Final

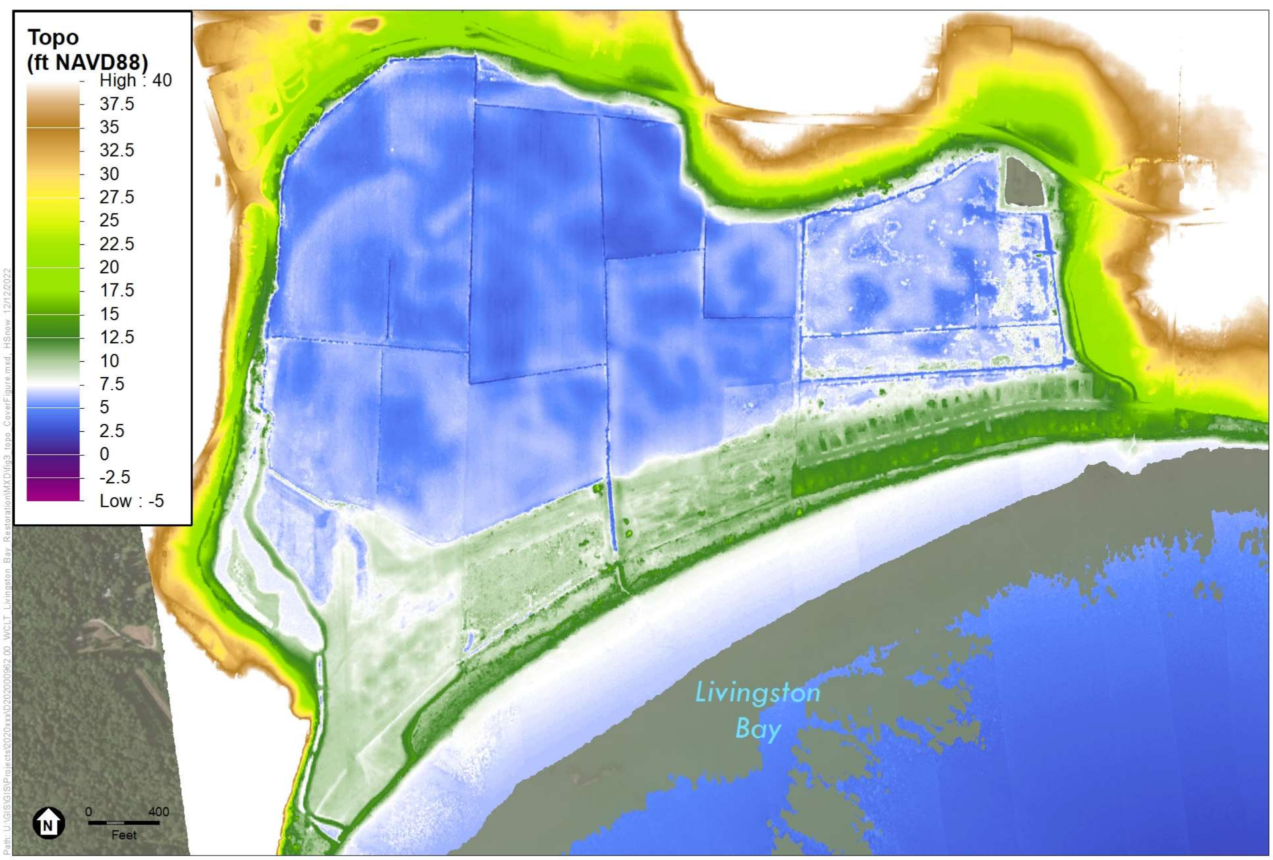
LIVINGSTON BAY RESTORATION

Feasibility Study

Prepared for
Whidbey-Camano Land Trust

December 2022

ESA



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Acronyms and Other Abbreviations

DSAY	Discounted Service Acre Year
ESA	Environmental Science Associates
LiDAR	Light Detection and Ranging
NAVD88	North American Vertical Datum of 1988
PSNERP	Puget Sound Nearshore Ecosystem Restoration Project
SC	specific conductance
TWL	total water level
WCLT	Whidbey Camano Land Trust

LIVINGSTON BAY RESTORATION

Feasibility Study

Abstract

The Whidbey Camano Land Trust (WCLT) contracted with Environmental Science Associates to assess the feasibility of restoring tidal habitat at the Livingston Bay project site on north Camano Island. WCLT is working with the Washington Department of Fish and Wildlife to jointly manage the restoration project.

WCLT has landowner acknowledgement forms (that may indicate wiliness to sell) for a subset of the large parcels composing the site, but the owners of some other parcels are currently not willing to sell. The study also identifies possible interim habitat enhancement options if meaningful estuary restoration cannot be accomplished on the currently available land. The project objectives include:

- Develop restoration scenarios based on current and future opportunities for land acquisition.
- Complete a restoration feasibility plan based on these scenarios.
- Evaluate consistency with process-based restoration principles.
- Determine which lands to acquire, if any, based on the results of the feasibility work.

Livingston Bay and its tidelands are part of the Greater Skagit-Stillaguamish Delta. Livingston Bay was identified as a Puget Sound Nearshore Ecosystem Restoration Project priority for its potential benefit to all eight species of salmonids in the Whidbey Basin, including threatened Puget Sound Chinook salmon. Additionally, over 90 percent of Western Washington's migrating waterfowl use the delta as an overwintering area. Successfully completing estuary restoration at Livingston Bay would restore historic tidal channels and provide vital estuarine rearing habitat for salmon, steelhead, cutthroat trout, and other fish species.

The following technical memoranda were generated and are included here as appendices:

- Appendix A: Drainage Infrastructure Memorandum
- Appendix B: Noxious Weed Survey
- Appendix C: Water Surface Elevation Analysis
- Appendix D: Hydrogeologic Evaluation
- Appendix E: Coastal Assessment and Tidal Channels
- Appendix F: Cost-Benefit Analysis

1. Background

1.1 Introduction and Problem Statement

Floodplain and coastal farmland in or near the Greater Skagit-Stillaguamish Delta are highly reliant on the ability of the land to drain excess water off fields in the spring and to withstand high water levels during floods or storms. Climate change predictions for the Puget Sound region indicate that sea levels will rise approximately 0.5 to 1 foot by 2050 and at least 2 feet by 2100 (Miller 2019). Higher sea levels may occur (NOAA 2022).

In addition, it is predicted that precipitation intensity may increase with climate change, resulting in higher storm water flow rates. Hence, flooding is expected to be higher, more intense, and more frequent during the winter months. These two scenarios result in a "coastal squeeze": Water levels from both upstream and downstream are increasing, thus negatively affecting the land use capabilities in the estuary floodplains, including residential, commercial, and agricultural functions. It should be noted that groundwater levels will likely increase in low lying areas as well, potentially changing any land uses once flooding is frequent.

Livingston Bay was identified as a Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) priority for its potential benefit to all eight species of salmonids in the Whidbey Basin (PSNERP 2012). The potential habitat restoration would be especially beneficial to Puget Sound Chinook salmon who are listed as threatened under the Endangered Species Act. Chinook salmon are highly dependent on estuary and marine nearshore habitats such as would be restored at the project site. The Livingston Bay project site is on north Camano Island (**Figure 1** and **Figure 2**), totaling 259 acres, was historically an intertidal estuary and wetland habitat but has been managed as diked farmland for the past 100+ years. Figure 3 provides an aerial photograph of the study area.

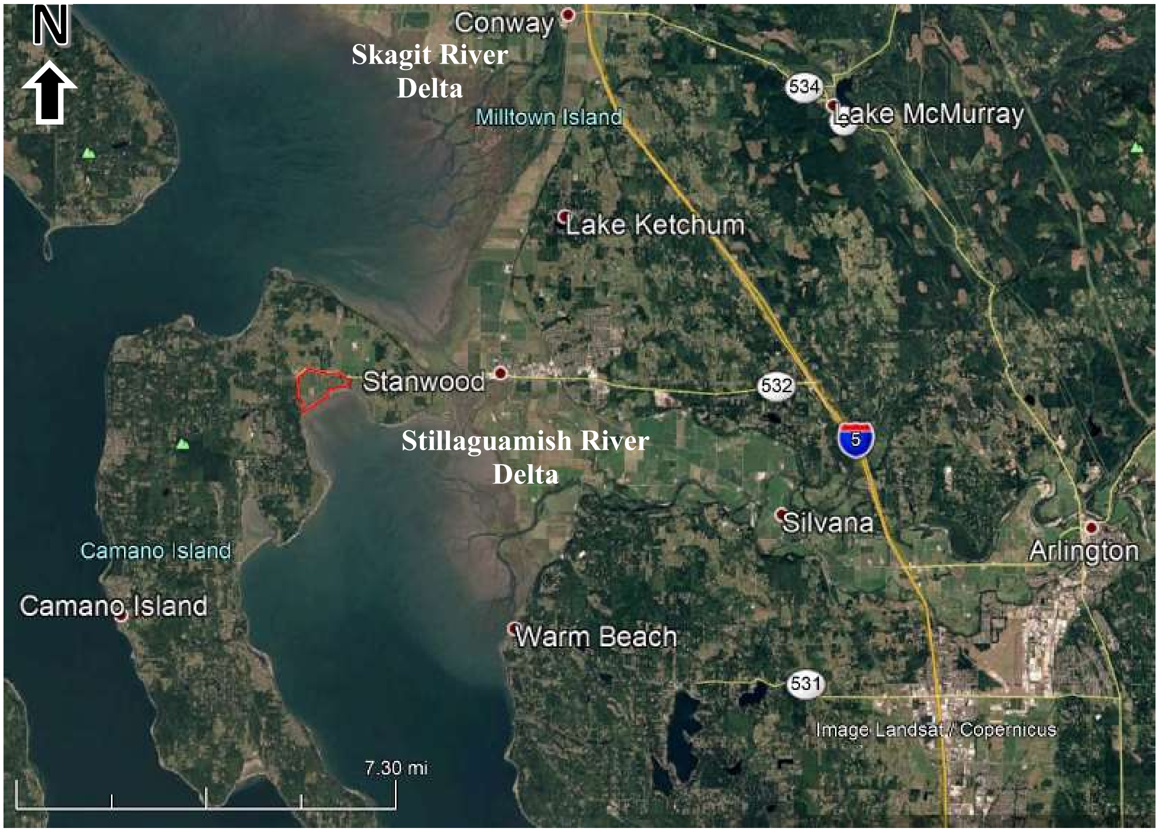
Five different landowners own the project site (Nelson, Leque, Sherman, Roberge, and WSDOT); two of these landowners are currently willing to sell or transfer their properties to the Whidbey Camano Land Trust (WCLT). The sale or transfer of these properties could enable WCLT to restore or enhance habitat on nearly 180 acres of the site in the near term while waiting for an opportunity to secure the remainder of the project site identified in the PSNERP conceptual design.

WCLT contracted with Environmental Science Associates (ESA) to assess the feasibility of restoring tidal habitat at the Livingston Bay project site. This study outlines the feasibility of the full PSNERP conceptual plan for the 300+ acre estuary restoration, as well as other scenarios based on current and expected future opportunities for land acquisition. The feasibility study results will enable WCLT to decide which lands to acquire if any.

1.2 Study Area and Surroundings

Livingston Bay is located on the northeastern tip of Camano Island, just west of Stanwood, Washington, and the Interstate 5 corridor (Figure 1). Livingston Bay empties into the larger Port

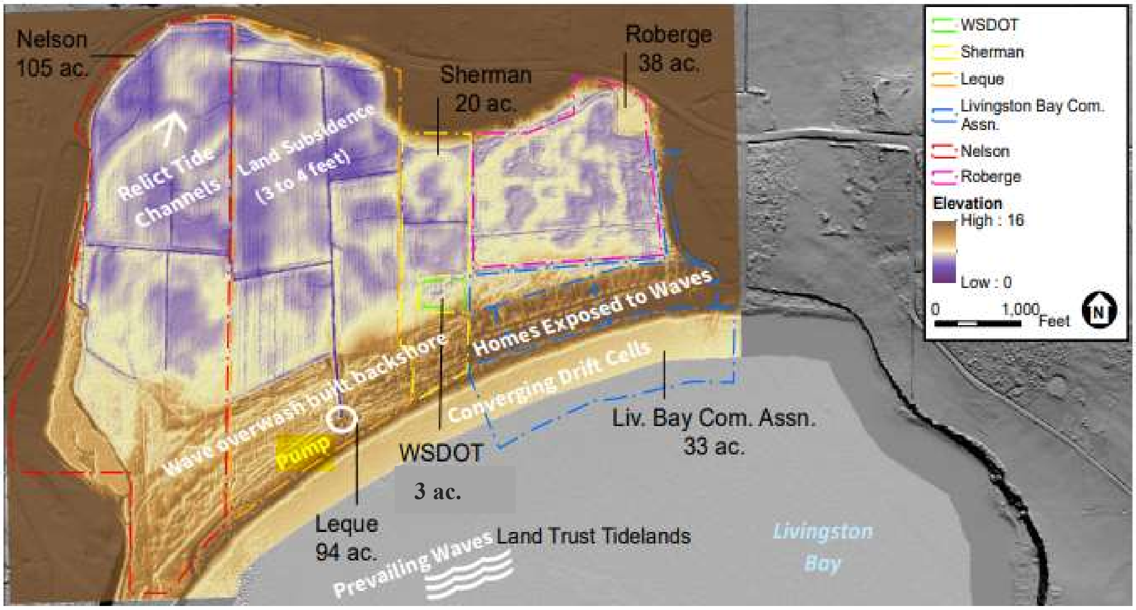
Susan and Puget Sound. The land directly north of Livingston Bay was diked in the early 1900s to create farmland.



SOURCE: Map produced by Environmental Science Associates in 2022
NOTES: The study area is shown in red. The Skagit River delta can be seen to the northeast of the study area. The Stillaguamish River delta is visible to the southeast.

Figure 1. Map of Surrounding Area

A dike protects the majority of the project site from tidal inundation. Some wave overwash has built up the backshore behind the western end of the dike. A narrow section along the higher, eastern portion of the dike is topped by Livingston Bay Shore Drive and contains the Livingston Bay Community Association, a residential development containing more than 50 homes (Figure 2). Four landowners actively farm the majority of the site (Nelson, Leque family, Sherman, and Roberge). Additionally, the Washington Department of Transportation (WSDOT) owns a small parcel between the Sherman parcel and the Livingston Bay Community. The WSDOT parcel was a habitat mitigation site. The Livingston Bay Community Association is adjacent to the proposed restoration. The farmland has subsided approximately 3–4 feet (elevation 5 to 6 foot NAVD88) relative to estimates of historical estuarine marsh surface (elevation 9 foot NAVD88). A pump located on property owned by the Leque family provides drainage control for all of the fields.



SOURCE: Map produced by Environmental Science Associates in 2022

Figure 2. Map of the Study Area, Showing Major Landowners and General Site Topography in feet NAVD88

1.2.1 History of the Study Area

The study area was historically a tidal estuary that supported a variety of vegetation and soil types. Relict tidal channels can still be seen in the Light Detection and Ranging (LiDAR) surface (Figure 2). The estuary was diked and drained in the late 19th or early 20th century and has been farmed ever since.

The prospective tidal estuary restoration site is bordered by residential and agricultural properties that rely on subsurface hydrologic conditions for water supply, septic system drain fields, and have root-zone conditions that support forage and other crops.

1.2.2 Summary of Previous Studies and Existing Data

Conceptual restoration alternatives were previously developed as part of the Puget Sound Nearshore Ecosystem Restoration Project Engineering Report (PSNERP 2012; Chapter 18). The full and partial PSNERP restoration alternatives provide additional restoration scenarios not constrained by existing agricultural land uses. Additional site information is provided in this report.

ESA used existing LiDAR data from the Washington State Department of Natural Resources, acquired in 2014, to conduct the inventory of existing conditions. ESA also consulted the previous 2012 PSNERP study mentioned above.

2. Project Description

ESA has conducted this feasibility study and conceptual design work to inform WCLT and the Washington Department of Fish and Wildlife of restoration opportunities at the Livingston Bay site. The site has some landowners are not willing to participate at this time. Furthermore, ongoing agricultural and residential uses in the areas surrounding potential restoration scenarios are assumed to continue in the future and must not be impacted by restoration. This study adds key technical information used to evaluate the restoration alternatives and develop recommended sequencing considerations for land management and restoration.

2.1 Project Goals

The overall goals of the feasibility study and conceptual design work are as follows:

- Develop restoration scenarios based on current and future acquisition opportunities.
- Complete a restoration feasibility plan based on these scenarios.
- Evaluate consistency with process-based restoration principles.
- Determine which lands to acquire, if any, based on the results of this study.

3. Study Deliverables

3.1 Study Boundaries

Figure 3 shows the boundaries of the feasibility study area. The feasibility study area includes the Livingston Bay Community which is a shoreline community with approximately 59 houses. The community development is not considered for conducting restoration, rather it is included for the evaluation of potential changes related to the restoration actions being evaluated. Similarly, the large tideflat parcel waterward of the community is not considered for restoration, but is include in the project evaluation.

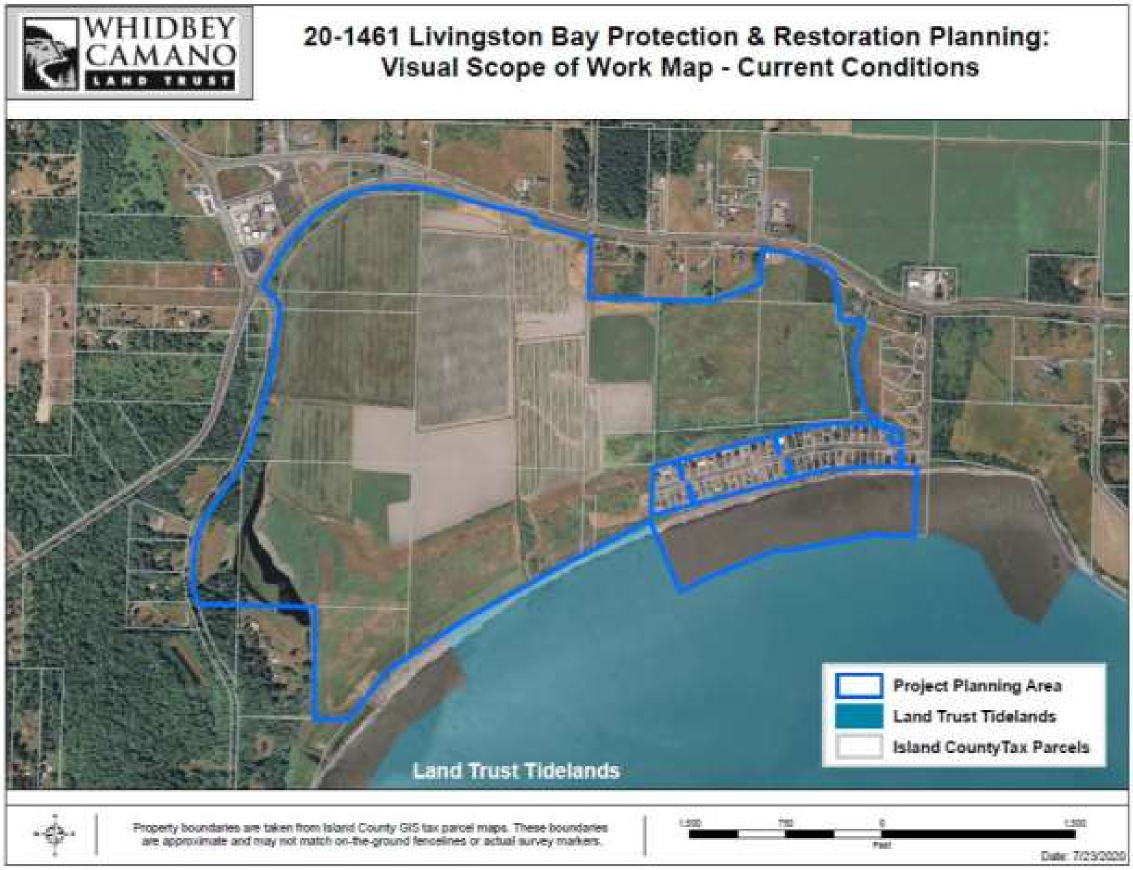


Figure 3. Study Boundary Map (Project Study Area Boundary in Blue)

3.2 Project Scenarios

The project scenarios or alternatives evaluated in this study include Partial Restoration (Scenario 1), a Partial Restoration with Land Swap (Scenario 2), and Full Estuary Restoration with a West Outlet (Scenario 3). **Table 1** summarizes the total area restored, linear feet of new levee construction, and rough cost estimate for each scenario. The scenarios are shown graphically in **Figures 4 through 6**.

Scenario 1, as with all scenarios, is a concept that covers a range of opportunities. Key to this scenario is a tidal connection from the Leque parcel through the Sherman parcel and to the Roberge parcel (see Figure 4). This connection can be located further north or south than is depicted depending on land ownership and willingness. Connection from the Roberge parcel to the creek (no published name, east side of Roberge parcel) was deemed infeasible due to private ownership and because the creek is higher in elevation than the marsh surface and, thus, could not provide an outlet.

Scenario 2 is similar to Scenario 1 but includes a 15 acre land swap as depicted in Figure 5. This land swap was proposed by Roger Nelson, the landowner to the west of the Leque parcel. The land swap entails the northernmost portion of Nelson's parcel for a same-sized portion on the southwestern margin of Leque's parcel. The northern 15 acres swapped acres included in the restoration have lower elevations than southern 15 acres that are adjacent and west of the current pump (shown as the proposed estuary outlet).

Scenario 3 depicts a full estuary restoration alternatives that would involve purchase of the majority of parcels as shown in Figure 6. Full estuary restoration may require flood protections for the Livingston Bay Community Association which could be assessed by the engineering team at a later phase of design. An intermediary managed storm water retention pond may be required (the Qwuloolt estuary restoration has an example). This is a significant engineered feature and it would displace or reduce restored tidal wetland.

TABLE 1.
PROJECT SCENARIOS

Scenario	Description	Area Restored (ac)	New Levee (LF)	Cost Estimate[1] ($MM)
1	Partial Restoration	118	9,640	14.4
2	Partial Restoration with Land Swap	111	10,270	15.6
3	Full Estuary Restoration with a West Outlet	219	3,080	16.8

NOTES: $MM = millions of dollars; ac = acres; LF = linear feet
SOURCE: Data compiled by Environmental Science Associates

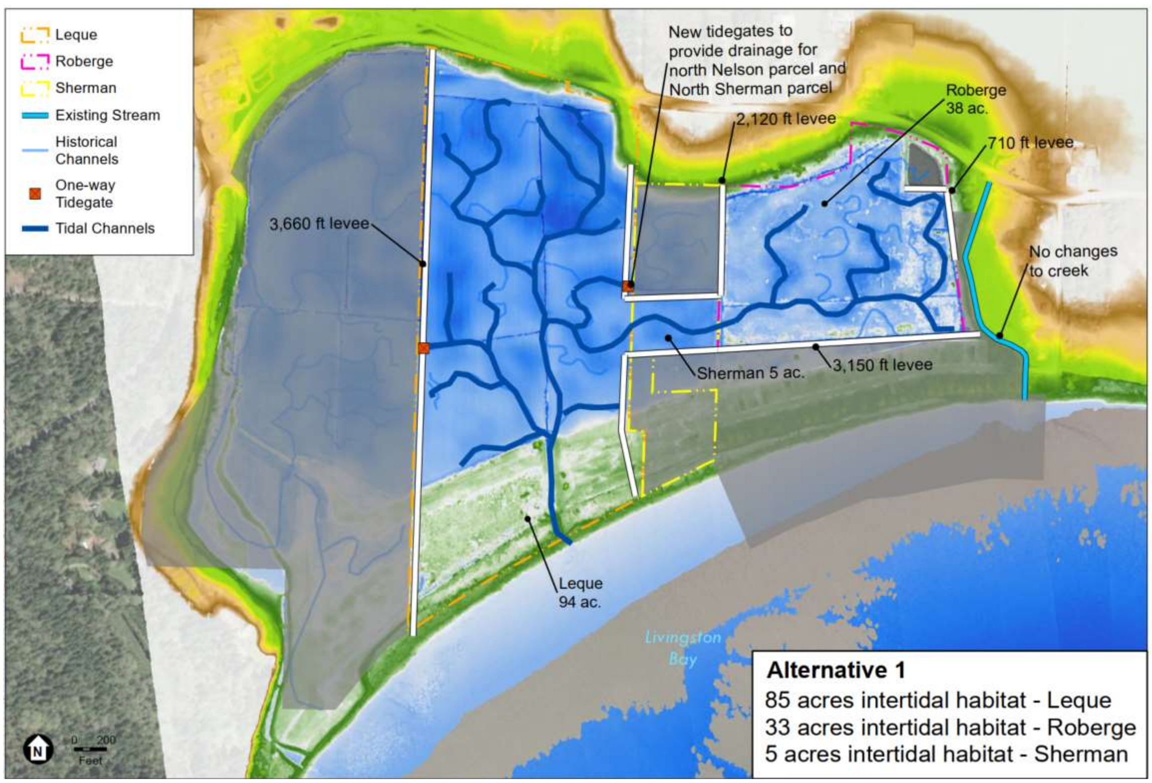


Figure 4. Scenario 1—Partial Restoration

1 Feasibility Study/"Order of Magnitude" Cost Estimates (for alternatives evaluation):For planning purposes we have provided order of magnitude estimates to allow cost comparison of alternatives. These cost estimates are intended to provide an approximation of total project costs appropriate for the conceptual level of design. These cost estimates are considered to be approximately -30% to +50% accurate and include a 35% contingency to account for project uncertainties (such as final design, permitting restrictions and bidding climate). These estimates are subject to refinement and revisions as the design is developed in future stages of the project.

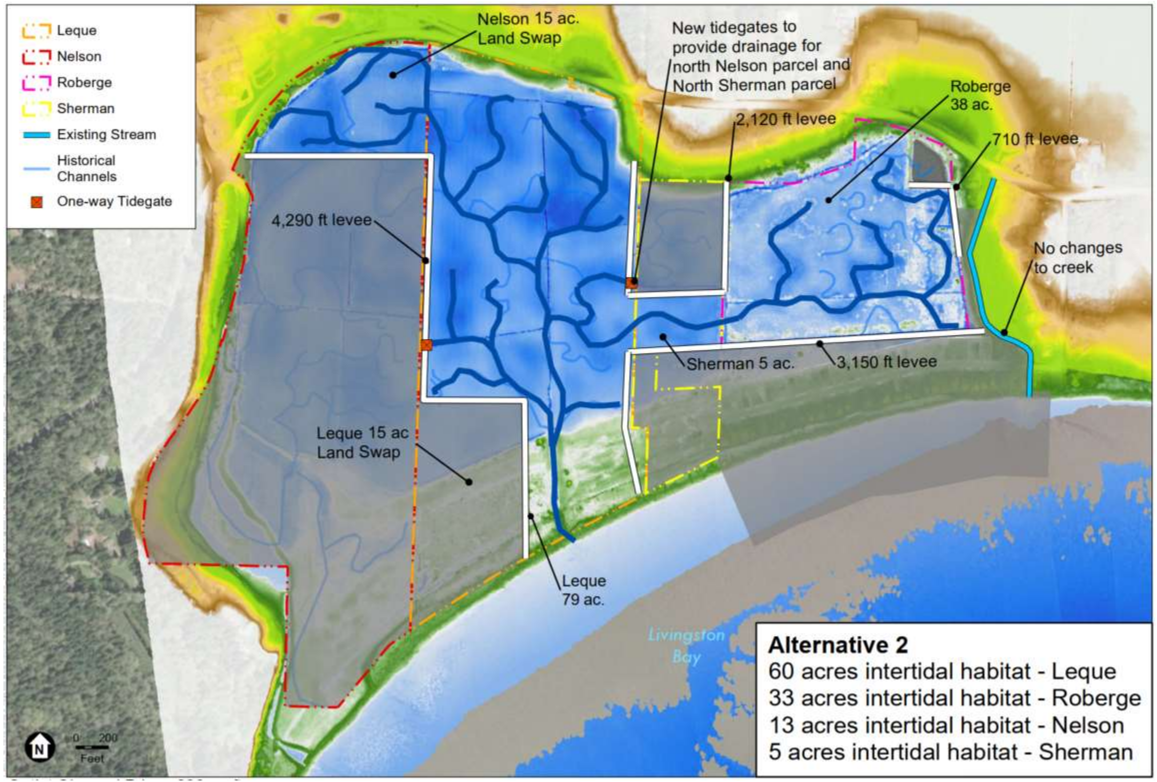


Figure 5. Scenario 2—Partial Restoration with Land Swap

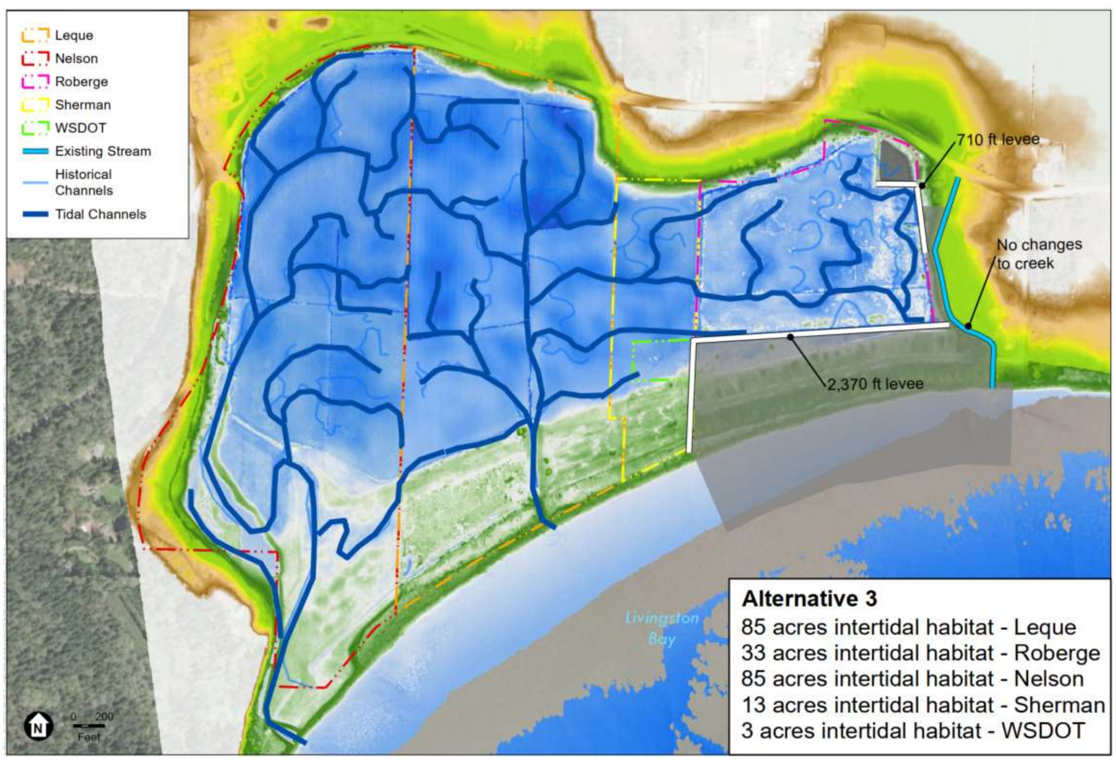


Figure 6. Scenario 3—Full Estuary Restoration with a West Outlet and not including the Livingston Bay Community Association (grey).

3.3 Drainage Infrastructure

This section outlines the existing drainage ditch network and the conditions of the pumps and pump stations at the project site. See Appendix A, "Drainage Infrastructure Memorandum," for a detailed description of the drainage infrastructure.

3.3.1 Drainage Network

Table 2 summarizes the drainage ditches' dimensions and observations. **Figure 7** shows the existing drainage network.

TABLE 2
PROJECT SITE DITCHES SUMMARY

Ditch	Dimensions			Notes
	Elevation (ft NAVD88)	Width (ft)	Length (ft)	
1	3–4	8	2,900	Heavily vegetated through most of its length.
2			2,560	Heavily vegetated; dimensions were not measured during the site visit.
3	3.5 to 4	8–10	1,150	Heavily vegetated. Two culvert crossings were found.
4–5	3	8		Ditches 4 and 5 are similar in geometry and conditions. Banks of ditches are vegetated, but bottoms are clear of vegetation.
6	5	9	1,170	The ditch is moderately vegetated at the bottom.
7	5.5 to 16	10–16	2,500	Ditch 7 varies from having vegetated banks and a clean bottom along its northern reach to being relatively clear of vegetation near the pump stations.
8	5	4–14	~200	Ditch discharged to the bay near elevation 8–9 ft (NAVD88). Heavily vegetated banks and some vegetation on the bottom.
9			1,500	Ditch 9 was not measured.
10			~2,100	The ditch could not be measured in the field.
11	4	11		Heavily vegetated.
12	3	4		Vegetated with a rectangular cross-section.
13	4	10		Vegetated with a rectangular cross-section.
14			~1,600	Ditch discharges to the bay near elevation 8 or 9 ft NAVD88.
15			~2,800	Ditch discharges to the bay. Dimensions were not measured.

NOTES: ft = feet; NAVD88 = North American Vertical Datum of 1988
Depth measured from top of bank land surface.
SOURCE: Data compiled by Anchor QEA in 2022

3.3.2 Pump Stations

Two pump stations are located at the downstream end of Ditch 7. Two wooden structures house the pumps. The smaller structure houses one pump (7.5 horsepower; 1,735 revolutions per minute). The larger structure houses at least two pumps (5 horsepower; 1,720 revolutions per minute). Based on the pumps' horsepower and the difference in elevation from Ditch 7 to Ditch 8, it is estimated that they can pump a combined 2,000-3,000 gallons per minute.[2]

[2] Pump information provided by Anchor QEA by observing existing electric motor mount plate on July 27, 2021.

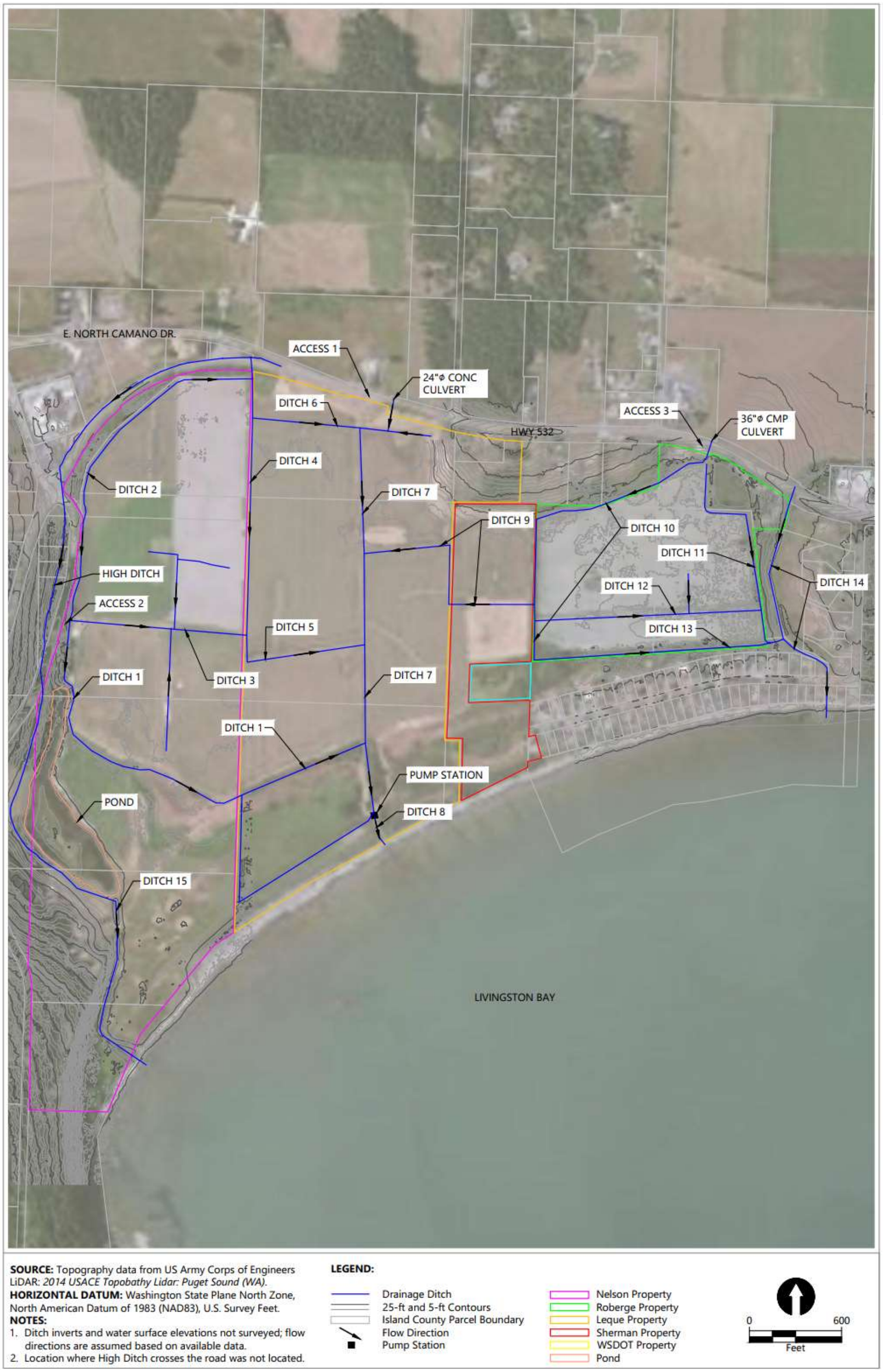


Figure 7. Drainage Infrastructure

3.4 Vegetation Survey

This section summarizes the findings of the vegetation survey which focused on noxious weeds. The survey aimed to identify and describe noxious weeds found on the study area parcels. This information was collected to understand potential vegetation maintenance issues that WCLT may need to plan for between the time parcels are acquired and restoration is constructed. Noxious weeds would require more active maintenance than other vegetation. See Appendix B, "Noxious Weed Survey," for the detailed report, which includes the following information:

- Mapped locations and descriptions of vegetation communities within the study area.
- Presence and classification of noxious weeds within the study area.
- Noxious-weed risk assessment.
- Potential management strategies.

3.4.1 Vegetation Communities

Observations of existing plant communities were recorded during the site survey. Based on these observations, plant communities present were further divided into eight distinctive groupings. **Figure 8** shows the vegetation communities identified in the survey, and **Table 3** describes these communities.

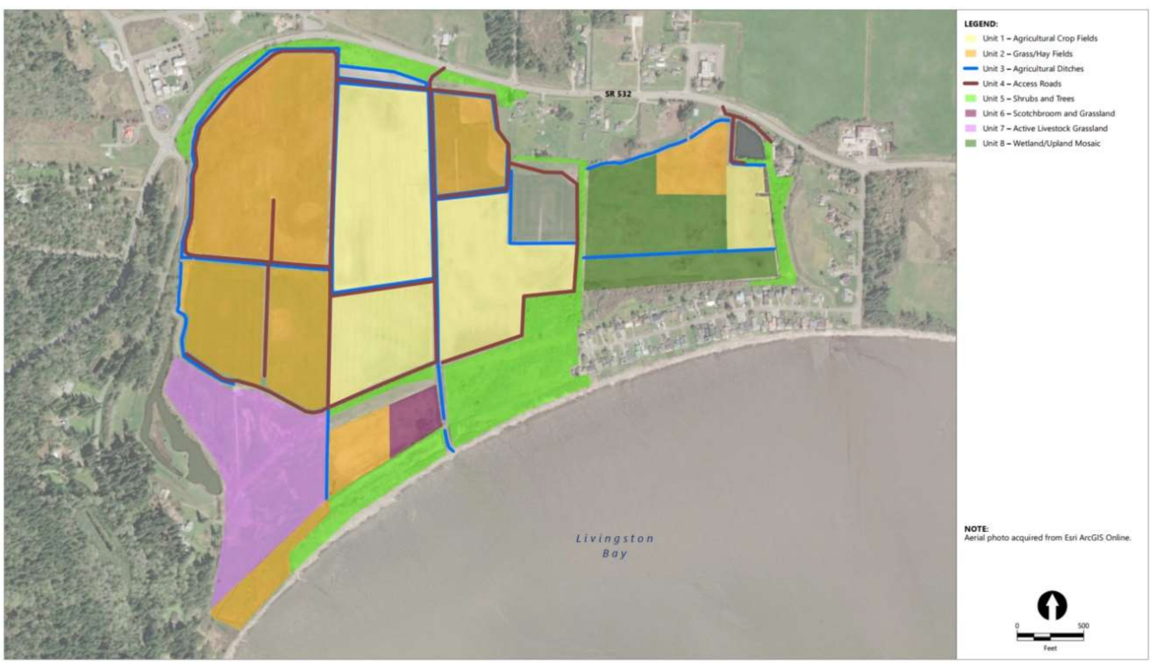


Figure 8. Observed Plant Communities (refer to Appendix B for full size figure)

TABLE 3
SUMMARY OF VEGETATION COMMUNITIES

Unit	Name	Description
1	**Agricultural Crop Fields**	This vegetation community unit is composed of actively managed agricultural field plots, including corn varieties, legumes, and cabbages.
2	**Grass/Hay Fields**	This vegetation community unit is composed of grass varieties and clovers that are regularly mowed to be baled for hay or cattle feed. These grass varieties are common, native grasses and some of the more palatable and important domestic hay grasses.
3	**Agricultural Ditches**	The term “agricultural ditch” describes any channel with the primary purpose of serving as an outlet for subsurface drainage to facilitate crop production. The agricultural ditches are situated between access roads and active field plot margins throughout the study area. This plant community unit includes upland and aquatic species and several noxious weeds.
4	**Access Roads**	Access roads throughout the study area are unpaved dirt roads. Soils are compacted and uneven as a result of regular use by heavy equipment. This plant community is composed of a range of native species, colonizers, and noxious species.
5	**Shrubs and Trees**	This plant community includes dense shrubs and trees and a wide variety of grasses and herbaceous species. Noxious weeds are present in this unit.
6	**Scotch Broom and Grassland**	This plant community unit is dominated by a Scotch broom (a noxious weed) along with mixed grasses and ground cover varieties. The growth of both grasses and noxious weeds appears to be even aged, consistent with regular maintenance.
7	**Active Livestock Grassland**	This plant community unit consists of grass varieties and ground cover actively grazed by livestock. Noxious weeds present in this unit include Canada thistle and bull thistle.
8	**Wetland/ Upland Mosaic**	In this unit, there are wetland features and evidence of standing water during wet seasons. The extent of the wetlands present was not delineated during the noxious weed survey. Noxious weeds present in this unit include reed canarygrass.

3.4.2 Observed Noxious Weeds

Class A, B, and C weeds were the target species for the Noxious Weeds survey. No Class A noxious weeds were found onsite. Thirteen species of Class B (regulated and non-regulated) and C (regulated and non-regulated noxious weeds were observed in the study area (**Table 4**). There were regulated and non-regulated species in both Class B and Class C. Island County will require control of the three Class B regulated species and two Class C regulated species observed onsite. The remaining eight species observed onsite will not require control, but it is recommended by Island County. Most were restricted to disturbed areas such as roadsides, irrigation ditches, or inactive agricultural field plots. These weeds were largely absent from adjacent managed and active agricultural crop fields, which were dominated almost entirely by selected agricultural plant species.

TABLE 4
NOXIOUS WEEDS OBSERVED ONSITE

Common Name	Scientific Name	Class	Unit Number
Canada thistle	*Cirsium arvense*	Regulated C	2, 3, 4, 7
Bull thistle	*Cirsium vulgare*	Regulated C	3, 4, 7
Field bindweed	*Convolvulus arvensis*	Non-Regulated C	5
Scotch broom	*Cytisus scoparius*	Non-Regulated B	5, 6
Wild carrot	*Daucus carota*	Non-Regulated C	2

Common Name	Scientific Name	Class	Unit Number
Hairy willowherb	*Epilobium hirsutum*	Regulated B	4
Common catsear	*Hypochaeris radicata*	Non-Regulated C	4
Tansy ragwort	*Jacobaea vulgaris*	Regulated B	4
Parrotfeather	*Myriophyllum aquiticum*	Regulated B	3
Reed canarygrass	*Phalaris arundinacea*	Non-Regulated C	2, 3, 5, 8
Himalayan blackberry	*Rubus armeniacus*	Non-Regulated C	4, 5
Evergreen blackberry	*Rubus laciniatus*	Non-Regulated C	4, 5
Common tansy	*Tanacetum vulgare*	Non-Regulated C	4

3.4.3 Recommendations

Control of the regulated and non-regulated noxious weeds should be planned for and implemented. Acquisition and restoration efforts under consideration for the study area present a risk for the increased spread of noxious weeds. Agricultural practices should be maintained on the existing agricultural fields until the site is restored to prevent the widespread establishment of noxious weeds. Water control and moist management techniques may also be considered. Regular efforts to control noxious weeds will also reduce the risk of noxious weed infestations during and after restoration.

Establishing tidal exchange and introducing saltwater from Port Susan will likely eliminate most or all noxious weeds below the high-tide line. Above that elevation, grading and other site disturbance are likely to increase the risk of a noxious weed infestation. Many of the noxious weeds present thrive in recently disturbed areas, meaning that earthwork and other restoration activity are likely to increase the risk of an infestation by noxious weeds in the short term. The use of thick mulch or cover crops is recommended as part of the restoration plan for the project. With tidal inundation, monitoring and treatment may be required post-restoration for invasive marsh plants, namely Spartina, which has been found after restoration on Leque Island.

3.5 Water Surface Elevation Analysis

This section summarizes the findings of the water surface analysis completed by ESA (see Appendix C, "Water Surface Elevation Analysis").

3.5.1 Water Level Measurements

ESA conducted hydrologic monitoring at the project site between July 2021 and June 2022 and compared the findings with existing measurements made at the nearby National Oceanic and Atmospheric Administration tide gage stations at Seattle and Tulare Beach (approximately 10 miles south of the project site in Port Susan. **Table 5** summarizes the data available at the site and collected by ESA for logger locations shown in **Figure 9**.

TABLE 5
AVAILABLE AND COLLECTED WATER LEVEL SURFACE DATA

ID	Source	Start Date	End Date
Seattle (Sta. 9447130)	NOAA	1/1/1899	7/31/2022
Tulare Beach (Sta. 9448043)	NOAA	5/23/2013	9/4/2013
Bay Gage	ESA	7/28/2021	6/29/2022
West Gage	ESA	7/28/2021	6/29/2022
North Gage	ESA	7/28/2021	6/29/2022
Pumphouse	ESA	7/28/2021	6/29/2022

NOTES: ESA = Environmental Science Associates; ID = identification; NOAA = National Oceanic and Atmospheric Administration; Sta. = Station
SOURCE: Data compiled by Environmental Science Associates in 2022

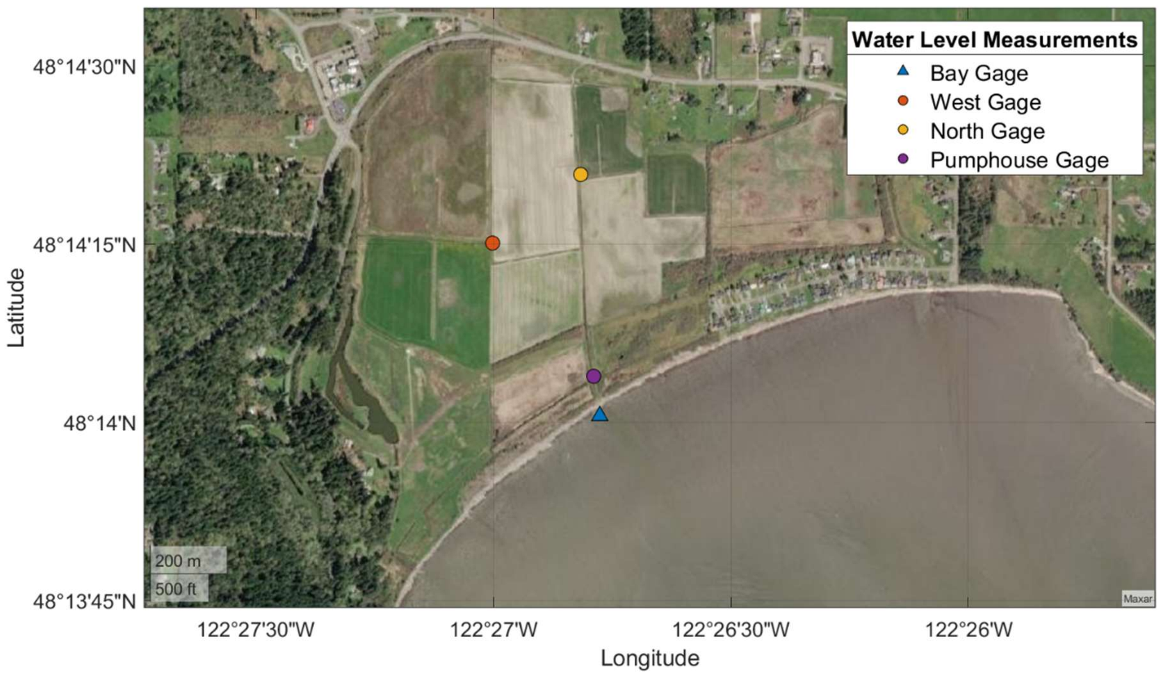


Figure 9 Locations of Water Level and Conductivity, Temperature, and Depth Measurements from ESA

3.5.2 Tidal Datum

Table 6 shows tidal datum relationships for the Seattle and Tulare Beach stations. The Seattle station's greater diurnal tide range (mean higher high water to mean lower low water) is 11.36 feet, compared to 11.08 feet for Tulare Beach station. Tulare Beach shows slightly higher values for most datums and is up to 0.3 foot higher for mean lower low water and the expected highest astronomical tide.

TABLE 6
TIDAL DATUMS (EPOCH 1983–2001)

Tidal Datum	Abbrev.	Seattle Elevation, feet NAVD88	Tulare Beach Elevation, feet NAVD88
Highest Observed (1/27/1983)[1]	HOT	12.14 (4:36 a.m.)	–
Highest Astronomical Tide	HAT	10.92	11.22
Mean Higher High Water	MHHW	9.02	9.05
Mean High Water	MHW	8.15	8.20
Mean Tide Level	MTL	4.32	4.45
Mean Sea Level	MSL	4.3	4.43
Diurnal Tide Level	DTL	3.34	3.51
Mean Low Water	MLW	0.49	0.71
North American Vertical Datum	NAVD	0.00	0.00
Mean Lower Low Water	MLLW	-2.34	-2.03
Lowest Astronomical Tide (6/22/1986)	LAT	-6.64	-6.50
Lowest Observed (1/4/1916)[1]	LOT	-7.38 (0:00 a.m.)	–

NOTES: Abbrev. = abbreviation for tidal datum; NAVD88 = North American Vertical Datum of 1988
1 The highest and lowest observed tide data are based on the recorded six-minute measurements.
SOURCE: Data compiled by Environmental Science Associates in 2022 from the National Oceanic and Atmospheric Administration.

3.5.3 Water Level Distribution

The Bay Gage installed by ESA shows a difference of 0.35 to 0.4 foot for the percentiles of 2 to 0.1 percent (higher values) when compared with the Seattle tide gage; this difference becomes smaller for the fifth and 10th percentiles. **Figure 10** shows the still-water-level probability for the Bay Gage and the Seattle Gage for the top 20 percentiles. The figure shows that the Bay tide gage installed at the project site at elevation 8.16 feet North American Vertical Datum of 1988 (NAVD88) represents only about 16 percent of the entire tidal cycle. This is because the gage was installed on the tidal flats in Livingston Bay which are high in elevation and only experience inundation for a small fraction of the tidal cycle.

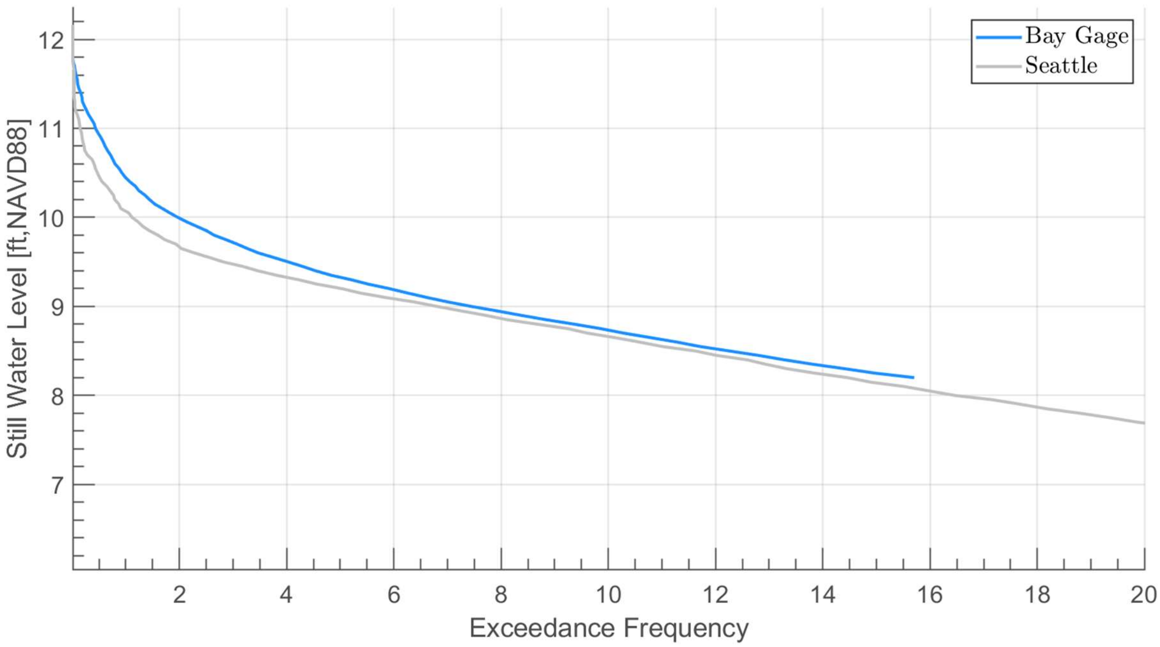


Figure 10 Still-Water-Level Probability for the Bay Gage and the Seattle Gage

3.5.4 Projected Sea Level Rise

Table 7 lists the projections of sea level rise for 2030, 2050, and 2100. The projections indicate that there is a medium risk (greater than 10 percent) that there will be a 0.5-foot increase in sea level rise by 2030, and that the risk will become much higher (greater than 70 percent) by 2050. Sea level will likely increase by 1 foot by 2050 and by 1–2 feet by 2100, and there is a medium risk that sea level rise will reach 3 feet by 2100. Not tabulated are higher values that are theoretically possible (e.g. 6 feet by 2100 per NOAA 2022).

TABLE 7
LIKELIHOOD (IN PERCENTAGES) OF SEA LEVEL RISE FOR LIVINGSTON BAY

Year	Low Emissions (RCP 4.5), ft				High Emissions (RCP 8.5), ft			
	0.5	1.0	2.0	3.0	0.5	1.0	2.0	3.0
2030	16	–	–	–	15	–	–	–
2050	74	13	–	–	79	18	–	–
2100	96	84	34	6	99	94	58	16

NOTES: ft = feet; RCP = Representative Concentration Pathway
SOURCE: Miller et al. 2019

3.6 Hydrogeologic Evaluation

This section summarizes key findings of the hydrogeological evaluation. See Appendix D, “Hydrogeologic Evaluation,” for the complete study.

The study included the following elements:

- Compilation and review of existing hydrogeologic data.
- Drilling and installation of on-site monitoring wells and shallow piezometers, and preparation of hydrogeologic cross-sections across the study area.
- Identification of local private wells for potential monitoring.
- Monitoring of groundwater levels and salinity in select monitoring and private wells.
- Collection and review of surface-water level and salinity data from ditch locations selected by ESA.
- Interpretation of the collected data.

This study provides a preliminary assessment of how diurnal tidal inundation associated with site restoration might affect groundwater conditions beneath adjacent lowland and upland properties. Of particular interest is whether the proposed restoration could cause groundwater salinization beneath adjacent areas of lowland agricultural land use or in water supply wells located on the upland.

Key Findings

A. Regional hydrogeologic characterization shows a subsurface stratified sequence of glacial and interglacial aquifers and aquitards. Shallow sediments noted below the lowlands include beach, marsh, and glaciomarine deposits.

B. Groundwater beneath the lowlands is derived from discharge from aquifers that underlie the uplands.

C. Specific conductance (SC), a measure of salinity, is low in the lowland monitoring wells, reflecting fresh groundwater discharge from the uplands. In contrast, water in ditches showed elevated SC values (typical of brackish water), as did groundwater in several shallow piezometers installed on-site. The reason for elevated salinity in the piezometers is unknown but may reflect the effects of sea spray, the salt concentration in the root zone, and/or historic episodes of site flooding.

D. Restoration would result in increased groundwater levels on the restored site and higher salinities in shallow soils caused by periodic inundation. This condition is not expected to cause saline intrusion of the upland aquifers because water levels in these aquifers will remain higher than in the lowland areas. However, engineering solutions may be required within the lowland areas to prevent saline water from migrating to adjacent agricultural and residential properties. For example, dikes separating restored properties from agricultural properties may benefit from a parallel ditch or managed wetland area and tide gate to control the lateral migration of shallow saline groundwater.

E. Proposed future studies include:

a. Measuring SC, chloride, and surveyed groundwater elevations in additional upland wells to confirm groundwater discharge to the lowlands from multiple directions.

b. Applying hydrogeologic guidance to consider additional monitoring points that support further understanding in related key locations. If restoration is not to be pursued, the project wells and piezometers could be decommissioned using appropriate methods.

c. Possibly employing groundwater modeling (e.g., two-dimensional "slice models") to assess the potential for net salinity migration across newly constructed dikes to adjacent agricultural properties.

3.7 Coastal Assessment and Tidal Channels

This section discusses coastal flooding, inlet stability, and channel sizing. See Appendix E, "Coastal Assessment and Tidal Channels," for a detailed analysis of the coastal process assessment at Livingston Bay. A summary of the findings of this study is listed below:

1. Winds are predominantly from the south-southeast and north-northwest and range from 5 to 40 miles per hour (mph), with most wind velocities between 5 and 20 mph. The annual maximum hourly average wind speed is 30.9 mph typically from south-southeast, and the 10-year wind speed is approximately 38.7 mph from the southeast direction.

2. Wind waves approach Livingston Bay from the South and Southeast direction. Most of the waves range from 1 to 2 ft with wave periods of 2-3 seconds. Larger waves can occur with wave heights of 4 to 5 ft and wave periods up to 4 seconds.

3. Modeling of waves approaching the project site shows strong refraction as they approach and spread into Livingston Bay and the modeling shows wave dissipation due to shoaling and wave breaking. The model results show that the west side of the project site is more protected from wind waves, while the east side is more exposed.

4. The preliminary coastal flood assessment indicates that for the typical berm crest elevation of 11.6 ft North American Vertical Datum of 1988 (NAVD88), the combined effect of water level and wave runup that will produce overtopping and water inflow to the site is close to the 1-year event with present conditions. These events may not have sufficient volume of water to fill the site entirely. The frequency of coastal inundations at the site will increase due to sea level rise.

5. Offshore waves produce an average annual total wave power of 0.6×10^9 ft-lbf/ft-year which ranges from 0.4 6×10^9 ft-lbf/ft-year to 0.85 6×10^9 ft-lbf/ft-year.

6. Mean longshore wave power near the proposed central tidal outlet channel (current pump location) indicates that waves will move sediment from west to east for all the years modeled. These results correspond to the defined littoral cells in the area that show sediment transport moving from west to east.

7. Evaluation of the proposed inlet alternatives using the Johnson (1973) stability diagram indicates that the evaluated inlet alternatives are well within the regime for always-open inlets. The proposed inlet remains in the always-open regime even with larger wave power and neap tidal prism. However, historical maps indicate that the primary outlet was at the western portion of Livingston Bay at the southwest corner of the Nelson parcel.

8. The tidal prism through the inlet is likely to increase with sea level rise, which would enhance the inlet's likelihood of staying open in the future.

9. A mudflat pilot channel 1,500 ft through the mudflat is proposed to increase the tidal influence at the project site from 16 percent to approximately 64 percent. The pilot channel will also reduce the risk of fish trapping in the newly-constructed tidal channels.

3.7.1 Geomorphic Setting

Livingston Bay's shoreline can be considered "swash-aligned." A swash-aligned beach is oriented, facing the predominant waves at a particular site, such that the larger wavefronts tend to reach the beach (after the shallow bay bottom refracts the waves). This is true of Livingston Bay's shoreline, which has aligned itself to the predominant wave direction with an orientation that slightly favors west to east littoral transport**.**

The beach fronting the proposed inlet area is composed primarily of fine sands and mud and armored with logs. The beach backshore is relatively low in elevation, with a berm elevation of 11.6 feet NAVD88. The horizontal beach transition to the mudflat is less than 30 feet. The berm elevation is formed by the waves and tides and the location of the logs. Decaying logs appear to be the main material of the berm.

3.7.2 Coastal Flooding

Total water levels (TWLs) at the site were estimated by combining the water levels near the site, the coincident wave runup on the shore, and the expected sea level rise according to the following relationship:

TWL(t) = SWL + Wave Runup + SLR(t), where t is time (indicating variable's time dependence)

An extreme-value analysis of the estimated 26 years of the TWL time series (shown above) was conducted. **Table 8** summarizes the return periods from the General Extreme Value (GEV) distribution for present and future conditions with rising sea levels.

TABLE 8
TOTAL WATER LEVEL ANALYSIS

Return Period (years)	Annual Probability of Occurrence	TWL Present (ft)	TWL 2030 (ft) 0.5 ft	TWL 2050 (ft) 1.0 ft	TWL 2100 (ft) 2.0 ft
MHHW	Daily	9.02	9.52	10.02	11.02
1	100%	11.4	11.9	12.4	13.4
2	50%	12.3	12.8	13.3	14.3

Return Period (years)	Annual Probability of Occurrence	TWL Present (ft)	TWL 2030 (ft) 0.5 ft	TWL 2050 (ft) 1.0 ft	TWL 2100 (ft) 2.0 ft
5	20%	12.8	13.3	13.8	14.8
10	10%	13.1	13.6	14.1	15.1
20	5%	13.3	13.8	14.3	15.3
50	2%	13.6	14.1	14.6	15.6
100	1%	13.8	14.3	14.8	15.8

NOTES: ft = foot or feet; MHHW = mean higher high water; TWL = total water level
SOURCE: Data compiled by Environmental Science Associates in 2022

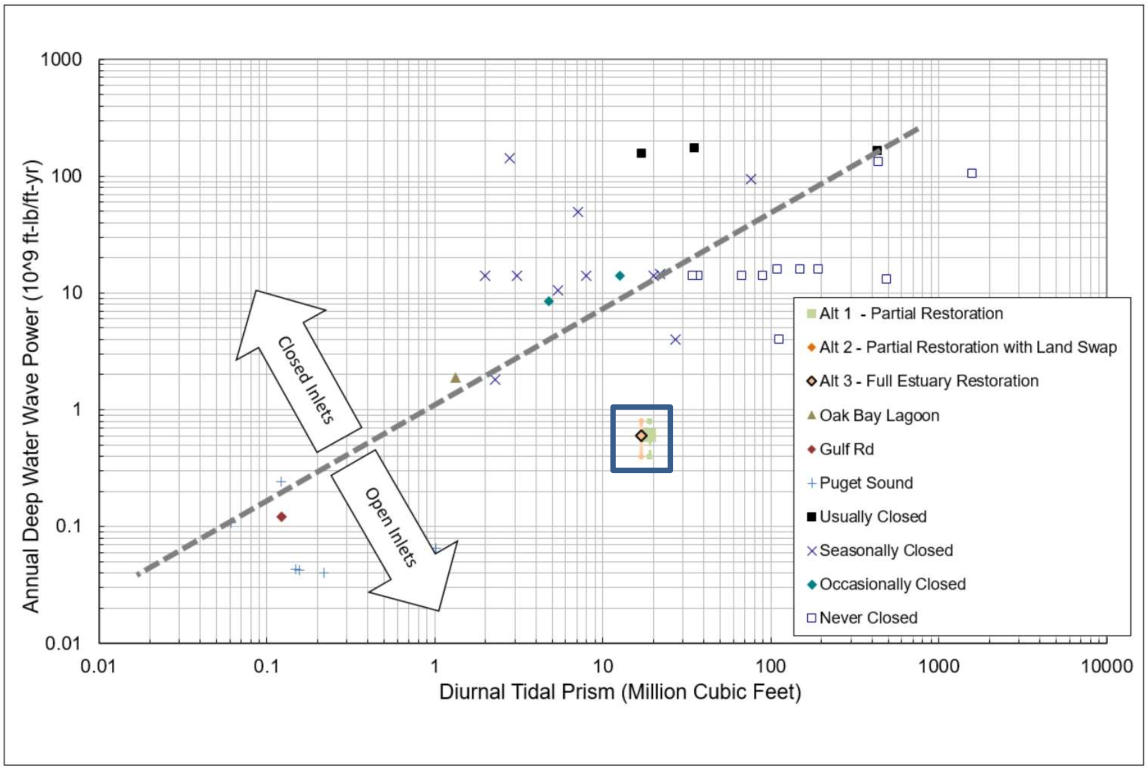
Results show that the 1-year event is close to overtopping the existing berm (11.6 feet NAVD88). By the year 2030, overtopping of the existing berm is likely to occur at a 1-year frequency, and by the year 2050, it is likely that these events will occur multiple times per year. Overtopping will result in saline water periodically entering properties of the Livingston Bay Community Association and existing agricultural areas via the beach berm (regardless of the proposed restoration project). Overtopping may also cause scour and/or failure of levees. The sea level rise estimates used are considered the medium risk and are described in Section 3.5.4 and in more detail in Appendix C.

3.7.3 Inlet Stability

Tidal inlets are dynamic systems with geomorphology that is determined by complex interactions of tides, waves, and sediment transport. Because the tides oscillate in both directions and there is a two-way coupling between the flow and the bed, an assessment of long-term inlet stability is challenging to characterize only with hydrodynamic modeling or even with hydrodynamics coupled with sediment transport modeling. Hence, inlet analyses typically consider applied geomorphology as well.

One common way to assess the potential for inlet stability is to apply a diagram that arranges different inlet sites by the relative wave power they receive and by their tidal prism. This is based on the approach described by Johnson (1973), who compiled data from reference lagoons in California spanning a range of average annual wave power and diurnal tidal prism. Based on the groupings of these data, Johnson classified inlets as open, seasonally open, or mostly closed, depending on the relative balance of wave power versus tidal prism. Note that sediment deposition and organic material from emergent wetland plants may reduce the tidal prism over time, depending on the rate relative to sea-level rise.

Figure 11 shows Johnson's (1973) classification diagram, with additional modifications (Battalio et al. 2007), and data from inlets through sand and gravel beaches, including several Puget Sound sites. Inlets with high wave power (i.e., greater sediment deposition in the inlet) relative to tidal power (i.e., scouring capability) tend to be closed most of the time and cluster in the upper left portion of the figure. Inlets with low wave power relative to tidal power tend to be open and cluster in the lower right portion of the figure. Inlets close to the threshold between open and closed may alternate between open and closed as waves and tides experience their natural fluctuations. **Figure 10** shows the results for the tidal prism of the proposed inlet scenarios and the wave power estimated in the section above. Results show that for all the scenarios evaluated, the inlet will likely remain open.



Source: Original methodology developed by Johnson (1973). Reference data compiled by ESA PWA (2013) and. Tidal prism of Livingston Bay inlet alternatives. Wave power estimate by ESA.

Figure 11. Modified Johnson Inlet Stability Diagram (blue box highlights project alternatives)

3.7.4 Tidal Channel Sizing

Hydraulic geometry design guidelines for the Puget Sound region were used to develop long-term equilibrium channel dimensions, including cross-sectional area, depth, and width, based on regressions developed for San Francisco Bay scaled to tidal characteristics observed in Puget Sound. **Table 9** summarizes the channel sizing for the proposed outlet, primary, and secondary channels. **Figure 12** shows a graphical representation of the typical sections of the tidal channels described in Table 9.

TABLE 9.
APPROXIMATE TIDAL CHANNEL SIZING

Channel	Top Width (feet)	Depth (feet below MHHW)	Side Slopes
Outlet	100	13	4:1
Primary	75	9	4:1
Secondary	45	7	2:1

NOTE: MHHW = mean higher high water
SOURCE: Data compiled by Environmental Science Associates in 2022

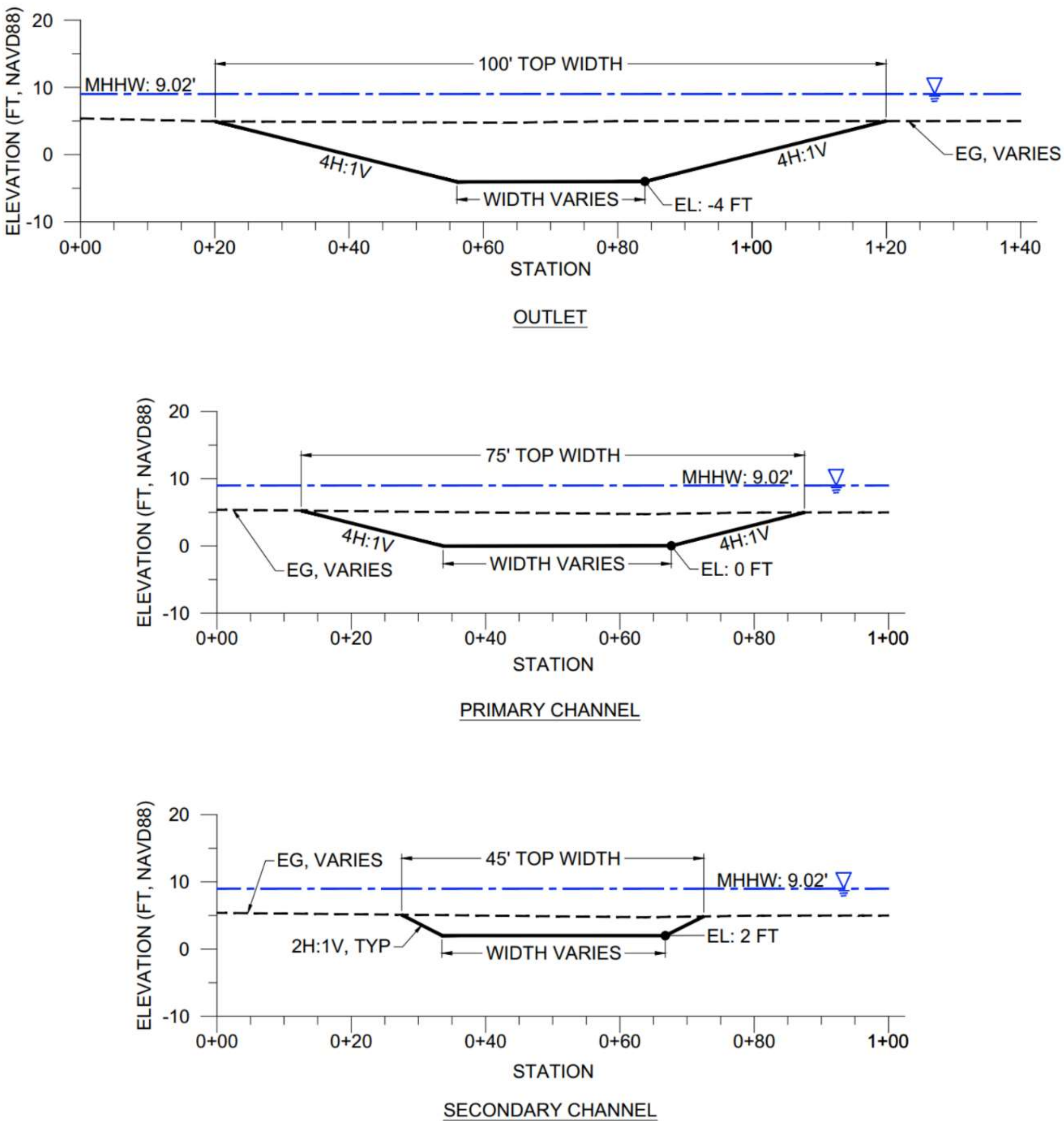
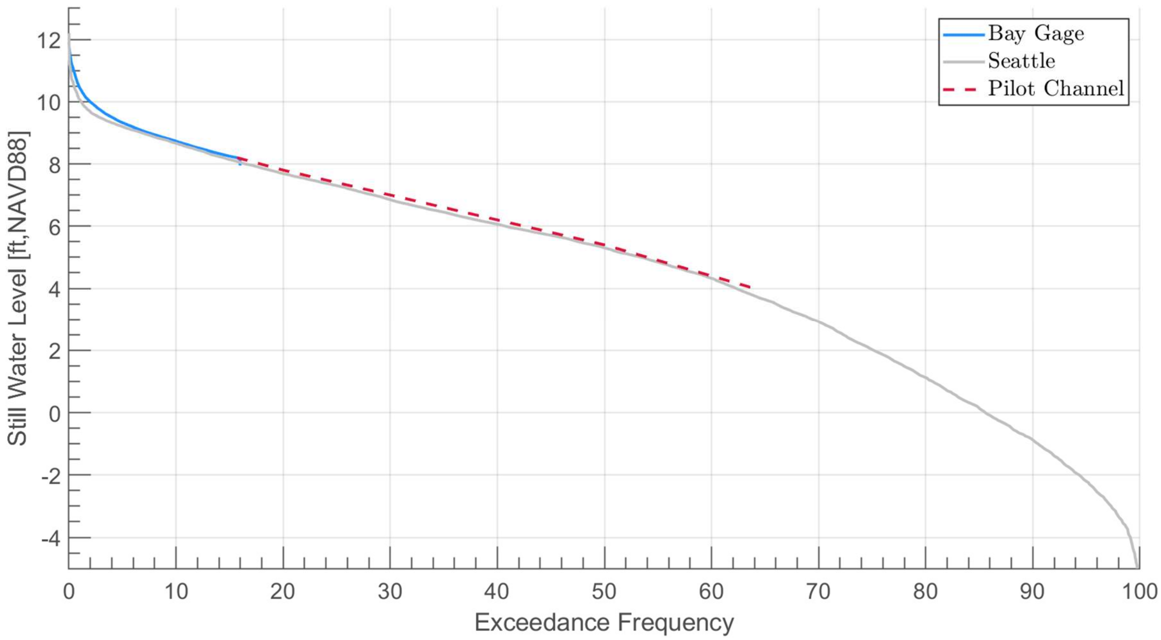


Figure 12. Typical Sections of Tidal Channels, Outlet (top), Primary Channel (middle), and Secondary Channel (bottom)

3.7.5 Mudflat Pilot Channel

The time scale for the outboard channel to scour to an equilibrium dimension that does not induce tidal muting of the site could be several years. This implies that tidal action at the project site, particularly at tides lower than 8 feet NAVD88, may be muted for several years after breaching and may influence the habitat establishment rate.

Dredging of a mudflat pilot channel through the outboard mudflat is proposed to help accelerate this process. This will allow the project site to increase regular tidal inundation and "washing" of the imported soil, which is needed to alter the soil's physical and chemical components that support wetland vegetation. This higher variation in elevation on the project site will allow different types of vegetation to establish and provides an allowance for vertical uncertainties in tidal hydraulics effects and vegetation establishment elevations. The proposed pilot channel will be approximately 1,500 feet long through the mudflat and will reach an elevation of 4 feet NAVD88 at the mudflat. Over time, the pilot channel will scour to hydraulically appropriate geometry, but providing even an undersized starter channels will considerably improve tidal exchange within the site. **Figure 13** shows that with this pilot channel, the estuary will be subject to tidal influence about 64 percent of the time instead of only 16 percent of the time if no pilot channel is included in the restoration.



NOTE: This graph shows the likely water level exceedance with a pilot channel excavated on the mudflat.

Figure 13. Still-Water-Level Exceedance for the Bay Gage (Present Conditions), Seattle Gage, and the predicted curve with a Pilot Channel

3.8 Cost-Benefit Analysis

This section summarizes the findings of the cost-benefit analysis. See Appendix F, "Cost-Benefit Analysis," for detailed information on these findings and the methodology used.

Habitat equivalency analysis is a model that was developed by the National Oceanic and Atmospheric Administration's National Marine Fisheries Service to assess both ecological services lost or gained, using (1) the relative habitat value pre- and post-project, (2) the size of the area affected, (3) the time a project will remain in place, and (4) the time it takes for the habitat to achieve full function, and discounting for less value of future functions and ecosystem services (Ehinger et al. 2015). Ecological services lost (debits) or gained (credits) are expressed in Discounted Service Acre Years (DSAYs), which allows for a service-to-service replacement approach rather than direct habitat replacement (e.g., 1 acre of wetland created to replace 1 acre of wetland affected).

The habitat equivalency analysis results are reported in DSAYs, representing the present value of all ecosystem services provided by 1 acre of habitat in 1 year. **Table 10** shows the ratio of cost and DSAY and the normalized cost, using Scenario 3 as the baseline. Scenario 3 shows the lowest cost per DSAY, followed by Scenarios 1 and 2. The benefits of Scenarios 1 and 2 are much smaller than those of Scenario 3, while the cost is marginally smaller than that of Scenario 3.

TABLE 10.
NORMALIZED COST AND FUNCTION BASED ON SCENARIO 3

Scenario	Description	Cost / DSAY	Benefits	Cost	Benefit / Cost
1	Partial Restoration	3,692	53%	86%	62%
2	Partial Restoration with Land Swap	4,139	51%	93%	55%
3	Full Estuary Restoration with a West Outlet	2,279	100%	100%	100%

NOTE: DSAY = Discounted Service Acre Years
SOURCE: Data compiled by Environmental Science Associates in 2022

4. Conclusions

4.1 Considerations for Engineering Design

1. Revisit having creek to east of site flow into the potential restoration area. This study concluded that outflow from the restoration site to the creek would not be feasible, but having the creek flow into the restoration site would be expected to be beneficial for ecological and practical reasons. Currently, the creek's culvert out to Livingston Bay is problematic for Island County and the community. This needs to be addressed as part of any future restoration project.

2. Consider fine sediment delivery from the Stillaguamish River using information from recent study by Eric Grossman, USGS. USGS did an analysis to inform the recent Iverson Marsh restoration feasibility analysis.

3. Future design phases should identify suitable reference sites to help inform the design.

4. Consider regional regression curves on tidal embayment outlet channels, as well as allometry calculations from Greg Hood, SRSC. Updated tidal embayment outlet channel guidelines are in preparation.

5. All restoration scenarios will require a more detailed coastal inundation study. For example, this study would inform the need for highway protection under Scenario 3. This protection would take the form of a habitat berm with forest and shrub native species. This study would also inform the necessity, size, and extents of levees that were shown only conceptually at this phase of the design.

4.2 General Conclusions

A complex and comprehensive set of analyses were completed as part of this Feasibility Study. The following is a short list of pertinent conclusions based on the more detailed analysis in the accompanying appendices:

1. Evaluation of the proposed inlet alternatives using the Johnson (1973) stability diagram indicates that the evaluated inlet alternatives are well within the regime for always-open inlets. The proposed inlet remains in the always-open regime even with larger wave power and neap tidal prism. An outlet to the west as shown in Scenario 3 is preferred from a geomorphic perspective; however, an outlet near the existing pump station could function for many years as depicted in Scenarios 1 and 2. The tidal prism through the inlet is likely to increase with sea level rise, which would enhance the inlet's likelihood of staying open in the future.

2. Establishing tidal exchange (frequent daily inundation) and introducing saltwater from Port Susan will likely eliminate most or all noxious weeds below the high-tide line. However, it may introduce Spartina.

3. Restoration may result in increased groundwater levels on the restored site and higher salinities in shallow soils caused by periodic inundation. This condition is not expected to cause saline intrusion of the upland aquifers because water levels in these aquifers will remain higher than in the lowland areas. However, engineering solutions may be required within the lowland areas to prevent saline water from migrating to adjacent agricultural and residential properties.

4. Restoration will increase the intermediate high water levels in the site under existing conditions. However, restoration may reduce flood risk associated with extreme events that overtop current beach berms. An assessment of flood potential for adjacent properties is needed.

5. ESA recommends a pilot channel on the mudflat for any of the 3 scenarios presented. The channel sizing analysis showed that the outlet channel should go to -4 FT NAVD. This is not feasible since it would require too much length of pilot channel excavation. Design of the pilot mudflat channel needs more refinement to avoid salmon entrapment and to avoid excessively large impacts to the mudflat.

6. Based on the cost-benefit analysis and the morphology of the site, ESA strongly recommends Scenario 3 even if parcel acquisition takes time to accomplish.

7. Scenarios 1 and 2 may increase groundwater and agricultural pumping requirements for adjacent parcels and hence an adverse flood impact. This is a flood risk unless a flood easement can be purchased, or other water management action can be taken on the WCLT (project) property.

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Appendix A
Drainage Infrastructure

ESA

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ANCHOR QEA

Memorandum

November 9, 2021

To: Sky Miller, ESA

From: Josh Sexton, PE, Anchor QEA, LLC

cc: Daniel Elephant and Paul Schlenger, ESA

Re: Livingston Bay Restoration Feasibility Study, Drainage Infrastructure

Introduction

This memorandum describes the existing drainage ditch network and infrastructure and provides a general assessment of the condition of the pumps and pump stations at the Livingston Bay site in support of the ongoing restoration feasibility study.

The Livingston Bay site is an approximately 3,200-acre area including farmland and residential areas located on the shore of Livingston Bay, near Stanwood, Washington (Figure 1). To support future restoration, levees and drainage ditches may need to be constructed to protect property and preserve natural salmon habitat offshore. Most of the site is flat with an approximate elevation of 5 to 7 feet North American Vertical Datum of 1988 (NAVD88). The site grades higher near Highway 532 (to the north), which has a road grade elevation of approximately 20 feet (NAVD88).

This memorandum includes the following:

- Description of drainage network and flow routing on the site
- General assessment of the condition of the existing pumps and pump stations

The investigation for this site included a desktop analysis of available topography data and a field visit to assess the general condition of the drainage network and infrastructure.

Drainage Network

Anchor QEA staff conducted a site visit on July 27, 2021, to determine flow routing and general conditions of the drainage network. The following subsections describe the drainage components that were accessible at the time of the site visit. The drainage ditches were assigned a number (1 through 15) for the purpose of this memorandum. The drainage network is shown in Figure 2.

Ditch 1

Ditch 1 is located on the southwest portion of the site and originates on the Nelson property (Figure 2) near Access 2. Ditch 1 flows south then southeast across the Nelson property. No culvert was located where the ditch is shown to turn northeast, but it was assumed to continue northeast to meet with the ditch crossing the Leque property and terminating at Ditch 7. Ditch 1 is 3 to 4 feet deep, 8 feet wide, and 2,900 feet long if it does in fact continue all the way to Ditch 7. The ditch is heavily vegetated through most of its length, which limits its maximum conveyance capacity. Ditch 1 passes through a culvert of undetermined size at its intersection with Ditch 7.

Ditch 2

Ditch 2 is located on the northern portion of the Nelson property and appears to have a high point about midway along its approximately 2,560-foot length. Ditch 2 flows from the midpoint south to Ditch 1 and north and east to Ditches 4 and 6. Flow from north of Highway 532 flows into Ditch 2 at the northern extent of the Nelson property from an 18-inch culvert. Ditch 2 was observed to be heavily vegetated but was not measured during the site visit. The property owner indicated that they no longer wanted the team on site and, therefore, some of the ditches and other features on the Nelson property were not accessed.

Ditch 3

Ditch 3 originates near Access 2 and bisects the Nelson property until its termination at Ditch 4. Ditch 3 is approximately 1,150 feet in length and has a rectangular cross section that is approximately 10 feet wide and 4 feet deep on the west end of the ditch, and 8 feet wide and 3.5 feet deep on the east end. Ditch 3 is heavily vegetated. Two culvert crossings were found on Ditch 3 near the west end: one approximately 13-foot-wide crossing and one 16-foot-wide crossing. The culvert sizes could not be determined at the time of the site visit.

Ditches 4 and 5

Ditches 4 and 5 are similar in geometry and condition. Ditch 4 originates near the northeast extent of the Nelson property (northwest corner of Leque property) at the intersection of Ditches 2 and 6. Ditch 4 flows to the south for approximately 1,600 feet before intersecting with Ditch 5. Both ditches have rectangular cross sections measuring approximately 8 feet on the bottom and 3 feet deep. The banks of both ditches were vegetated, but the bottoms were clear of vegetation. Ditch 5 passes through a 24-inch-diameter culvert at its intersection with Ditch 7.

Ditch 6

Ditch 6 runs east-west along the northern portion of the Leque property for approximately 1,170 feet. Water flows from each end of Ditch 6 to Ditch 7. A 24-inch-diameter culvert conveys water across Highway 532 to Ditch 6 approximately 200 feet east of its intersection with Ditch 7. Ditch 6 is moderately vegetated in the bottom and has a rectangular cross section measuring approximately 9 feet wide by 5 feet deep.

Ditch 7

Ditch 7 nearly bisects the Leque property, flowing north to south from its intersection with Ditch 6 to its termination at the pump station forebay at the southern end of the property. The 2,500-foot ditch has a mostly rectangular cross section measuring approximately 10 feet wide and 5.5 feet deep. The ditch widens and deepens significantly where it enters the pump station forebay. The pump station forebay widens to about 16 feet wide and over 10 feet deep. Ditches 1, 5, and 9 flow into Ditch 7. Ditch 7 varies from having vegetated banks and clean bottom along its northern reach to being relatively clear of vegetation as it nears the pump station.

Ditch 8

Ditch 8 receives pumped flow from the pump station's 12-inch steel discharge pipe and two 10-inch high-density polyethylene (HDPE) discharge pipes and outfalls to the mudflats of Livingston Bay. The ditch is approximately 200 feet long and has a rectangular cross section approximately 14 feet wide by 5 feet deep. Ditch 8 narrows to about 4 feet wide 20 feet upstream of the mudflats, then widens again to 10 feet wide at the outlet. Flow is discharged to the bay near elevation 8 or 9 feet (NAVD88). The ditch has heavily vegetated banks and some vegetation on the bottom.

Ditch 9

Ditch 9 flows east to west across the Sherman property and north along the Leque property before turning west again to flow into Ditch 7. The total length of Ditch 9 is approximately 1,500 feet. The eastern portions of the Leque property and the Sherman property were not accessed during the site visit; therefore, Ditch 9 was not measured.

Ditch 10

Ditch 10 originates at the northern end of the Roberge property where a 36-inch corrugated metal pipe culvert crosses under Highway 532. Ditch 10 flows southwest along the property until it reaches the Sherman property, where it turns south. The Roberge property was heavily overgrown with reed canarygrass, and we could not measure Ditch 10 in the field. Using aerial imagery, Ditch 10 measured approximately 2,100 feet long.

Ditch 11

Ditch 11 flows predominantly north to south along the east side of the Roberge property. The ditch is heavily vegetated along the entire length observed. At the southern end of the Ditch 11, flows are joined with Ditches 12 and 13 and continue to Ditch 14. Ditch 11 contained a significant amount of standing water at the time of observation. The rectangular cross section measured approximately 11 feet wide and 4 feet deep.

Ditches 12 and 13

Ditches 12 and 13 both originate at the western edge of the Roberge property and flow from west to east across the southern portion of the property. Both ditches terminate at Ditch 14. Both ditches are vegetated and have rectangular cross sections. Ditch 12 measured approximately 4 feet wide and 3 feet deep, while Ditch 13 measured 10 feet wide and 4 feet deep.

Ditch 14

Ditch 14 conveys flow under Highway 532 and runs north to south to the east of the Roberge property. The ditch is approximately 1,600 feet long from the south edge of the highway to the outfall at the mudflats of Livingston Bay. Ditches 11 and 13 flow into Ditch 14 approximately 670 feet upstream from the outfall. From its confluence with Ditches 11 and 13, Ditch 14 continues southeast and south behind and between some residential properties before discharging to the bay. Flow is discharged to the bay near elevation 8 or 9 feet (NAVD88).

Ditch 15

Ditch 15 flows north to south along the west side of the Nelson property. The ditch flows into a constructed pond approximately 5 acres in area before continuing south to discharge into Livingston Bay. Ditch 15, and the pond, were not accessible during the site visit and thus were not measured. Using aerial imagery and topographic data, Ditch 15 is estimated to be approximately 2,800 feet in length including its path through the pond.

Pump Stations

Two pump stations are located at the downstream end of Ditch 7. The wooden structures each sit on a concrete base 8 to 10 feet tall. The larger of the structures is 10 feet by 10 feet at the base and tapers to about 5 feet square at the top. The smaller structure is 4 feet by 8 feet. Pumps housed in the structures draw water from the forebay to the north and discharge to Ditch 8 through a 12-inch steel discharge pipe and two 10-inch HDPE discharge pipes. All three pipes have flap gates installed where they discharge to Ditch 8.

Both structures were locked at the time of the site visit, and the pumps could not be observed at that time. Following the visit, photographs of the pumps and interior of the pump station were reviewed. Select photographs are presented in Attachment 1. Based on this review, the smaller structure houses at least one pump (7.5 HP; 1,735 RPM) that appears to be in good to fair condition. Electrical controls and boxes and other appurtenances also appear in good to fair condition. The larger structure appears to house at least two pumps (5 HP; 1,720 RPM) in good to fair condition. What could be seen of the discharge pipes appeared to be in good condition as well. A flow test was not performed, nor is the design discharge rate of the pumps known. Based on the pumps' horsepower and difference in elevation from Ditch 7 to Ditch 8, it is estimated they can pump a combined 2,000 to 3,000 gallons per minute (4.5 to 6.7 cubic feet per second).

Figures

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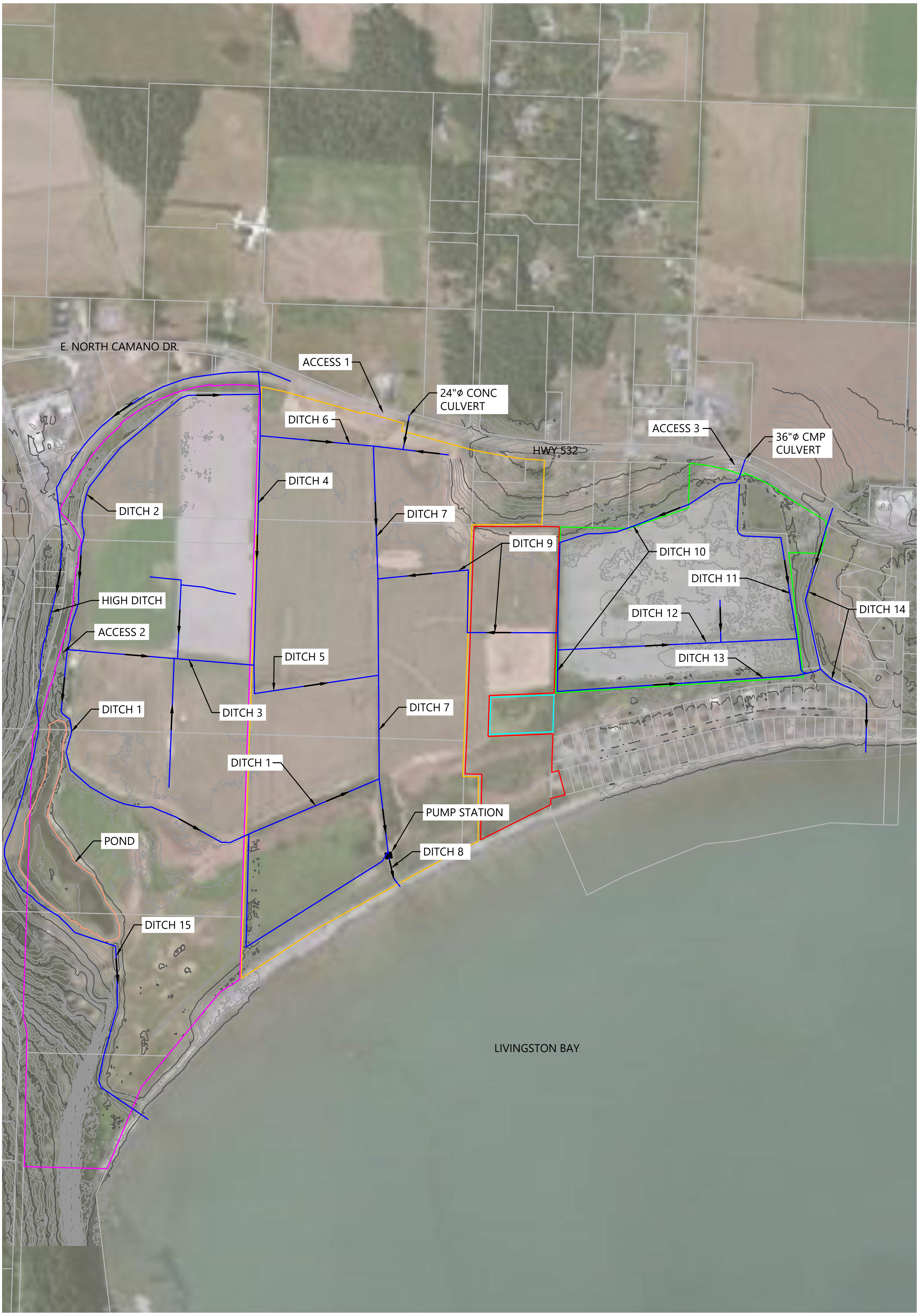
Figure 1
Site Vicinity Map

Drainage Infrastructure Memo
Livingston Bay Restoration Feasibility Study



SOURCE: Topography data from US Army Corps of Engineers LiDAR: *2014 USACE Topobathy Lidar: Puget Sound (WA).*
HORIZONTAL DATUM: Washington State Plane North Zone, North American Datum of 1983 (NAD83), U.S. Survey Feet.
NOTES:
1. Ditch inverts and water surface elevations not surveyed; flow directions are assumed based on available data.
2. Location where High Ditch crosses the road was not located.

LEGEND:
- Drainage Ditch
- 25-ft and 5-ft Contours
- Island County Parcel Boundary
- Flow Direction
- Pump Station
- Nelson Property
- Roberge Property
- Leque Property
- Sherman Property
- WSDOT Property
- Pond

0 600
Feet

Publish Date: 2021/12/01 3:06 PM | User: jsexton
Filepath: K:\Users\jsexton\Camano_Island\Figures\Drainage_Memo_Figures.dwg Figure 2

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Figure 2
Drainage Infrastructure
Drainage Infrastructure Memo
Livingston Bay Restoration Feasibility Study

Attachment 1

Selected Site Photographs

Photograph 1
Ditch 7: Typical of Less Vegetated Ditches

Photograph 2
Ditch 1: Typical Heavily Vegetated Ditch

Photograph 3
Ditch 6

Photograph 4
Confluence of Ditches 12, 13, and 14

Photograph 5
Pump Station Structures

Photograph 6
Pump Station Forebay

Photograph 7
Pump Station Discharge Pipes

Photograph 8
Ditch 8 Looking South

Appendix B
Noxious Weed Survey

ESA

1605 Cornwall Avenue
Bellingham, Washington 98225
360.733.4311

ANCHOR QEA

Memorandum

November 5, 2021

To: Whidbey Camano Land Trust and Environmental Science Associates (ESA)

From: Laura Caron, Calvin Douglas, John Small, and Erik Pipkin, Anchor QEA, LLC

Re: Noxious Weed Survey – Livingston Bay Restoration Feasibility Study, Camano Island, Island County, Washington

Introduction

This report was prepared for the Whidbey Camano Land Trust and Environmental Science Associates for the proposed Livingston Bay Restoration Project. The Project includes the restoration of agricultural lands adjacent to Livingston Bay in Camano Island, Washington. The purpose of this report is to identify and describe noxious weeds found within the study area parcels. This report includes the following information:

- Mapped locations and descriptions of vegetation communities within the study area
- Presence and classification of noxious weeds within the study area
- Noxious weeds risk assessment
- Potential management strategies

Study Area

The noxious weed survey study area is defined as including the following 12 parcels adjacent to Washington State Route 532 and Livingston Bay Land Trust Tidelands (Figures 1 and 2):

- Leque properties totaling 93.49 acres (parcels R33220-022-3210, R33229-466-3270, R33229-346-3180, and R33229-340-4000)
- Washington State Department of Transportation properties totaling 2.3 acres (parcel R33229-408-4300)
- Roberge properties totaling 38.79 acres (parcels R33229-478-4880, R33220-004-5180, R33221-020-0350, and R33228-338-0300)
- Livingston Bay Community Association properties totaling 32.65 acres (parcels S7380-02-0000A-0, S7380-00-0000A-0, and S7380-00-0000B-0)

A majority of the parcels in the study area are in active agricultural production with drainage ditches, drainage pumping, and tide gates. The study area also contains fallow lands and a wetland mitigation project. The study area is accessed on dirt or gravel farm roads. Properties of the Livingston Bay Community Association are a combination of maintained common areas on the perimeter and shoreline, as well as residential parcels located within these perimeter lands. See

Figure 1 for a map showing the study area and associated parcel divisions by landowner. See Figure 2 for individual county parcel lines with corresponding parcel numbers.

Study Goals and Objectives

The noxious weed survey identified the general location and presence of noxious weeds in the study area and provides a baseline of information for analysis and potential future surveys. For the survey, the term "noxious weed" includes species listed as noxious by the Washington State Noxious Weed Control Board (WSNWCB 2021) and any additional species that the Island County Noxious Weed Control Board (ICNWCB 2021) may be tracking as noxious weeds. Noxious weeds listed as Class A, Class B, and Class C were target species for the survey because of requirements to control and take management measures for these categories; however, non-regulated noxious weeds were included in the survey as well.

Methods

The goals of the noxious weed survey were to categorize plant community units within the study area based on the vegetation communities present and to identify the general location and presence of noxious weed species. The noxious weed survey consisted of a pre-field review of existing information, field surveys, and documentation of the results. Survey methods are described in the following subsections. Anchor QEA conducted an on-site field survey of all parcels in the study area on July 27, 2021.

Pre-Field Review

Existing information on noxious weeds and previous information for the study area is limited. No known dedicated noxious weed surveys have been conducted for the parcels within the study area. South of Livingston Bay, on the eastern shore of Camano Island, previous studies were conducted for the 120-acre Iverson Preserve in summer 2012 as part of their Noxious Weed Management Plan to establish long-term management strategies (Stein 2014). That study identified 15 species currently on the Washington State Noxious Weed List. It was anticipated that similar species might be present in the Livingston Bay study area.

Field Survey

The noxious weed survey was performed by walking through the study area, identifying plant community units based on vegetation communities, and marking the general location and presence of noxious weeds on aerial photographs. The entire study area was visually observed from access roads or trails. Plant species were identified or confirmed using *Plants of the Pacific Northwest Coast Revised Edition* (Pojar and Mackinnon 2014) and *A Field Guide to the Common Wetland Plants of Western Washington & Northwest Oregon* (Cooke 1997). Plant community units identified during the survey are shown in Figure 3.

Results

While conducting the site survey, observations of the existing plant communities were recorded. Based on these observations, plant communities present were further divided into eight distinctive groupings. A plant community is the fundamental, basic unit of a habitat. This assemblage is composed of different plants growing together in the same geographic location that are ecologically related through their ability to grow together, sharing the available resources. Additionally, the relative density of individual species is important because the dominant species are what makes these groupings distinct from one another. Dominant species also indicate the specific physical and biological conditions present. Adaptation, competition, and natural selection play a major part in determining how each of these communities grows. As shown in Table 1, many native plants observed were found in multiple communities of the study area.

Table 1
Observed Native and Common Plants

Common Name	Scientific Name	Stratum	Unit Number						
			2	**3**	**4**	**5**	**6**	**7**	**8**
American vetch	*Vicia americana*	Herb			X				
Bitter cherry	*Prunus emarginata*	Tree				X			
Broad-leaf cattail	*Typha latifolia*	Herb		X					X
Colonial bentgrass	*Agrostis capillaris*	Herb	X				X	X	
Creeping buttercup	*Ranunculus repens*	Herb	X						
Curly dock	*Rumex crispus*	Herb		X	X		X	X	
Douglas meadowsweet	*Spirea douglasii*	Shrub				X			
Field horsetail	*Equisetum arvense*	Herb			X				
Field meadow-foxtail	*Alopecurus pratensis*	Herb	X				X	X	
Fringed willowherb	*Epilobium ciliatum*	Herb			X				
Great plantain	*Plantago major*	Herb			X				
Hardstem bulrush	*Schoenoplectus acutus*	Herb							X
Jointed rush	*Juncus articulatus*	Herb		X					
Narrow-leaf fireweed	*Chamaenerion angustifolium*	Herb			X				
Nettle-leaf goosefoot	*Chenopodium murale*	Herb			X			X	
Nootka rose	*Rosa nutkana*	Shrub			X	X			
Pacific crabapple	*Malus fusca*	Tree				X			
Pineapple weed	*Matricaria discoidea*	Herb			X				

Common Name	Scientific Name	Stratum	Unit Number						
			2	3	4	5	6	7	8
Quackgrass	*Agropyron repens*	Herb	X				X	X	
Rattail radish	*Raphanus caudatus*	Herb			X				
Red alder	*Alnus rubra*	Tree				X			
Red clover	*Trifolium pratense*	Herb	X		X		X	X	
Ryegrass	*Lolium perenne*	Herb	X				X	X	
Silverweed	*Potentilla anserina*	Herb							X
Soft rush	*Juncus effusus*	Herb		X					
Swamp rose	*Rosa pisocarpa*	Shrub				X			
Tall fescue	*Festuca arundinacea*	Herb	X				X	X	
Tall Oregon-grape	*Mahonia aquifolium*	Shrub			X	X			
Timothy grass	*Phleum pratense*	Herb	X				X	X	
Twinberry	*Lonicera involucrata*	Shrub				X			
Velvet grass	*Holcus lanatus*	Herb	X				X	X	
White clover	*Trifolium repens*	Herb	X		X		X	X	

Unit 1 – Agricultural Crop Fields

This plant community unit is composed of actively managed agricultural field plots, including corn varieties, legumes, and cabbages. Fields appear tilled, well-drained, and are planted in approximately 30-inch rows throughout. Fields are surrounded on all sides by agricultural drainage ditches.

Unit 2 – Grass/Hay Fields

This plant community unit is composed of grass varieties and clovers that are regularly mowed to be bailed for hay or cattle feed. These grass varieties are common, native grasses as well as some of the more palatable and important domestic hay grasses. Mixed among the fringes of the unit, both clovers and noxious weeds were observed. Noxious weeds present in this unit include Canada thistle (*Cirsium arvense*), reed canarygrass (*Phalaris arundinacea*), and wild carrot (*Daucus carota*).

Unit 3 – Agricultural Ditches

The term “agricultural ditch” is used to describe any channel with a primary purpose to serve as an outlet for subsurface drainage to facilitate crop production. These ditches are critical components to viable agricultural production but also connect to other local water resources. A pump station and tide gate allow drainage from these ditches onto the tidal flats and estuary in Livingston Bay as well as the Land Trust Tidelands. The agricultural ditches are situated between access roads and active field plot margins throughout the study area. Standing water with a range of approximately 2 to 6 feet in depth was observed. The width of the agricultural ditches ranges from approximately 5 to 8 feet.

This plant community unit includes upland and aquatic species and several noxious weeds. Water in the ditches was frequently stagnant with associated algae species. Dominant plant species consist of broad-leaf cattail (*Typha latifolia*) and soft rush (*Juncus effusus*). Noxious weeds present in this unit include parrotfeather (*Myriophyllum aquiticum*), Canada thistle, bull thistle (*Cirsium vulgare*), reed canarygrass, evergreen blackberry (*Rubus laciniatus*), and Himalayan blackberry (*Rubus armeniacus*).

Unit 4 – Access Roads

Access roads throughout the study area are unpaved, dirt roads. Soils are compacted and uneven due to regular use by heavy equipment. They serve as permanent, low-traffic access for ongoing maintenance and agricultural activities. Access roads are approximately 12 feet wide with an additional 2-foot, mowed buffer on either side.

This plant community is composed of a range of native species, colonizers, and noxious species. Dominant plant species consist of grasses, clovers, and Nootka rose (*Rosa nutkana*). Noxious weeds present in this unit include hairy willowherb (*Epilobium hirsutum*), tansy ragwort (*Jacobea vulgaris*), Canada thistle, bull thistle, common catsear (*Hypochaeris radicata*), Himalayan blackberry, evergreen blackberry, and common tansy (*Tanacetum vulgare*).

Unit 5 – Shrubs and Trees

This plant community includes dense shrubs and trees and a wide variety of, grasses and herbaceous species. Dominant plant species include Nootka rose, tall Oregon-grape (*Mahonia aquifolium*), twinberry (*Lonicera involucrata*), and red alder (*Alnus rubra*). Noxious weeds present in this unit include field bindweed (*Convolvulus arvensis*), Scotch broom (*Cytisus scoparius*), reed canarygrass, Himalayan blackberry, and evergreen blackberry.

Unit 6 – Scotch Broom and Grassland

This plant community unit is dominated by Scotch broom (a noxious weed) along with mixed grasses and ground cover varieties. Much of the Scotch broom shows evidence of previous maintenance treatments through a combination of spraying and mowing. The growth of both grasses and noxious weeds appears even aged, consistent with regular maintenance.

Unit 7 – Active Livestock Grassland

This plant community unit consists of grass varieties and ground cover actively grazed by livestock. Noxious weeds present in this unit include Canada thistle and bull thistle.

Unit 8 – Wetland/Upland Mosaic

In this unit, there are wetland features and evidence of standing water during wet seasons. The extent of the wetlands present was not delineated during the noxious weed survey. Irregular mowing can be seen in varied age groupings of plant assemblages throughout the unit. This plant community unit is dominated by reed canarygrass with patches of hardstem bulrush (*Schoenoplectus acutus*), broad-leaf cattail, and soft rush. Noxious weeds present in this unit include reed canarygrass.

Noxious Weeds

Class A, Class B, and Class C weeds were the target species for this survey because the ICWCB requires control or management measures to be taken for these categories. A total of 13 noxious weed species were located in the study area (Table 2). No Class A noxious weeds were located. General information on each of the target species (species classification and location) is provided in Table 2. More information on all noxious weed species can be found at the Washington Noxious Weed Control Board website (http://www.nwcb.wa.gov/) and the Island County Noxious Weed Control Board website (http://www.islandcountywa.gov/).

Table 2
Observed Noxious Weeds

Common Name	Scientific Name	Class	Unit Number
Canada thistle	*Cirsium arvense*	Regulated C	2, 3, 4, 7
Bull thistle	*Cirsium vulgare*	Regulated C	3, 4, 7
Field bindweed	*Convolvulus arvensis*	Non-Reg. C	5
Scotch broom	*Cytisus scoparius*	Non-Reg. B	5, 6
Wild carrot	*Daucus carota*	Non-Reg. C	2
Hairy willowherb	*Epilobium hirsutum*	Regulated B	4
Common catsear	*Hypochaeris radicata*	Non-Reg. C	4
Tansy ragwort	*Jacobaea vulgaris*	Regulated B	4
Parrotfeather	*Myriophyllum aquiticum*	Regulated B	3
Reed canarygrass	*Phalaris arundinacea*	Non-Reg. C	2, 3, 5, 8
Himalayan blackberry	*Rubus armeniacus*	Non-Reg. C	4, 5
Evergreen blackberry	*Rubus laciniatus*	Non-Reg. C	4, 5
Common tansy	*Tanacetum vulgare*	Non-Reg. C	4

Note: Classifications of observed noxious weeds are based on the 2021 Island County Noxious Weed List.

Class B Noxious Weeds

Class B noxious weeds are designated as regulated in counties where they are limited in distribution or where they are a local priority. Property owners in Island County are required to control these species. Non-regulated Class B noxious weeds are already widespread. Property owners in Island County are not required to control these species but control is recommended where possible (ICNWCB 2021).

Class C Noxious Weeds

Class C noxious weeds are generally widespread but may be selected on a local level. The Island County Noxious Weed Board has designated two species (Canada and bull thistle) as regulated Class C weeds wherein the potential threat and the feasibility of control play a factor. Property owners in Island County are required to control these species. Forty-nine additional non-regulated Class C weeds have been identified by Island County, which property owners are not required to control, but control is recommended where possible (ICNWCB 2021).

Discussion and Recommendations

Noxious weeds are non-native plants that are highly destructive, competitive, and difficult to control. They can reduce crop yields, destroy native plant and animal habitat, damage recreational areas, clog waterways, lower land values, and poison humans and livestock. People have introduced non-native species both intentionally, such as in gardens or for erosion control, or accidentally, such as in contaminated seed mixes, hay, aquarium plants, or other materials. A small number of these introduced species have turned out to be highly invasive and damaging. Noxious weeds now occur in all parts of Island County.

Washington's noxious weed law (RCW 17.10) requires landowners—including city, county, and state land agencies—to control or eradicate certain noxious weeds that occur on their property. The county noxious weed program is available to provide information on identification and control methods. Landowners can choose the control method they feel is most appropriate for their property. A coordinated effort is required to prevent new noxious weeds from establishing and to control and eradicate the weeds already present.

To help protect the state's resources and economy, the Washington State Noxious Weed Control Board adopts a state noxious weed list each year (WAC 16-750) that categorizes weeds as Class A, B, or C based on distribution in the state, abundance, and level of threat (how dangerous the plant is to humans, animals, private and public lands, and native habitats). Each county weed board then passes a county weed list that specifies which weeds landowners are required to control in that county. The county list includes, at a minimum, all Class A weeds and those Class B and C weeds that landowners are required to control in that county. Sometimes additional weeds are recommended for control.

Noxious Weed Risk Assessment

During the Livingston Bay noxious weed surveys, infestations of three regulated Class B species, one non-regulated Class B species, two regulated Class C species, and seven non-regulated Class C species were located within and near the study area. Control or management measures for these target noxious weed species are the responsibility of property owners. It appears that there have been ongoing control efforts by some of the parcel landowners to control Scotch broom. However, evidence of significant efforts to control or eradicate Canada thistle and bull thistle was not observed. It is uncertain if the lack of control over these species has allowed them to spread throughout the study area, particularly where lands are recently disturbed or agricultural fields are no longer active. Many of the noxious species present could be controlled or eliminated with regular control by landowners.

A number of populations of Class B and Class C noxious weeds were observed in the study area. Most were restricted to disturbed areas such as roadsides, irrigation ditches, or inactive agricultural field plots. These weeds were largely absent from adjacent managed and active agricultural crop fields, which were dominated almost entirely by selected agricultural plant species.

Acquisition and restoration efforts under consideration for the study area present a risk for increased spread of noxious weeds. It is recommended that agricultural practices be maintained on the existing agricultural fields until the site is restored in order to prevent widespread establishment of noxious weeds. Regular efforts to control noxious weeds will also reduce the risk of noxious weed infestation during and after restoration.

Establishing tidal exchange and the introduction of saltwater from Port Susan will likely eliminate most or all noxious weeds below the high tide line. Above that elevation, grading and other site disturbance are likely to increase the risk of noxious weed infestation. Many of the noxious weeds present thrive in recently disturbed areas, meaning that earthwork and other restoration activity are likely to increase the risk of noxious weed infestation in the short term. The use of thick mulch or cover crops is recommended as part of the restoration plan for the project.

References

Cooke, S., 1997. *A Field Guide to the Common Wetland Plants of Western Washington & Northwestern Oregon*. Seattle Audubon Society. Seattle, Washington. May 1997.

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Pojar, J., and A. Mackinnon, 2014. *Plants of the Pacific Northwest Coast: Washington, Oregon, British Columbia & Alaska Revised Edition*. British Columbia Ministry of Forests and Lone Pine Publishing. Vancouver, British Columbia. 2014.

Stein, J., 2014. *Iverson Preserve Noxious Weed Management Plan 2013-2020*. Island County Noxious Weed Control Board. Coupeville, Washington. January 2014.

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Figures

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Figure 1
Study Area
Noxious Weed Survey
Livingston Bay Restoration Feasibility Study

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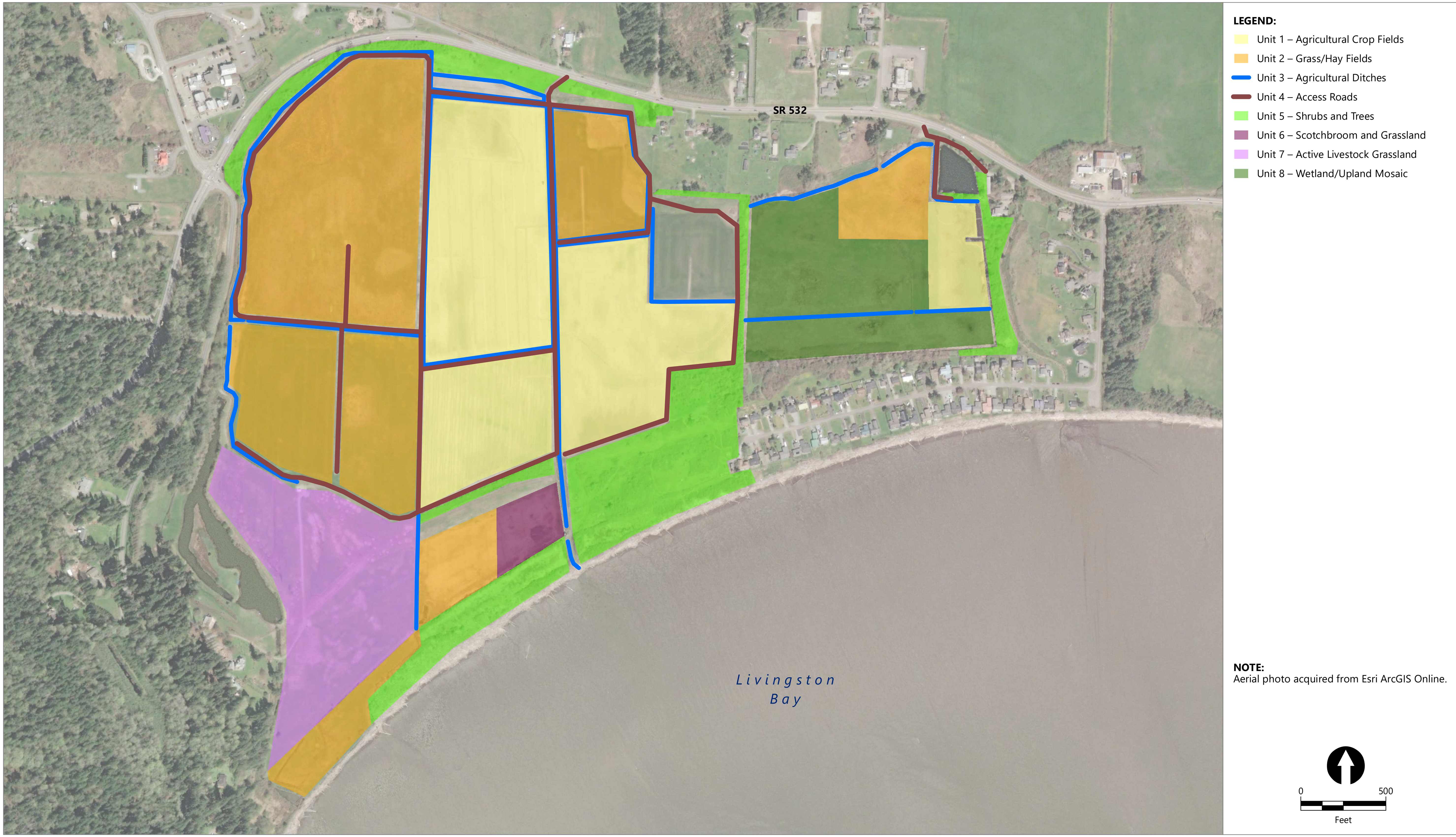
Figure 2
Parcel Map
Noxious Weed Survey
Livingston Bay Restoration Feasibility Study



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ANCHOR QEA

Figure 3
Observed Plant Communities
Noxious Weed Survey
Livingston Bay Restoration Feasibility Study

Appendix C
Water Surface Elevation Analysis

ESA

WATER SURFACE ELEVATION ANALYSIS

This technical memorandum summarizes findings from the hydrology monitoring completed by Environmental Science Associates (ESA) between July 2021 and June 2022 and presents a comparison with measurements made at the nearby National Oceanic and Atmospheric Administration (NOAA) tide gage stations at Seattle and Tulare Beach.

Water Level Data

NOAA's Seattle tide gage (Station [Sta.] 9447130), located in Elliott Bay, provides records of representative long-term tide levels for the project site. Other nearby measurements were made at Tulare Beach (NOAA, Sta. 9448043) from May to September 2013**. Figure 1** shows the locations of the NOAA Seattle and Tulare Beach stations relative to the project area.

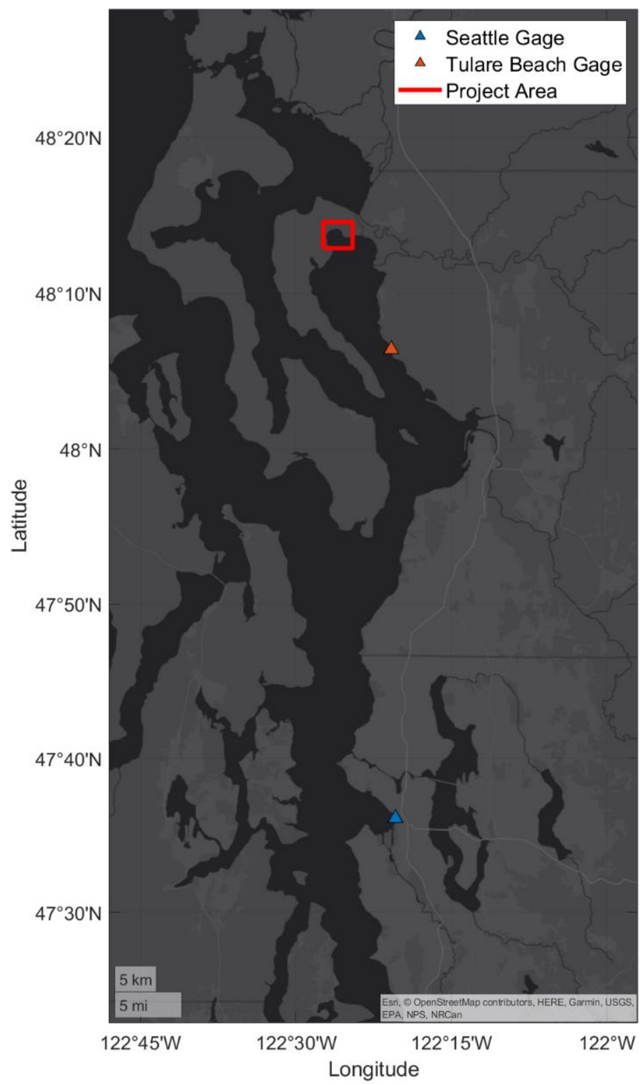

Figure 1 Project Location and National Oceanic and NOAA's Tide Gages

ESA deployed two water level gages (the Bay Gage and West Gage) and two sensors measuring conductivity, temperature, and depth (CTD'd) (the North Gage and Pumphouse Gage) on Livingston Bay near the project site and in the project site's channels. The West, North, and Pumphouse gages were located within the relic marsh channels, and the Bay Gage was located on Livingston Bay (**Figure 2**). These water level gages and CTD sensors took measurements from July 2021 to June 2022. The CTD sensors collected data at 15-minute intervals, the gages were surveyed with a Real-Time Kinematic Global Positioning System at the time of deployment, and water levels were corrected for local barometric pressure from a barometric logger.

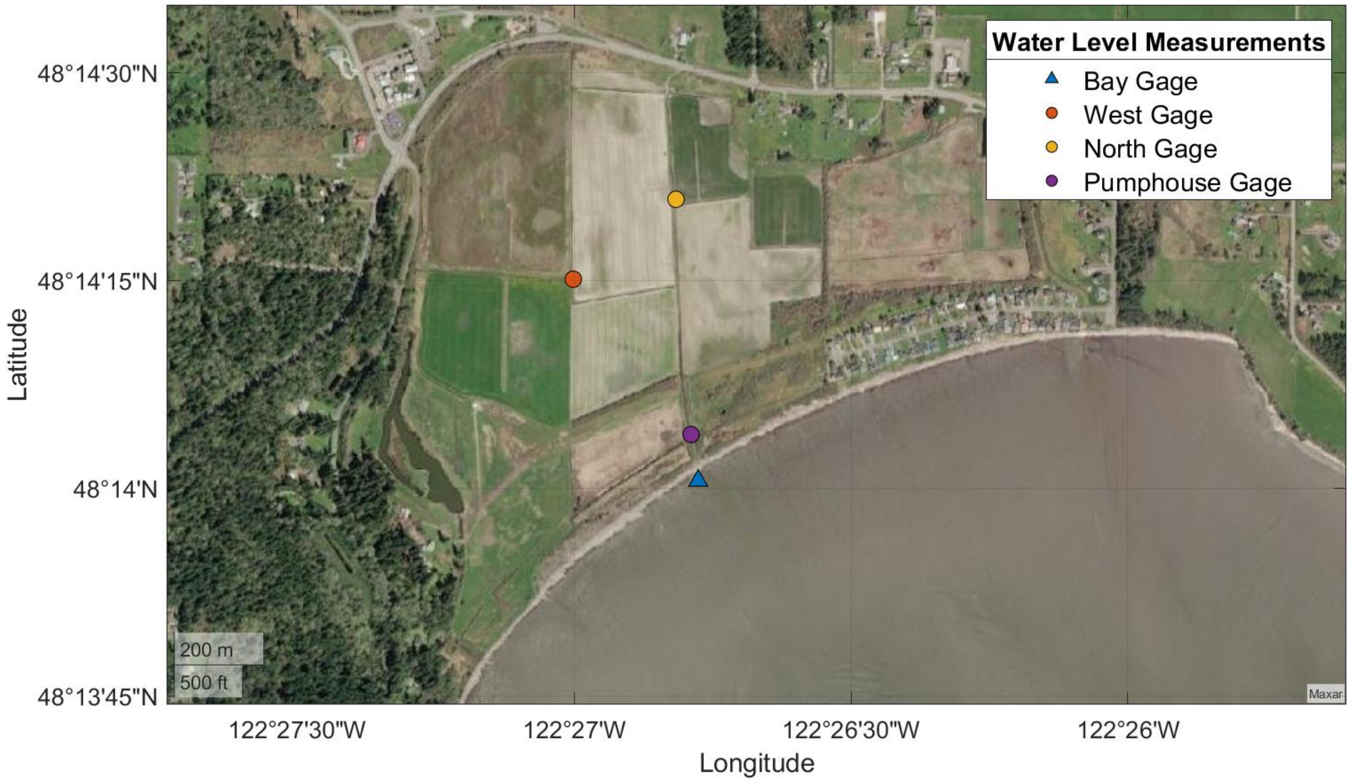

Figure 2 Locations of Water Level and Conductivity, Temperature, and Depth Measurements from ESA

Table 1 summarizes the available and collected water level data used in this study. **Figure 3** shows records of water level measurements obtained from July 2021 to June 2022 at the Bay water level gage and Seattle tide gage, along with tide predictions at the Tulare Beach tide gage station.

TABLE 1
AVAILABLE AND COLLECTED WATER LEVEL SURFACE DATA

ID	Source	Start Date	End Date
Seattle (Sta. 9447130)	NOAA	1/1/1899 00:00	7/31/2022 00:00
Tulare Beach (Sta. 9448043)	NOAA	5/23/2013 18:00	9/4/2013 18:00
Bay Gage	ESA	7/28/2021 19:00	6/29/2022 12:00
West Gage	ESA	7/28/2021 17:45	6/29/2022 10:30
North Gage	ESA	7/28/2021 17:00	6/29/2022 11:30
Pumphouse	ESA	7/28/2021 15:00	6/29/2022 12:00

NOTES: ESA = Environmental Science Associates; ID = identification; NOAA = National Oceanic and Atmospheric Administration; Sta. = Station
SOURCE: Data compiled by Environmental Science Associates in 2022

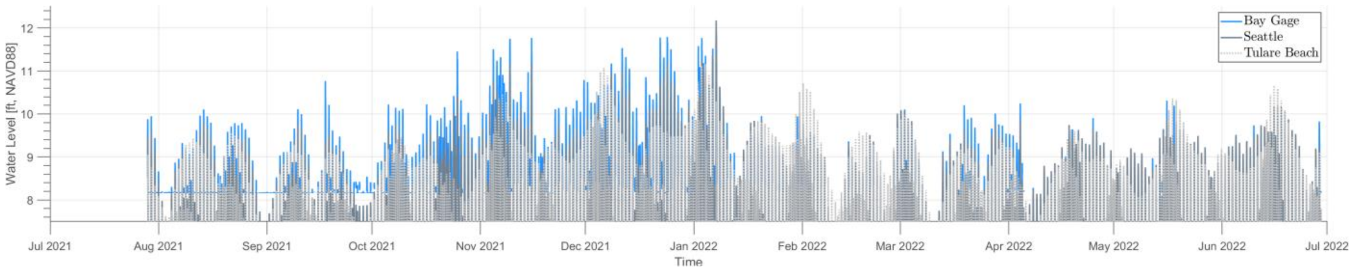

Figure 3 Water Level Measurements at the Bay Gage (ESA) and Seattle Gage (NOAA) and Water Level Predictions at Tulare Beach (NOAA)—July 28, 2021, to June 29, 2022

Measurements at the Bay Gage show higher water level elevations, ranging from 0.2 foot to 1.2 feet. **Figure 4** shows water level measurements at the Bay Gage compared with the Seattle station measurements and the predictions from Tulare Beach in October 2021.

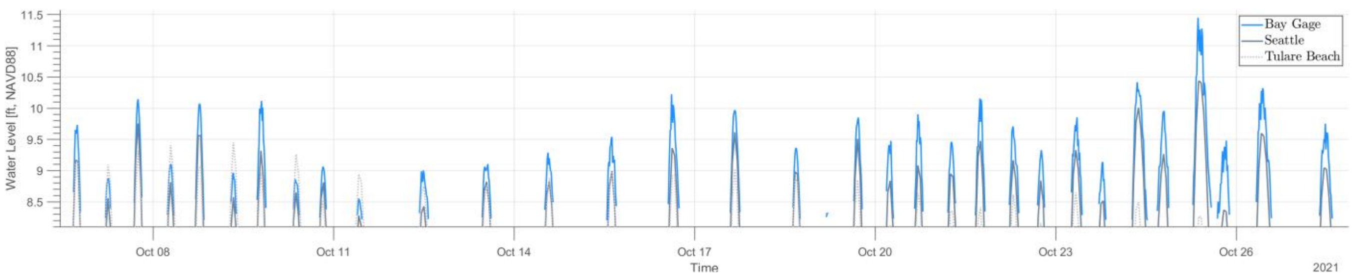

Figure 4 Water Level Measurements at the Bay Gage (ESA) and Seattle Gage (NOAA) and Water Level Predictions for Tulare Beach (NOAA)—October 7–27, 2021

Figure 5 shows conductivity, temperature, and water level measurements conducted at the project site from June 2021 to July 2022. During water surface elevations below 2 feet, the West Gage shows a difference in water elevation and often remains constant when compared with water elevations at the Pumphouse and North gages. Conductivity values at the Pumphouse and North gages show similar values when water levels are above 2 feet, and the tides influence the Pumphouse conductivity values. (Lower values are closer to freshwater and higher values represent brackish water.) In contrast, conductivity at the North Gage shows little variation.

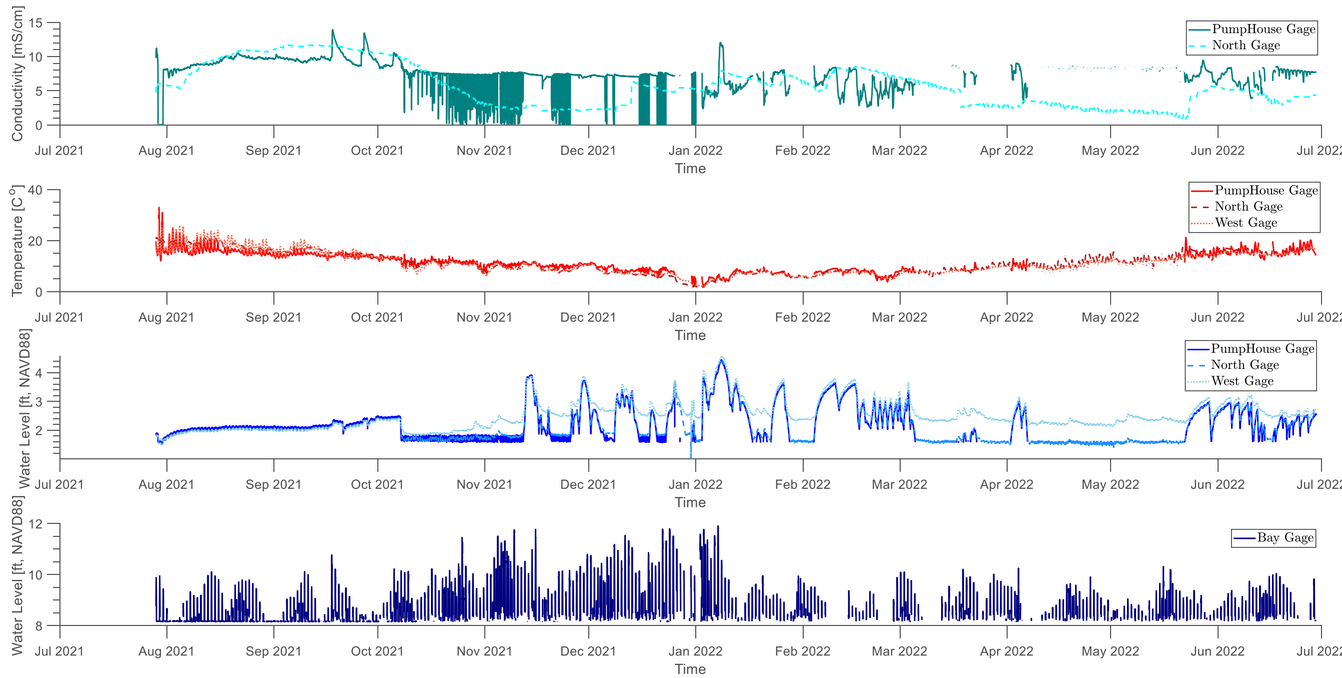

Figure 5 Conductivity, Temperature, and Water Level Measurements on the Project Area Channels at the West, North, and Pumphouse Gages and Water Level Measurements at the Bay Gage—June 28, 2021, to June 29, 2022

Tide Datums

Table 2 shows tidal datum relationships for the Seattle and Tulare Beach stations. The Seattle station's greater diurnal tide range (mean higher high water to mean lower low water) is 11.36 feet and 11.08 feet for the Tulare Beach station. Tulare Beach shows slightly higher values for most datum and up to +0.3 foot higher for mean lower low water (MLLW) and the expected highest astronomical tide (HAT).

TABLE 2
TIDAL DATUMS (EPOCH 1983–2001)

Tidal Datum	Abbrev.	Seattle Elevation, feet NAVD88	Tulare Beach Elevation, feet NAVD88
Highest Observed (1/27/1983)[1]	HOT	12.14 (4:36 a.m.)	–
Highest Astronomical Tide	HAT	10.92	11.22
Mean Higher High Water	MHHW	9.02	9.05
Mean High Water	MHW	8.15	8.20
Mean Tide Level	MTL	4.32	4.45
Mean Sea Level	MSL	4.3	4.43
Diurnal Tide Level	DTL	3.34	3.51
Mean Low Water	MLW	0.49	0.71
North American Vertical Datum	NAVD	0.00	0.00
Mean Lower Low Water	MLLW	-2.34	-2.03
Lowest Astronomical Tide (6/22/1986)	LAT	-6.64	-6.50
Lowest Observed (1/4/1916)[1]	LOT	-7.38 (0:00 a.m.)	–

NOTES: Abbrev. = abbreviation for tidal datum; NAVD88 = North American Vertical Datum of 1988
1 The highest and lowest observed tide data are based on the recorded six-minute measurements.
SOURCE: Data compiled by Environmental Science Associates in 2022 from NOAA.

Water Level Distribution

Table 3 shows the water level percentile from the NOAA Seattle tide gage and the ESA Bay Gage. The Bay Gage shows a difference of 0.35 to 0.4 foot for the percentiles of 2 to 0.1 percent (higher values); this difference becomes smaller for the 5th and 10th percentiles. **Figure 6** shows the still-water-level probability for the Bay Gage and the Seattle Gage for the top 20 percentile. Figure 6 shows the same results as Table 3, with a larger difference when compared with the Seattle station for the highest percentile above 5 percent.

TABLE 3
WATER LEVEL PERCENTILES

Percentile (%)	Seattle Gage (ft, NAVD88)	Bay Gage (ft, NAVD88)
0.1	11.15	11.5
1	10.05	10.45
2	9.65	10
5	9.2	9.35
10	8.65	8.75
25	7.3	–
50	5.3	
75	2	
90	-0.9	
99	-3.95	
99.9	-5.65	

NOTE: ft, NAVD88 = feet, North American Vertical Datum of 1988
SOURCE: Data compiled by Environmental Science Associates in 2022

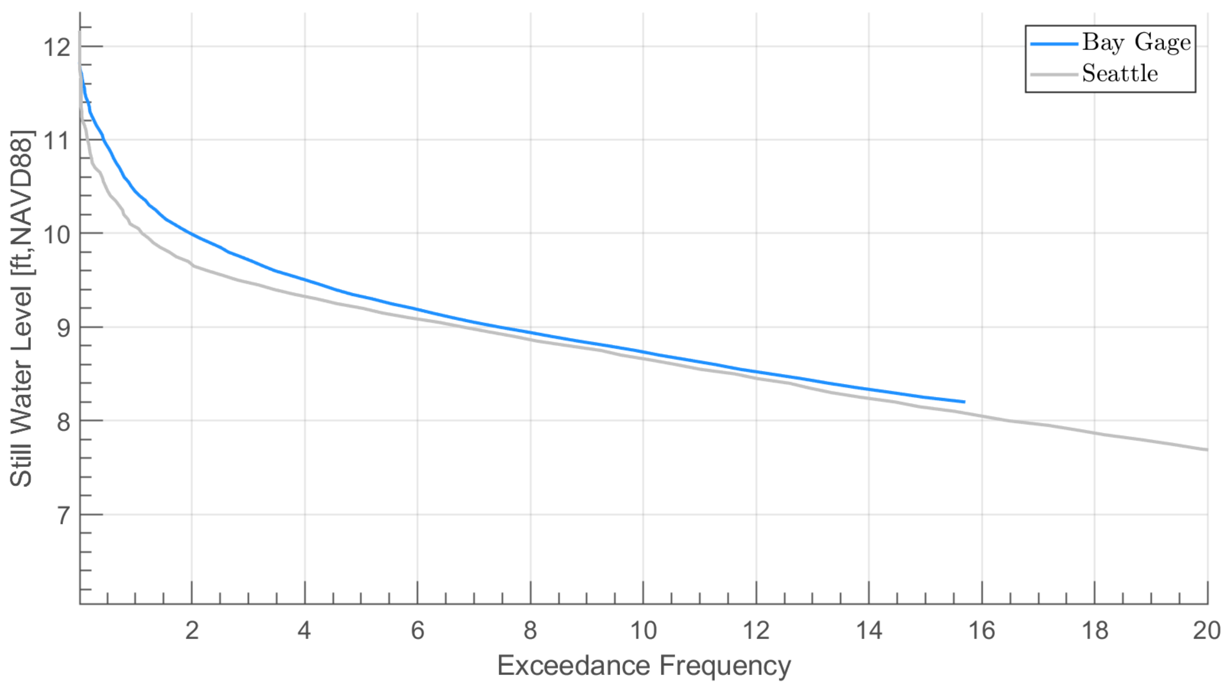

Figure 6 Still-Water-Level Probability for the Bay Gage and the Seattle Gage

Table 4 shows a selection of high still-water elevations observed at the NOAA Seattle Gage and the ESA Bay Gage between July 2021 and June 2022. As shown, in most cases the Bay Gage registered water elevations that ranged from 0.4 foot to 1.3 feet higher than those recorded in Seattle. Except for the January 7, 2022 event, the Seattle Gage recorded lower elevations than the Bay Gage. The recorded value during this event in Seattle was almost 2 feet higher than the predicted value. Several factors contributed to this event in Seatle been higher than normal. For example, before this high tide, nearly 4 inches of rain fell, and upland flooding was at its highest stage during that winter. Other factors included a low-pressure weather system and higher winds that generated waves and pushed water to the coast. During this event at the project site, water surface elevation was high enough to overtop the beach and inundate inland.

TABLE 4
SELECTION OF HIGH STILL-WATER ELEVATIONS OBSERVED AT THE NOAA SEATTLE GAGE AND THE ESA BAY GAGE

Event	Seattle Gage ft, NAVD88	Bay Gage ft, NAVD88
September 17, 2021	9.4	10.7
October 25, 2021	10.5	11.3
November 9, 2021	11.2	11.7
November 15, 2021	11.2	11.8
December 11, 2021	11.0	11.5
December 24, 2021	11.2	11.7
January 7, 2022[1]	12.2	11.9
April 4, 2022	9.9	10.3

NOTES: ESA = Environmental Science Associates; ft, NAVD88 = feet, North American Vertical Datum of 1988; NOAA = National Oceanic and Atmospheric Administration

[1] Overtopping event. Seattle water level higher than predicted.
SOURCE: Data compiled by Environmental Science Associates in 2022

Surface Water Levels and Tides

Figure 7 shows measurements at the relict tidal channels and Livingston Bay during water elevations at the channels below 2 feet. During this time, the Pumphouse Gage shows variations between fresh and brackish water; the variations are in sync with the tidal variations. The North Gage does not show variations due to the tides, but it moves from brackish water to freshwater when the water level remains below 2 feet. Water surface elevations at the Pumphouse and North gages show small variations in correlation with the tides while the water surface remains below 2 feet. The West Gage appears unchanged and does not correlate with the changes in the tides.

Once the surface water elevation goes above 2 feet, conductivity becomes stable (the water becomes more brackish), and the water surface elevation does not appear to show variability due to the tides. **Figure 8** shows the January 7, 2022 event when elevation of the water level resulted in the inundation of the site. The water became more brackish as water from Livingston Bay overflowed over the site. The North Gage shows a delay in this increase of salinity and remains constant after the event.

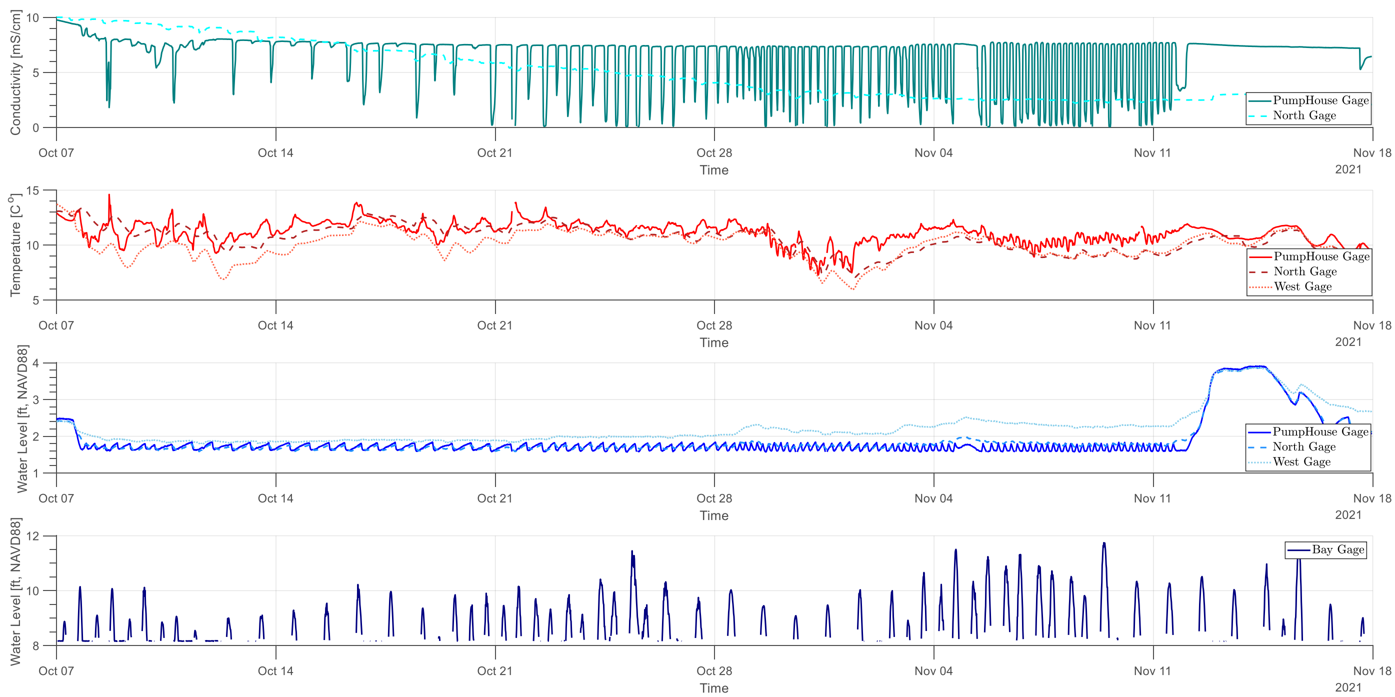

Figure 7 Conductivity, Temperature, and Water Level Measurements during Low Water Surface Elevations at the Relict Tidal Channels—October 7 to November 18, 2021.

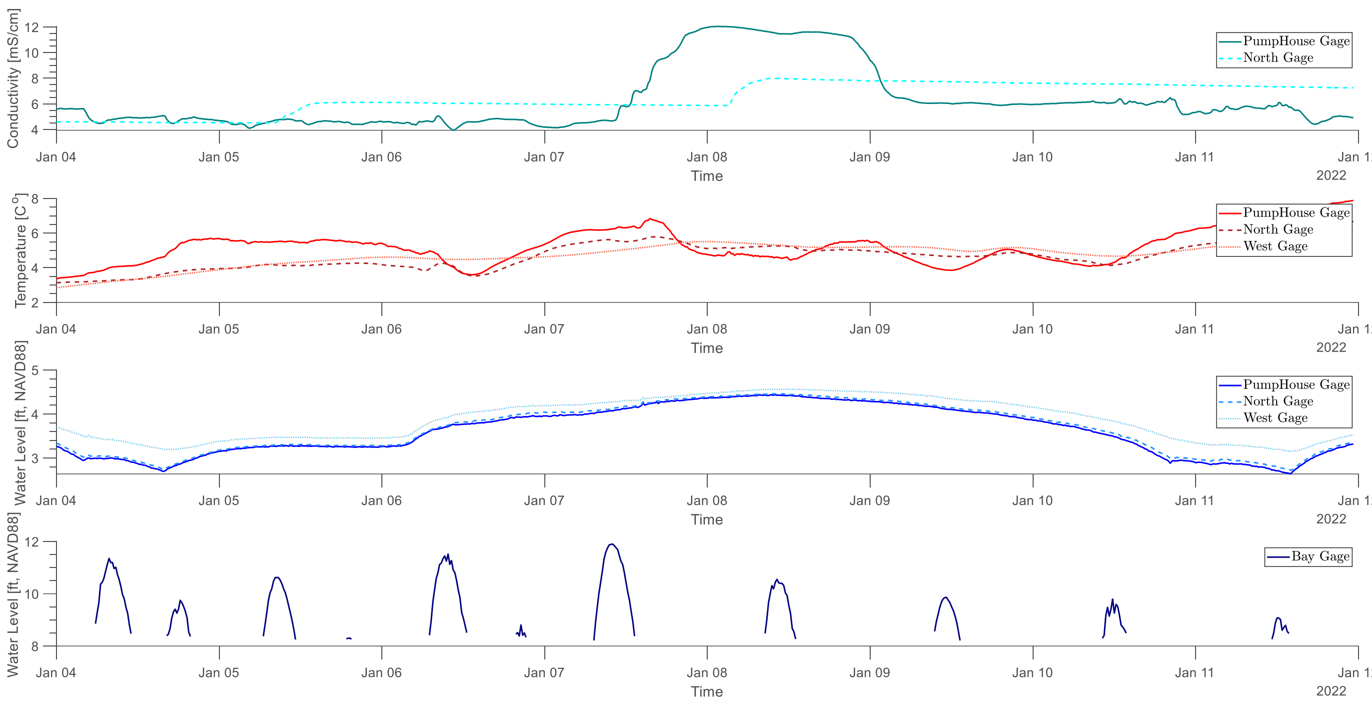

Figure 8 Conductivity, Temperature, and Water Level Measurements during an Overtopping Event—January 7, 2022

Projected Sea Level Rise

Table 5 summarizes the projected sea level rise at the site from the Washington Coastal Resilience Project and *Projected Sea Level Rise for Washington State—A 2018 Assessment* (Miller et al. 2019). The table lists the projections of sea level rise for 2030, 2050, and 2100. The projections show that there is a medium risk (greater than 10 percent) that there will be a 0.5-foot increase in sea level rise by 2030, and that the risk will become much higher (greater than 70 percent) by 2050. Sea level will likely increase by 1–2 feet by 2100, and there is a medium risk that sea level rise will reach 3 feet by 2100.

TABLE 5
LIKELIHOOD (IN PERCENTAGES) OF SEA LEVEL RISE FOR LIVINGSTON BAY

Year	Low Emissions (RCP 4.5), ft				High Emissions (RCP 8.5), ft			
	0.5	1.0	2.0	3.0	0.5	1.0	2.0	3.0
2030	16	–	–	–	15	–	–	–
2050	74	13	–	–	79	18	–	–
2100	96	84	34	6	99	94	58	16

NOTES: ft = feet; RCP = Representative Concentration Pathway, blue medium risk, yellow high risk
SOURCE: Miller et al. 2019

Based on these projections and the high still-water elevations shown in Table 4, overtopping events like the one recorded on January 7, 2022, will increase in frequency by 2030 and are likely to become common (occurring several times a year) by 2050.

Extreme Still-Water Level

Sea Level Trends

NOAA calculated linear mean sea-level trends at the Seattle tide gage between 1899 and 2021. The trend shows an increase in relative sea level of approximately 2.07 ± 0.14 millimeters per year, equivalent to a relative increase of 0.68 foot over 100 years. ESA utilized the available tidal data to develop a tide time series that was corrected (normalizing) for historic sea level rise. To normalize present-day flood risk, the trend in historical water level data was removed according to this rate of absolute sea level rise (**Figure 9**). In the past, water level increases were determined by multiplying the historical sea-level-rise rate by the number of years before the present. Raising the historic elevations and detrending the data removes the effects of lower historic sea levels and thus provides an unbiased way to compare the effects of individual extreme water-level events at present sea levels and into the future.

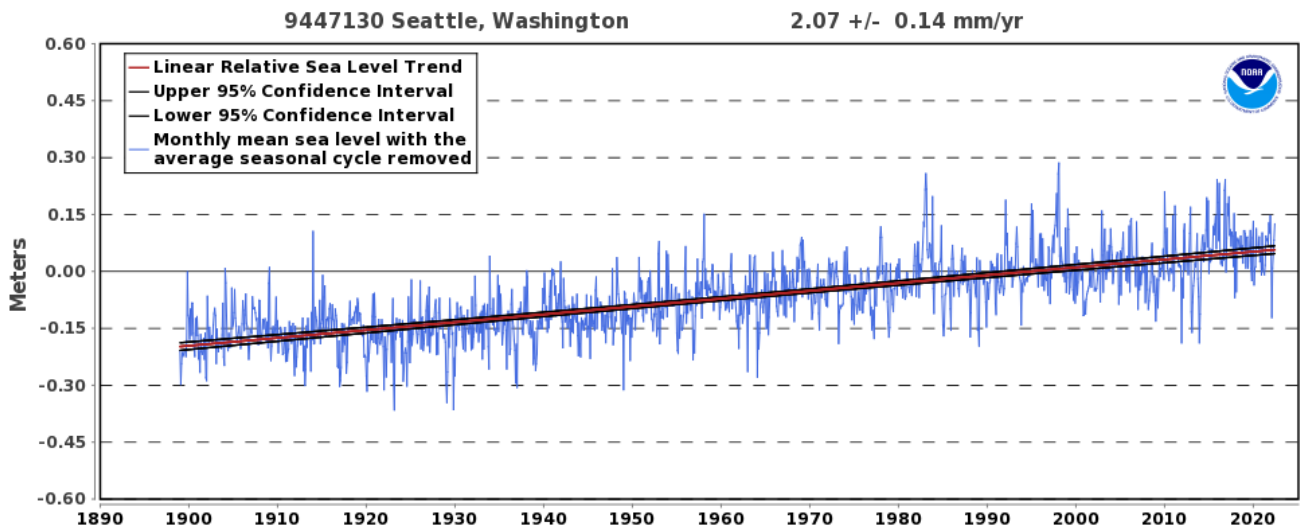

Figure 9 Monthly Mean Sea Level Trend from 1899 to 2021 at the Seattle Station

Extreme Analysis

An extreme value analysis of 62 years of the recorded water levels from 1961 to 2022 was conducted based on the detrended tide data at the Seattle tide station. The maximum still-water level elevation from each year was obtained from the detrended time series and fit to a Gumbel distribution, a Weibull distribution, and the Generalized Extreme Value Distribution (GEV) as shown graphically in (**Figure 10**). Several distributions were examined to find the best distribution for the data set. The GEV distribution provides the best fit for the majority of extreme events. **Table 6** summarizes the extreme still-water levels obtained from the GEV distribution based on the detrended tide data.

TABLE 6
EXTREME STILL-WATER LEVEL VALUES FOR PRESENT-DAY SEA LEVELS

Return Period (years)	Elevation (feet GEV, NAVD88)
1	10.3
2	11.5
5	11.9
10	12.1
20	12.3
50	12.5
100	12.6

NOTES: GEV = Generalized Extreme Value Distribution; NAVD88 = North American Vertical Datum of 1988
SOURCE: Data compiled by Environmental Science Associates in 2022

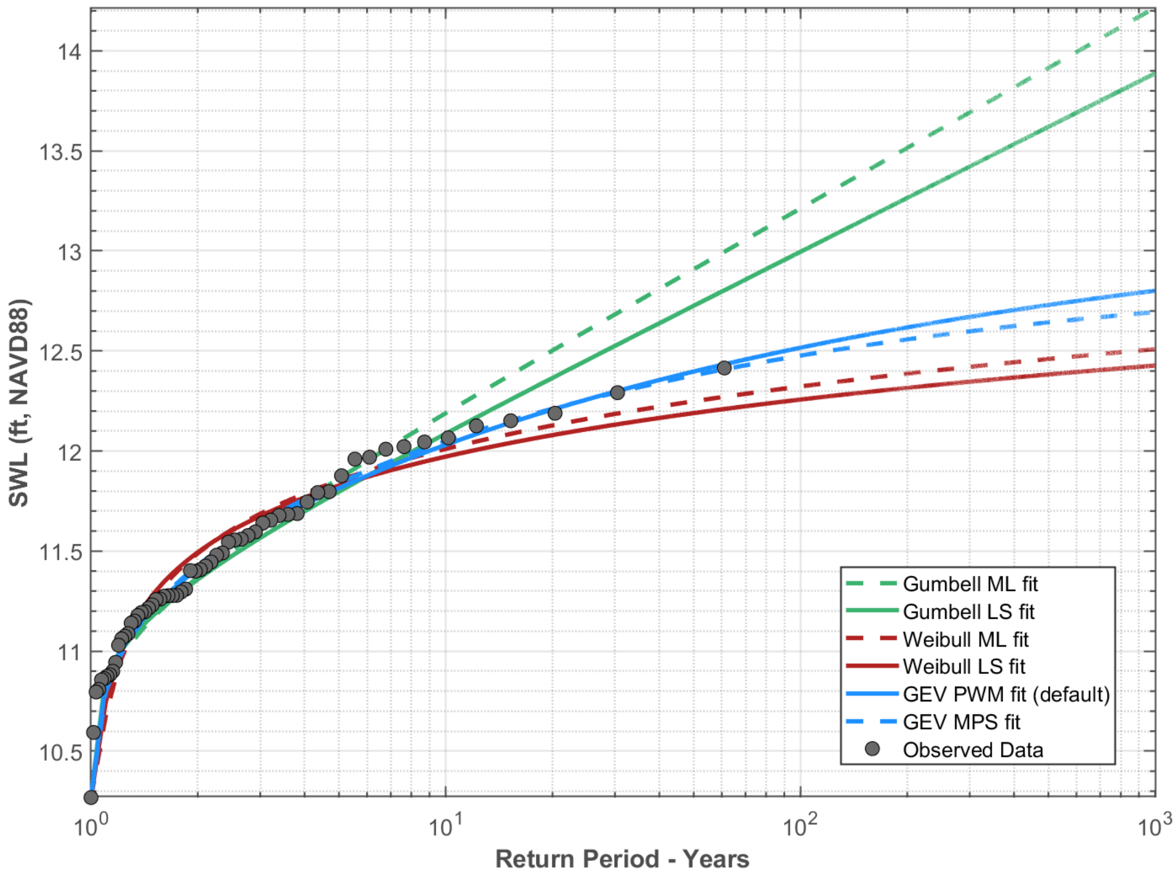

Figure 10 Detrended Still-Water Level Extreme Value Analysis for Seattle Station

Reference

Miller, I. M., H. Morgan, G. Mauger, T. Newton, R. Weldon, D. Schmidt, M. Welch, and E. Grossman. 2018. *Projected Sea Level Rise for Washington State—A 2018 Assessment*. A collaboration of Washington Sea Grant, University of Washington Climate Impacts Group, University of Oregon, University of Washington, and U.S. Geological Survey. Prepared for the Washington Coastal Resilience Project. Updated July 2019.

Appendix D
Hydrogeologic Evaluation

ESA

APPENDIX XX
HYDROGEOLOGIC EVALUATION OF PROPOSED LIVINGSTON BAY RESTORATION SITE

September 2022

APPENDIX XX
HYDROGEOLOGIC EVALUATION OF PROPOSED LIVINGSTON BAY RESTORATION SITE

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September 1, 2022
Project 518300090

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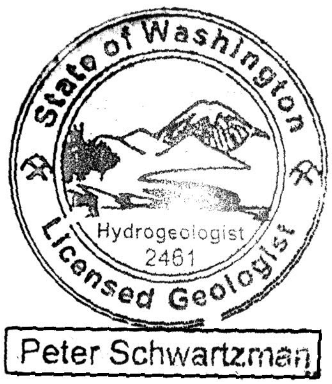
APPENDICES

Appendix PGG-A: Well Logs

SIGNATURE

This report, and Pacific Groundwater Group's work contributing to this report, were reviewed by the undersigned and approved for release



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1.0 INTRODUCTION

Pacific Groundwater Group (PGG), a subsidiary of Mott MacDonald, was retained as a subcontractor by Environmental Science Associates (ESA) to provide the Whidbey Camano Land Trust (WCLT) with an evaluation of hydrogeologic conditions in the Livingston Bay vicinity. Portions of this lowland area are under consideration for possible dike removal and habitat restoration. Project details and an overall site description are provided in the attached main report.

PGG's scope of work included: compilation/review of existing hydrogeologic data; drilling and installation of onsite monitoring wells and shallow piezometers, preparation of hydrogeologic cross sections across the study area; identification of local private wells for potential monitoring; monitoring of groundwater levels and salinity in select monitoring and private wells; collection and review of surface-water level and salinity data from ditch locations selected by ESA; and interpretation of the collected data. PGG's interpretation provides a preliminary assessment of how diurnal tidal inundation associated with site restoration might affect groundwater conditions beneath adjacent lowland and upland properties. Of particular interest is whether the proposed restoration could cause groundwater salinization beneath adjacent areas of lowland agricultural land use or in water-supply wells located on the upland.

This appendix summarizes the field investigation performed by PGG and presents the results of PGG's data interpretation. The project study area is shown on **Figure 1-1**. A summary of key findings and recommendations is presented in the executive summary (Section 2). Well drilling and monitoring procedures are described in Section 3 and detailed description of local hydrogeologic conditions is presented in Section 4. Section 5 presents preliminary analysis of how the proposed restoration is likely to change hydrogeologic conditions beneath the site and surrounding areas, and Section 6 provides recommendations for more detailed studies to answer remaining questions.

PGG's work was performed, and this report prepared using generally accepted hydrogeologic practices used at this time and in this vicinity for exclusive application to the study area and for the exclusive use of ESA and WCLT. This is in lieu of other warranties, express or implied.

2.0 KEY FINDINGS

A. The proposed restoration site occupies the lowlands adjacent to Livingston Bay surrounded by upland areas to the west, north and east. Regional hydrogeologic characterization shows a subsurface stratified sequence of glacial and interglacial aquifers and aquitards. Shallow sediments noted below the lowlands include beach, marsh and glaciomarine deposits.

B. Groundwater beneath the lowlands is derived by discharge from aquifers that underly the uplands. PGG installed two "nests" of shallow and deep monitoring wells and four shallow piezometers in the study area. Lowland groundwater levels are depressed (in some cases below sea level) due to hydraulic connection to drainage ditches with low water levels (controlled by a tide gate).

C. Specific conductance (SC), a measure of salinity, is low in the lowland monitoring wells, reflecting fresh groundwater discharge from the uplands. In contrast, water in ditches showed elevated SC values (typical of brackish water), as did groundwater in several shallow piezometers installed onsite. The reason for elevated salinity in the piezometers is unknown, but may reflect the effects of sea spray, salt concentration in the root zone and/or historic episodes of site flooding.

D. Restoration would result in increased groundwater levels on the restored site and higher salinities in shallow soils due to periodic inundation. This condition is not expected to cause saline intrusion of the upland aquifers because water levels in these aquifers will remain higher than in the lowland. However, within the lowland, engineering solutions may be required to prevent migration of saline water to immediately adjacent agricultural properties. For example, dikes separating restored properties from agricultural properties may benefit from a parallel ditch and tide gate to control the lateral migration of shallow saline groundwater.

E. If WCLT decides to proceed with a restoration alternative, recommendations for additional investigation include:

- Measuring SC, chloride and surveyed groundwater elevations in additional upland wells to confirm groundwater discharge to the lowlands from multiple directions.
- Apply hydrogeologic guidance to consider additional monitoring points that support further understanding in related key locations. If restoration not to be pursued, decommission the project wells and piezometers using appropriate methods.
- Consider employing groundwater modeling (e.g. 2D "slice models") to assess the potential for net salinity migration across newly constructed dikes to adjacent agricultural properties.

3.0 WELL DRILLING & MONITORING PROCEDURES

The area proposed for restoration encompasses portions of the lowland immediately north of Livingston Bay on the northeastern "lobe" of Camano Island. PGG oversaw installation of two monitoring well clusters, each comprised of one shallow and one deep well upon lowland parcels where access was available. PGG intended to install up to eight shallow piezometers across the lowland; however, site access (agricultural activity and dense vegetation) limited installation to four locations. Datalogging transducers, capable of measuring water level, temperature and (in some cases) specific conductance (SC) were installed in the monitoring wells, at three gage locations in onsite drainage ditches, and immediately offshore for measuring Livingston Bay tides. Data were collected for 11 months. Water level and SC (an indicator of salinity) were measured in the shallow piezometers during all site visits, and water level was measured in a single domestic well with available access on the upland. All monitoring points were surveyed to relate water-level elevation (WLE) to sea level.

3.1 INSTALLATION OF WELLS AND PIEZOMETERS

PGG oversaw the installation of the two monitoring well clusters, each comprised of one shallow and one deep well, on July 20 and 21, 2021. Well cluster N1 was installed on the Leque property and well cluster N2 was installed on the Nelson property (**Figure 1-1**). The monitoring wells (N1S, N1D, N2S and N2D) were installed in accordance with WAC 173-160 by Holocene Drilling Inc. using the hollow stem auger drilling method and a SPT hammer/split-spoon sampling method. Shallow borings were advanced to depths between 10 and 16.5 feet below ground surface (bgs) and deep boring were advanced to depths of 51.5 feet bgs (N1D) and 50 feet bgs (N2D).

All monitoring wells were constructed using 1.5-inch schedule-40 PVC riser pipe and 1.5-inch 20-slot PVC screens (five-foot long). All the monitoring well screens were set at the bottom of the borings. A sand pack (10-20 silica sand pack) was installed adjacent to the screen and a hydrated bentonite seal was installed up to ground surface. Monitoring well completions are summarized on **Table 3-1** and associated geologic logs and as-built diagrams are presented in **Appendix A**.

PGG first observed the drilling of Well N2D (deep). Based on observed subsurface conditions, PGG selected a completion zone for Well N2S (shallow), which was installed by the driller (without PGG oversight) approximately 5 feet to the north. During the drilling of well N1D, silty and cobbly shallow sandy sediments were sufficiently dense to appear "till-like" and were interpreted as unsuitable for installation of an immediately adjacent shallow monitoring well. The property owner gave PGG permission to install the shallow well (N1S) approximately 55 feet to the west of N1D. Thus, in contrast to the N2 cluster, PGG observed drilling of both shallow and deep N1 monitoring wells, and subsurface conditions varied between the two borings. **Appendix A** does not include a geologic log for Well N2S because it is assumed to have the same geology as N2D.

In boring N2D, the top four feet were variably comprised of unsaturated silt and sand with localized occurrences of organics and oxidation. These vadose zone soils are likely associated with marsh deposits and the Puget Silty Clay Loam soil described in Section 4.1. Underlying saturated slightly silty sands extended from 4 to 16 feet bgs, where a silt and clay aquitard was observed from approximately 16 to 36 feet bgs. This aquitard was underlain by interbedded water bearing sands and silts which produced flowing artesian conditions. Monitoring well N2D was completed between 45 and 50 feet bgs in the water-bearing silts and sands, which was not fully penetrated at the total borehole depth of 51.5 feet bgs. The water level in the completed well was not measured at time of drilling due to flowing artesian conditions.

PGG did not observe the drilling of N2S. The well was designed from logged subsurface conditions in adjacent well N2D and was screened in the slightly silty sands between depths of 5 to 10 feet bgs. Depth to water in the completed well at time of drilling was 2.65 feet bgs, but may not represent a stabilized static water level.

In the deep boring N1D, dense, silty to very silty fine sands (with occasional cobbles and gravels) were encountered from approximately 2 to 35 feet bgs. Based on observed silt contents and the fact that they served to confine underlying artesian conditions, these sediments exhibited relatively low permeability. The silty sands were underlain by water bearing fine to medium sands that extended through (and possibly beyond) the total boring depth of 51.5 feet bgs. Well N1D was completed in the water bearing sands between depths of 45 to 50 feet bgs. Water level in the completed well was not measured at time of drilling due to flowing artesian conditions.

In the shallow boring N1S (located 55 feet west of N1D), silty gravel was observed in the upper two feet and was underlain by sandy silt to a depth of 13.5 feet. None of these sediments were saturated; however, saturated sand was encountered between 13.5 and 15.5 feet bgs which produced an artesian (non-flowing) water level of about 1.1 feet bgs. This water-bearing sand was underlain by a lower-permeability unit consisting of fine to medium sandy silt to the total boring depth of 16.5 feet. Well N1S was completed across the water bearing sand and overlying sandy silt between depths of 10 to 15 feet bgs.

In addition to the four monitoring wells, PGG installed four shallow piezometers on July 20, 2021 using a 3-inch hand auger (locations shown on **Figure 1-1**). All hand augured piezometer installations were constructed using 1.5-inch schedule 40 PVC riser pipe with hand cut slots occurring within the bottom foot of the riser pipe and terminated with a slip cap PVC tail pipe. Whereas P4, P5 and P7 were completed to depths of 5 feet, P6 was completed to 7 feet depth. Excavated soils were used to backfill any annular space between the piezometer and the excavated boring. Encountered shallow subsurface conditions appeared consistent with marsh sediments (described in Section 4.1) and consisted of:

- P4 – Dry, light brown, silty, sand underlain by wet, grey silt with observed wood debris.
- P5 – Dry, light brown, clayey, silt underlain by wet, gray blue silt.

- P6 – Dry, light brown, silty, sand underlain by moist, clayey, silt with observed mottling.
- P7 – Dry, light brown, sand and silt, underlain by wet gray, sandy, silt with observed wood debris.

At the time of installation, water levels in the piezometers ranged from 3.3 to 6.3 feet bgs (to "dry" in P7), Given the expected low permeability of encountered shallow soils, these water levels likely had not yet fully stabilized. Nevertheless, unsaturated conditions clearly occurred between the land surface and the wet soils observed during auguring.

3.2 WATER-LEVEL AND SALINITY MONITORING

Water-level elevations (WLE's) were monitored in the four monitoring wells, the four shallow piezometers, the three ditch gages and the tidal monitoring gage (**Figure 1-1**). All but the shallow piezometers were equipped with datalogging transducers that provided high-frequency time-series data. Data were downloaded from the transducers and manually measured at all monitoring points on site visits performed on November 17/18, 2021; March 17/18, 2022 and June 29, 2022. Although PGG attempted to access four private wells on the uplands surrounding the site; only one could be accessed due to well construction and project budget limitations. Salinity (as expressed by SC) was monitored at all locations except one of the three ditch sites, the tidal station (where salinity will be equivalent to Livingston Bay), and the private well (which was not equipped with a pump).

3.2.1 Groundwater Monitoring

Datalogging probes were installed in the four monitoring wells on November 21, 2021. Probes purchased for the monitoring wells included two Van Essen CTD-Divers (capable of measuring conductivity, temperature and water depth) and two TD-Divers (capable of measuring temperature and water depth. The CTD-Divers were installed in wells N1D and N1S and the TD Divers were installed in wells N2D and N2S on the November visit. The two Diver pairs were swapped between the two well clusters in the March visit and were not moved for the remainder of the project. Because the Diver probes are unvented, a Van Essen Baro-Diver was installed onsite to collect barometric data needed for barometric compensation of the CTD- and TD-Diver data. The probes were installed close to the well screens so that measurements of SC and T would be representative of aquifer conditions. Measurements were set for 15-minute intervals.

PGG visited the site for the first data download in March 2022. At that time, PGG confirmed the calibration of the CTD Divers to SC standard solutions and employed a calibrated YSI EcoSense EC300A Conductivity Meter to profile SC in the four monitoring wells. The profiling showed insignificant variation of SC with depth and confirmed the SC values measured by the CTD Divers. Water levels in the monitoring wells were measured manually using an electronic water-level measuring tape. These manual measurements were accurate to within several hundredths of a foot and were used to translate datalogger pressure readings (water-level above probe) to water-level elevations based on surveyed wellhead elevations. For the flowing artesian monitoring wells, PGG installed above-ground casing extenders constructed with clear tubing and measured water-level height above the measuring point with a tape measure. For all monitoring wells and piezometers, the measuring point was the top of the 2-inch PVC casing, which was surveyed by ESA to the NAVD88 elevation datum within an accuracy of +/- 0.1 feet.

Depth to water and SC in the four shallow piezometers was measured during all site visits and was measured once in the off-site private well[1]. Due to staffing issues, all manual measurements were lost from the third site visit; however, the digital data downloads were retained.

3.2.2 Surface-Water Monitoring

ESA installed CTD-Divers at the "Pumphouse" and "North" ditch gages and installed TD-Divers at the "West" ditch gage and the "Bay" tidal monitoring gage on July 28, 2021. Monitoring point locations are shown on **Figure 1-1** and the design of ditch monitoring installations is described in the main report. Each ditch site includes a stage gage for visually observing water level. On each of PGG's three data collection site visits, we downloaded the Divers and recorded water-level stage from the stage gages[2]. As noted above, data from the (unvented) Divers were compensated with data from the Baro-Diver, and ESA surveyed the stage gages to the NAVD88 elevation datum within an accuracy of +/- 0.1 feet. The Diver's were programmed to take measurements every 15 minutes.

It should be noted that the tidal monitoring point was positioned relatively high on the beach to provide access for downloading, such that it typically only recorded the timing of the daily high-high tide. As described in the main report, ESA found that high-high tide at Livingston Bay typically lags behind Seattle tides by around 20 to 30 minutes. Based on NOAA's tidal benchmark at Tulare Beach (9448043), mean sea level (MSL) occurs at 4.4 feet NAVD88, mean low low water (MLLW) is about -1.6 feet NAVD88, and high tides are known to exceed 10 feet NAVD88. Tides are highest during winter months, as is the likelihood of storm surges.

3.2.3 Data Management

PGG managed the groundwater data and ESA managed the surface-water and tidal data. All digital WLE and SC groundwater data downloaded from the probes were stored in a Microsoft Excel database. Data files from the non-vented Diver probes were compensated for barometric pressure variations prior to importing into the database. Surveyed wellhead elevations and manual groundwater level measurements were also imported into the database. The database translated time-series pressure data from the probes (i.e. water level above probe) to time-series water-level *elevations* by first calculating the elevations of the manual measurement (i.e. measuring point elevation minus depth to water) and then correlating one of the manual measurements to the nearest (in time) probe measurement. PGG compared the probe-derived WLE's and manual WLE's to identify drift in the digital data – which turned out to be relatively insignificant. Where drift occurred, PGG made corrections by applying a "correction factor" to the digital data interpolated between the two manual water-level measurements. All data were maintained in the NAVD88 vertical datum.

4.0 HYDROGEOLOGIC CONDITIONS

PGG evaluated the hydrogeologic framework of the study area based on maps of surficial geology and soils and interpretation of geologic logs from wells and borings. As described in Section 3.1, PGG logged and oversaw installation of two monitoring well clusters (shallow/deep) and four shallow piezometers on the project site. In addition to referencing an existing regional hydrogeologic cross section, geologic logs from neighboring wells were compiled and used to construct two local hydrogeologic cross sections through the site. Water-level monitoring (described above) was used to develop groundwater lev-

[1] Additional depth to water data for this well were on record with Island County and were very close to the PGG measurement taken in March 2022.

[2] Downloads at the tidal station were performed at low tide when the station was dry in order to facilitate access.

el hydrographs and synoptic (i.e. "snapshot") groundwater elevation maps. These water-level data were used to evaluate groundwater flow directions and groundwater-level responses to tidal variations and precipitation. PGG also obtained time-series measurements of SC to evaluate temporal and spatial variations in salinity.

4.1 HYDROGEOLOGIC FRAMEWORK

Hydrogeologic conditions differ significantly between upland and lowland areas. Upland areas are underlain by stratified sequences of glacial and interglacial sedimentary deposits, whereas lowland areas are underlain by beach and marsh deposits which are expected to overly the stratified glacial and interglacial sediments. The upland areas cover most of Camano Island whereas lowland areas include the coastal margins of Camano Island such as Livingston Bay.

Figure 4-1 shows surficial geology mapped across the study area, with detailed descriptions of units provided on **Table 4-1**. The lowland area is mapped as primarily containing Holocene (recent) deposits, including: beach deposits (Qb), marsh deposits (Qm) and artificial fill (af) used to construct dikes:

- Qb: Beach deposits are comprised of loose, moderately to well-sorted and well-rounded sand and gravel along modern shorelines, and may include boulders, silt, pebbles, clay, and wave-worn shell fragments. Locally deposits are derived from shore bluffs and underlying units and/or are carried in by longshore drift.

- Qm: Marsh deposits generally comprise 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. Originally deposited in a saltwater or brackish estuarine or lagoonal (marsh) environment these deposits occur near highest tide levels and are covered with salt-tolerant vegetation.

- af: Artificial fill includes engineered and nonengineered fills consisting of clay, silt, sand, gravel, organic matter, rip-rap, and/or debris placed to elevate and reshape the land. Mapped areas are shown where fill is readily verifiable, relatively extensive, and appears sufficiently thick to be geotechnically significant.

The project site is largely covered with Qm, marsh deposits that are generally fine-grained silt and clay with some organic material. Mapped Qm correlates to mapped Puget silty clay loam soil. This soil is described as 85 to 95 percent silt- and clay-sized particles (USDA 2008).

Within the study area, the Camano Island upland is predominantly covered with Everson glaciomarine drift ($Qgdm_e$) and glaciomarine deltaic outwash deposits ($Qgom_e$) with exposed windows of underling Vashon till (Qgt[3]). Geologic mapping in adjacent areas and hydrogeologic interpretation shows that the Qgt is often underlain by Vashon advance outwash (Qga).

- $Qgdm_e$: The glaciomarine drift is a clayey to silty diamicton (poorly sorted mixture) with variable content of gravel clasts that also includes silt, clay, and sand. The drift was deposited in marine water during a period of time (the Everson Interstade) when sea level was higher rel-

[3] Nomenclature for the geologic units have been simplified for this report based on descriptions provided in Dragovish et al (2002) and Schasse et al (2009). Geologic units $Qgdm_e$ and $Qgom_e$ have been combined and are designated as $Qgxm_e$ in this report and associated maps and cross-sections.

ative to land than at present and icebergs and shelf ice contributed debris released by melting of the ice. Shells of marine organisms living on the sea floor were occasionally buried in the sediments (Easterbrook and Anderson 1968).

- $Qgom_e$: The glaciomarine outwash is generally a loose sand, and sand-gravel mixtures with minor interlayered silt and silty sand interlayered with the glaciomarine drift. The outwash was deposited when seawater incursion raised base level in the area to the glaciomarine limit (maximum relative seawater elevation), which caused strandlines (i.e., former shorelines), delta fans, and shore terraces to form at that elevation. Discontinuous strandlines are mapped on **Figure 4-1**.

- Qgt: The till is also a diamicton, but is generally more compact, less stratified, and less likely to contain fossils. Basal till is typically deposited between glacial ice and the land surface under the massive pressure of overlying ice. In addition to till exposures on the upland, windows of till are also exposed on the lowland surrounding the project site and may be either remnant (i.e., adjacent areas have been eroded away) or may reflect the undulating nature of till deposition (i.e., adjacent areas may have till at depth).

- Qga: The advance outwash is a stratified, moderately to well-sorted, moderately to very dense, medium to coarse sand, pebbly sand, and sandy gravel, with minor amounts of fine silty sand or sandy silt, and clay interbeds with scattered lenses and layers of pebble-cobble gravel. The advance outwash was deposited by outwash channels at the terminus of the glacier as it advanced southward during the Vashon glaciation. These proglacial deposits were overridden and compacted by the advancing ice.

Cross-section A-A' (**Figure 4-2**) was prepared by the USGS (Jones et al, 1985) and provides a regional interpretation of Camano Island glacial/interglacial stratigraphy interpreted by Jones et al (1985). This regional interpretation shows a series of aquifers and aquitards that are mapped across Camano and Whidbey Islands. The regional aquifers are lettered from A to E; A is the deepest and oldest aquifer (absent in the project area) and E is the shallowest and youngest. The cross-section illustrates the occurrence of two major aquifers ("Aquifer D" and "Aquifer C"), both of which are characterized in the report as regionally extensive. Aquifer D is shown as occurring near or slightly above msl and Aquifer C near or below msl. A third, higher-elevation aquifer ("Aquifer E") is mapped as thin (<30 feet thick) west of the project site and absent on the east. The hydrogeologic units defined by Jones et al can be missing in places, and their presence beneath the northeast lobe of Camano Island or the immediately adjacent lowland has not been confirmed by local hydrogeologic characterization.

Cross-sections B-B' and C-C' were prepared by PGG by assessing private well logs available from Island County and the Department of Ecology. Cross-section B-B' (**Figure 4-3**) extends southwest to northeast and cross-section C-C' (**Figure 4-4**) extends from west to east. Both cross-sections traverse across both the uplands and the lowlands in the project area.

In preparing these sections, PGG differentiated between:

- Relatively permeable medium- to coarse-grained sediments (e.g. sand and sand/gravel),
- Mixtures of medium to coarse grained sediments and fine-grained sediments that arelikely to reduce permeability (e.g. silty sand),
- Predominantly fine-grained low-permeability sediments dominated by silt and clay that are expected to function as an aquitard, and
- Glacial till (also expected to function as an aquitard), a dense diamicton sometimes designated as 'hardpan' on driller's logs.

Locally, cross-sections B-B' and C-C' show that in the lowland areas, marsh deposits (Qm) appear to overlie Everson glaciomarine drift and outwash (jointly designated as Qgxm($_e$) on the cross-sections due to interpreted interlayering of sedimentary facies). In the highland areas, Qgxm($_e$) sediments appear show considerable textural variability ranging from sand/gravel/silt to silt/clay deposits which is an indication of their variable environment of deposition (ranging from submarine to coastal), as also evidenced by numerous strandlines on the surficial geology map (**Figure 4-1**). The Vashon Till (Qgt) and Everson glaciomarine sediments (where the till is absent) unconformably overlie the Vashon advance outwash (Qga), the primary sand and gravel aquifer within the project area.

It should be noted that the private wells located on Camano Island were logged by drillers and associated geologic descriptions may not be as accurate as those generated by geologists. Both cross sections show a thick deposit of till-like sediments east and west of the project site (most often represented as till or hard-pan on the driller's logs but sometimes represented as silt/gravel or sand/silt) immediately below the Camano Island upland. This is inferred to be Qgt$_v$ and as noted above, it is generally underlain by gravelly deposits of the Qgas, which contains the sea-level aquifer. However, because both Qgt and Qgdm$_e$ are both diamictons (differentiated by density and potential presence of shells), it is possible that driller's interpretation of till may in fact be Qgdm$_e$.

It should also be noted that all but one of the upland wells used to construct local hydrogeologic cross sections appear to be completed in the sea level aquifer ("Aquifer D"). PGG's deeper monitoring sells (N1D and N2D) are also interpreted completed in Aquifer D. Apparently, yields from Aquifer D wells have been sufficient to meet the needs of most local residences and small water systems.

4.2 RECHARGE AND DISCHARGE

Groundwater on Camano Island is predominantly recharged from precipitation. A small portion of recharge is also supplied by septic systems and agricultural irrigation; however, these recharge mechanisms are sourced by wells and therefore do not provide "new" water to the groundwater flow system. The USGS (Sumioka & Bauer, 2004) characterized climate in Island County, which includes the Livingston Bay study area:

> Island County has a temperate, marine climate with dry summers and wet winters. Average annual maximum temperature for 1984-2000 was 57.9 °F at Coupeville on Whidbey Island; average annual minimum temperature for the same period was 41.7 °F. July typically is the warmest month, with an average maximum temperature of 71.3 °F and January is the coldest month, with a long-term average minimum temperature of 50.3 °F (Western Region Climate Center, 2001).
>
> Data from PRISM (Precipitation-Elevation Regression on Independent Slopes Model; Daly and others, 1994) indicate that average annual precipitation from 1961 to 1990 ranged from 35 inches on southern Whidbey Island to 29 inches on northern Whidbey Island, and from 25 inches on western Camano Island to about 31 inches on the northern part of Camano Island nearest the mainland.

Figure 4-5 shows the USGS isohyetal map for Island County. Precipitation in the Livingston Bay study area is about 29 to 31 in/yr. PGG (2012) previously reviewed precipitation data for two nearby climate stations (Coupeville and Arlington, 1948-2005) and found that 65 percent of the precipitation generally falls between the months of November and April.

The USGS estimated recharge on Whidbey and Camano Islands based on consideration of factors such as precipitation, temperature, solar insolation, soil properties, land cover (Sumioka & Bauer, 2003). Their study area included the northeast "lobe" of Camano Island, which is included in the project study area. For areas where fine-grained unconsolidated deposits occur at the land surface (typical within the study area), precipitation recharge was predominantly estimated to occur within two categories: 0 to 4 in/yr and 4 to 8 in/yr. These rates applied to soils developed upon upland Everson glaciomarine drift ($Qgdm_e$), upland Vashon till (Qgt_v), and lowland marsh deposits (Qm, coincident with Puget Silty Clay Loam).

Groundwater predominantly discharges to local surface-water features such as ditches and Livingston Bay. Discharge also occurs to evapotranspiration where groundwater levels are within several feet of the land surface and to coastal springs above sea level.

4.3 GROUNDWATER LEVELS AND FLOW DIRECTIONS

Figure 4-6 presents a WLE hydrograph of continuous data from the ditch gages and monitoring wells, and "snapshot" (i.e. synoptic) data from the shallow piezometers. Note that piezometer data from late July 2021 may be unreliable (too low) since measurements were taken at the time of installation, possibly before water levels equilibrated. The data show the following:

- WLE's in the ditches, several of the shallow piezometers and (shallow) monitoring wells N1S and N2S occur below mean sea level (4.4 feet NAVD88). This occurs year-round at the ditch gages and in N2S, and seasonally elsewhere. Below-sea-level WLE's occur because WLE's in the ditches are controlled by the tidegate immediately downstream of the Pumphouse gage, which limits hydraulic connection to Livingston Bay to periods of low tide.
- WLE's in the ditches are highest at the West Gage and lower at the North and Pumphouse gages. WLE's at the pumphouse gage are only slightly lower than at the ditch gage, which reflects a fairly flat hydraulic gradient in the ditch that directly flows to the tide gate. Ditch WLE's appear to show instances where the tidegate does not fully close and water levels rise up in response to saltwater inflow from the bay. Discrete (diurnal) tidal responses are not noted (or insignificant) in the ditches when the tide gate is functioning but are more readily observed when the tide gate is not fully closing.
- Continuous WLE records from the monitoring wells show a seasonal low in August/September 2021 and a seasonal high in March/April 2022. Relative to the shallow monitoring wells, higher WLE's in the deep monitoring wells indicate an upward hydraulic gradient consistent with the lowland functioning as an area of groundwater discharge. Groundwater from the upland is expected to flow towards (and discharge to) the lowland because the lowland has (artificially) low shallow groundwater elevations due to the influence of the drainage ditches. The steepest upward hydraulic gradient is observed at the N2D/N2S cluster on the western edge of the site (8 to 9 feet of WLE difference is noted between the two wells). In contrast, about 2 to 4 feet of WLE difference is noted in the N1D/1S monitoring well cluster.
- PGG evaluated WLE responses to tidal fluctuations and precipitation events over a 9-week period in the spring of 2022. **Figure 4-7** shows WLE's plotted against precipitation measured at the "Stanwood 0.7N" monitoring station (about 4 miles east of the site, as shown on **Figure 1-1**)[4]. The extent to which precipitation events at this monitoring station reflect micro-climate events at the project site is unknown. The data show that:
    - Considerable "noise" at the Pumphouse Gage, with muted propagation to the North Gage but no propagation to the West Gage. These variations could potentially be associated with rogue waves hitting the tidegate.

[4] Data downloaded from SC ACIS2 (rcc-acis.org).

- o All three ditch gages show minor tidal variations on the order of about 0.1 feet or less. Among groundwater monitoring points, consistent tidal variations (smaller than those observed in the ditches) are notable in N2S and N1D, intermittent responses are observed in N1S, and few (and nearly immeasurable) responses are observed in N2D.
- o The data do not demonstrate a strong relationship between precipitation events and groundwater responses. While the most significant responses would be expected in the shallow monitoring wells, correlated responses are intermittent and sometimes appear to precede the measured precipitation event (possibly a result of micro-climatic variations). In addition, some WLE peaks appear to be correlated with lower-intensity precipitation events whereas other such events do not show similar responses. [The lack of notable responses in shallow monitoring well N1S may be due to the fact that surficial sediments are quite silty and tend to confine the first occurrence of saturation observed during drilling, as described in Section 3.1]. In some cases, short-term WLE variations in the deep monitoring wells are larger than in the shallow monitoring wells.
- o Events occur where ditch WLE's rise and fall over several days but show no tidal variation (e.g. early April on **Figure 4-7**, and multiple events on **Figure 4-6**. The cause of these observed events is unknown.

- WLE's in the ditches, several of the shallow piezometers and (shallow) monitoring wells N1S and N2S occur below mean sea level (4.4 feet NAVD88). This occurs year-round at the ditch gages and in N2S, and seasonally elsewhere. Below-sea-level WLE's occur because WLE's in the ditches are controlled by the tidegate immediately downstream of the Pumphouse gage, which limits hydraulic connection to Livingston Bay to periods of low tide.

Figures 4-8 and **4-9** show "snapshots" of WLE elevation taken in late July and mid November 2021 (respectively). Similar to the WLE hydrographs, the maps also show the upward gradients in the two monitoring well clusters and the fact that groundwater elevations are higher than ditch elevations (for both shallow and deep monitoring well completions as well as piezometers[5]). Although the maps show only one upland well (BV7, west of the lowland), the WLE in this well is lower than typical WLE's on the lowland, reflecting expected groundwater discharge towards the lowland from the upland. In fact, because WLE's on the lowland are below mean sea level in Livingston Bay, a steeper hydraulic gradient is expected to occur from the upland to the lowland than from the upland to the bay. Thus, under current conditions, local upland groundwater discharge may slightly emphasize flow to the lowland versus flow to the bay.

Static WLE's in the shallow piezometers, shown on both the 11-month WLE hydrograph and the snapshot maps, range from about 2.6 to 7.3 feet NAVD88. Lower values may have occurred in mid-July 2021; however, these measurements were taken at the time of installation when water levels may not have equilibrated. The highest WLE's are observed in P7, which is located closest to the coastline on (higher elevation) beach sediments rather than (lower elevation) marsh deposits and may represent locally differing hydrogeologic conditions.

4.4 GROUNDWATER/SURFACE-WATER CONNECTIONS

As ditch WLE's are lower than lowland groundwater elevations, groundwater is expected to discharge to the ditches. The extent to which ditches dominate groundwater flow patterns depends on the permeability

[5] Note that the WLE's shown for piezometers for July 2021 may be artificially low because they were measured at the time of installation, before water levels may have equilibrated with surrounding soils.

of the sediments on the bottoms and sides of the ditches, the degree to which the ditches penetrate the shallow sediments, and the texture (i.e. permeability) of shallow sediments in the immediate vicinity of the ditches. It is clear, however, that the depressed WLE's in the ditches have a major influence in causing depressed WLE's in lowland shallow groundwater.

4.5 GROUNDWATER AND SURFACE-WATER SALINITY

Figure 4-10 shows a time-series plot of SC (an indicator of salinity) in the monitoring wells, piezometers and ditch gages. Salinity in Livingston Bay is expected to range from around 18 to 22 parts per thousand (Yang, 2008), which roughly correlates to SC values of 29 to 35 mmhos/cm[6]. SC values measured in all four monitoring wells are relatively low (<0.6 mmhos/cm) which is within the range of fresh groundwater with no sign of saltwater intrusion. SC data from these monitoring wells show no short-term (e.g. tidal) or seasonal variations, thus suggesting a relatively constant source of fresh groundwater discharging to the lowland. In contrast, SC at the Pumphouse Gage (light green) shows significant short-term variation with high values typically ranging between 7 and 10 mmhos/cm and extreme peaks on the order of 14 mmhos/cm and lows as low as freshwater values. SC data from the North Gage do not show similar short-term variability. SC trends at the North Gage vary over longer time periods and are more consistent from one measurement to the next. Differences between observed trends at the gages may be related to pump on/off conditions at the Pumphoue Gage and associated turbulence and flow reversals at the pump intakes. In any case, SC measurements from the two ditch gages are significantly higher than those observed in the monitoring wells.

SC values in the shallow piezometers are generally higher than in the shallow monitoring wells but lower (or similar to) those observed at the ditch gages. The one exception is P7, which exhibits low SC values, high WLE's, and is completed in beach deposits rather than marsh deposits (Section 4.3). Whereas the shallow monitoring wells are completed at depths of 5 to 10 feet bgs (N2S) and 10 to 15 feet bgs (N1S), the piezometers are open to shallow sediments at depths of 4 to 5 feet bgs. As noted above, N1S appears to be completed under confining fine-grained sediments (and thus may be insulated by shallow sources of salinity); however, drilling of N2S mostly encountered sandy sediments from the ground surface to the completion zone (i.e. no notable confinement).

SC snapshots on **Figures 4-8** and **4-9** show that SC values in P4 and P6 occur at a similar magnitude as those observed in the ditches. The data show that the uppermost several feet of saturated soils (e.g. within 5 feet of the land surface) can be more saline than the underlying shallow groundwater encountered in the monitoring wells. Significant variability is noted between the piezometers, which points to non-uniform processes for shallow soil salinization. Possible influences on shallow soil salinity include: potential local seepage from ditches, salt deposition via sea spray, subsurface salt concentration via plant water uptake and seawater recharge during historic inundation events[7]. Among these possibilities:

- Flow out of ditches is not supported by reliable WLE measurements taken thus far. Measurements taken in November 2021 and March 2022 show that WLE's in piezometers are generally higher than those in ditches. While the July 2021 measurements showed the opposite, it's likely that the piezometers had not yet equilibrated and their WLE's were not representative. Additional mid- to late-summer measurements would be needed to determine if instances occur where WLE's suggest flow from ditches into adjacent shallow groundwater.

[6] https://www.oceanlife.it/index.php/en/19-notizie/370-water-salinity-converter-en

[7] In the Leque Island study (PGG, 2012) the occurrence of more saline shallow groundwater overlying fresher deeper groundwater was attributed to periodic inundation events when levees were overtopped and fields flooded with seawater.

- Salt deposition and concentration in the root zone may influence soil salinities; however, measurement of the lowest SC in the piezometer closest to the coast (P7) may not explain the observed distribution. Predicting the geographic distribution of the balance between deposition and concentration, along with possible dilution by patterns of rainfall runoff and infiltration, can be complex.
- Inundation events have occurred that may have recharged shallow soils with saline water. ESA has reviewed historical photos of flooding across the site from the 1970s and 1997, along with a WCLT video from January 30th 2021 of standing water across the site[8]. When flooded, the photos show much of the site with standing water, except for the higher areas along the coastal berm (e.g P7 location).

Beyond these observations, this preliminary review cannot define the absolute causes of observed salinities in the shallow soil.

5.0 HYDROGEOLOGIC CHANGES FROM PROPOSED RESTORATION

Restoration alternatives for the Livingston Bay site are described in the main report and would include dike removal, backfilling of existing ditches, development of a new drainage network and constructing new dike(s) to protect adjacent lowland property from tidal inundation. The alternatives range from restoring just the Leque parcel, to incorporating a land swap which would allow restoration of the northern portion of the Nelson parcel, to restoring the entire lowland with the exception of existing residential areas (parcel areas are shown on **Figure 5-1**). Identified concerns associated with the proposed restoration include saltwater intrusion of drinking water aquifers that surround the lowland and salinization of shallow soils on agricultural properties immediately adjacent to the restored areas. The following sections provide a preliminary hydrogeologic assessment of both concerns.

5.1 POTENTIAL FOR SALTWATER INTRUSION OF DRINKING WATER AQUIFERS

Based on the conceptual hydrogeologic model described above, the potential for saltwater intrusion in the drinking water aquifer tapped by upland wells above the lowland (Aquifer D) is very low. Upon restoration, periodic tidal inundation of the restored lowland area is expected to cause associated shallow groundwater elevations (e.g. those seen in the piezometers) to rise by several feet. This rise could potentially propagate to deeper groundwater beneath the lowland (e.g. as observed in the monitoring wells) and further propagate to connected groundwater beneath the upland. If higher WLE's *do* propagate into Aquifer D, as long as upland WLE's remain higher than lowland WLE's, a new equilibrium would develop that would actually *decrease* the potential for saltwater intrusion beneath the upland. Upland WLE's are expected to remain above shallow lowland WLE's because the current WLE difference is on the order of 8-10 feet, and lowland WLE's would only rise by several feet. Intrusion potential would decrease because the elevation of the expected saltwater interface would decrease based on the principal of Ghyben-Herzberg (Ghyben 1888 and Herzberg 1901). This principal shows that the ratio of the freshwater WLE above MSL to the depth of the saltwater interface below MSL is proportional to a factor based on the

[8] It's not clear whether the 1/30/2021 flooding was from coast side or large precipitation (or both). The meteorology from that week shows that there were sustained south winds, moderately high tides and also a few days of moderate rainfall.

density difference between fresh and saline water[9]. Therefore, higher WLE's in Aquifer D would result in deeper occurrence of saltwater within the aquifer (assuming that saltwater currently resides within Aquifer D).

PGG mapped Island County chloride data from local wells to survey evidence for the occurrence of saline water in Aquifer D. Assuming that most of the local wells shown on **Figure 5-1** are completed in the aquifer, the map shows predominantly low chloride concentrations (<40 mg/L) in most wells. One well north of the Roberge property (4UX) shows a (single measurement) chloride value of 81 mg/L, and two wells east of the Roberge property (3MB and 3MY) show maximum observed values of 180 and 115 mg/L (respectively). Well 4UX is a domestic well completed 20 feet below MSL. Nearby wells completed at similar elevations do not show notably elevated chloride. Well 3MB is a public water system well that supplies the 68-connection Livingston Bay Community Association. The well is completed 43 feet below MSL and expected heavy pumping from this well could potentially cause upconing of underlying saline water such that the saltwater interface draws closer to the well intake. Well 3MY is a public water system well that supplies the Camano Island Dental Center. The well is completed 38 feet below MSL and its pumping demand is unknown. However, it should be noted that both wells 3MB and 3MY exhibit relatively elevated hardness (190 and 337 mg/L, respectively) which could be associated with the elevated chlorides but not associated with saltwater intrusion (hardness information is unavailable for Well 4UX).

Vulnerability to saltwater intrusion is best jointly indicated by both chloride concentration and WLE relative to MSL (Island County, 2001). Because chloride concentrations can be influenced by hardness, WLE's provide additional accuracy in defining vulnerability (ibid.). Among the roughly 70 wells shown on **Figure 5-1**, only two have surveyed WLE's (both around 6.4 feet NAVD88 (2 feet MSL) and showing low chloride concentrations). In some areas of the surrounding upland (e.g. north of he Nelson and Leque properties), there are few wells and a lack of associated SC and WLE data (**Figure 5-1**). Collecting data from more wells in these areas would improve associated assessment of saltwater intrusion vulnerability. However, as noted above, as long as upland groundwater elevations remain higher than lowland groundwater elevations, the restoration alternatives are not expected to increase the potential for saltwater intrusion in the offsite drinking water wells. It is worth noting that the same conclusion was reached for PGG's evaluation of the Leque Island restoration (PGG, 2012), which was supported by groundwater modeling reviewed by both State and Federal agencies.

5.2 POTENTIAL FOR SALINIZATION OF ADJACENT SHALLOW SOILS

Periodic tidal inundation in the restored areas will increase the salinity of the underlying shallow soils. If a dike is constructed to separate the restored area from adjacent property, WLE's in the restored areas will exceed groundwater elevations beneath the adjacent property during tidal inundation. This periodic difference in water levels across the dike could cause a net migration of saline water from the restored area to the adjacent property. The potential for such migration would depend on a number of factors, including the depth and locations of periodic drainage on the restored property and the permeability of local soils. Engineering solutions, such as adding a drainage ditch adjacent and parallel to the dike, could be employed with the aim of controlling the potential for saline migration and protecting adjacent fields. Additional analysis, such as groundwater modeling, is recommended once a design alternative is selected to assess the potential for net chloride migration across the dike and the efficacy of engineering solutions.

[9] Typical marine conditions (salinity = 35 parts per thousand) yield a ratio between WLE and depth to the saltwater interface of about 40. Because the salinity of Livingston Bay is slightly lower, the ratio would be slightly lower than 40.

6.0 RECOMMENDED ADDITIONAL ANALYSIS & NEXT STEPS

If WCLT decides to pursue one of the restoration alternatives, based on the findings documented above, PGG provides the following recommendations to advance this preliminary investigation to a more comprehensive study:

1. Measure SC, chloride and surveyed WLE's in additional upland Aquifer D wells surrounding site to confirm that upland WLE's are sufficiently higher than lowland WLE's and that groundwater is generally fresh in key neighboring areas.
2. The appropriate time to decommission the project monitoring wells and piezometers will depend on how WCLT decides to proceed with this restoration opportunity. Continued monitoring, and possible addition of new monitoring locations (piezometers and monitoring well clusters), may be worthwhile depending on whether restoration will be pursued and the selected restoration plan. Based on the selected approach, hydrogeologic guidance should be sought regarding continued monitoring. Once decommissioning is deemed appropriate, WCLT should retain a qualified driller to decommission the wells. Particular care will be needed to decommission the deep monitoring well completions, as artesian flow will require high density sealing materials to offset the artesian pressure. Piezometers can be decommissioned by manually extracting the PVC and backfilling remaining empty holes with bentonite chips.
3. Consider employing groundwater modeling (e.g. 2D "slice models") to assess the potential for net salinity migration across newly constructed dikes to adjacent agricultural properties. Modeling should be based on proposed restoration designs and possibly supplemental analysis of soil hydraulic properties.

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Table 3-1
Summary of Piezometer and Monitoring Well Construction

Well Id	Site Name	Riser Length (ft)	Screen Length (ft)	Screen Bottom (ft)	Tail Pipe Length (ft)	Boring Depth (ft bgs)	Well Depth (ft bgs)	Screened Interval (ft bgs)	Ecology ID	Easting	Northing	Land Surface Elevation (ft)	Stick Up (ft)	MP Elevation (ft)	DTW (ft bmp)
N1S	Leque Property	9.77	5	15	0.25	16.5	15	10.0-15.0	BMT-499	1247674.7660	456458.6065	5.30	(0.23)	5.07	1.09
N1D	Leque Property	44.76	5	50	0.25	51.5	50	45.0-50.0	BMT-498	1247729.0070	456458.7795	5.95	(0.24)	5.71	*
N2S	Nelson Property	4.47	5	10	0.25	10	10	5.0-10.0	BMT-496	1245353.6710	454915.4815	6.27	(0.53)	5.74	2.65
N2D	Nelson Property	44.70	5	50	0.25	50	50	45.0-50.0	BMT-497	1245352.3980	454920.8695	6.29	(0.30)	5.99	*
P4	Nelson Property	4.02	1	5.02	0.25	5.02	5.02	4.02-5.02	NA	1246142.8900	456316.1835	4.95	-	4.95	4.24
P5	Nelson Property	4.04	1	5.04	0.25	5.04	5.04	4.04-5.04	NA	1245634.1810	456324.9275	5.57	-	5.57	3.34
P6	Roberge Property	6.46	1	5.9	0.25	5.9	5.9	4.90-5.90	NA	pending	pending	pending	1.56	pending	6.29
P7	Leque Property	4.06	1	5.06	0.25	5.06	5.06	4.06-5.06	NA	1246868.9870	454393.1745	7.69	-	7.69	Dry

NOTES:
"MP" = measuring point, "WL" = water level, "bgs" = below ground surface, "MW" = monitoring well, "B" = boring, "bmp" = below measuring point, "DTW" = depth to water.
Piezometer P6 pending survey
Easting and northing coordinates are in the NAD83 (2011), WA Zone N, epoch 2010.00, Feet
Elevations are in NAVD88 (GRS80 Geoid 12B), and are reported to the nearest hundred foot.
DTW for monitoring wells and piezometers were measured 7/21/2021. Piezometer DTW's may not have fully equilibrated before measurement.
* monitoring wells N1d and N2D were flowing at the time of drilling and no water level was collected.

Table 4-1 Descriptions of Geologic Units within Project Area

Geologic Unit	Unit Description (Combined)
Fill (**af**)	Clay, silt, sand, gravel, organic matter, rip-rap, and debris placed to elevate and reshape the land; includes engineered and nonengineered fills; shown where fill is readily verifiable, relatively extensive, and appears sufficiently thick to be geotechnically significant.
Beach deposits (**Qb**)	Loose, moderately to well-sorted and well-rounded sand and gravel along modern shorelines; may include boulders, silt, pebbles, and clay; locally includes wave-worn shell fragments; derived from shore bluffs and underlying deposits and (or) carried in by longshore drift.
Marsh deposits (**Qm**)	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. Contacts between marsh, Skagit River fluvial, and tidal flat environments are commonly gradational or masked by agricultural modifications, and thus are generally inferred.
Everson Interstade Glaciomarine Drift, undivided (**Qgdm(e)**)	Clayey to silty diamicton with variable content of gravel clasts; also includes silt, clay, and sand; contains sparse shells, generally marine; dark gray where unweathered; mostly weathers to buff, but ranges to olive gray, ash gray, or white; commonly forms dry, vertical face with failure-prone, vertical desiccation cracks with dark brown staining; best exposures along east shores of Triangle Cove and Livingston Bay; massive to rhythmically bedded, commonly with sharp upper and lower, unit-bounding unconformities (Domack, 1984); mostly loose and soft, but locally hard and compact. May resemble till (Domack, 1982, 1984; Domack and Lawson, 1985), but in general, till lacks fossils and glaciomarine drift has a finer-grained, smoother-feeling matrix, is less compact, and more likely to be stratified. Unit is sea-floor sediment and consists mostly of glacial flour. Its textural diversity reflects proximity of the ice front (Domack, 1983; Dethier and others, 1995).
Everson Interstade glaciomarine deltaic outwash deposits (**Qgom(e)**)	Sand, and sand-gravel mixtures with minor interlayered silt and silty sand; generally loose; most deposits are at least a few tens of feet thick; forms a marine delta - turbidite complex (Carlstad, 1992; Polenz and others, 2005) with a horizontally bedded, sandy sea-floor facies, an overlying delta-front foreset-bedded facies, and a capping deltaic top-set, channelized facies. Intimate interlayering with glaciomarine drift indicates submarine deposition for most areas mapped as unit Qgom(e), although it may locally include terrestrial outwash deposits. Terrestrial ablation or flow 'till' is locally associated with outwash and typically consists of soft to stiff clayey or silty diamicton; may include moderately to poorly sorted, silty sandy gravel or sandy boulder-cobble gravel deposits with some silt.

Geologic Unit	Unit Description (Combined)
Vashon Stade till (**Qgt**)	Typically unweathered, unsorted mixture of dense to very dense diamicton clay through boulder-size material deposited directly by ice; includes extensive areas of compact (advance outwash?) sand; compact, well-developed facies resemble concrete; locally ranges to loose in ablation till and well-sorted in some sand-dominated areas; erratic boulders common on surface; gray where fresh; oxidizes yellowish brown; permeability very low in compact diamicton but locally high in sandy or loose facies; most commonly matrix supported; cobbles and boulders commonly faceted and (or) striated; may include flow banding; typically forms vertical faces in coastal bluffs; locally resembles unit Qgdm(e) (see that unit). Till unconformably overlies bedrock, advance outwash, and much less commonly, older glacial and nonglacial units. Most till deposits have had their surface fluted by overriding ice and form a patchy and seemingly randomly distributed cover that varies from 0 to at least 100 ft thick (as reflected in some water well records), with 2 to 30 ft most common.
Vashon Stade advance outwash sand (**Qva**)	Mostly lacustrine sand with layers of silt; well stratified, moderately to well-sorted, moderately to very dense, medium to coarse sand, pebbly sand, and sandy gravel, with minor amounts of fine silty sand or sandy silt, and clay interbeds with scattered lenses and layers of pebble-cobble gravel; thinly to very thickly bedded with sub-horizontal bedding or generally south-dipping cross-stratification Sands are typically medium or light gray when dried and weather tan or pale yellowish brown.

Modified from Dragovich et al (2002) and Schasse et al (2009)

K:\Peter\Livingston\GIS\SiteMap.mxd 8/9/2022

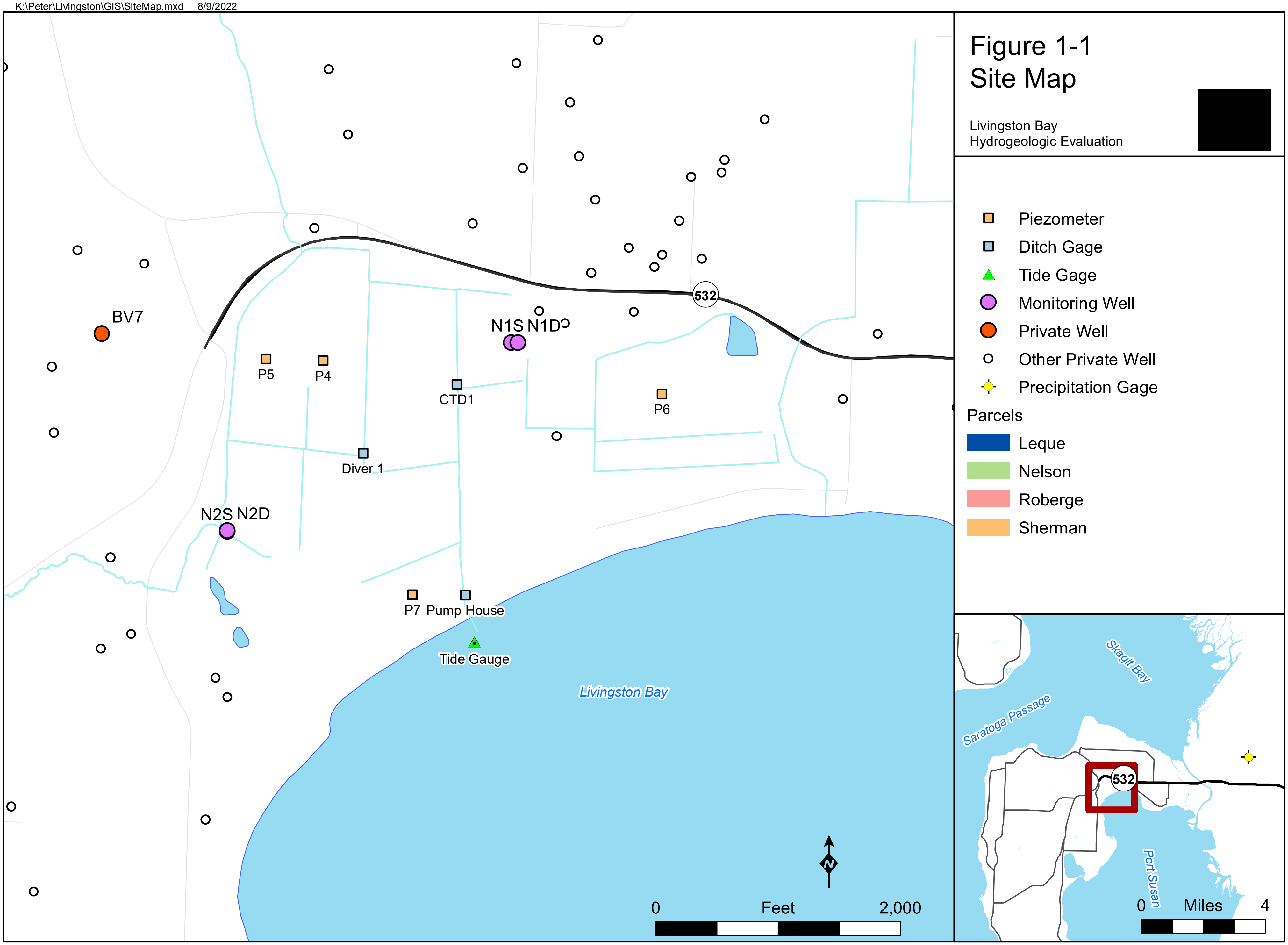

Figure 1-1
Site Map

Livingston Bay
Hydrogeologic Evaluation

[redacted]

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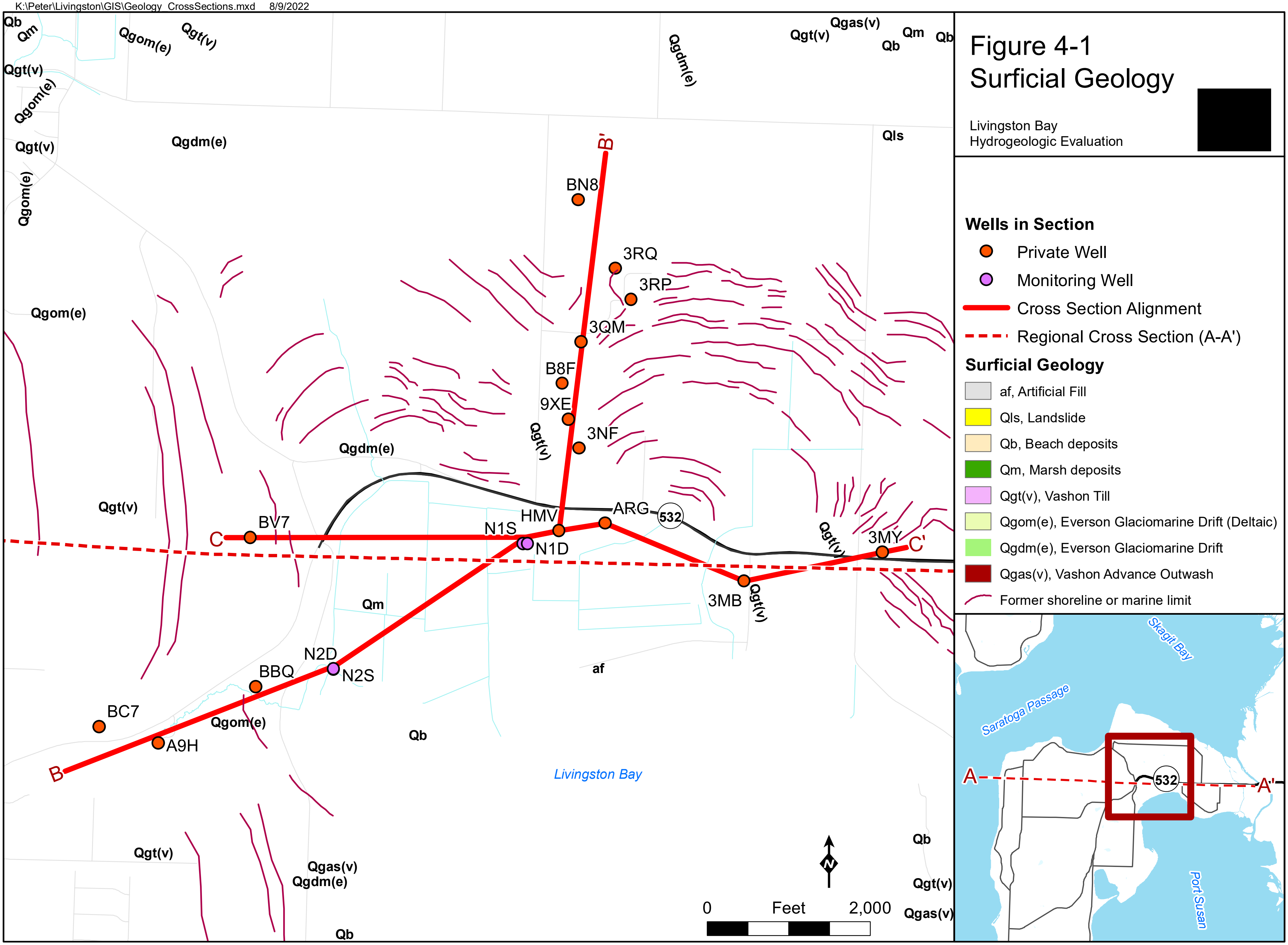
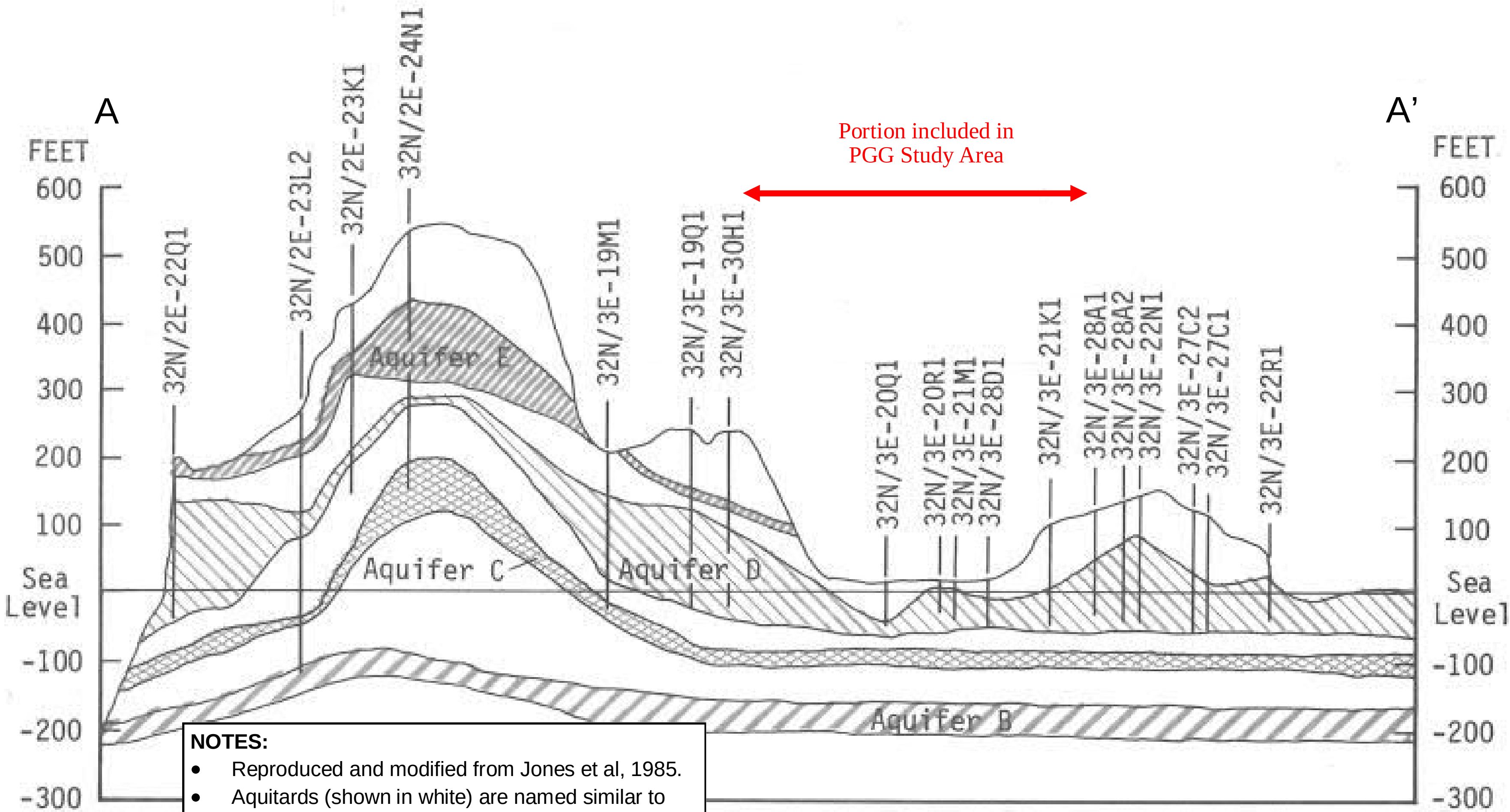


Figure 4-1
Surficial Geology

Livingston Bay
Hydrogeologic Evaluation



NOTES:

- Reproduced and modified from Jones et al, 1985.
- Aquitards (shown in white) are named similar to aquifers, with "Aquitard D" representing the low-permeability layer immediately *below* "Aquifer D".

Figure 4-2
Regional Hydrogeologic Cross Section A-A'

Livingston Bay
Hydrogeologic Evaluation

PGG
A Mott MacDonald Company

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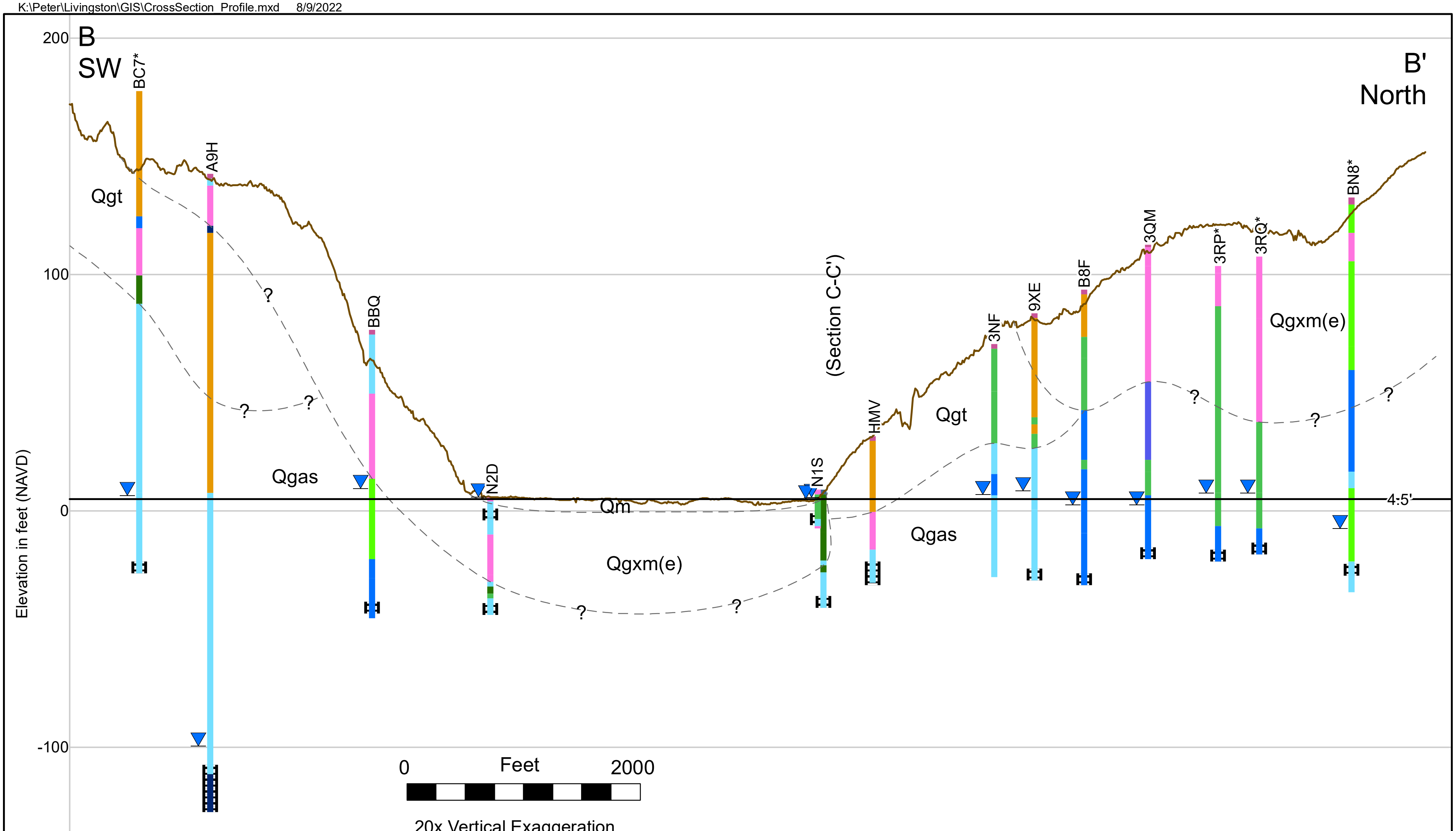


HMV Well ID

Screened Interval

Water Level

Land Surface

Interpreted Geologic Contact

* Indicates well projection >250 ft

Well Log Interpretation

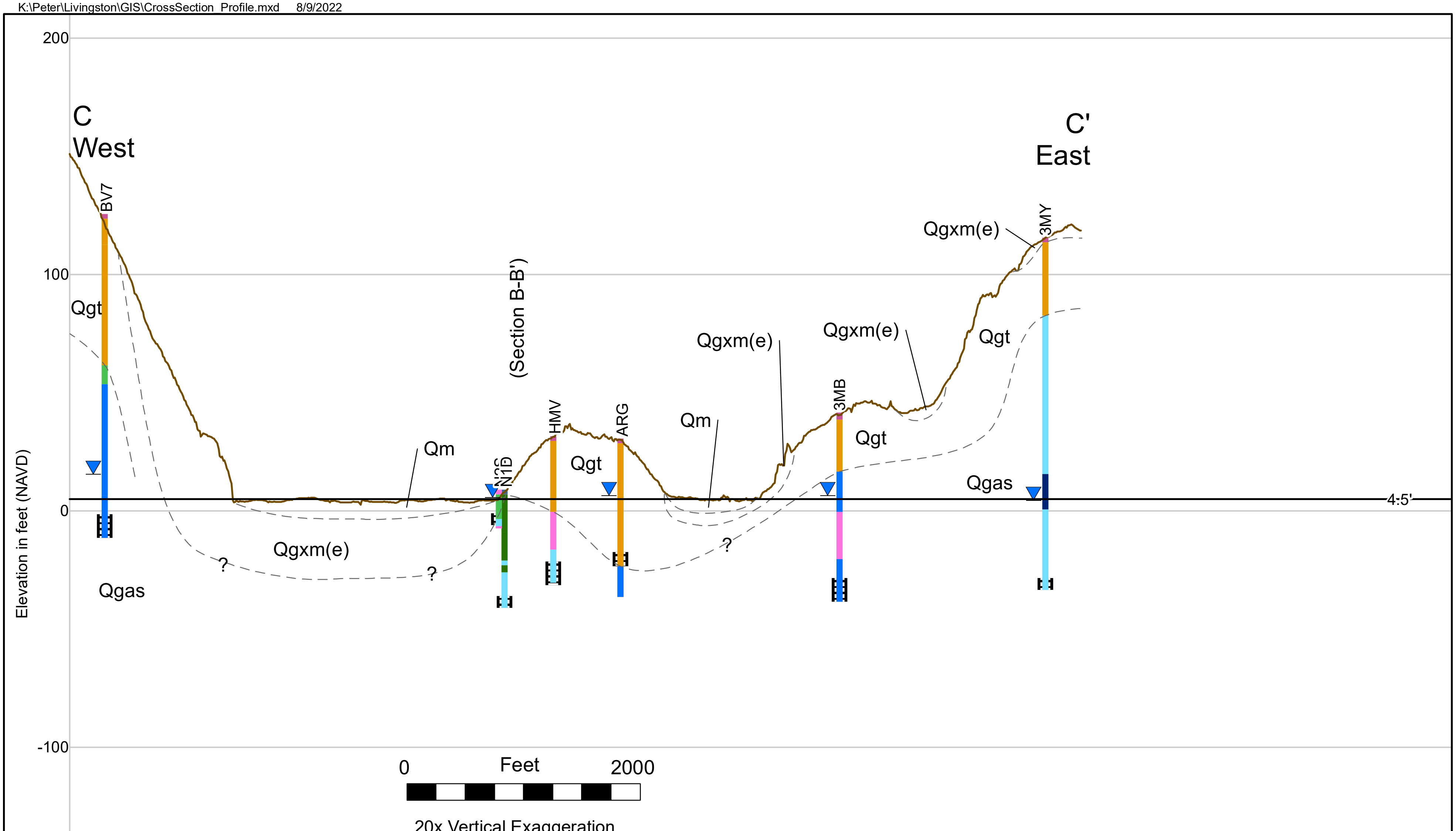
- 1a - Gravel
- 1b - Sand + Gravel
- 1c - Sand
- 2a - Sand + Gravel + Silt/Clay (non-water-bearing)
- 2b - Sand + Silt/Clay (non-water-bearing)
- 3a - Silt + Clay
- 4 - Glacial Till or Driller's designation of "hardpan"

Geologic Units

- Qm - Marsh Deposits
- Qgxm(e) - Everson Glaciomarine drift and outwash
- Qgt - Vashon Till
- Qgas - Vashon Advance Outwash

Figure 4-3
Cross Section B-B'

Livingston Bay
Hydrogeologic Evaluation



HMV Well ID

Screened Interval

Water Level

Land Surface

Interpreted Geologic Contact

* Indicates well projection >250 ft

Well Log Interpretation

- 1a - Gravel
- 1b - Sand + Gravel
- 1c - Sand
- 2a - Sand + Gravel + Silt/Clay (non-water-bearing)
- 2b - Sand + Silt/Clay (non-water-bearing)
- 3a - Silt + Clay
- 4 - Glacial Till or Driller's designation of "hardpan"

Geologic Units

- Qm - Marsh Deposits
- Qgxm(e) - Everson Glaciomarine drift and outwash
- Qgt - Vashon Till
- Qgas - Vashon Advance Outwash

Figure 4-4

Cross Section C-C'

Livingston Bay
Hydrogeologic Evaluation

[redacted]

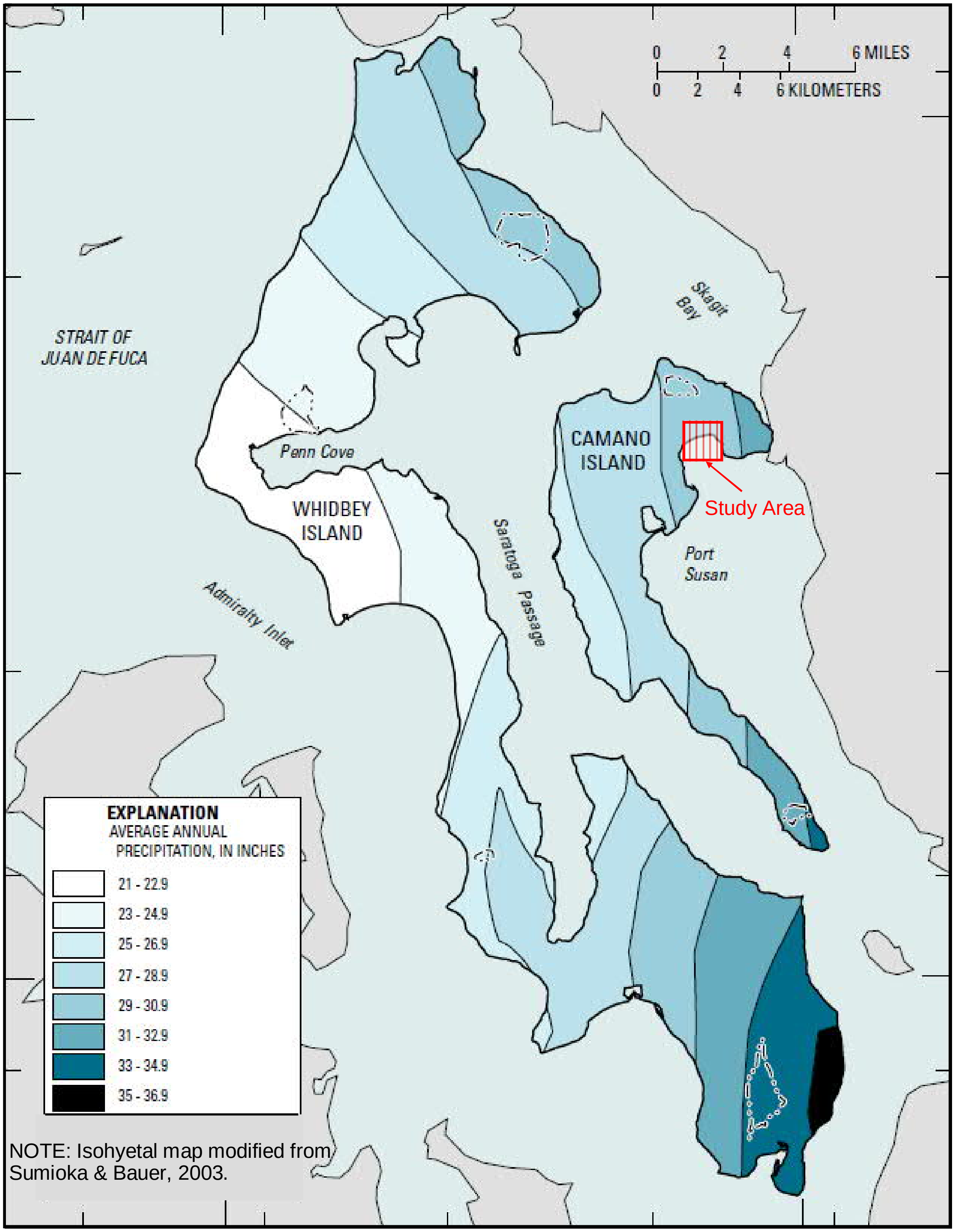


Figure 4-5
Isohyetal Map

Livingston Bay
Hydrogeologic Evaluation

PgG

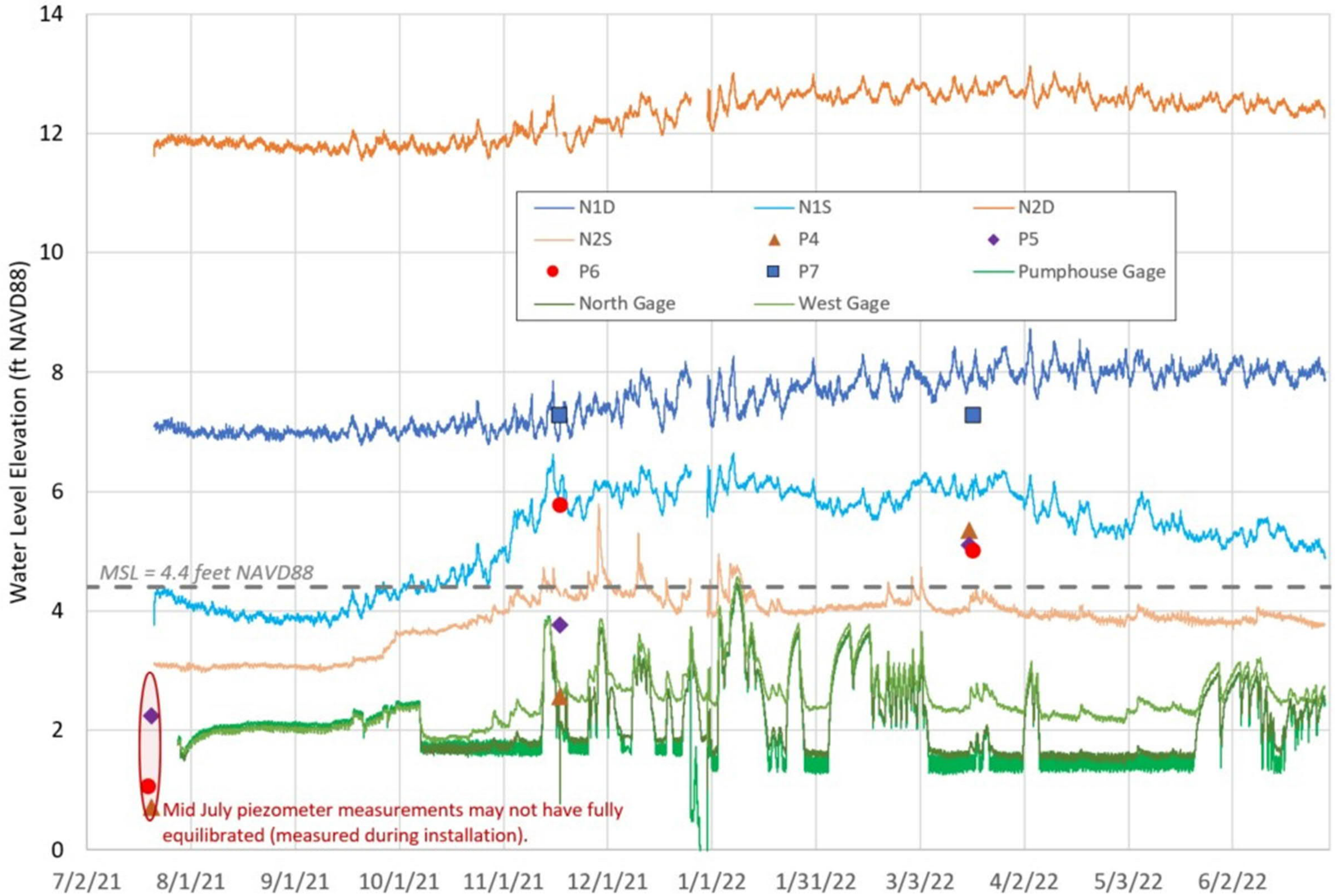


Figure 4-6
Water-Level Elevation Hydrograph

Livingston Bay
Hydrogeologic Evaluation

PgG
A Mott MacDonald Company

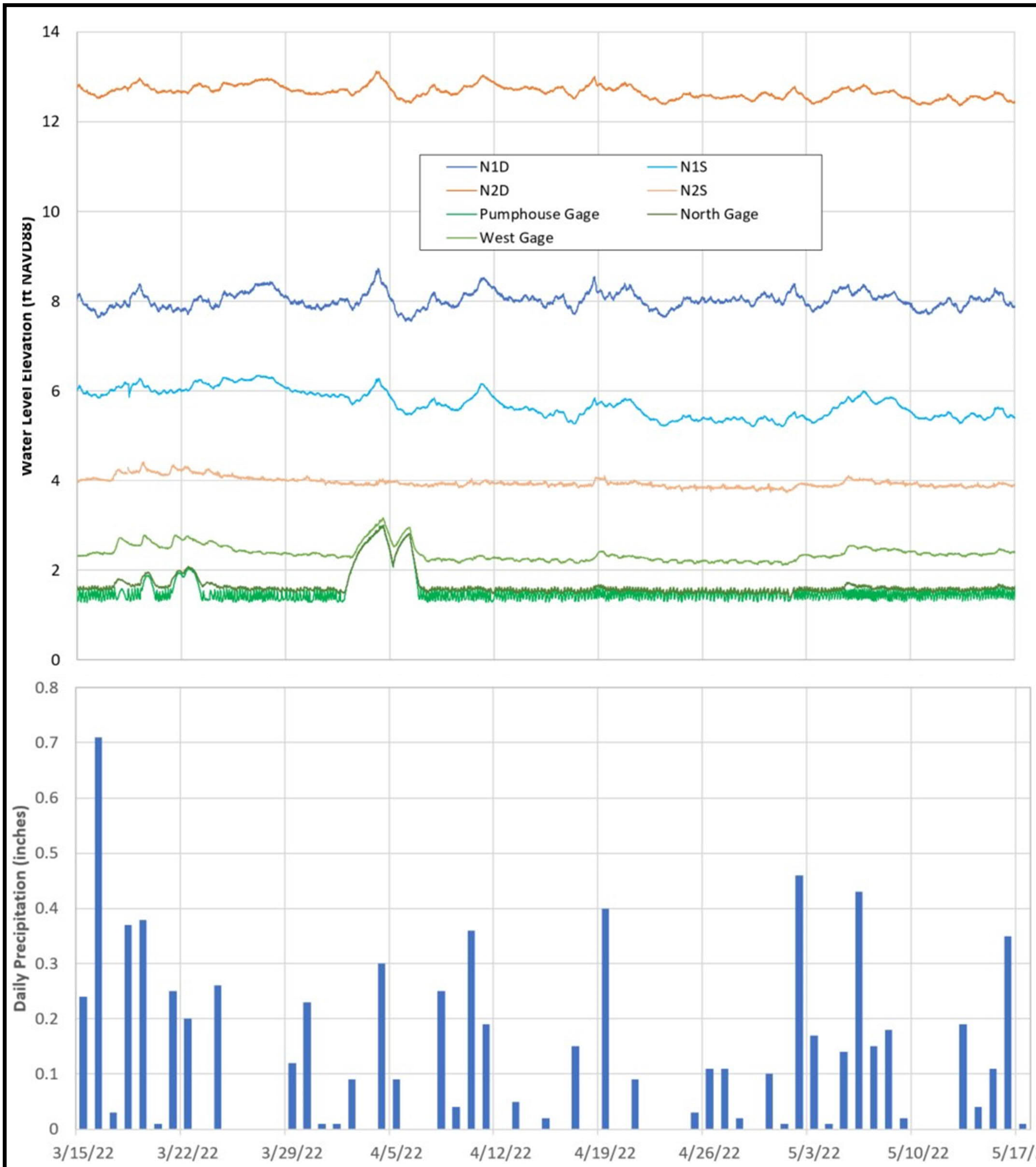


Figure 4-7
Water-Level Elevation vs. Precipitation

Livingston Bay
Hydrogeologic Evaluation

PgG

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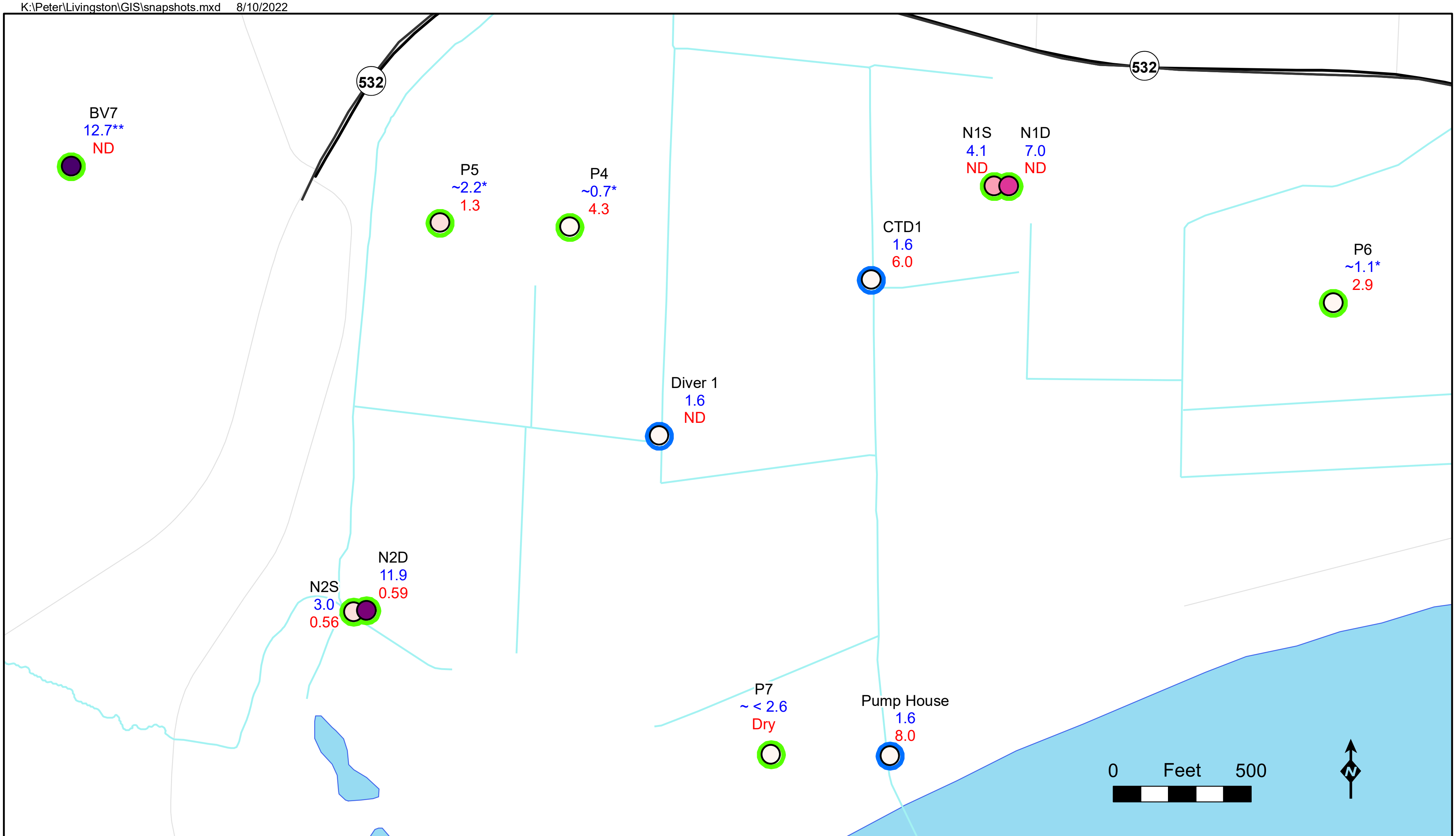

Water Level Elevation NAVD88

- 0-2
- 2.1 to 4
- 4.1 to 6
- 6.1 to 8
- 8.1 to 12
- 12.1 to 14

Groundwater Monitoring Points

Surface Water Monitoring Points

Map ID
Water Level Elevation (Feet NAVD88)
Specific Conductance (mmhos/cm)

Notes:
Mean Sea Level = 4.4 feet NAVD88.
* - Piezometer water levels in late July were at time of installation and may not have fully equilibrated.
** - Based on three measurements taken on 6/29/22, 8/15/2003 and 6/13/2002 (all within a 0.5-foot range).
ND = No Data

Figure 4-8
WLE and SC at Monitoring Points in Late July 2021

Livingston Bay
Hydrogeologic Evaluation

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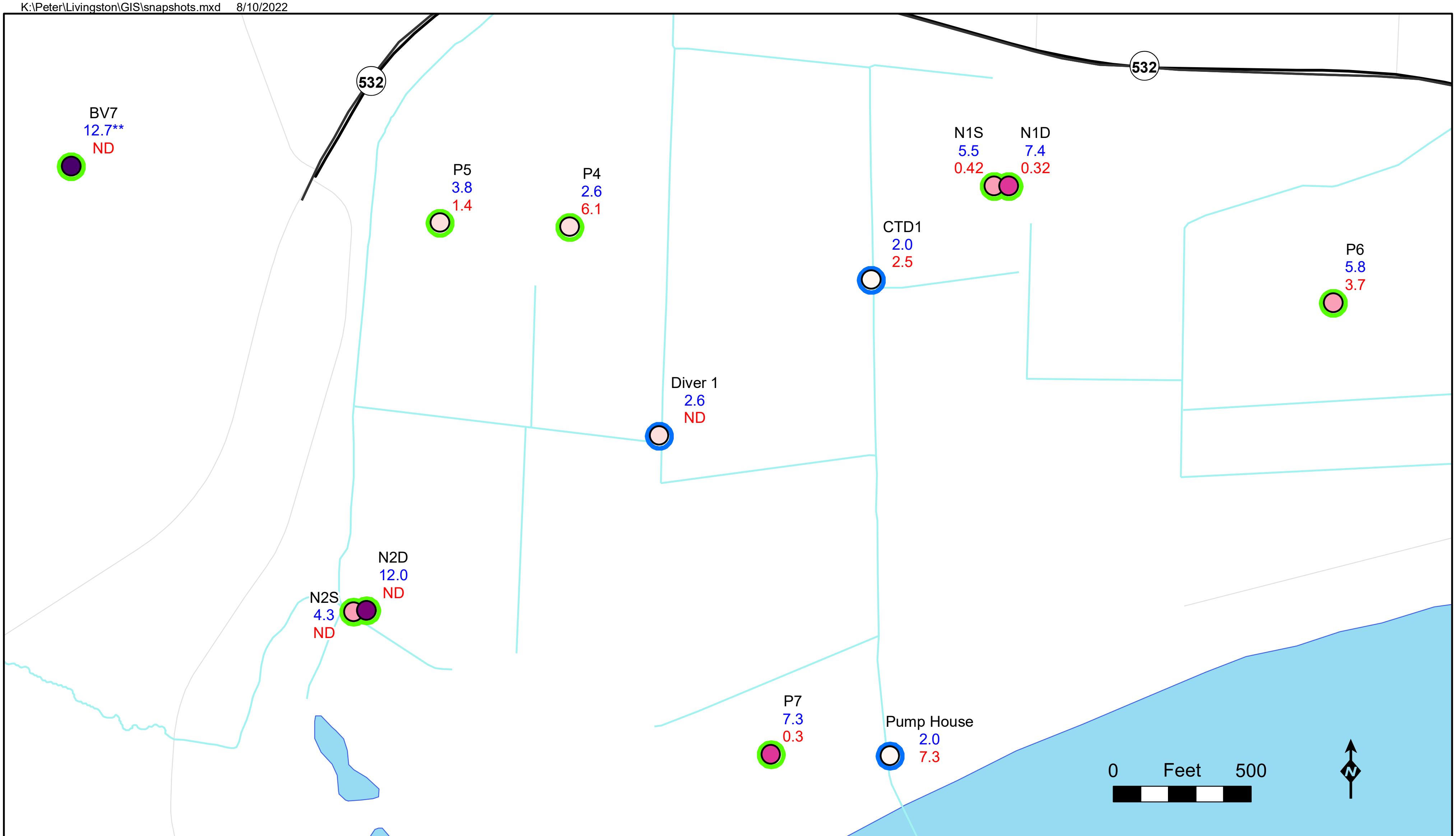

Water Level Elevation NAVD88

- 0-2
- 2.1 to 4
- 4.1 to 6
- 6.1 to 8
- 8.1 to 12
- 12.1 to 14

Groundwater Monitoring Points

Surface Water Monitoring Points

Map ID
Water Level Elevation (Feet NAVD88)
Specific Conductance (mmhos/cm)

Notes:
Mean Sea Level = 4.4 feet NAVD88.
* - Piezometer water levels in late July were at time of installation and may not have fully equilibrated.
** - Based on three measurements taken on 6/29/22, 8/15/2003 and 6/13/2002 (all within a 0.5-foot range).
ND = No Data

Figure 4-9
WLE and SC at Monitoring Points in Mid November 2021

Livingston Bay
Hydrogeologic Evaluation

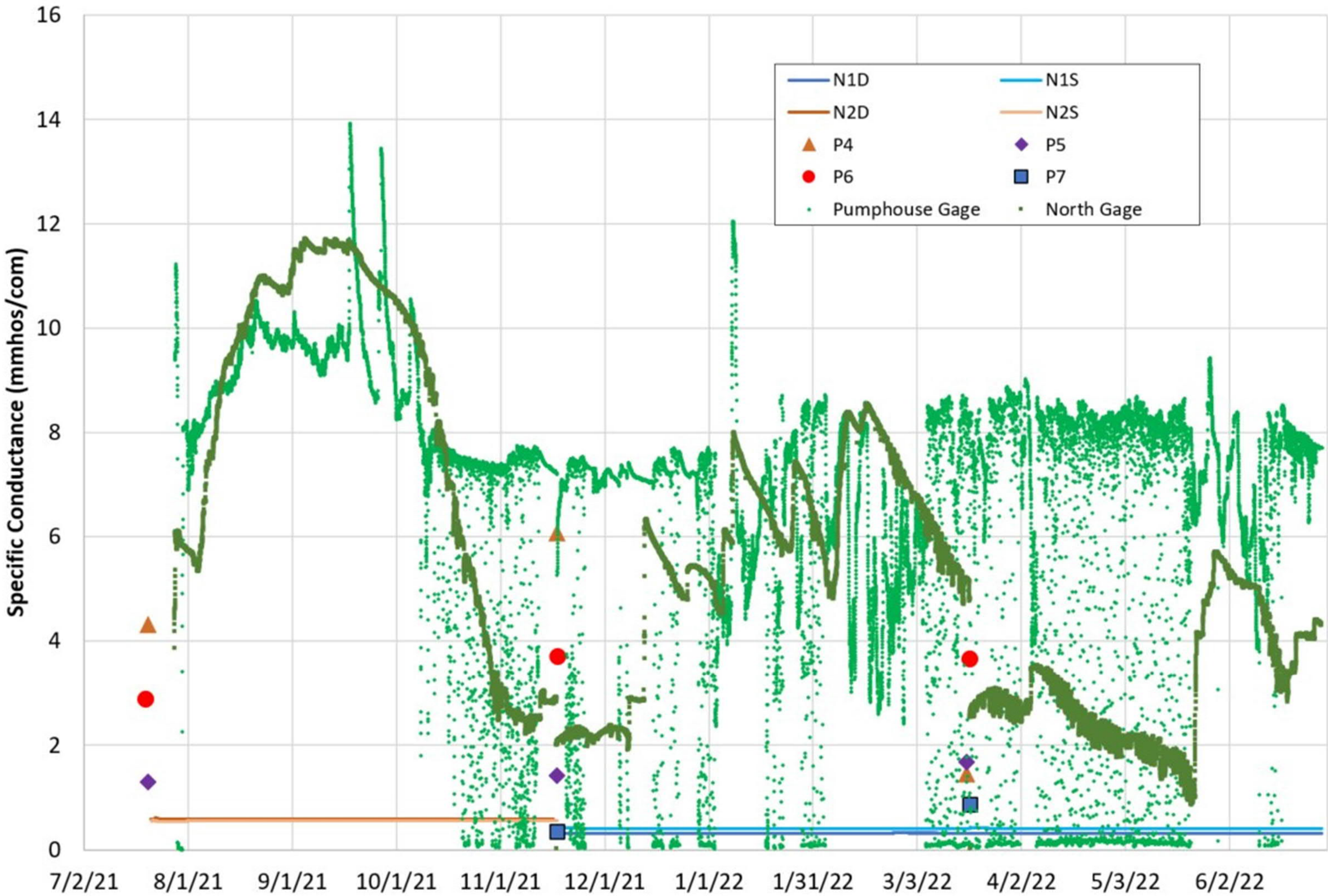

Figure 4-10
Specific Conductance Hydrograph

Livingston Bay
Hydrogeologic Evaluation

PgG
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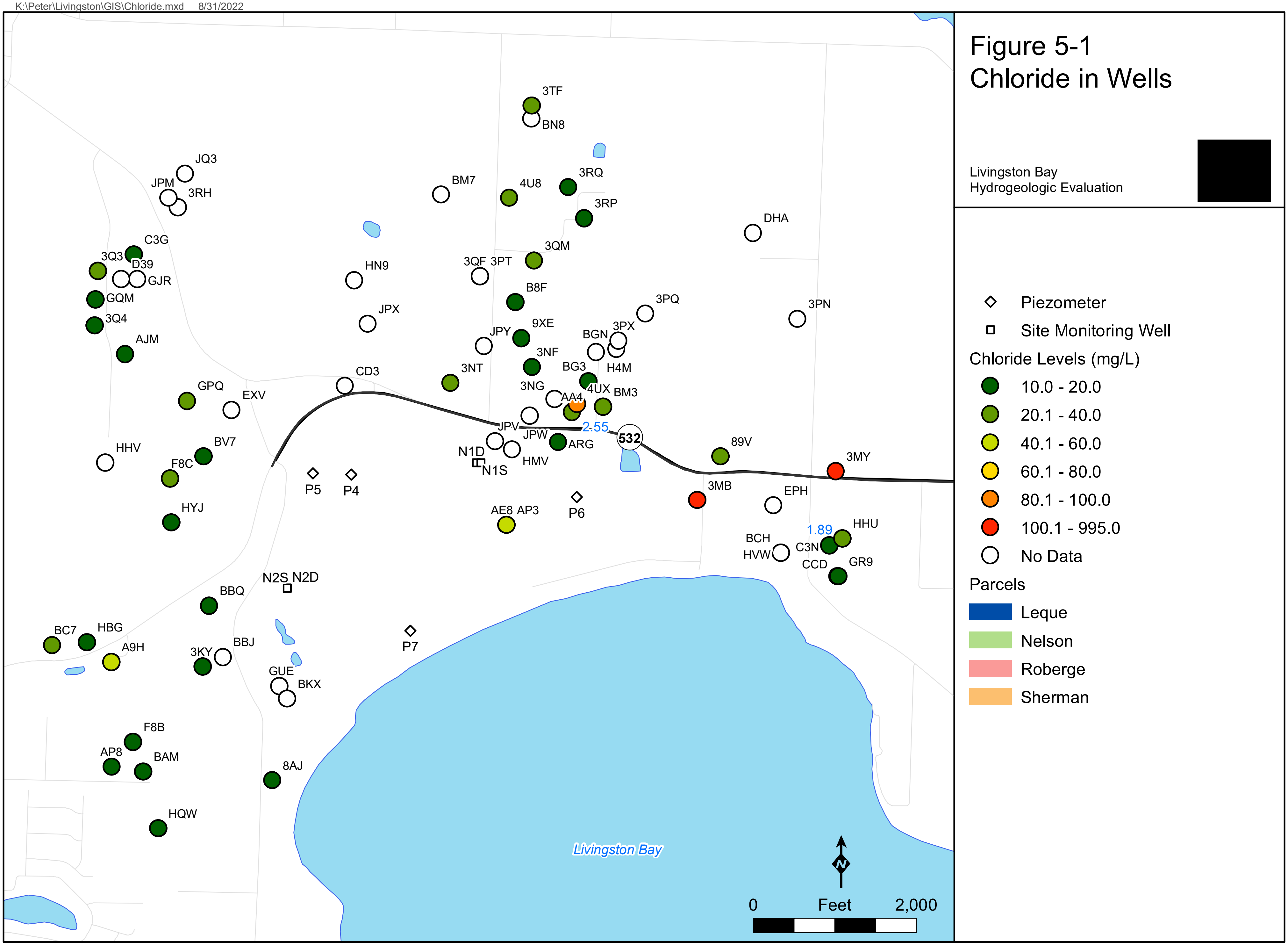
Figure 5-1
Chloride in Wells

Livingston Bay
Hydrogeologic Evaluation



APPENDIX PGG-A
WELL LOGS

Depth (ft)	Geology	Sample Recovery	Log	Well Construction

Log

Depth (ft)	Log
0	Loose, dry, light brown, clayey, SILT. (Trace organics)
	Medium stiff, moist, SILT. (Oxidation)
	Very loose, moist to wet, light gray, medium to coarse SAND. (Woody debris)
5	Loose, wet, gray, slightly silty, fine to coarse SAND. (Occassional gravels) 7 feet bgs Thin zone less than 1-inch, light brown, SILT.
10	Very loose, wet, gray, slightly silty, fine to medium SAND.
15	Medium stiff, wet, light brown to light gray, slightly clayey, SILT. (Trace fine sand)
20	Medium stiff, wet, gray to light green, CLAY and SILT.
25	
30	Hard, wet, light gray to gray, medium to coarse SAND. (Trace silt, occassional gravels)
35	Dense, wet, silty, gravelly, SAND.
	Hard, wet, light green, brown mottled, CLAY and SILT. (Occassional sands)
	Dense, wet, light brown to light gray, silty, fine to coarse SAND. (Occassional gravels up to 1-inch in diameter)
40	Hard, wet, light gray silty, fine to coarse SAND. (Occassional gravels up to 1-inch in diameter)
	Dense, wet, medium to coarse SAND. (Trace silt)
	Hard, moist, sandy, SILT. (Occassional gravels)
45	Dense, wet, fine to medium SAND. (Trace silt, heaving)
50	

Well Construction

Depth to water: water flowing, unable to measure at time of drilling

Flush mount steel monument.

Concrete (0-2 ft)

3/8-inch chip bentonite seal (2-43 ft)

2-inch diameter threaded schedule 40 PVC riser pipe with o-ring seals (0-45 ft)

6-inch diameter borehole (0-50 ft)

10-20 silica sand pack (43-50 ft)

2-inch diameter 20 slot PVC screen with a PVC threaded end cap (45-50 ft)

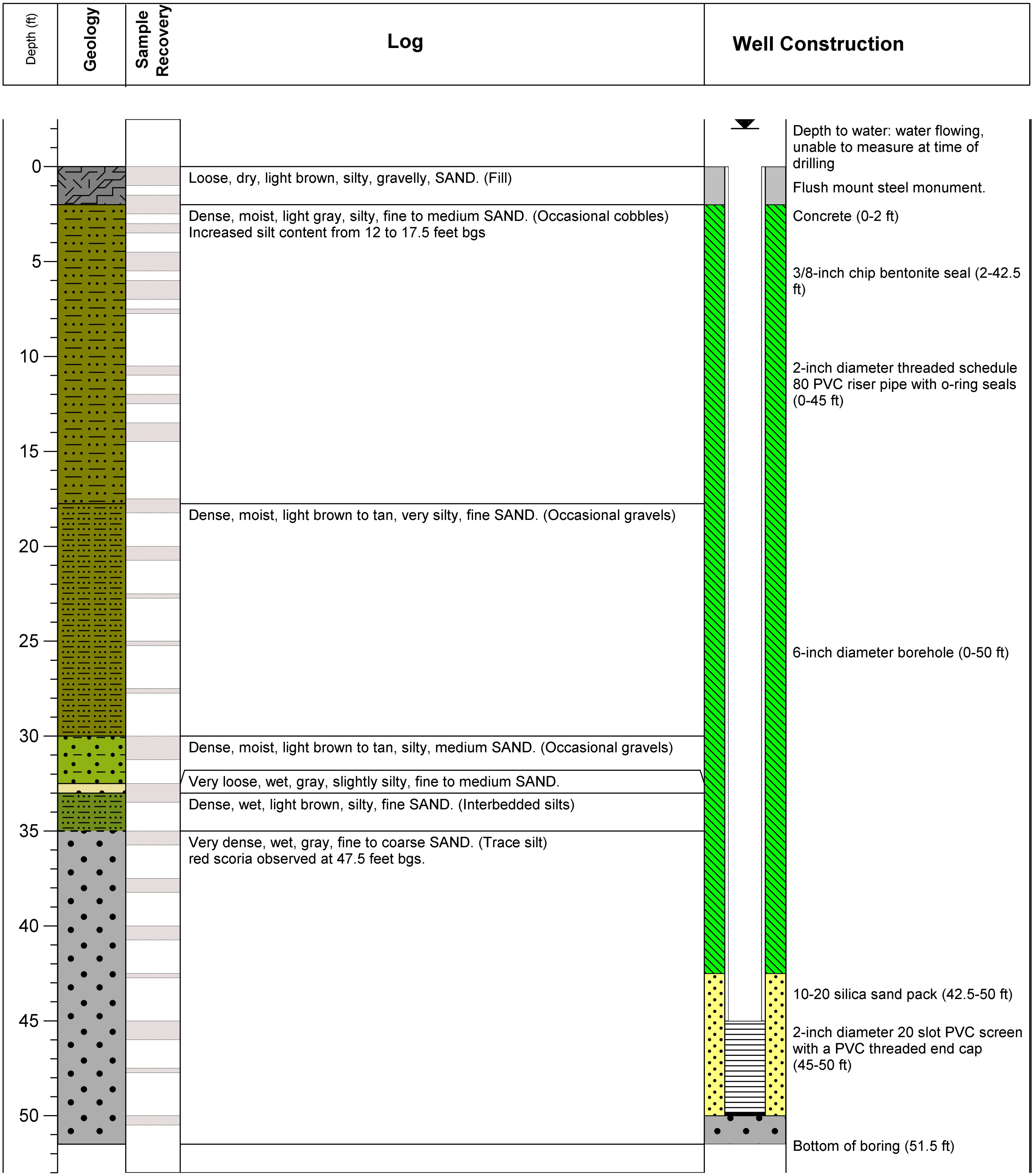
Bottom of boring (50 ft)

Project Name: Livingston Bay
Drilling Firm/ Method: Holocene Drilling/ HSA
Consultant/ Logged by: PGG/Travis Klaas
Depth to Water: Flowing
Vertical Datum: NAVD 88
Land Surface Elevation: 6.29 ft

Ecology ID: BMT 497
Drill Date: 7/20/2021
Horizontal Datum: NAD 83/11
Northing: 454920.8695
Easting: 1245352.398
BGS = below ground surface

FIGURE XX
GEOLOGIC LOG AND AS-BUILT
N2 DEEP
Livingston Hydrogeologic Evaluation
Camano, WA
JZ2141-518300090

PgG



Project Name: Livingston Bay
Drilling Firm/ Method: Holocene Drilling/ HSA
Consultant/ Logged by: PGG/Travis Klaas
Depth to Water: Flowing
Vertical Datum: NAVD88 (GRS80 Geoid 12B)
Land Surface Elevation: 5.94 ft

Ecology ID: BMT 498
Drill Date: 7/21/2021
Horizontal Datum: NAD 83/11
Northing: 456458.7795
Easting: 1247729.007
BGS = below ground surface

FIGURE XX
GEOLOGIC LOG AND AS-BUILT
N1 DEEP
Livingston Hydrogeologic Evaluation
Camano, WA
JZ2141-518300090

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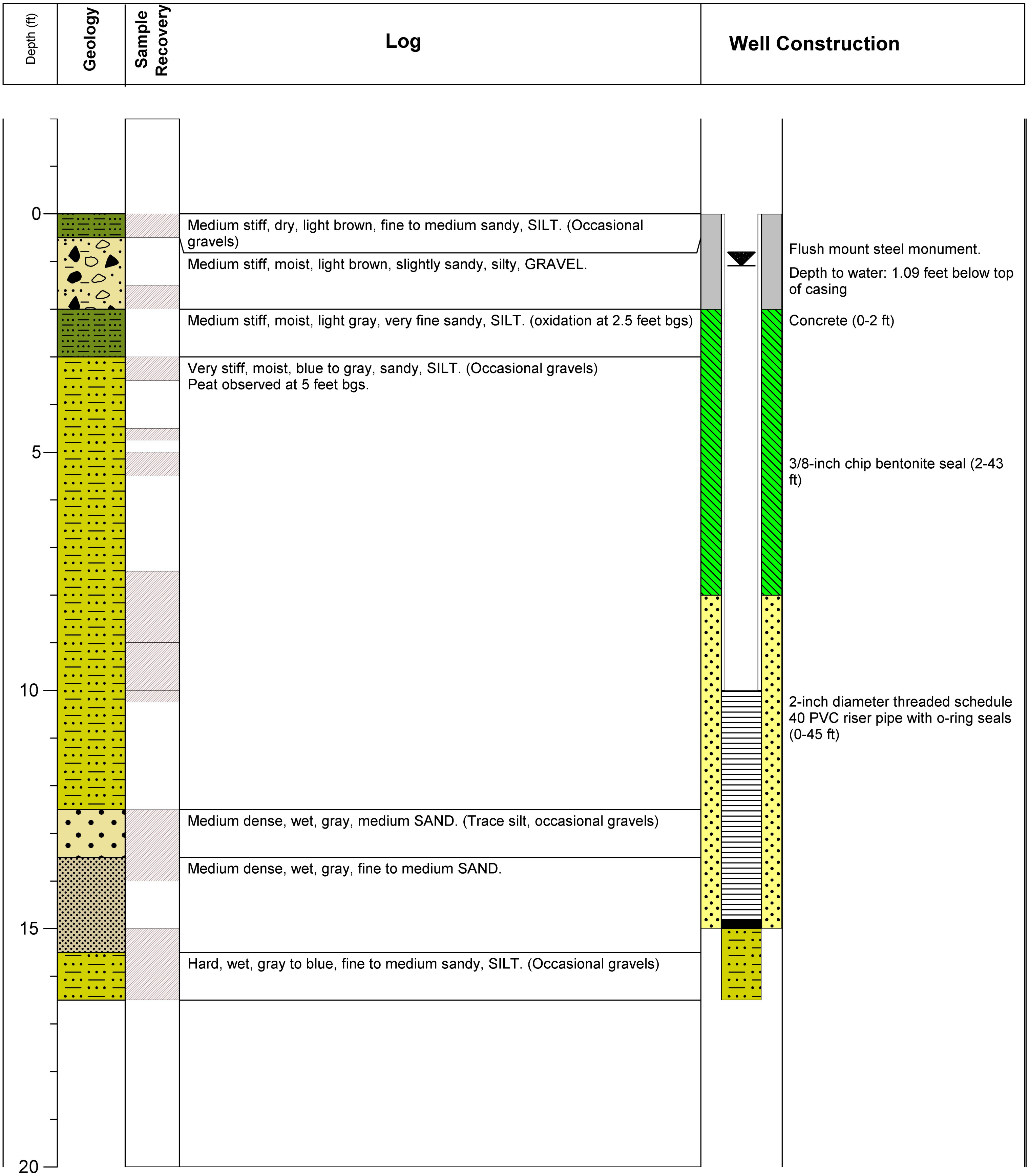

Project Name: Livingston Bay
Drilling Firm/ Method: Holocene Drilling/ HSA
Consultant/ Logged by: PGG/Travis Klaas
Depth to Water: 1.09
Vertical Datum: NAVD 88
Land Surface Elevation: 5.12 ft

Ecology ID: BMT 499
Drill Date: 7/20/2021
Horizontal Datum: NAD 83/11
Northing: 456458.3885
Easting: 1247674.771
BGS = below ground surface

FIGURE XX
GEOLOGIC LOG AND AS-BUILT
N1 SHALLOW
Livingston Hydrogeologic Evaluation
Camano, WA
JZ2141-518300090

PGG

Appendix E
Coastal Assessment and Tidal Channels

ESA

Coastal Assessment and Tidal Channels

Introduction

This memorandum summarizes Environmental Science Associates (ESA's) preliminary coastal process assessment at Livingston Bay to support the design and evaluation of conceptual design alternatives to restore tidal connectivity to Livingston Bay.

Once tidal connectivity is restored, and a channel is excavated, the inlet would be subject to geomorphic change, primarily from wind waves and tides transporting sediment. Since this would be a natural and dynamic system, some amount of geomorphic change is expected as waves and tides shape the inlet. However, if wave-driven sediment deposition overwhelms the tidal scouring, the inlet may become blocked and eventually closed at times. The primary purpose of this assessment is to establish inlet stability and tidal channel geometry for the proposed alternatives.

ESA reviewed historical maps and studies documenting physical processes and geomorphology in Port Susan and Livingston Bay, gathered and analyzed available topographic, wind, and water level data, and used this to estimate wind waves, wave runup, and inlet stability and assessed tidal channel geomorphology using empirical relationships.

Given the budget and schedule limitations, ESA relied on readily available public data and estimated only wind waves offshore of the project site. Further refinement is recommended in a future phase of work should the project proceed to a more detailed study and/or design level.

Summary of Findings

Based on the wave modeling, inlet stability analysis, and channel geometry analysis conducted for the proposed alternatives for tidal connection, ESA found the following:

1. Winds are predominantly from the south-southeast and north-northwest and range from 5 to 40 miles per hour (mph), with most wind velocities between 5 and 20 mph. The annual maximum hourly average wind speed is 30.9 mph, typically from the south-southeast, and the 10-year wind speed is approximately 38.7 mph from the southeast direction.

2. Wind waves approach Livingston bay from the South and Southeast direction. Most waves range from 1 to 2 ft with wave periods of 2-3 seconds. While larger waves range from 4 to 5 ft with wave periods up to 4 seconds.

3. Modeling of waves approaching the project site shows strong refraction as they approach and spread into Livingston Bay, and the modeling shows wave dissipation due to shoaling and waves breaking. The model results show that the west side of the project site is more protected from wind waves, while the east side is more exposed.

4. The preliminary coastal flood assessment indicates that for the typical berm crest elevation of 11.6 ft North American Vertical Datum of 1988 (NAVD88), the combined effect of water level and wave runup that will produce overtopping and inundation of the site is close to the 1-year event with present conditions. The frequency of coastal inundations at the site will increase due to sea level rise.

5. Offshore waves produce an average annual total wave power of $0.6x10^9$ ft-lbf/ft-year, ranging from 0.4 $6x10^9$ ft-lbf/ft-year to 0.85 $6x10^9$ ft-lbf/ft-year.

6. Mean Longshore wave power on the central channel show that waves will move sediment from west to east for all the modeling years. These results correspond to the defined litoral cells in the area that show sediment transport moving from west to east.

7. Evaluation of the proposed inlet alternatives using the Johnson (1973) stability diagram indicates that the evaluated inlet alternatives are well within the regime for always-open inlets. The proposed inlet remains in the always-open regime even with larger wave power and neap tidal prism.

8. The tidal prism through the inlet is likely to increase with sea level rise, which would enhance the inlet's likelihood of staying open in the future.

9. A mudflat pilot channel 1,500 ft through the mudflat is proposed to increase the tidal influence at the project site from 16 percent of the time to approximately 64 percent of the time.

Data Gathering

Topographic, wind, water level, and wave data were gathered as part of this study and were used as inputs for wind wave hindcast and wave modeling, wave runup and overtopping, and inlet stability. Details on the data sets used are described in this section. Where possible, long-term data sets were used to allow a more accurate statistical representation of extreme events.

Topography and Bathymetry

Topography and bathymetry were sourced from the 2014 Puget Sound 1/3 arc-second NAVD88 digital elevation model (DEM). The National Oceanic and Atmospheric Administration (NOAA) compiled the DEM using measurements throughout Puget Sound from 1894 to 2014. Light Detection and Ranging (LiDAR) with higher resolution data were used at the project site.

Water Levels

Water level data were taken from the Seattle and Tulare Beach stations (**Figure 1)**. Long-term water level records were obtained from the Seattle tide stations. **Table 1** lists the tidal datums from the Seattle Station and the station near the project site at Tulare Beach. Tulare Beach shows slightly higher values for most datums and up to +0.3 foot higher for mean lower low water (MLLW) and the expected highest astronomical tide (HAT).

TABLE 1
TIDAL DATUMS (EPOCH 1983–2001)

Tidal Datum	Abbrev.	Seattle Elevation, feet NAVD88	Tulare Beach Elevation, feet NAVD88
Highest Observed (1/27/1983)[1]	HOT	12.14 (4:36 a.m.)	–
Highest Astronomical Tide	HAT	10.92	11.22
Mean Higher High Water	MHHW	9.02	9.05
Mean High Water	MHW	8.15	8.20
Mean Tide Level	MTL	4.32	4.45
Mean Sea Level	MSL	4.3	4.43
Diurnal Tide Level	DTL	3.34	3.51
Mean Low Water	MLW	0.49	0.71
North American Vertical Datum	NAVD	0.00	0.00
Mean Lower Low Water	MLLW	-2.34	-2.03
Lowest Astronomical Tide (6/22/1986)	LAT	-6.64	-6.50
Lowest Observed (1/4/1916)[1]	LOT	-7.38 (0:00 a.m.)	–

NOTES: Abbrev. = abbreviation for tidal datum; NAVD88 = North American Vertical Datum of 1988
1 The highest and lowest observed tide data are based on the recorded six-minute measurements.
SOURCE: NOAA 2022

Wind Data

Wind data were collected from the four nearby meteorological stations listed in **Table 2** and shown in **Figure 2**: Arlington Airfield (AWO), Oak Harbor (OAK), Whidbey Naval Air (NUW), and Paine Field (PAE).

TABLE 2
WIND DATA RECORDS EVALUATED IN THIS STUDY

Station Name	ID	Years of Record	Source
Arlington Airfield	AWO	1996–2022	ASOS
Oak Harbor	OAK	1981–2008	ASOS
Whidbey Naval Air	NUW	1945–2022	NAS
Paine Field	PAE	1941–2022	ASOS

Wind data from the four stations were analyzed using MATLAB to summarize direction and statistics. Wind data from Arlington Airfield were selected because of the similarity of wind distribution with the orientation of Port Susan Bay and the long record. The raw data were evaluated, and questionable values were removed. Data were adjusted to a standardized duration of two minutes and corrected from wind overland to wind over water according to Resio and Vincent (1977) and the *Coastal Engineering Manual* (CEM) (USACE 2006).

Wind Analysis

Winds in Puget Sound are generated by the interaction of atmospheric forcing and the region's topography, resulting in local patterns on the order of 3 miles (Overland and Walter 1983). Wind patterns within Port Susan are generally understood to follow along the topography of Camano Islands and Port Susan Bay.

ESA reviewed regional wind data at the nearby station Arlington Airfield. The wind record at Arlington Airfield station (1996–2021) was selected because of its proximity (13 miles to the southeast) and directional distribution that aligns with the shorelines of Port Susan Bay. The hourly wind data were adjusted as described in the previous section. **Figure 3** shows the wind speed time series from 1996 to 2021. **Figure 4** shows the annual wind speed distribution and direction for the adjusted data at Arlington Airfield station. Wind direction is reported in the typical meteorological convention (the direction from which the wind is blowing). Winds most commonly blow from the north and northwest and from the south and southeast, consistent with wind patterns at stations throughout Puget Sound. Winds from the south and southeast exhibit the highest wind speeds, reaching maximums that exceed 25 mph. **Figure 5** provides a seasonal distribution of winds, exhibiting a typical pattern dominated by south winds during the winter, north winds in summer, and mixed winds from the north and south during other seasons.

All of the wind roses show a bimodal distribution of wind directions consistent with regional meteorology, and the wind distribution at Arlington Airfield follows the expected directional distribution of winds at Port Susan and Livingston Bay.

Extreme Wind Speeds

The adjusted Arlington Airfield data were used for an extreme-value analysis of the annual maximum wind speed (**Figure 6**). For each of the 26 years in the record, the annual maximum wind speed from any direction was identified, and these annual maximums were fit to a Generalized Extreme Value (GEV) function. The Gumbel and Weibull extreme-value functions were also tested on the annual maximums, but these functions did not provide as good a fit to the data as the GEV function. Results show that one-year events reach up to 30.9 mph, and a 10-year event will reach wind speeds up to 38.7 mph (**Table 3**).

TABLE 3
EXTREME WIND SPEED VALUES

Return Period (years)	Wind Speed (miles per hour)
1	30.9
2	34.0
5	36.7
10	38.7
20	40.8
50	43.8
100	46.3

Wave Analysis

ESA employed numerical methods to simulate wave conditions offshore of the project site. This analysis aimed to estimate the size, frequency, and directional distribution of nearshore wind waves arriving in Livingston Bay. This information was used to support the project site's wave runup analysis and inlet stability.

Wind Wave Hindcast

A wind-wave hindcast is a calculation of wave conditions using measured winds and other data associated with the geometry of the water body, which in this case, is the Port Susan Bay area. Wind wave hindcasting is performed in the absence of measured wave data. The wind speed and direction, duration of the wind, length across which the wind is blowing (fetch), and water depth across that fetch are the parameters that determine the wave height, wave period, and direction of the locally generated wind waves at the site. There are several methods for computing wind-wave generation. This study used empirical equations published by the U.S. Army Corps of Engineers in its CEM (USACE 2006) for estuaries, bays, and smaller water bodies where the land limits the area available for wave growth.

The methods used in this study are consistent with more detailed contemporary models as shown in previous studies in the Puget Sound area (PWA 2004; FEMA 2005; ESA 2016, ESA 2017a, and ESA 2017b).

The wave hindcast modeling methodology is called “composite fetch” because it represents the open-water wind generation area by a fan of fetch lines emanating upwind from the location of wave prediction. “Fetches” are the areas of open water available for wind wave generation. When the length of a fetch limits wave growth, as is the case for Port Susan Bay, the conditions are considered “fetch-limited” rather than “duration-limited.”

While local winds generate the waves that drive geomorphic processes at Livingston Bay, the shoreline’s location relative to other landforms constrains the wind waves that reach the bay to a limited number of dominant fetches. The geometry suggests that southeasterly fetches are especially important for generating waves that arrive at the site. The fetch lengths for the study were obtained by drawing straight lines from a point inside Livingston Bay to the nearest land boundary on the upwind side at 10-degree intervals. **Figure 7** shows the fetches used on this study.

Hindcast Wave Time Series

Significant wave heights for individual fetch directions were first calculated using the CEM method. The wave hindcast resulted in a time series of hourly wave conditions for a 26-year period (1996–2021) representative of the conditions at the mouth of Livingston Bay. The results are shown in **Figure 8**. Gaps in the time series indicate times when wind or tide data were not available to generate hindcast conditions. Most of the waves range from 1 to 2 ft in wave height and wave periods from 2-3 seconds. Large waves are between 3 to 5 ft and with wave periods up to 4 seconds. **Figure 9** shows the offshore wave height and wave direction distribution at the mouth of Livingston Bay. Wave direction is reported in meteorological convention (the direction of where the waves are coming from). Waves arriving from the southeast at 150 to 170 deg are the most common and with the highest wave heights (> 3ft) which coincides with the longest fetch direction at Port Susan Bay as shown on **Figure 7.**

Extreme Wave Analysis

An extreme value analysis was conducted on the estimated 26-year wave height time series. A maximum wave height value for each year was found and fit to Gumbel, Weibull, and GEV distributions, with the GEV MPS (Maximum Product of Spacings) distribution showing the best fit (**Figure 10**). **Table 4** summarizes the return periods from the GEV distribution. The one-year event is below a wave height of 3 ft and the 100-year significant show a wave height estimated of 6.5 ft.

TABLE 4
WAVE EXTREME ANALYSIS

Return Period (years)	Wave Height (feet)
1	2.7
2	3.4
5	4.0
10	4.5
20	5.0
50	5.8
100	6.5

Wave Modeling

Wave height, length, and direction transform as waves propagate into shallow water. The primary transformation processes in Port Susan Bay and Livingston Bay are shoaling and refraction. During shoaling, a wave slows and increases in height and steepness. Shoaling waves tend to lose energy due to higher water velocities and ultimately break when their steepness exceeds a threshold also dependent on the waves and depths. Refraction is the change in wave direction that occurs as waves enter shallow water at an angle to the bottom elevation contours. Refraction can cause waves to focus and, in cases like Livingston Bay, to spread and lose height.

The wave field at Port Susan and Livingston Bay is characterized by wind waves propagating into shallow water from deep water. As the waves propagate from deep to shallow water, their direction and heights transform. This transformation process was simulated using a two-dimensional wave model developed for and applied to the project site. The Simulating Waves Nearshore (SWAN) model was used to predict the wave conditions likely to occur in response to the wind speed, wind direction, water level, and bathymetry. SWAN is a two-dimensional wave model that employs third-generation wave processes. The relevant wave processes included in the SWAN model include generation, refraction, shoaling, and breaking. The SWAN model was implemented using the Delft3D modeling suite (Deltares 2014). **Figure 11** shows the model extents and the model grid geometry. An example of model wave height and direction for an extreme wind event at 40 mph is shown in **Figure 12** from winds coming from the south (180 degrees) and southeast (150 degrees).

For these wind conditions, the model predicts significant wave heights of approximately 3.5 ft offshore of the project site and wave heights of about 2 to 2.5 ft in the nearshore adjacent to the project site. Results also show strong refraction and shoaling effects as the waves enter Livingston Bay.

Coastal Flooding

Wave runup was modeled using the estimated wave parameter time series (See Wave Analysis Section) and the still-water-level time series applied to a beach slope of 12:1, and the Direct Integration Method was used to calculate hourly wave runup (FEMA 2005). Total water levels (TWLs) estimated using simplified slopes are typically higher than TWLs calculated using actual profiles because the simplified slope is projected vertically above the actual shoreline profile elevations to simulate the potential wave runup and TWL at the shoreline.

TWL is estimated by combining the water levels near the site, the coincident wave runup on the shore and the expected sea level rise according to the following relationship:

$$TWL(t) = SWL(t) + Wave\ Runup(t) + SLR, \text{ where } t \text{ is time}$$

Extreme Total Water Level Analysis

An extreme value analysis of the estimated 26 years of the total water level time series (shown above) was conducted. A maximum wave height value for each year was found and fit to Gumbel, Weibull, and GEV distributions, with the GEV PWM distribution showing the best fit (**Figure 13). Table 5** summarizes the return periods from the GEV distribution for present conditions and for future conditions with sea level rise.

TABLE 5
TOTAL WATER LEVEL ANALYSIS

Return Period (years)	Annual Probability of Occurrence	TWL Present (ft)	TWL 2030 (ft) 0.5 ft	TWL 2050 (ft) 1.0 ft	TWL 2100 (ft) 2.0 ft
MHHW	Daily	9.02	9.52	10.02	11.02
1	100%	11.4	11.9	12.4	13.4
2	50%	12.3	12.8	13.3	14.3
5	20%	12.8	13.3	13.8	14.8
10	10%	13.1	13.6	14.1	15.1
20	5%	13.3	13.8	14.3	15.3
50	2%	13.6	14.1	14.6	15.6
100	1%	13.8	14.3	14.8	15.8

NOTES: ft = feet; MHHW = mean higher high water; TWL = total water level

Results show that the 1-year event is close to overtopping the existing berm (present berm crest elevation at 11.6 ft, NAVD) and by the year 2030, overtopping of the berm is likely to have a one-year frequency, and by the year 2050 these events will likely occur multiple times a year. Sea level rise estimates used in this study are considered medium risk (See Appendix C, Table 5).

Geomorphic Setting

The beach fronting the proposed inlet area is composed primarily of fine sands and mud and armored with logs. The beach backshore is short, with a berm elevation of 11.6 ft NAVD88. The beach transition to the mudflat is less than 30 ft. The berm elevation is formed by the waves and tides and the location of the logs. Decaying logs appear to be the main material of the berm.

Livingston Bay's shoreline can be considered 'swash-aligned'. A swash-aligned beach is oriented, facing the predominant waves at a particular site, such that the larger wave fronts tend to reach the beach (after the shallow bay bottom refracts the waves). This is true of Livingston Bay's shoreline, which has aligned itselft to the predominant wave direction **(Figure 14).**

The project shoreline exists as part of the littoral cell WRIA 6-ISLAND Section 29, which moves from west to east (left to right when facing the shoreline from the bay). A littoral cell east of the project site (section 29) shows transport from east to west. The littoral cells are depicted in **Figure 15.** Detailed evaluations of drift at the project site scale are not available from prior analyses.

Wave Power

Total wave power at a site, and the longshore component of wave power, are useful parameters for analyzing inlet stability. This is because wave power is closely related to sediment transport, so it can be used as a surrogate for understanding how the bed of the inlet may experience changes (e.g. filling with sediment) under certain wave conditions or how the inlet may migrate laterally across the beach. Estimated wave power, 'P' (in units of ft-lbf/s/ft of crest length), is calculated as:

$$P = \frac{\gamma g H^2 T}{32\pi}$$

Where γ is the unit weight of seawater (64.1 lbf/ft^3), g is the acceleration of gravity (32.2 ft/s^2), H is the root-mean-square wave height (ft), and T is the wave period. For each hour of the wave hindcast time series, wave power was computed using the equation above, and an offshore wave power time series was generated. The total wave power per year from 1996 to 2021 is shown in **Figure 16** and **Table 6** summarizes the results of the wave power computations. As shown in the table, offshore waves produce an average total annual wave power of 0.6x109 ft-lbf/ft-year, ranging from 0.4 6x10^9 ft-lbf/ft-year to 0.85 6x10^9 ft-lbf/ft-year. **Figure 17** shows the mean wave power per month, showing the months with the most energy from January to March and October to December.

TABLE 6.
ANNUAL WAVE POWER OFFSHORE OF PROJECT SITE

Year	Wave Power (ft-lbf/ft-year)	Year	Wave Power (ft-lbf/ft-year)
1996	0.47×10^9	2009	0.52×10^9
1997	0.85×10^9	2010	0.67×10^9
1998	0.75×10^9	2011	0.70×10^9
1999	0.87×10^9	2012	0.65×10^9
2000	0.53×10^9	2013	0.50×10^9
2001	0.63×10^9	2014	0.58×10^9
2002	0.66×10^9	2015	0.58×10^9
2003	0.61×10^9	2016	0.59×10^9
2004	0.42×10^9	2017	0.41×10^9
2005	0.48×10^9	2018	0.49×10^9
2006	0.70×10^9	2019	0.38×10^9
2007	0.79×10^9	2020	0.66×10^9
2008	0.53×10^9	2021	0.63×10^9
		Average	$\mathbf{0.60 \times 10^9}$

The directionality of the wave power (known as the 'longshore' component of wave power, $\mathbf{P_{ls}}$) is calculated as $\mathbf{P_{ls} = P \sin\alpha \cos\alpha}$, where α is the wave angle relative to the shore normal angle. The longshore component of wave power gives an estimate of the directionality and wave energy variability on the nearshore. This is important because the direction of wave power can influence the direction of inlet migration and because the rate of transport can influence the speed of migration. **Figure 18** shows the mean longshore wave power as a daily and monthly average for the whole wave record for the beach in front on the central channel (Scenario 1 and 2 from the Feasibility Study Report, Figure 4 and 5) and on the west channel (Scenario 3 from the Feasibility Study Report, Figure 6). Results show that longshore wave power moves from west to east for both locations, with a stronger signal from the west channel and smaller wave power longshore component at the central channel.

Inlet Stability Approach

Tidal inlets are dynamic systems whose geomorphology is determined by complex interactions of tides, waves, and sediment transport. Because the tides oscillate in both directions, and there is two-way coupling between the flow and the bed, an assessment of long-term inlet stability is challenging to characterize with just hydrodynamic modeling or even hydrodynamics coupled with sediment transport modeling. Hence, inlet analyses typically consider applied geomorphology as well.

Tidal inlets whose openings are stable maintain a balance between wave-driven processes that tend to close the channel and tide-driven processes that tend to scour it. As such, inlet stability is often assessed by comparing these opposing processes.

Wave power can characterize the sediment input, while tidal prism (the volume of water exchanged during a tidal cycle) can characterize the scouring influence of tides. Additionally, examining nearby reference inlet sites with similarities can be used to better understand the potential inlet stability at the site.

One common way to assess the potential for inlet stability is to apply a diagram that arranges different inlet sites by the relative wave power they receive and by their tidal prism. This is based on the approach by Johnson (1973), who compiled data from reference lagoons in California spanning a range of average annual wave power and diurnal tidal prism. Based on the groupings of these data, Johnson classified inlets as open, seasonally open, or mostly closed, depending on the relative balance of wave power versus tidal prism. Historically, this approach has been largely used at sandy beach sites, but Puget Sound sites have also been added as part of the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP 2011).

Figure 19 shows Johnson's (1973) classification diagram, with additional modifications (Battalio et al. 2007), and data from inlets through sand and gravel beaches, including several Puget Sound sites. Inlets with high wave power (i.e., greater sediment deposition in the inlet) relative to tidal power (i.e., scouring capability) tend to be closed most of the time and cluster in the upper left portion of the figure. Inlets with low wave power relative to tidal power tend to be open and cluster in the lower right portion of the figure. Inlets close to the threshold between open and closed may alternate between open and closed as waves and tides experience their natural fluctuations. **Figure 19** shows the results for the tidal prism of the proposed inlet scenarios (**Table 7 and Figure 4 thorugh 6** on the Livingston Feasibility Study report) and the wave power estimated in the section above. Results show that all cases evaluated are on the open inlet section.

While the use of this diagrammatic approach indicates open-inlet conditions may be expected due to the estimated wave and tide conditions, it is important to understand that the beach composition at the site is much more variable than that of many of the reference sites included in the diagram. In particular, the presence of large woody debris, especially at the upper extents of the beach profile, makes it challenging to rely solely on predictive methods. Debris could partially or fully block the inlet at times and could encourage or impede the ability of the inlet to migrate naturally on the beach.

TABLE 7.
ANNUAL WAVE POWER OFFSHORE OF GREENBANK MARSH

Scenario Num	Scenarios	Tidal Prism (acre-feet)
1	Partial Restoration	430
2	Partial Restoration with Land Swap	390
3	Full Estuary Restoration Central Outlet	300
3	Full Estuary Restoration West Outlet	400

Tidal Channels

The conceptual channel layout for Livingston Bay shown in the conceptual design drawings is based on several primary objectives:

- The channel layout and breach location is limited by the alignment of levees needed to protect non-project areas for each alternative. The number of channel breaches is limited for Alternative 1 and 2 to a single breach due to the limited shoreline area within the project bounds.
- Channel geometric design follows local guidance on hydraulic design of tidal channels. ESA relied on the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) Conceptual Engineering Appendix guidance for hydraulic channel design (PSNERP 2011). The estimate is consider a first approach on estimating channel sizing and do not consider subsidence at the project site.
- Historical channel alignments on-site were reoccupied to the extent possible. Historical channel alignments are preferred hydraulic pathways for water flowing across the site and are most likely self-sustaining.
- Where historical channel alignments are unknown, channel shapes from nearby historical channels in similar restoration sites or the neighboring Skagit River Delta were transposed and replicated at Livingston Bay. Channels were placed in low-lying areas of the site to facilitate connectivity and to reduce excavation costs.
- Channel density and sinuosity are based on observed historical channel alignments within the site, other nearby Port Susan Bay estuary restoration sites, and in the Skagit River delta.
- Channels are roughly aligned with existing agricultural ditches to the extent possible to minimize construction costs.
- Future design refinements should adjust channel layout for patterns of shear stress (erosion and deposition) based on 2D numerical modeling results. Channels and other grading elements should be refined using model results to ensure good site connectivity, minimize high-velocity hot spots, and maximize channel sustainability.
- Future design refinements should compare the channel sizing using other available hydraulic geometry sizing methods, such as those from Skagit River Systems Cooperative and Blue Coast Engineers (in development).

Tidal Geometry

Geometry design guidelines for the Puget Sound region were used to develop long-term equilibrium channel dimensions, including cross-sectional area, depth, and width, based on regressions developed for San Francisco Bay but scaled to tidal characteristics observed in Puget Sound. **Table 8** summarizes the channel sizing that goes from the outlet, primary, and secondary channels. **Figure 20** shows a graphical representation of the typical sections of the tidal channels described in **Table 8**.

TABLE 8.
CHANNEL SIZING

Channel	Top Width (feet)	Depth (feet below MHHW)	Side Slopes
Outlet	100	13	4:1
Primary	75	9	4:1
Secondary	45	7	2:1

NOTE: MHHW = mean higher high water

Mudflat Pilot Channel

The time scale for the outboard channel to scour to an equilibrium dimension that does not induce tidal muting of the site could take several years. This implies that tidal action at the project site, particularly at tides lower than 8 ft NAVD may be muted for several years after breaching and may influence the habitat establishment rate.

Dredging of a mudflat pilot channel through the outboard mudflat is proposed to help accelerate this process. This will allow the project site to increase regular tidal inundation and “washing” of the imported soil, which is needed to alter the soil's physical and chemical components that support wetland vegetation. This higher variation in elevation on the project site will allow different types of vegetation to establish and provides an allowance for vertical uncertainties in tidal hydraulics effects and vegetation establishment elevations. The proposed pilot channel will be approximately 1,500 feet long through the mudflat and will reach an elevation of 4 feet NAVD88 at the mudflat. **Figure 21** shows that with this pilot channel, the estuary will be subject to tidal influence about 64 percent of the time instead of only 16 percent of the time if no pilot channel is included in the restoration.

Discussion

Based on the available information, ESA believes that the proposed inlet would very likely be stable and remain open.

The wave analysis presented above is consistent with nearby observations, and it produced wave power results similar to those produced by other efforts by ESA at similar exposed shorelines in Puget Sound (ESA, 2015, 2016, 2017a, 2017b).

According to the Johnson (1973) classification, the proposed inlet is positioned well away from the open/closed threshold. This implies that its tidal prism provides a fair amount of resilience to closure. Increases in Puget Sound water levels as a result of projected sea level rise would increase the duration and depth of flow through the inlet, yielding a larger tidal prism. Because a larger tidal prism is associated with increased stability of an open inlet, future sea level rise would enhance the inlet's likelihood of staying open.

A pilot channel through the mudflat approximately 1500 feet long connecting the project site with the mudflat at Elevation 4.0 ft, NAVD is proposed to increase tidal influence at the project site from 16 percent of the time to approximately 64 percent of the time.

Inlet Design Recommendations

Based on the findings from the analyses described above, as well as the project team's experience with the management and restoration design of other tidal inlets, ESA recommends that the design of the Livingston Bay inlet consider the following refinements:

- Over-excavate the inlet channel to provide additional accommodation space for sedimentation, thereby providing additional resilience to short-term inlet closure. Over-excavation will likely induce sediment capture until an equilibrium condition is attained.

- Place material excavated from the channel east of the inlet mouth on the shoreline. This placement site would move sediment to the downdrift side of littoral transport, where it is unlikely to be transported into the inlet.

- Dredge a pilot channel through the mudflat to increase tidal inundation and tidal interaction at the project site.

Proposed Future Work

A future phase of work should consider including the following factors beyond the scope of this memorandum.

Nearshore Waves Estimate. Estimates of wave transformation from deep to shallow water and the refraction, shoaling and wave breaking of the waves nearshore were done for a few cases with the model

SWNA . Predicting the nearshore wave climate at the site for the full wind wave time series (26 years) will improve the estimations of wave power and longshore sediment transport rates at the site and coastal flooding estimates.

Sediment Transport versus Tidal Prism. Bruun and Gerritsen (1960) classify the stability of an inlet by evaluating the ratio of spring tidal prism to total annual littoral drift. This ratio, often called the Bruun ratio, characterizes the capacity of tidal flows to scour sediment entrained by the inlet from the littoral drift.

Tidal Inlet Geometry versus Tidal Prism. Hydraulic geometry relationships between the tidal prism and the cross-sectional area of the inlet channel have been verified with a large amount of empirical evidence (Jarrett 1976; Townsend 2005). Hughes (2002) extended the relationship for smaller inlets. Reference channels at nearby lagoons may provide valuable insight on channel morphology and design.

Inlet Morphology. As geomorphic features linked to the inlet, flood and ebb shoals are relevant factors in the inlet's sediment budget and long-term morphology. Constraints on the natural migration of the inlet relative to longshore sediment transport should be considered.

Episodic Closure. In addition to the average annual wave conditions, the proposed inlet may be vulnerable to closure during large storm events that could close the inlet, overwhelming it with sediment before tidal forces could be mobilized to scour away deposited materials. Estimates of extreme-wave scenarios generated by high winds aligned with the maximum fetch would be needed to evaluate potential event closures of the inlet.

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FIGURES

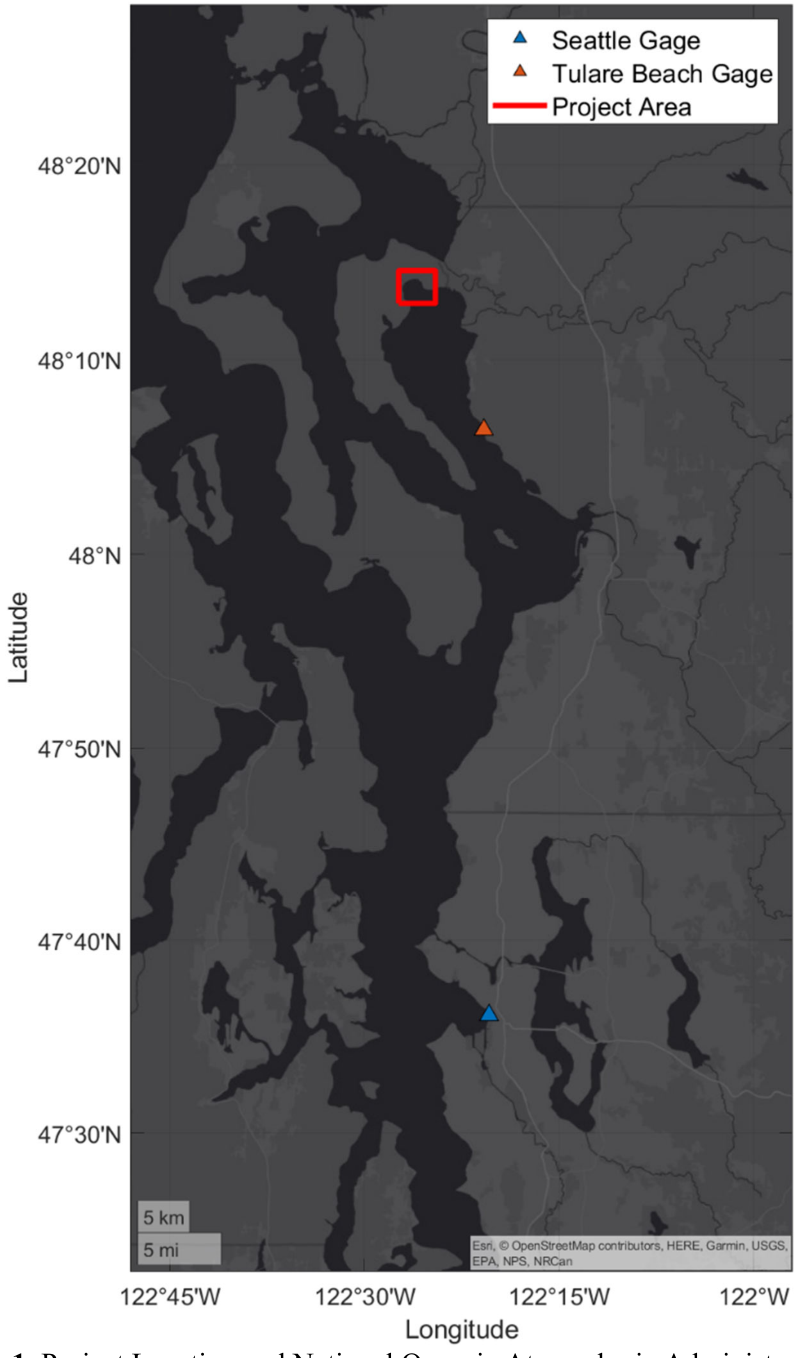


Figure 1. Project Location and National Oceanic Atmospheric Administration Tide Gages

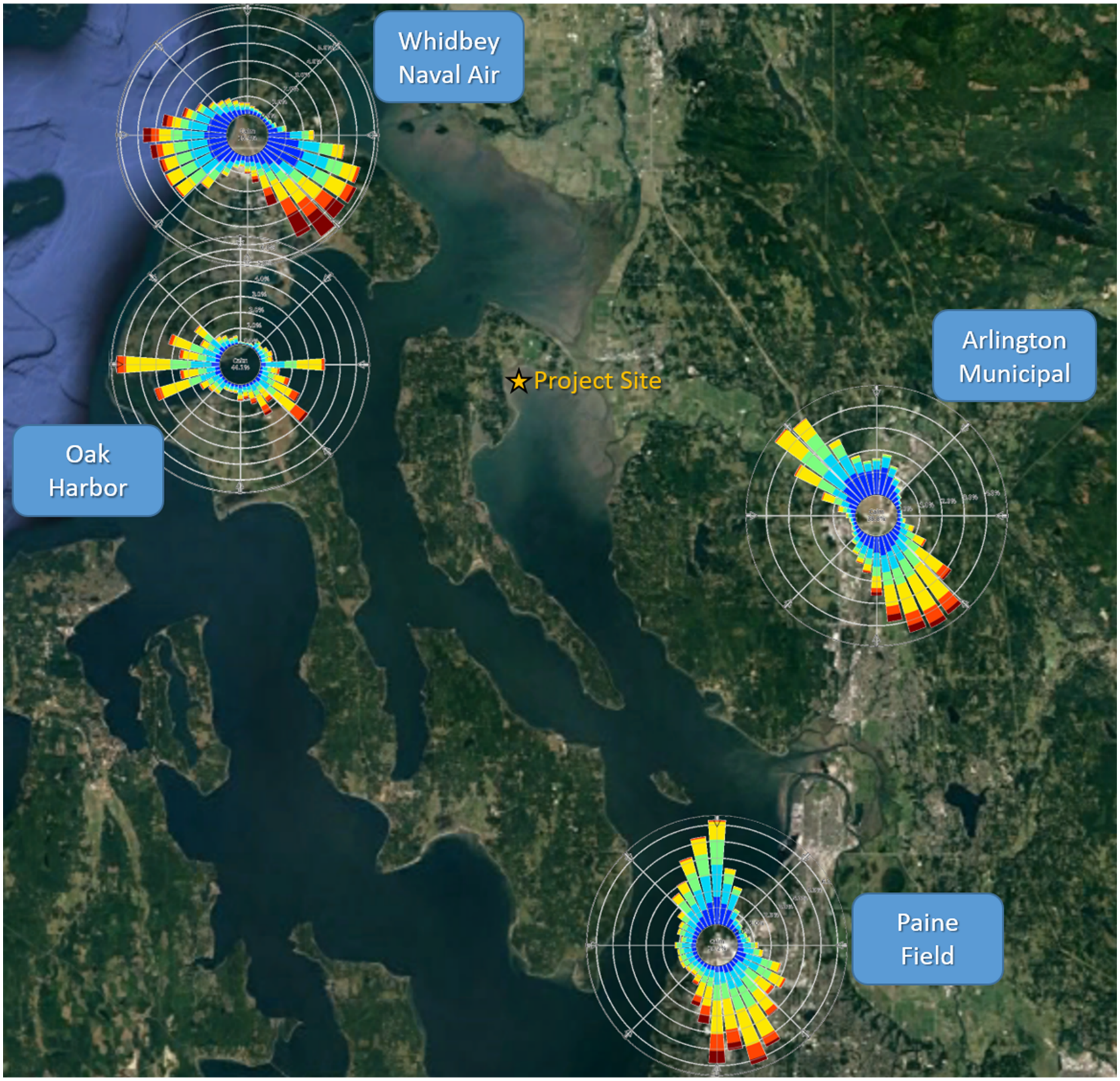


Figure 2. Wind Data at Nearby Stations

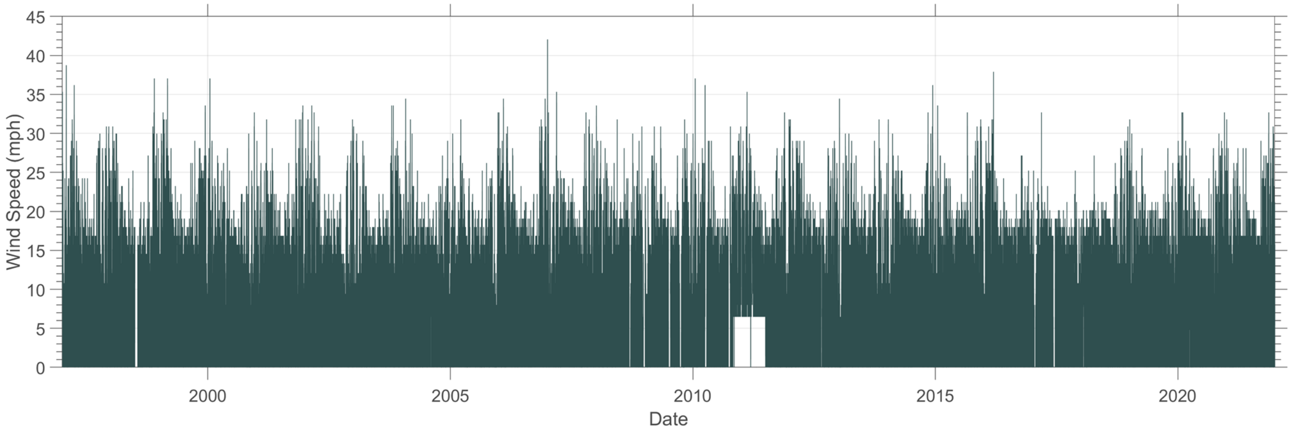


Figure 3. Wind Time Series, 1996 to 2021

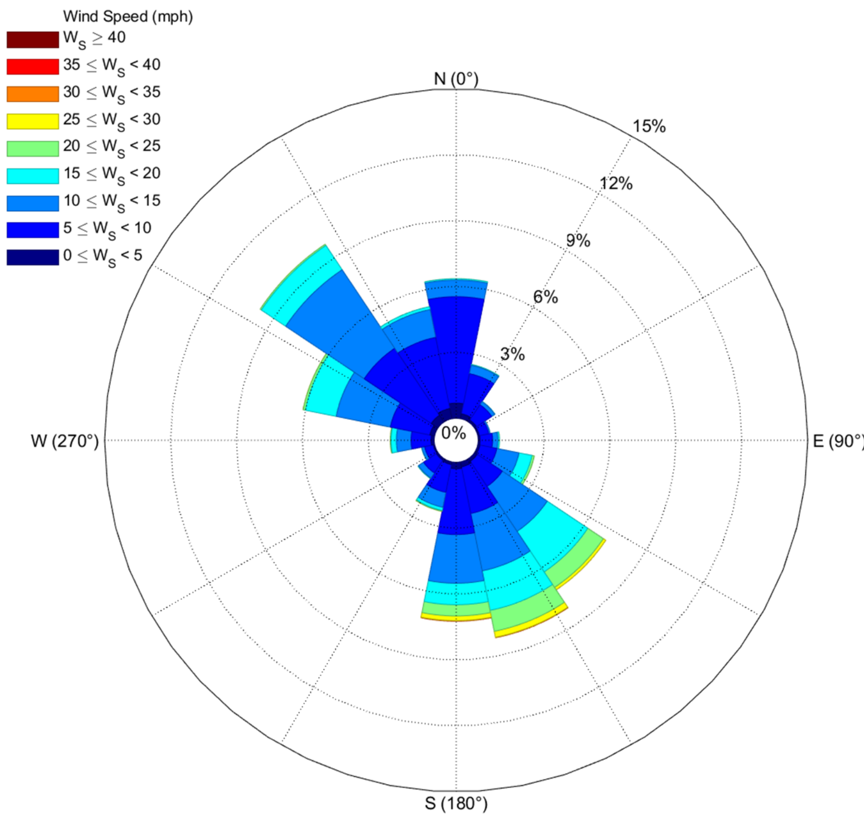


Figure 4. Arlington Airfield Station—Annual Distribution of Wind Direction

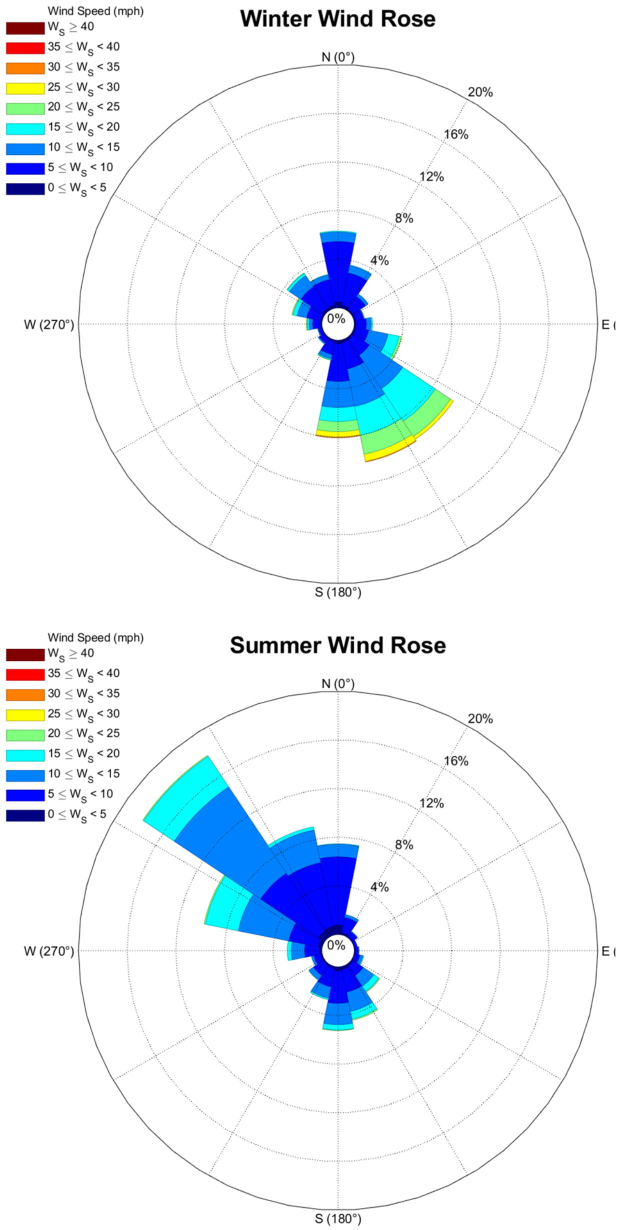


Figure 5. Arlington Airfield Station—Seasonal Wind Roses

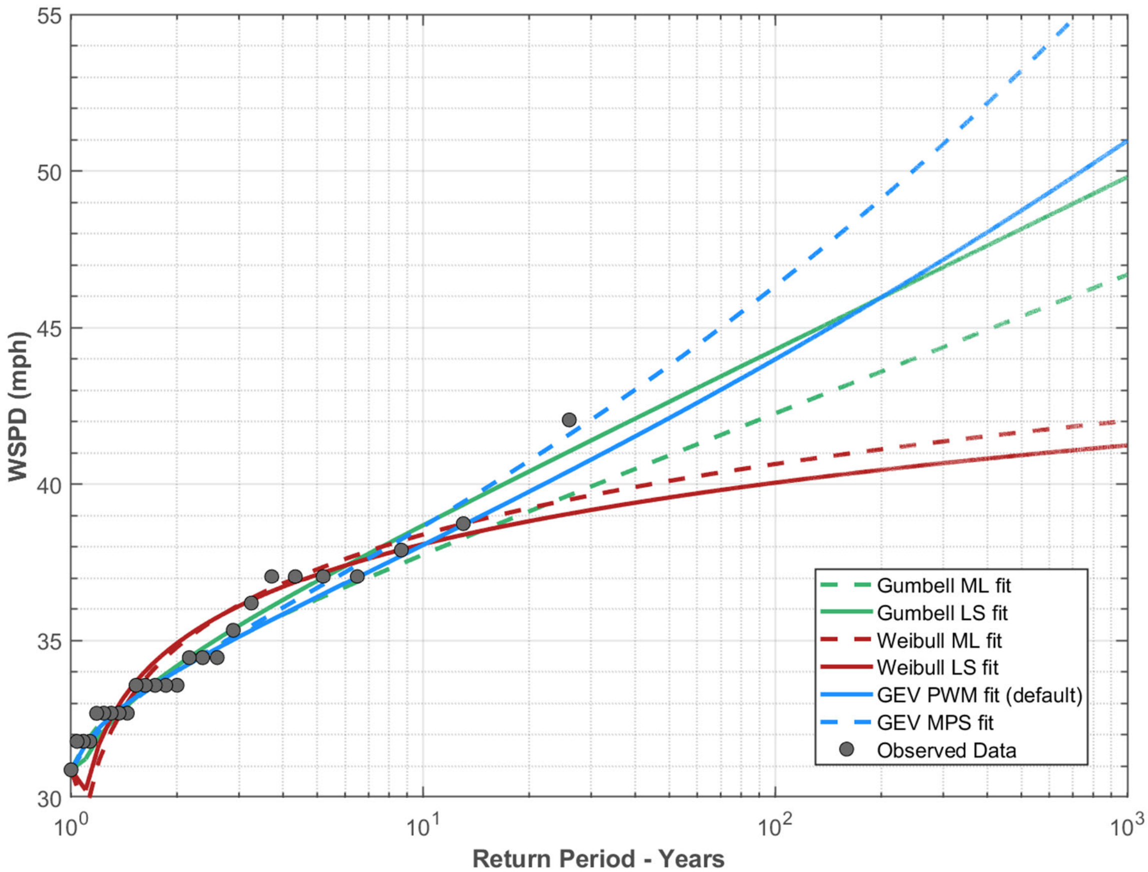


Figure 6. Wind Extreme Value Analysis

Figure 7. Fetch Directions for Livingston Bay

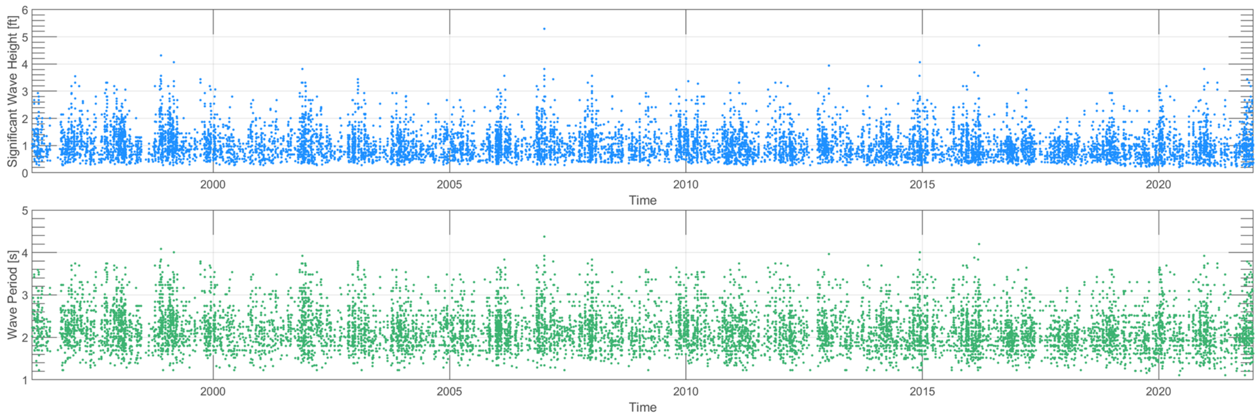


Figure 8. Wave Time Series from the SWAN Model Implementation for the Significant Wave Height (top), Peak Wave Period (bottom) from 1996 to 2021

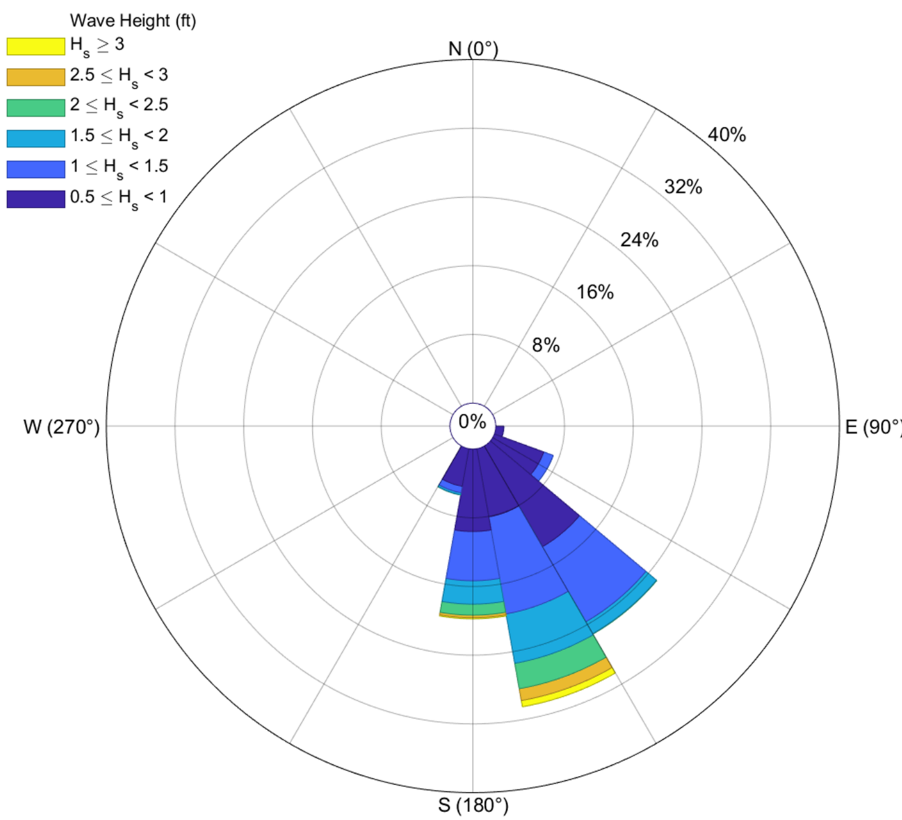


Figure 9. Offshore Wave Distribution from the Wind Wave Time Series from 1996 to 2021

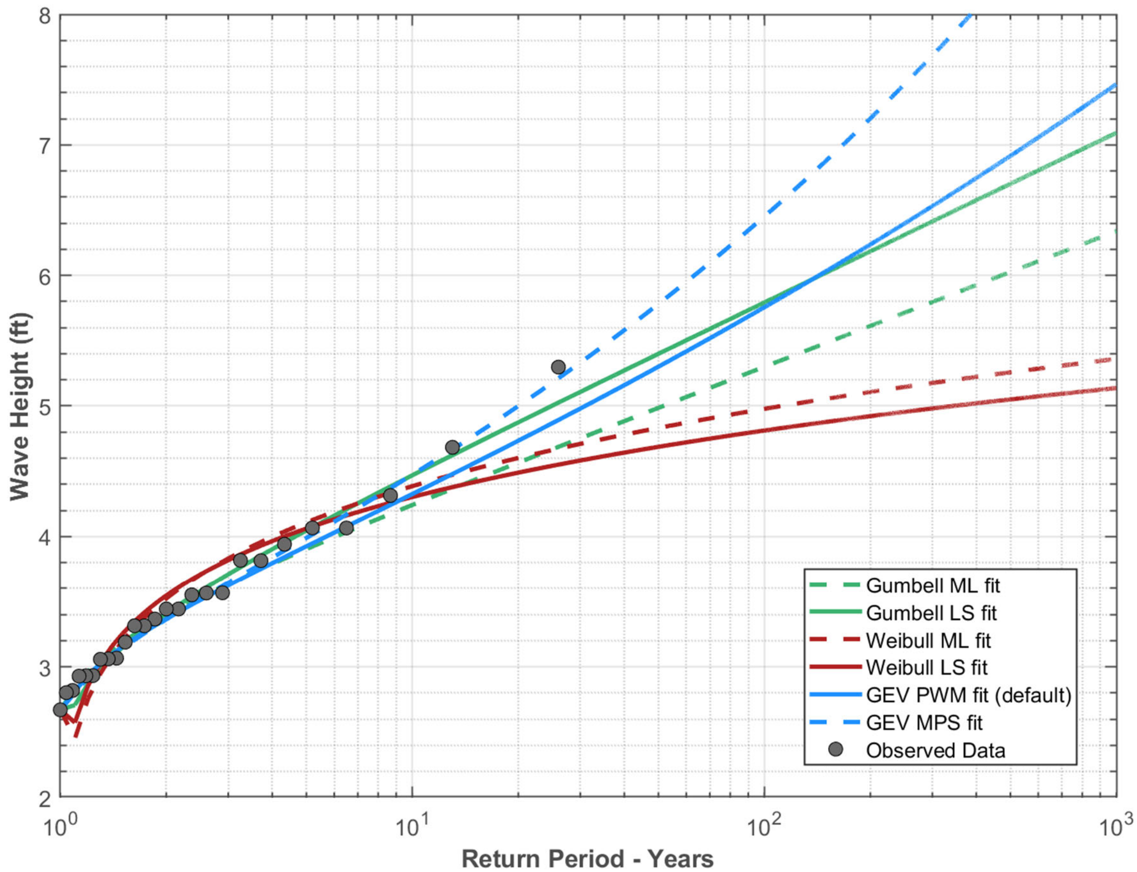


Figure 10. Extreme Value Wave Height Analysis

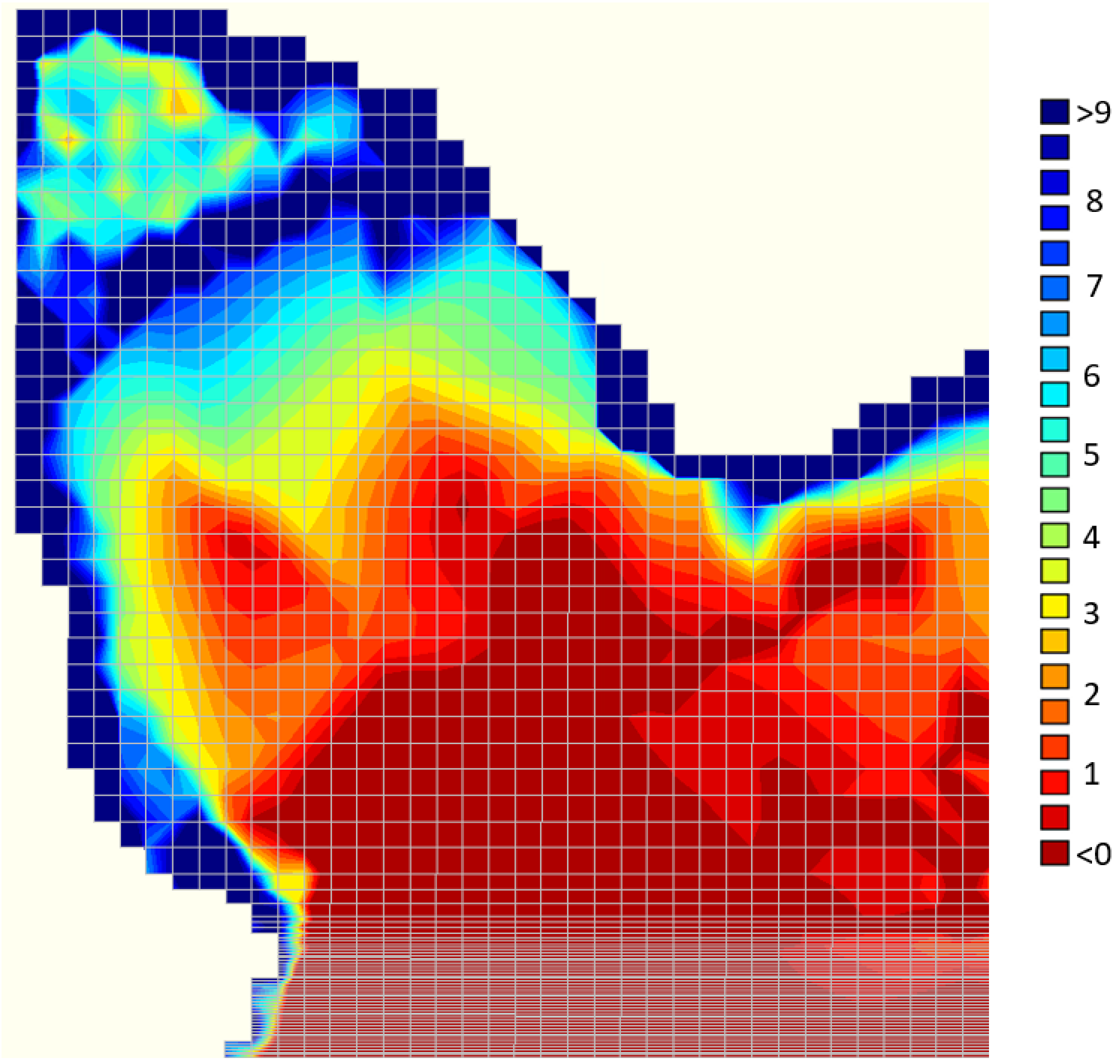


Figure 11. SWAN Wave Model Grid Coverage and Bathymetry

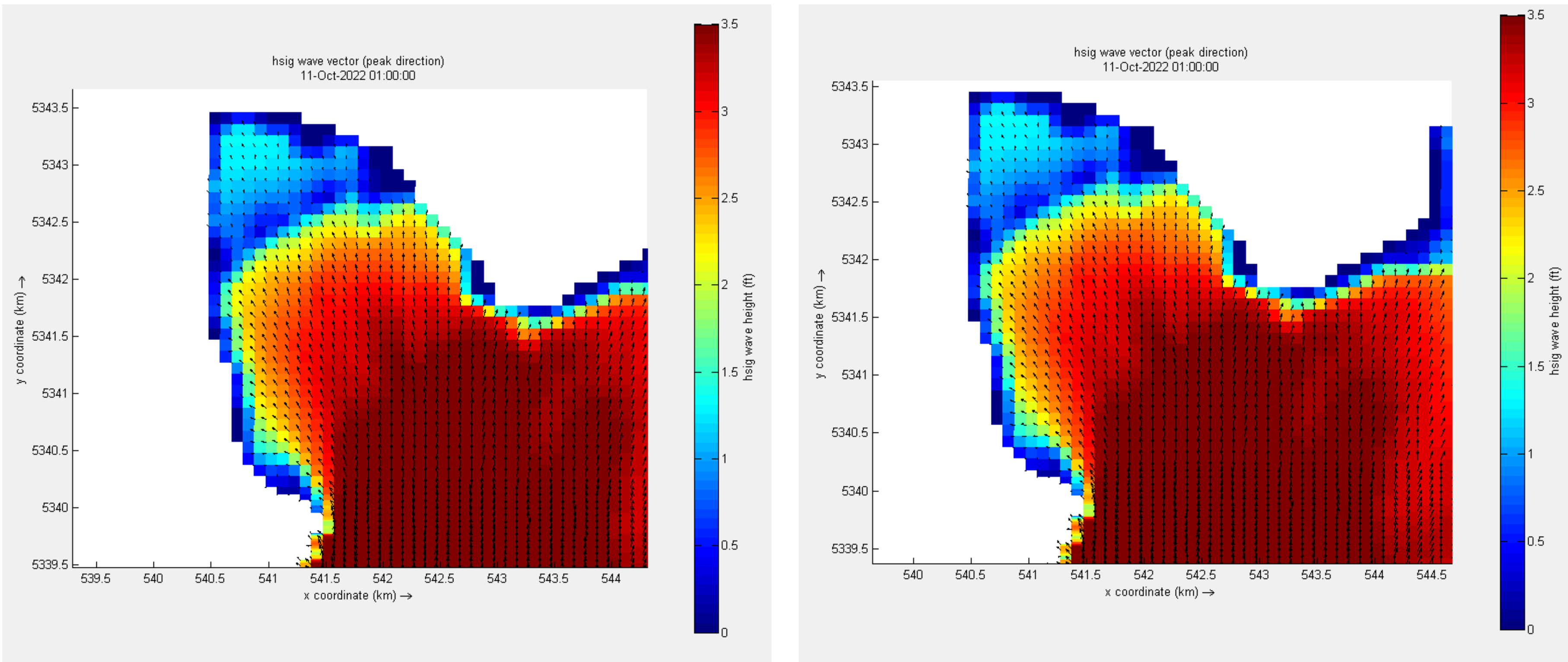


Figure 12. Wave Field from SWAN for 40 mph Winds Coming from the South (180 degrees) (left) and from the Southeast (150 degrees) (right)

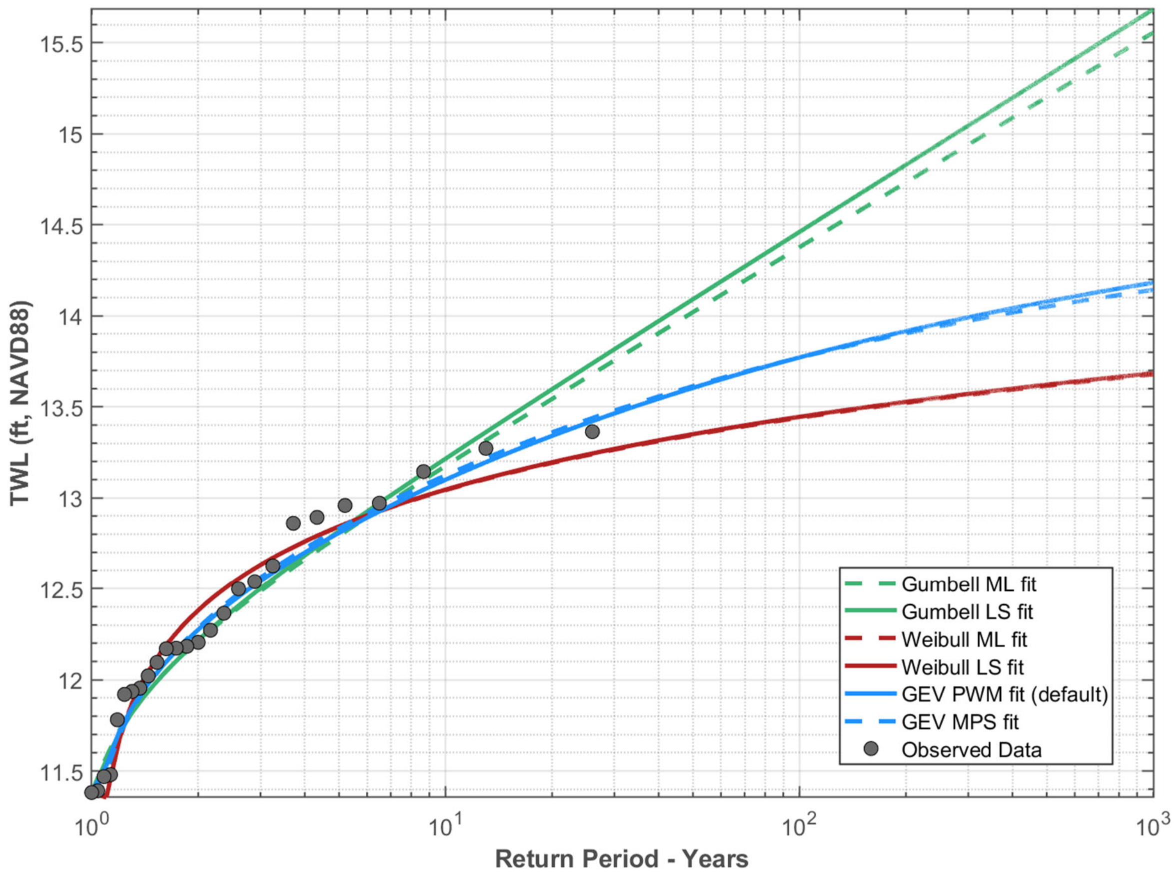


Figure 13. Total Water Level Extreme Analysis - Present Conditions

Figure 14. Shoreline Aligned to Predominant Wave Directions

Figure 15. Drift Cells at Livingston Bay, with Drift from West to East (green, section 29) and Drift from East to West (orange, section 28)

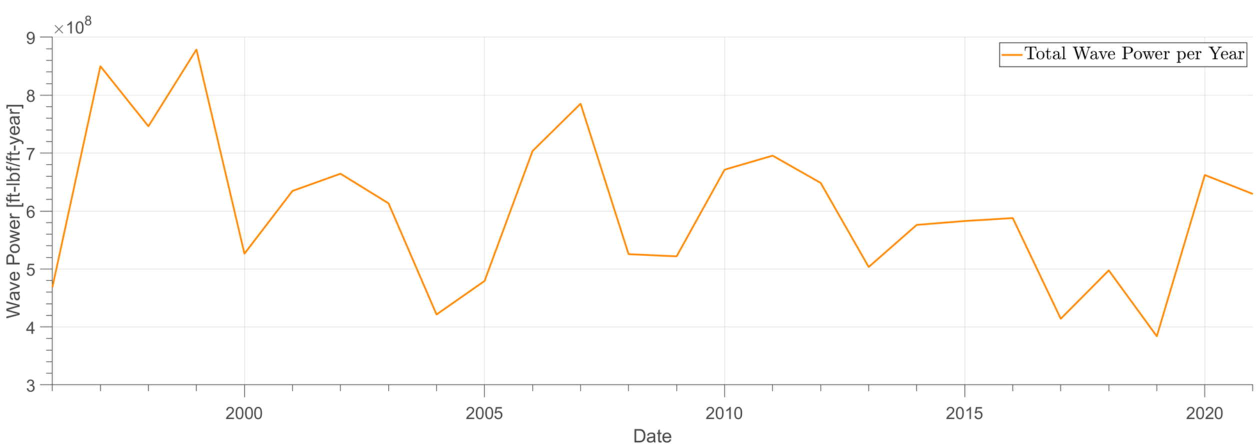


Figure 16. Total Wave Power per Year

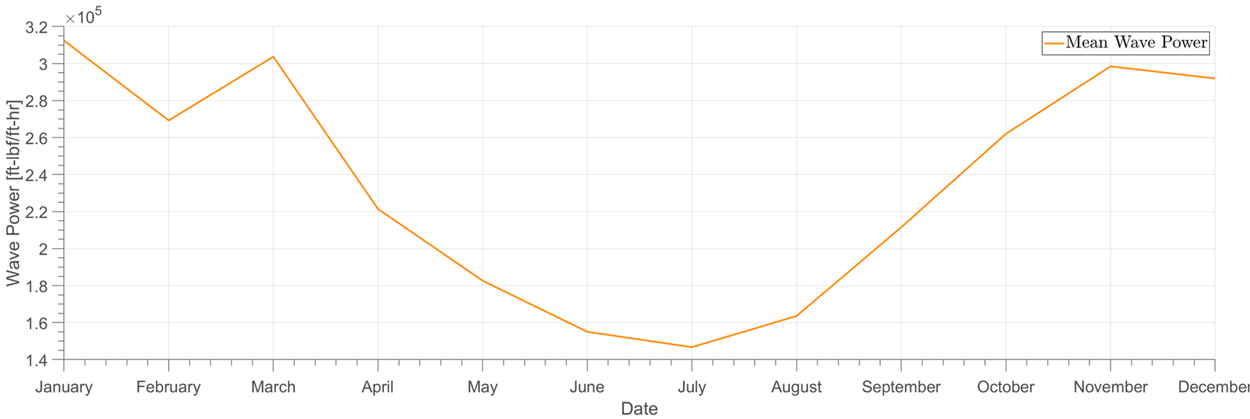


Figure 17. Mean Wave Power per Each Month

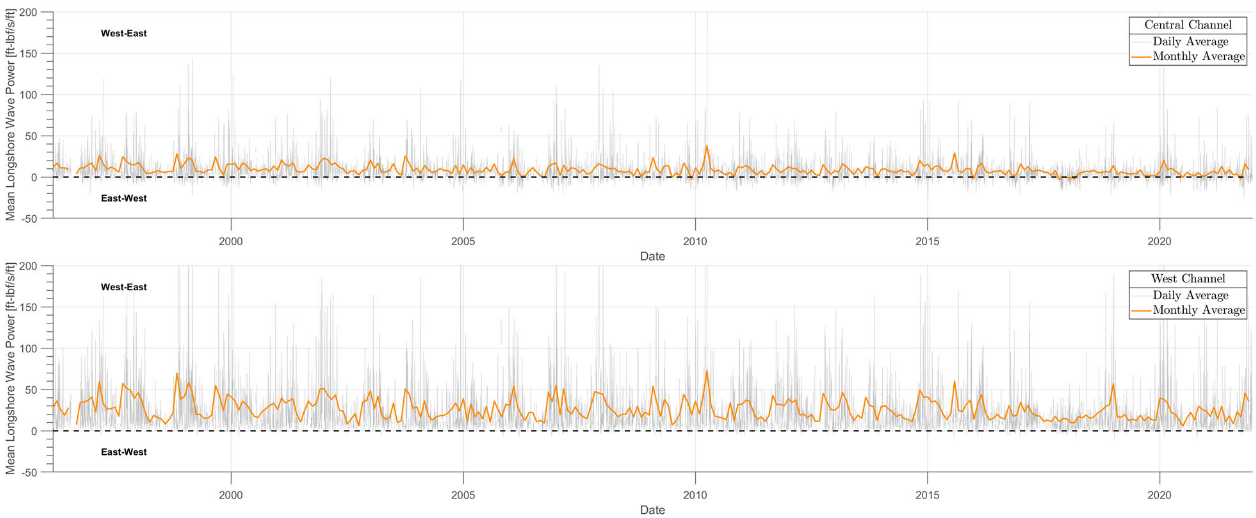
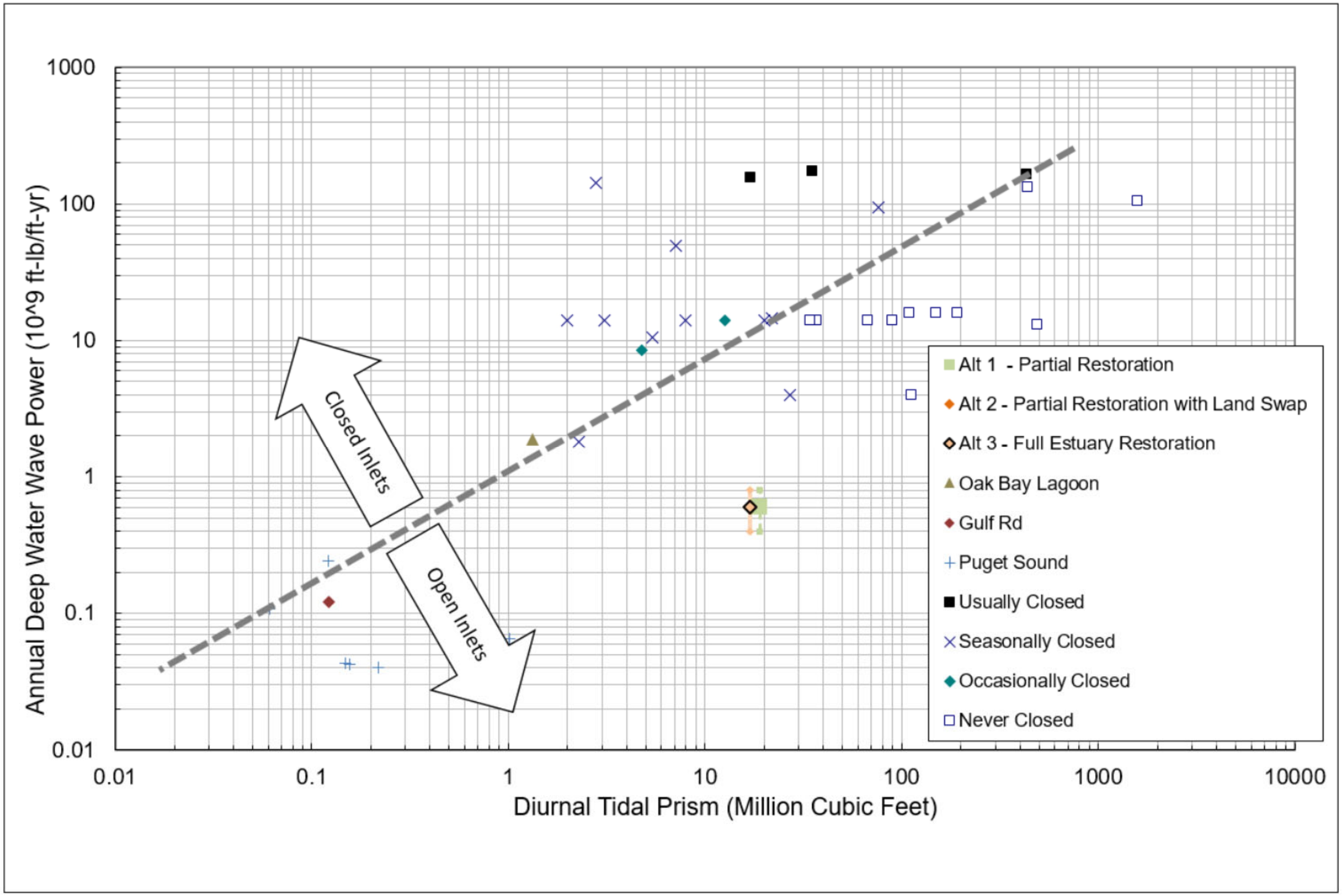


Figure 18. Mean Longshore Wave Power. Central



Source: Original methodology developed by Johnson (1973). Reference data compiled by ESA PWA (2013) and. Tidal Prism of Livingston Bay Inlet alternatives. Wave Power estimate by ESA.

Figure 19. Modified Johnson Inlet Stability Diagram

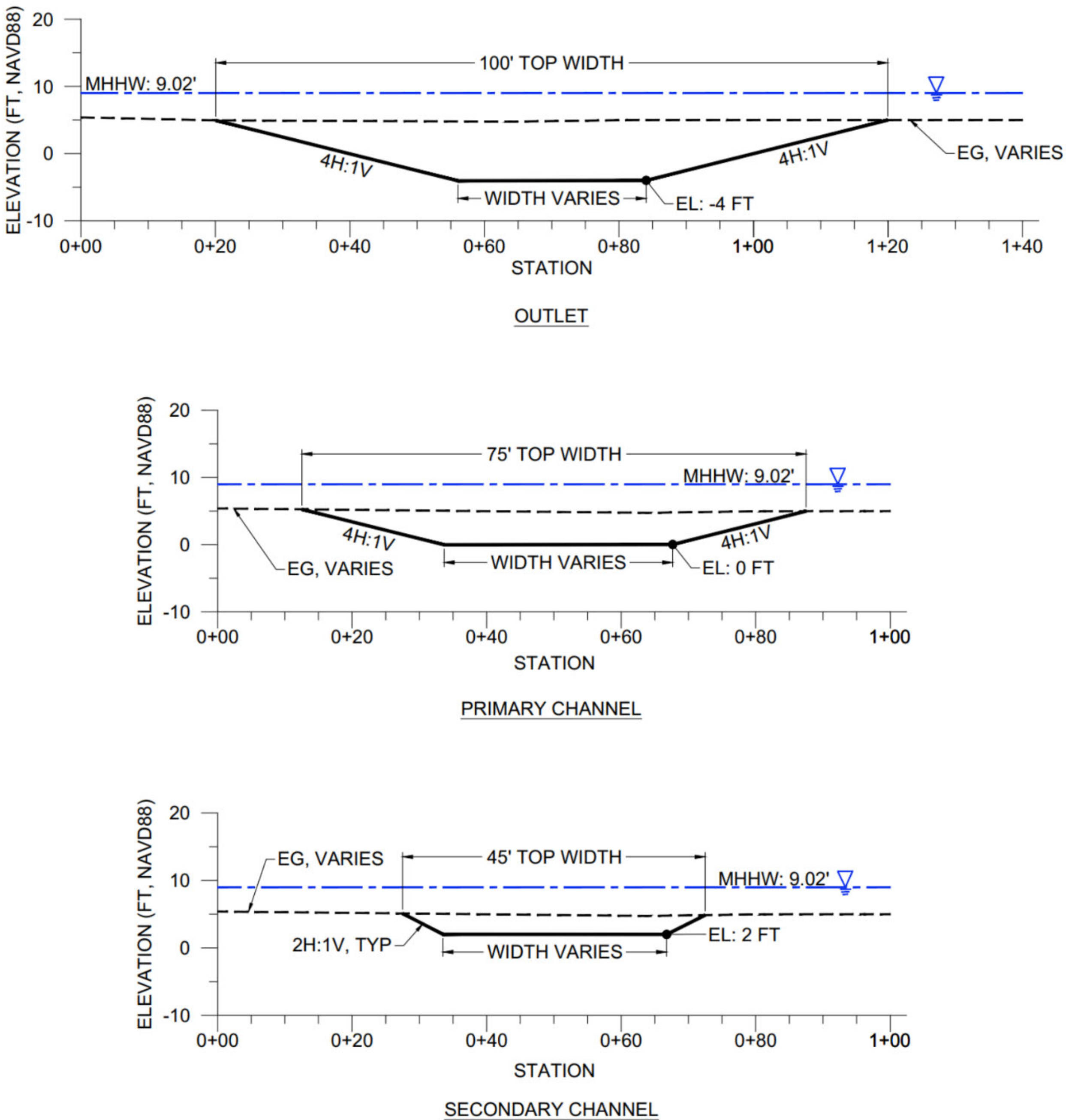
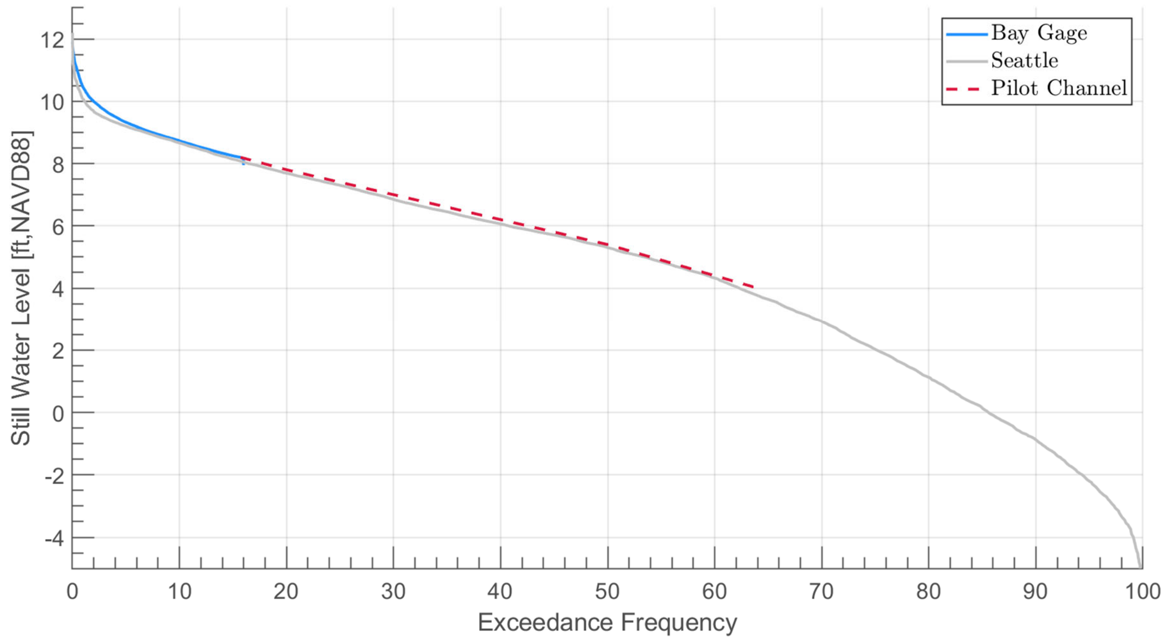


Figure 20. Typical Sections of Tidal Channels, Outlet (top), Primary Channel (middle), and Secondary Channel (bottom)



NOTE: This graph shows the likely water level exceedance with a pilot channel excavated on the mudflat.

Figure 21. Still-Water-Level Exceedance for the Bay Gage (Present Conditions), Seattle Gage, and the predicted curve with a Pilot Channel

Appendix F
Cost-Benefit Analysis

ESA

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ANCHOR QEA

Memorandum

November 4, 2022

To: Dan Elephant, Sky Miller, and Paul Schlenger, Environmental Science Associates

From: John Small and Cheryl Jenkins, Anchor QEA, LLC

Re: Cost Benefit Analysis Using Habitat Equivalency Analysis for Potential Restoration of Habitat in Livingston Bay

Introduction

The purpose of this memorandum is to describe the estimated cost/benefit analysis of three different habitat restoration scenarios proposed for several parcels in Livingston Bay. The project is located on Camano Island on the north end of Livingston Bay in Washington. The proposed restoration site currently consists of upland agricultural land and is proposed to be converted to a combination of mudflat, saltmarsh, and vegetated buffer habitat with tidal channels throughout.

Methods

Habitat equivalency analysis (HEA) is a model that was developed by the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service to assess both ecological services lost or gained using: 1) the relative habitat value (RHV) pre- and post-project; 2) the size of the area affected; 3) the time a project will remain in place; 4) the time it takes for the habitat to achieve full function; and 5) discounting for less value of future functions and ecosystem services (Ehinger et al. 2015). Ecological services lost (debits) or gained (credits) are expressed in Discounted Service Acre Years (DSAYs), which allows for a service-to-service replacement approach rather than direct habitat replacement (e.g., 1 acre of wetland created to replace 1 acre of wetland impacted). Under this framework, the services and functions a habitat unit provides for a species or group of species are used to offset the services lost by impacts to another habitat unit.

The steps for implementing an HEA are as follows:

1. Determine the pre- and post-project **acreages** for each habitat type.
2. Use HEA to score the attributes for each habitat type in both the pre- and post-project scenarios for the predicted impacts caused by depletion of flow (debits) and for the functional uplift anticipated by the mitigation project (credits).
3. The attribute scores will be summed for each habitat type and divided by the highest scoring habitat type (the site-specific "gold standard") to determine the **relative functional habitat value**.

4. Define the **base year** (not used in this analysis), which is used in quantifying the duration of impacts; in this case it could be used to understand different net ecosystem benefit (NEB) of a phased approach to construction by accounting for the temporal lag between phases.
5. Determine the **project life** (not used in this analysis), or how long the impacts or restoration benefits will last.
6. Determine the **time to full function** (not used in this analysis), or how long it will take for the different habitat types to mature and reach the full function assumed in the post-project assessment and scoring.
7. Run these inputs through the HEA model to determine the total present habitat value, which includes a 3% discounting factor for each year after the base year (defined in Step 4), to determine the debits or credits as DSAYs.

In this framework, it is assumed that the impacts will be sufficiently offset if the credits from the offset project are equal to the debits from the flow depletion, and an NEB will be realized if the credits are greater than the debits.

Input Parameters

For this analysis, the area of impact will include those provided for the three different restoration scenarios (Figures 1 through 3). Existing conditions were determined using available aerial imagery and light detection and ranging (LiDAR) topography to determine relative elevations within the proposed project area. Potential restoration habitats are also based on existing elevations to determine which type of habitat would be suitable within topographic contours. Elevations within the proposed project area range from -5.24 feet to +13.83 feet North American Vertical Datum of 1988 (NAVD88).

To determine the properly functioning conditions of the site based on the existing elevations, a series of reference sites within the greater Livingston Bay/northern Port Susan were identified. The LiDAR elevations within each reference site were used to create a histogram allowing outliers to be excluded prior to defining elevations for each habitat categories. Habitat categories and their corresponding elevations used in this analysis include the following:

- **Upland habitat:** existing condition of entire proposed project area due to existing drainage infrastructure and the future condition of areas above +13 feet
- **Vegetated buffer:** +10 to +13 feet
- **Saltmarsh:** +5 to +10 feet
- **Intertidal mudflat:** -5 to +5 feet
- **Subtidal:** below -5 feet
- **Tidal channel:** based on the geometry of the tidal channel networks in each scenario

Relative Habitat Values

Habitats provide varying levels of service to different natural resources. Habitat values identified for the HEA are used both in quantifying loss of functional value and in assessing benefits (gains in functional value) associated with restoration project development. Value adjustment categories of "fully functional" and "baseline adjusted" were created to be applied to marsh, intertidal, and shallow subtidal habitats. The "fully functional" category is based primarily on the idea that adjacent desirable habitat enhances overall production within a habitat complex. Habitats that are "baseline adjusted" generally have no adjacent habitat that can be enhanced. Adjustments to habitat values in restoration planning are beneficial to providing maximum benefits. For a habitat complex to be assigned a "fully functional" value, a marsh must be associated with an adjacent vegetated buffer habitat, an intertidal habitat must be associated with an adjacent vegetated buffer or fully functioning marsh, and a shallow subtidal habitat must be associated with an adjacent fully functioning intertidal habitat (Iadanza 2001).

For this project, saltmarsh habitat was assigned an RHV of 1.0 (optimal conditions), tidal channels were assigned an RHV of 0.95, intertidal mudflat habitat was assigned an RHV of 0.8, and vegetated buffer habitat was assigned an RHV of 0.5. The existing habitat was categorized as upland and assigned an RHV of 0.0.

Timing and Time Intervals

The base year is the year the impact is expected to occur. The base year for the proposed project is the expected first year of remedial construction, which has yet to be determined. In the case of a phased construction, each phase would have a different base year.

Recovery of the habitat to full function is the amount of time it takes for the habitat to recover from remedial construction and attain its full habitat function. For the purposes of this analysis, it is assumed mudflat and tidal channel habitat will reach full function in 3 years, saltmarsh habitat in 8 years, and vegetated buffer habitat in 20 years. The project life was set at 300 years in the HEA model to represent that the project life is in perpetuity. A standard discount rate of 3% was used to compound past impacts and discount future impacts to a net present value. This discount rate is typically assumed in HEA (NOAA 2000).

Results

The HEA results are reported in DSAYs. A DSAY represents the present value of all ecosystem services provided by 1 acre of habitat in 1 year. The evaluation will compare baseline habitat conditions assuming no cleanup activities during the project life to the post-remediation habitat conditions resulting from the project, including the construction period. Table 1 shows the result of the HEA calculations. Table 2 shows the estimated cost per DSAY for each scenario.

Table 1
Estimated DSAYs for Each Restoration Scenario

Existing Habitat	RHV	Restored Habitat	Area (Acres)	RHV	DSAYs
Scenario 1					
Upland	0.0	Saltmarsh	76.06	1.0	2,359.77
		Intertidal mudflat	24.75	0.8	660.096
		Vegetated buffer	7.92	0.5	104.152
		Tidal channel	24.48	0.95	775.313
		Total	**133.21**	**--**	**3,899.33**
Scenario 2					
Upland	0.0	Saltmarsh	65.82	1.0	2,042.07
		Intertidal mudflat	28.54	0.8	761.178
		Vegetated buffer	5.59	0.5	73.511
		Tidal channel	28.16	0.95	28.16
		Total	**128.12**	**--**	**3,768.63**
Scenario 3					
Upland	0.0	Saltmarsh	157.77	1.0	4,894.834
		Intertidal mudflat	25.97	0.8	692.635
		Vegetated buffer	15.11	0.5	198.704
		Tidal channel	50.06	1.0	1,585.465
		Total	**248.91**	**--**	**7,373.638**

Table 2
Cost per DSAY for Each Scenario

Scenario	DSAYs	Estimated Cost	Cost/DSAY
1	3,899.33	$14,400,000	$3,692.94
2	3,768.63	$15,600,000	$4,139.44
3	7,371.638	$16,800,000	$2,279.01

Table 3
Normalized Cost and Function Based on Scenario 3

Scenario	Benefit	Cost	Benefit/Cost
1	53%	86%	62%
2	51%	93%	55%
3	100%	100%	100%

Conclusion

The tables and information outlined in this memorandum provide an estimated cost per DSAY for each proposed restoration scenario to allow a comparison of costs to ecosystem benefits. Based on the analysis, Scenario 3 would have the lowest cost per DSAY, followed by Scenario 1. Scenario 2 would have the highest cost per DSAY. Normalizing the three scenarios can clarify that the benefits of Scenarios 1 and 2 are greatly discounted while construction costs of the other scenarios (1 and 2) are only marginally less expensive.

References

Ehinger, S.I., J.P. Fisher, R. McIntosh, D. Molenaar, and J. Walters, 2015. *Use of the Puget Sound Nearshore Habitat Values Model with Habitat Equivalency Analysis for Characterizing Impacts and Avoidance Measures for Projects that Adversely Affect Critical Habitat of ESA-Listed Chinook and Chum Salmon*. Working Draft. National Marine Fisheries Service, Oregon-Washington Coastal Office. April 2015.

Iadanza, N.E., 2001. *Determining Habitat Value and Time to Sustained Function*. Prepared by the National Oceanic and Atmospheric Administration National Ocean Service for the Commencement Bay Natural Resource Trustees. September 11, 2001.

NOAA (National Oceanic and Atmospheric Administration), 2000. *Habitat Equivalency Analysis: An Overview*. NOAA Damage Assessment and Restoration Program, Department of Commerce. Revised October 4, 2000. Appendix A of *Hylebos Waterway Natural Resource Damage Settlement Proposal Report: Habitat Restoration-Based Approach for Resolving Natural Resource Damage Claims Relating to the Hylebos Waterway of the Commencement Bay Nearshore/Tideflats Superfund Site Combined with a Proposal for Allocating Liability for Settlement Purposes*.

Figures

LEGEND:

Parcels in Scenario

Channel Type

- Outlet
- Primary
- Secondary

Habitat

- Vegetated Buffer
- Saltmarsh
- Mudflat

NOTES:

1. Aerial imagery is USDA, National Agriculture Imagery Program, 2019.
2. Habitat types based on elevation data from USACE/USGS topobathy LiDAR: Puget Sound (WA), 2014.

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ANCHOR QEA

Figure 1
Scenario 1
Cost Benefit Analysis
Livingston Bay Restoration

LEGEND:

Parcels in Scenario

Channel Type

- Outlet
- Primary
- Secondary

Habitat

- Vegetated Buffer
- Saltmarsh
- Mudflat

NOTES:

1. Aerial imagery is USDA, National Agriculture Imagery Program, 2019.
2. Habitat types based on elevation data from USACE/USGS topobathy LiDAR: Puget Sound (WA), 2014.

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Figure 2
Scenario 2
Cost Benefit Analysis
Livingston Bay Restoration

LEGEND:

Parcels in Scenario

Channel Type

- Outlet
- Primary
- Secondary

Habitat

- Vegetated Buffer
- Saltmarsh
- Mudflat

NOTES:

1. Aerial imagery is USDA, National Agriculture Imagery Program, 2019.
2. Habitat types based on elevation data from USACE/USGS topobathy LiDAR: Puget Sound (WA), 2014.

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Figure 3
Scenario 3
Cost Benefit Analysis
Livingston Bay Restoration