cove should be larger than 160 feet for the system to function naturally. The effects of the narrower than natural channel are likely to be as follows:

- The typical channel bifurcation inside the embayment will not occur until after the channel passes under the bridge.
- The flood tidal delta will form somewhat further inside the barrier embayment than would naturally occur.
- The interior tidal channel which typically parallels the barrier spit may continue to result in increased velocities on the west side of the bridge abutment.
- The small lagoon between the bridge and the primary tidal channel will form some small pools like a bend in river as this will be a convergence zone of the higher velocities under the bridge and through the primary tidal channel.

Because of the location of the bridge it is important that the area in the small lagoon outside of the bridge be maintained at the current size (not filled) and may even get larger as it is expected to be dynamic. This small lagoon will provide refuge to fish in the smaller pools and somewhat make up for the narrower than natural bridge opening by providing habitat complexity in the inlet of the barrier lagoon.

8. SUMMARY

Proposed Options 1 and 2 will allow tidal exchange of water at higher tidal elevations and some sediment exchange (Option 2 only) but neither option will fully re-establish the tidal channel or the dormant components of the barrier embayment. Option 1 will have minimal effect on coastal dynamics.

Option 2 is expected to result in changes to the small lagoon formed behind the extension of the spit and across the inter-tidal zone. Hydraulic modeling suggests the velocity regime in the tidal channel associated with Option 2 will be ebb tide dominated (not flood tide dominated as typical for barrier embayments). The outer tidal-delta and nearshore shellfish beds will be altered by this asymmetry in flow and potentially lead to increased deposition of sediment across the nearshore shellfish beds. The small lagoon may also be enlarged and a network of small channels across the inter-tidal zone will form, causing some interruption to the littoral drift along the spit.

Inside the lagoon, Options 1 and 2 will increase the salt marsh around the fringe of the lagoon due to the drop in water level which will marginally improve water quality. There are no changes in sediment erosion or accretion expected to occur at the YMCA docks due to Option 1 or 2.

Proposed Options 3 and 4 with an open tidal channel Whiteman Cove will provide tidal flushing of water and sediment to Whiteman Cove and result in the modification of the shoreline in the vicinity of the inlet. The channel opening will re-distribute sediment adjacent to the tidal channel inside the lagoon and through the nearshore area outside of the lagoon. It's expected that the inlet channel and tidal deltas will undergo the most adjustment and change in the 1 to 2 years immediately following construction and will gradually return to a similar morphology as observed in historical aerial photographs (e.g. 1951). Gradual shifts in the locations of small network of tidal channels or slow migration of the primary tidal channel might occur in the long-term but it is expected that the inlet channel size would not change significantly after the initial adjustment. Reference sites indicate a preference for migration of the channel to the north for embayments along the eastern shoreline of Case Inlet.

Options 3 and 4 will cause initial changes in the area of the shellfish beds outside the lagoon due to increased tidal flows over a portion of the shellfish bed area. Following implementation of Options 3 or 4, a network of small channels across the inter-tidal zone will develop and littoral drift interrupted by the tidal channel flow will result in deposition in the historic tidal delta area. Most of these adjustments will occur within the first year after re-opening and should stabilize by the end of the second year.

Inside the lagoon, Options 3 and 4 will increase the salt marsh and tide flat area around the entire lagoon due to the approximate 5-foot drop in water level. Flood elevations are not anticipated to change significantly from the current FEMA BFE. The orientation of the channel to the north will limit the penetration of wave energy into the lagoon.

Only minimal differences in coastal dynamics are expected between Option 3 and Option 4. Option 3 will result in higher tidal velocities in the channel because of the narrower width at the bridge crossing but this should have only a minimal impact on the location of the flood tidal delta and interior tidal channels. In general, the barrier lagoon system is expected to function close to the historic condition after the implementation of either Option 3 or 4.

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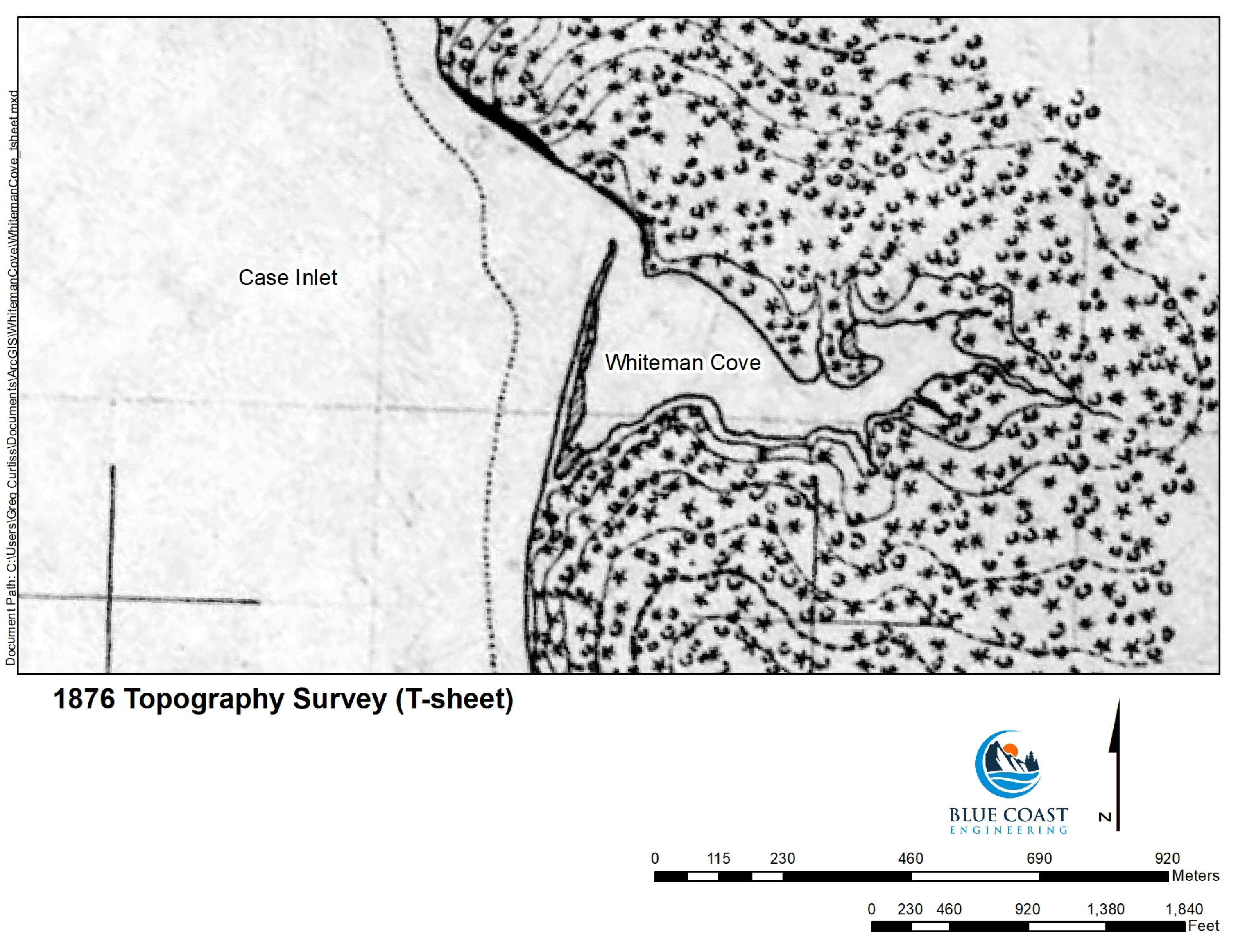

Figure 1. 1876 topography survey (T-sheet).

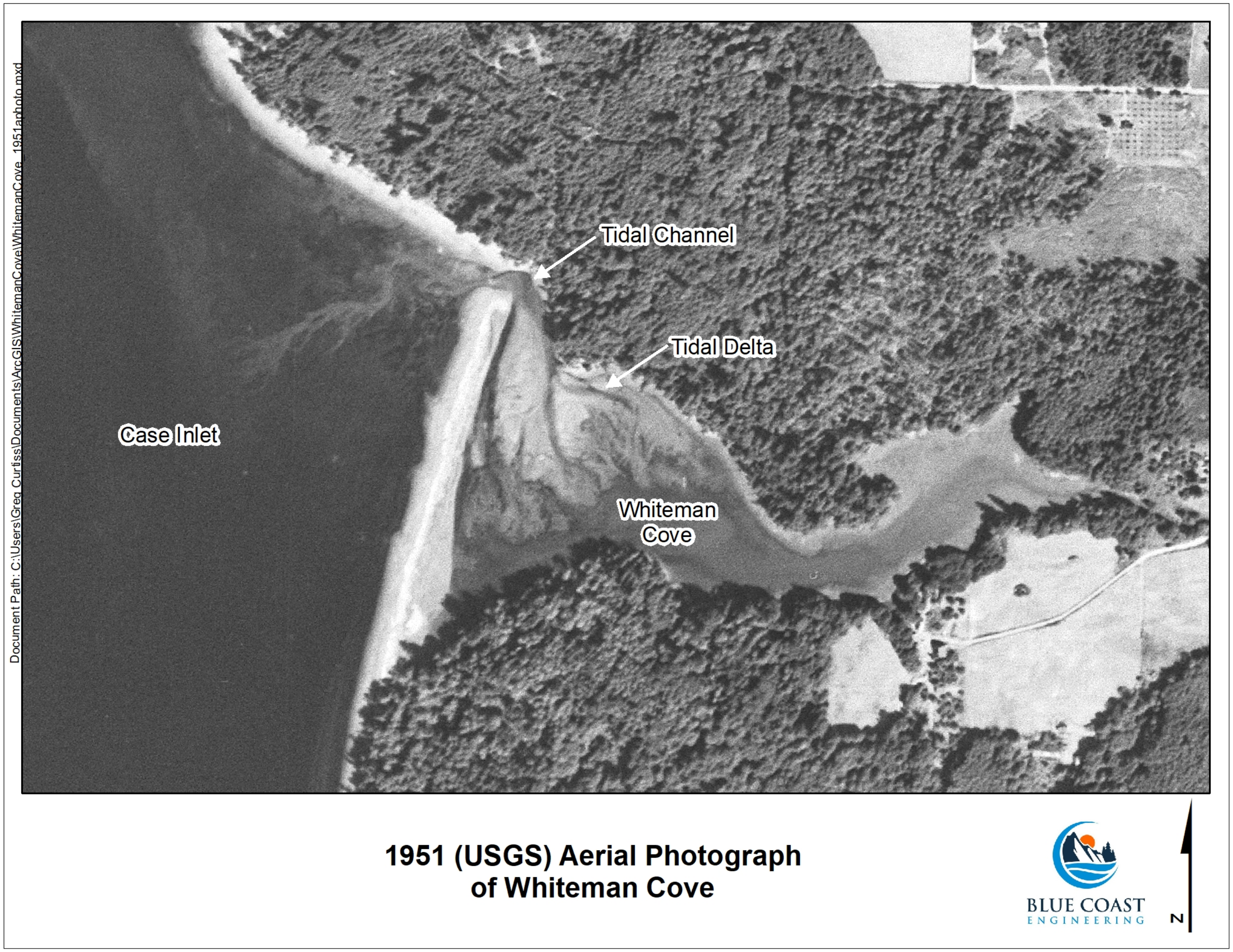

Figure 2. 1951 USGS aerial photograph of Whiteman Cove

Figure 3. Department of Ecology shoreline oblique aerial photographs 1977 and 2016

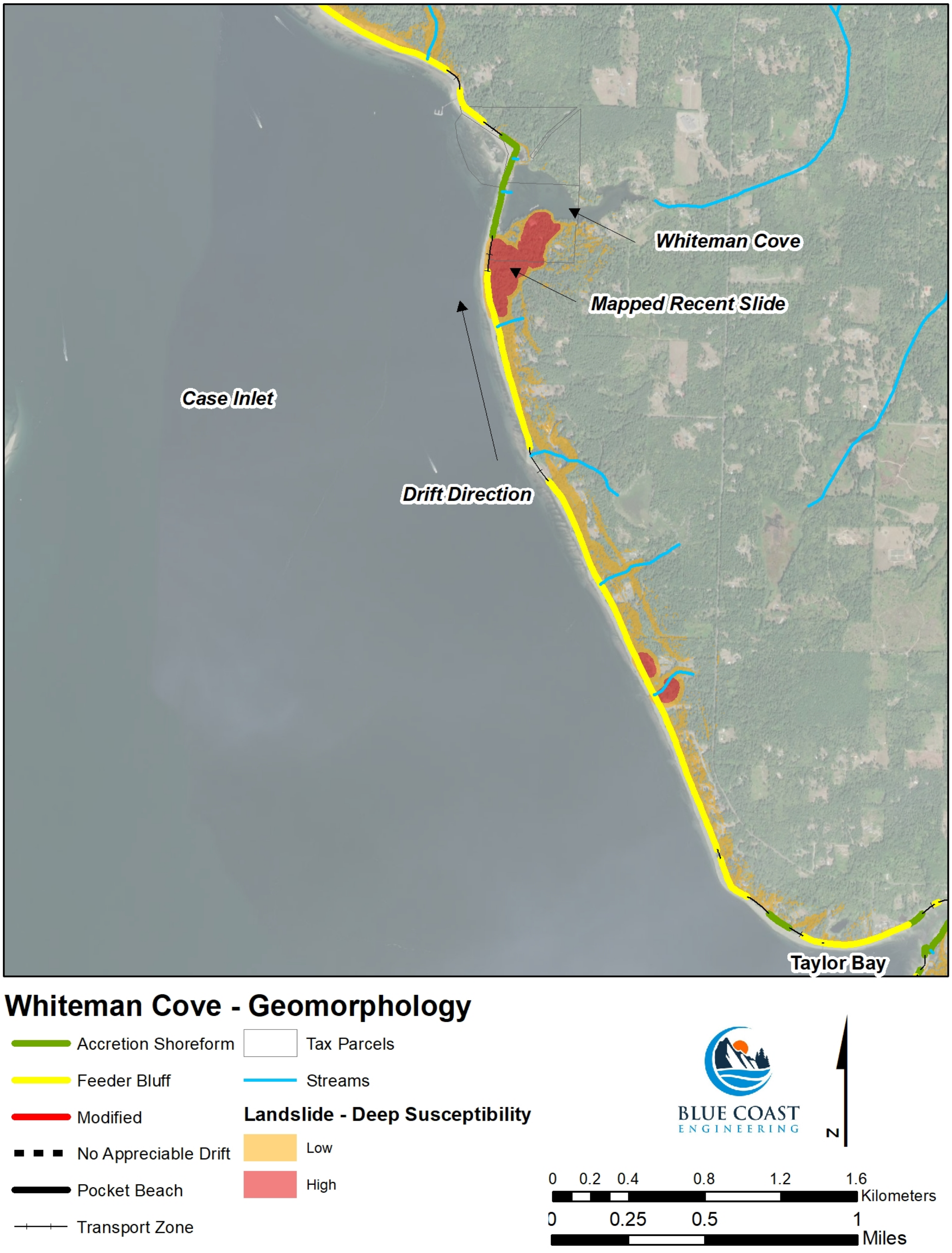

Figure 4. Whiteman Cove site geomorphology

Figure 5. Department of Ecology shoreline oblique aerial photograph 2016. Shaded area in orange highlights coarser sediment along Joemma State Park to the northwest of Whiteman Cove.

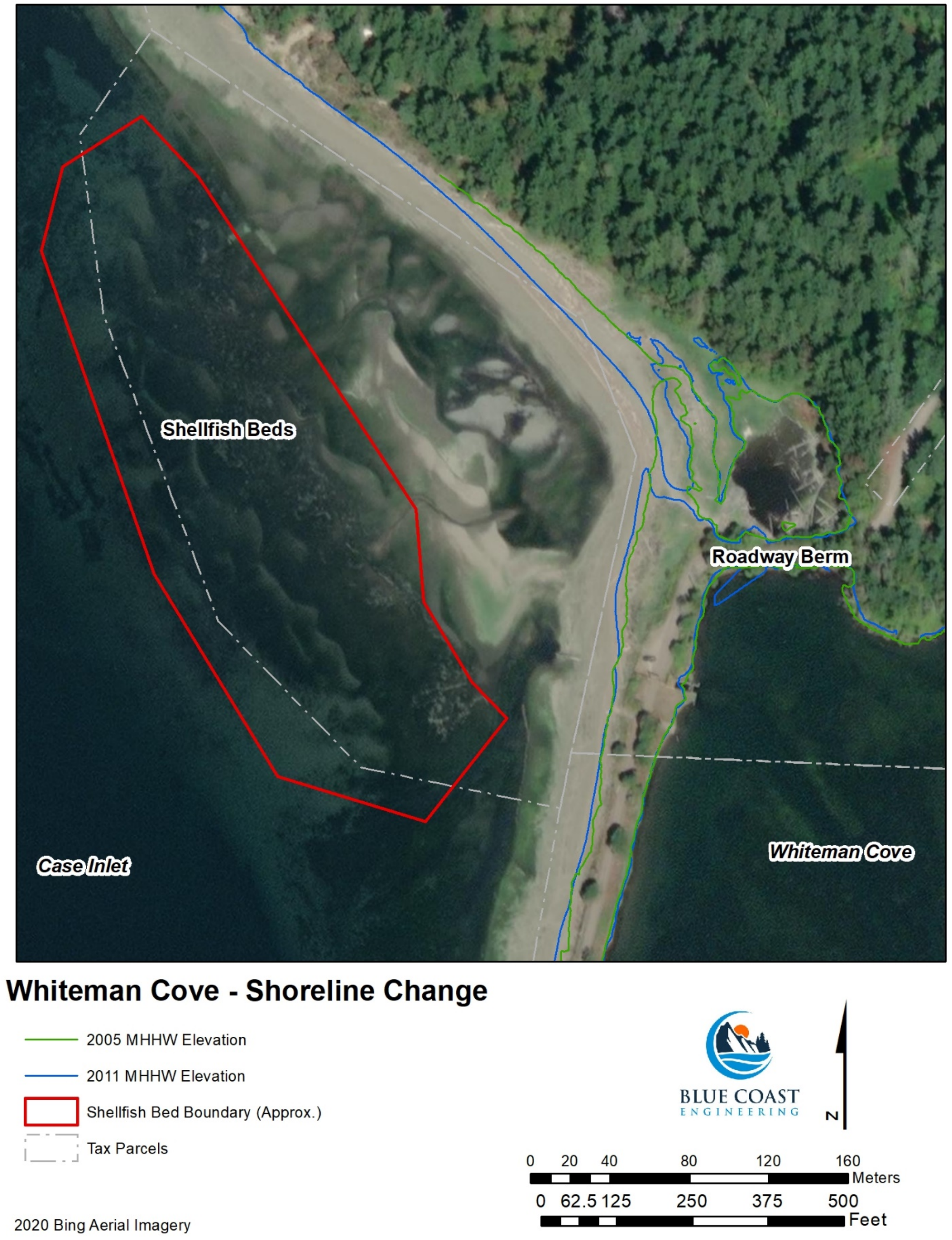

Figure 6. Analysis of shoreline change at MHHW tidal datum using LiDAR from 2005 and 2011.

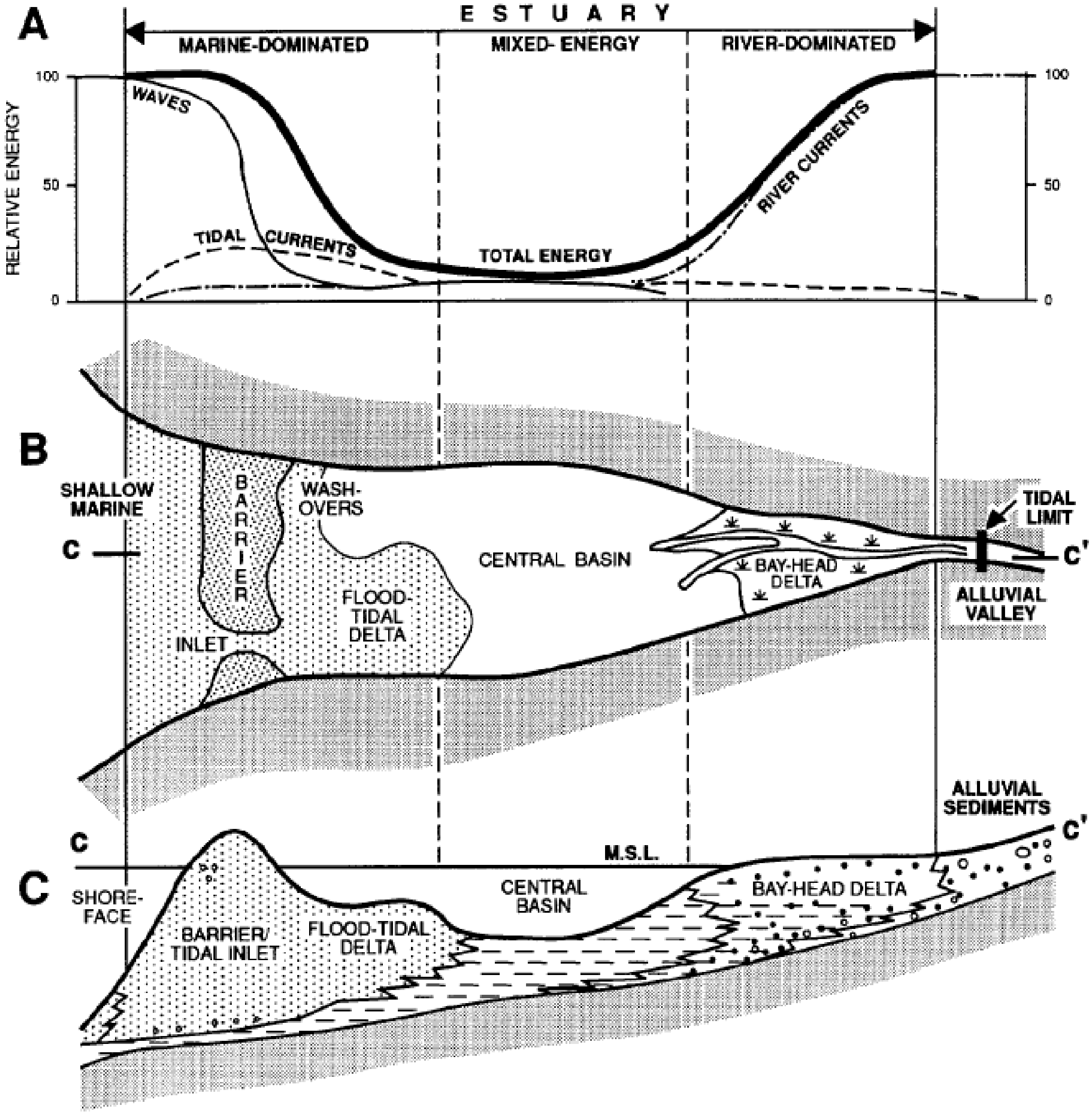

Figure 7. Wave dominated barrier estuary and estuary can be replaced with embayment for application within Puget Sound (adapted from Dalrymple et al 1992).

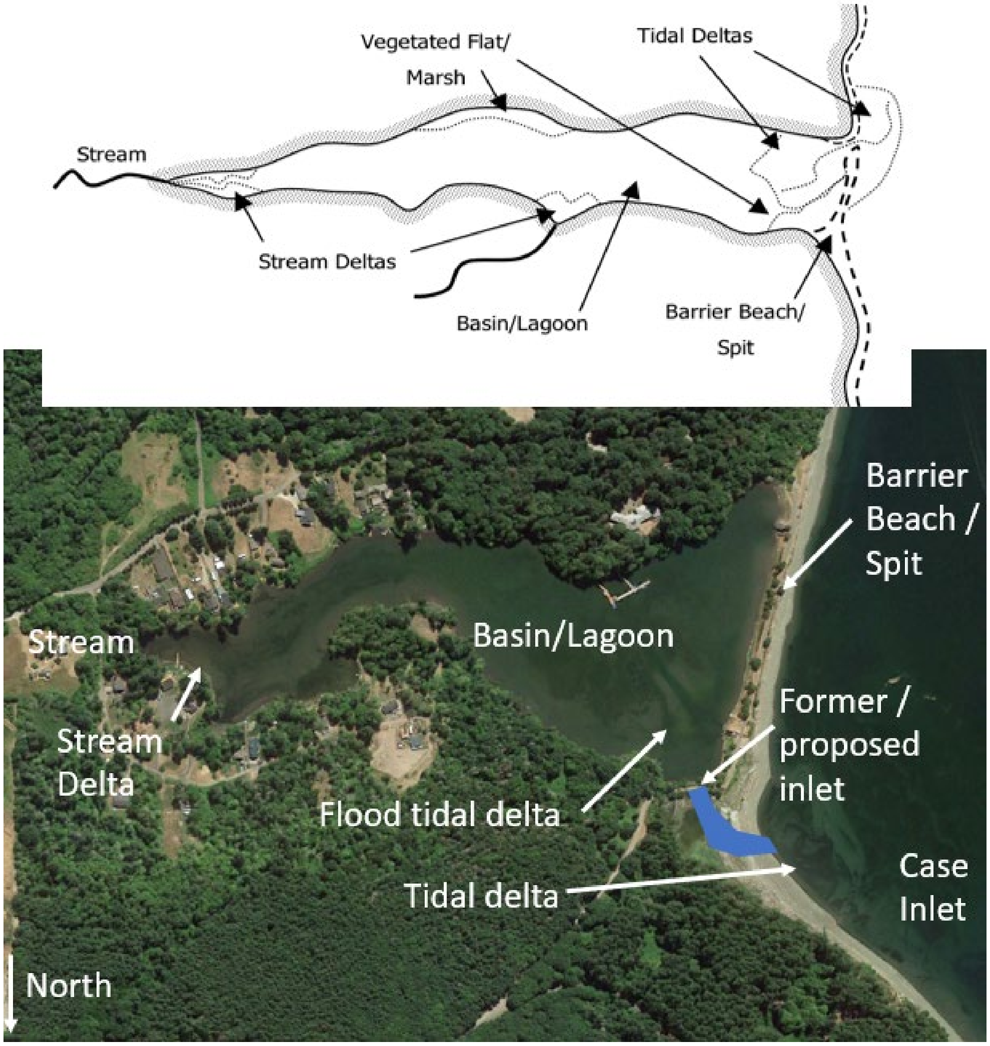

Figure 8. Whiteman Cove conceptual geomorphic site model.

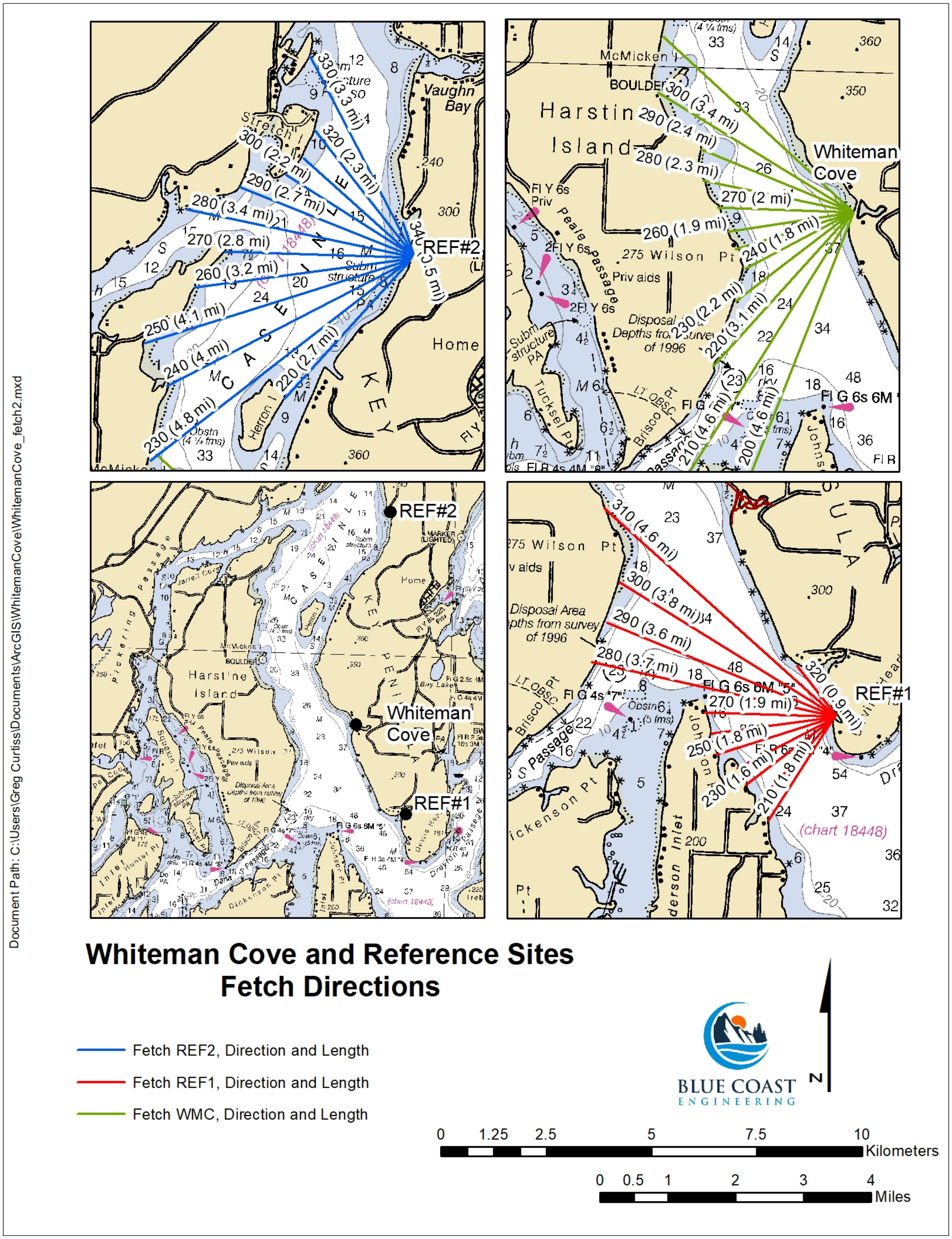

Figure 9. Whiteman Cove and reference site fetch directions

Figure 10. Reference site figure