Hydraulic and Water Quality Modeling of Restoring Salmon Habitat in the Nooksack River Estuary

Final Report

Table of Contents

Section 1 Introduction 1-1

1.1 REPORT ORGANIZATION AND CONTENTS 1-2

Section 2 Technical Approach to Hydraulic Evaluation 2-1

2.1 FULL EQUATIONS (FEQ) HYDRAULIC MODEL 2-1

2.2 PURPOSE OF THE HYDRAULIC ANALYSIS 2-2

2.3 DATA SOURCES AND COMPARISONS 2-3

2.3.1 Tidal Data 2-3

2.3.2 Topography Data 2-4

Section 3 Restoration Alternatives Analysis and Modeling Results 3-1

3.1 DESCRIPTION OF PROPOSED RESTORATION ACTIVITIES 3-2

3.1.1 Restoration Activities Common to All Alternatives 3-3

3.1.2 Description of Four Restoration Alternatives 3-5

3.2 SALTWATER INUNDATION ANALYSIS 3-10

3.2.1 Alternative 1: Full Sea Wall, Dike and Levee Removal 3-10

3.2.2 Alternative 2: Seawall Breach and Right Bank Levee Removal 3-13

3.2.3 Alternative 3: Limited Seawall and Levee Breaching 3-15

3.2.4 Alternative 4: Contained Breaches and Passage Corridor 3-17

3.2.5 Summary of Saltwater Inundation Analysis 3-19

3.2.6 Managing Salinity Migration 3-20

3.3 FRESHWATER FLOODING ANALYSIS 3-21

3.3.1 Hydraulic Model Setup of 100-Year Design Flood 3-21

3.3.2 Freshwater Flooding Modeling Results 3-23

3.3.3 Summary of Freshwater Flooding Analysis 3-24

3.3.4 Evaluation of Water Levels in Smuggler's Slough 3-31

Section 4 Conclusions and Recommendations 4-1

List of Tables

Table 3-1. Activities Common to All Restoration Alternatives....3-4
Table 3-2. Alternative 1 Results: Inundation and Roadway Elevations....3-11
Table 3-3. Alternative 2 Results: Inundation and Roadway Elevations....3-13
Table 3-4. Alternative 3 Results: Inundation and Roadway Elevations....3-15
Table 3-5. Alternative 4 Results: Inundation and Roadway Elevations....3-17
Table 3-6. Summary of Saltwater Inundation Hydraulic Modeling Results....3-19
Table 3-7. Proposed Kwina Slough Breach Geometry and Gate Settings....3-23
Table 3-8. Summary of Freshwater flooding for the 100-Year Design Flood (elevations in NGVD29)..3-25
Table 4-1. Summary of Saltwater Inundation Hydraulic Modeling Results....4-3

List of Figures

Figure 1-1. Nooksack and Lummi Rivers Estuary Restoration Evaluation Area....1-2
Figure 2-1. FEQ Model of the Project Area....2-2
Figure 2-2. Comparison of Cherry Point Tidal Data: NOS vs. Tides and Currents Software....2-4
Figure 2-3. Scatter Plot Comparing LiDAR and Whatcom County Topography Data....2-5
Figure 2-4. Comparison of LiDAR and Whatcom County Topography Data....2-6
Figure 3-1. Tidal Protections Along Lummi Bay....3-2
Figure 3-2. Project Area with Restoration Alternative Components Indicated....3-3
Figure 3-3. Components of Alternative 1....3-6
Figure 3-4. Components of Alternative 2....3-7
Figure 3-5. Components of Alternative 3....3-8
Figure 3-6. Components of Alternative 4....3-9
Figure 3-7. Alternative 1: Predicted Inundation Durations....3-12
Figure 3-8. Alternative 2: Predicted Inundation Durations....3-14
Figure 3-9. Alternative 3: Predicted Inundation Durations....3-16
Figure 3-10. Alternative 4: Predicted Inundation Durations....3-18
Figure 3-11. Illustration of Potential Saltwater Seepage Through a Road Embankment....3-20
Figure 3-12. FEQ Model of the Project Area....3-22
Figure 3-13. Predicted Inundation for the 100-Year Design Flood, Existing Conditions....3-26
Figure 3-14. Predicted Inundation for the 100-Year Design Flood, Alts. 1-3 + Kwina Slough SRT Closure @ 6.7 ft....3-27
Figure 3-15. Predicted Inundation for the 100-Year Design Flood, Alts. 1-3 + Kwina Slough SRT Closure @ 7.7 ft....3-28
Figure 3-16. Predicted Inundation for the 100-Year Design Flood, Alt. 4 + Kwina Slough SRT Closure @ 6.7 ft....3-29
Figure 3-17. Predicted Inundation for the 100-Year Design Flood, Alt. 4 + Kwina Slough SRT Closure @ 7.7 ft....3-30
Figure 3-18. Delineation of Proposed Wetland Enhancement Project near Smuggler's Slough....3-32
Figure 3-19. Smuggler's Slough Drainage Ditch Connections in the Vicinity of Low Lands....3-33

Section 1
Introduction

In the Nooksack River watershed, restoring viable salmon habitat has become an important part of the strategy to recover depleted fish stocks. Near the mouth of the Nooksack and Lummi Rivers, large portions of the historic estuary have been isolated from river flows and tidal influence since the mid-1920s after the construction of a sea wall and a series of levees. The area behind the levees was converted from wetlands to agriculture and intensively drained. The process of agricultural development removed vast tracks of the estuary that could function as valuable and productive salmon habitat.

The purpose of this project is to evaluate a series of alternative scenarios for restoring portions of the historic estuary and improving fish passage. Figure 1-1 shows the evaluation project area. The evaluation focuses on the hydraulic aspects of the restoration scenarios by using the detailed Full Equations (FEQ) hydraulic model of the lower Nooksack River system to estimate the extent of saltwater and freshwater flooding under each of the alternative scenarios. This rigorous, planning-level hydraulic evaluation will provide sufficient information for Lummi Department of Natural Resources (LNR) staff to move forward with a set of preferred restoration activities. To help LNR select a preferred alternative and proceed with design, land acquisition and other actives, the project team developed the following list of project goals:

- ⇨ Clearly demonstrate the areas that would become inundated under each restoration alternative. LNR staff can use the inundation mapping to identify any affected parcels and to develop a plan for additional land acquisition before implementing related restoration projects.

- ⇨ Determine how often portions of the project area would be under water. The duration analysis will help identify the extent of the area that will be converted from agricultural use to salt marsh. LNR staff can use the duration analysis to help predict the types of vegetation and habitat that will develop in different portions of the delta.

- ⇨ Identify any roadways that would become submerged as a result of the restoration alternatives. Overtopping roadways, particularly evacuation routes, would either eliminate an alternative from consideration or drive the need for a road raising component to the restoration activities.

- ⇨ Summarize the potential impacts to crop production associated with each alternative and recommend any drainage improvements that would reduce the likelihood of salt intrusion into active farming areas.

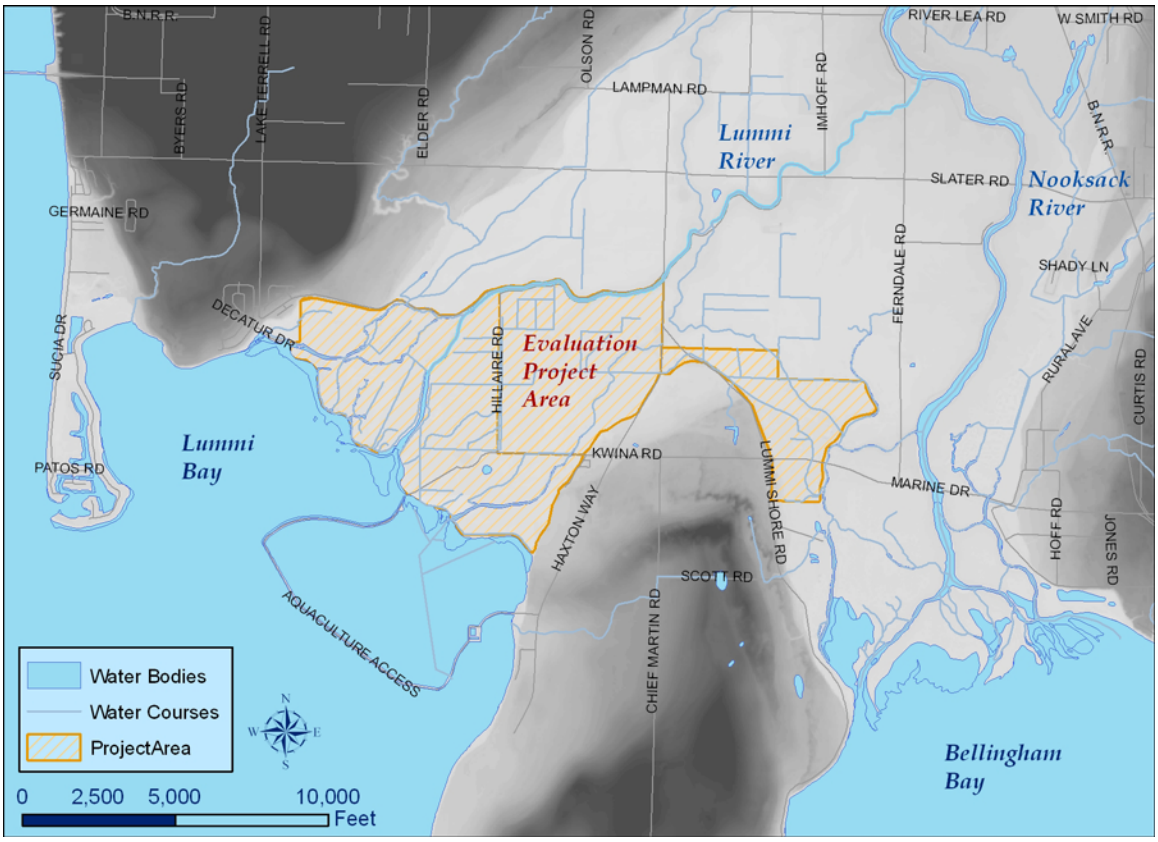

Figure 1-1. Nooksack and Lummi Rivers Estuary Restoration Evaluation Area

1.1 Report Organization and Contents

The remainder of this report is divided into three sections:

- ⇨ **Section 2** describes the technical approach to evaluate the hydraulic aspects of the restoration alternatives. It describes the FEQ hydraulic model, input data sources and statistical analysis methods.

- ⇨ **Section 3** describes the restoration alternatives analysis and results. It contains saltwater inundation maps, summary tables comparing predicted water surface elevations to roadway elevations, and a discussion of the expected impacts to agricultural production. This section also describes the freshwater flooding analysis and how each restoration alternative would affect the 100-year flood elevations.

- ⇨ **Section 4** summarizes the results of the hydraulic evaluation and describes several key issues to address as LNR proceeds with the design and construction of habitat restoration projects within the evaluation project area.

Section 2 Technical Approach to Hydraulic Evaluation

The technical evaluation was based on the FEQ hydraulic model of the lower Nooksack River system. The existing conditions FEQ model was modified to represent each of the restoration alternatives, including removing or breaching the sea wall/levees and adding or removing tide gates. The specific restoration alternative components are described in detail in Section 3.

This section describes the composition of the FEQ model of the lower Nooksack River system and how the FEQ model was setup to address the purpose of this study. This section also describes the input data sets used in the analysis and data quality assessments that were performed before proceeding with the hydraulic modeling evaluation.

2.1 Full Equations (FEQ) Hydraulic Model

FEQ is a fully-dynamic hydraulic model of one-dimensional (1D) unsteady flow in open channels and through control structures, such as gates and weirs. FEQ solves the St. Venant equations of fluid flow at each time step during a model simulation to predict water surface elevations and velocities throughout a model network. The FEQ software was developed by Linsley, Kraeger Associates, Ltd (LKA). LKA also developed the lower Nooksack River FEQ model, in association with the Whatcom County Flood Control Zone District. The lower Nooksack River FEQ model has been used for numerous flood control and restoration studies, including a Ducks Unlimited sponsored study along the Marietta Slough.

The lower Nooksack River model simulates the Nooksack and Lummi River delta area as a series of level-pool reservoirs. Figure 2-1 shows the Lummi River cross-sections and level-pool reservoirs in the FEQ model. The green polygons show the extent of each level-pool reservoir and the label (after the LRLPZ prefix) indicates the reservoir's name. In some cases, two different level-pool reservoirs are combined in the FEQ model (e.g., pools D and E were delineated separately but are combined in the model). The level-pool reservoir names are used in the freshwater flooding summary table included in Section 3.

Each level-pool reservoir has an associated stage-storage-discharge table that determines (a) the water surface elevation based on the volume of water in the pool and (b) the discharge to adjacent pools. Wherever possible, the stage-discharge part of the level-pool reservoir description uses the physical features of the delta to estimate flow rates between the pools, such as modeling roadway boundaries between pools as broad-crested weirs.

The lower Nooksack River FEQ model has been calibrated to recorded stream flow data and observed high water marks along the Nooksack River main stem during various, large storm/flow events, including the November 1990, November 1995 and November, January and February 2002 events. Calibration is an on-going effort; Whatcom County Flood Control Zone District and LKA are refining the model calibration and adding structure/hydraulic detail in various parts of the lower Nooksack River system whenever new information and/or data are collected. More recently, the October and November 2003 events were added to the calibration.

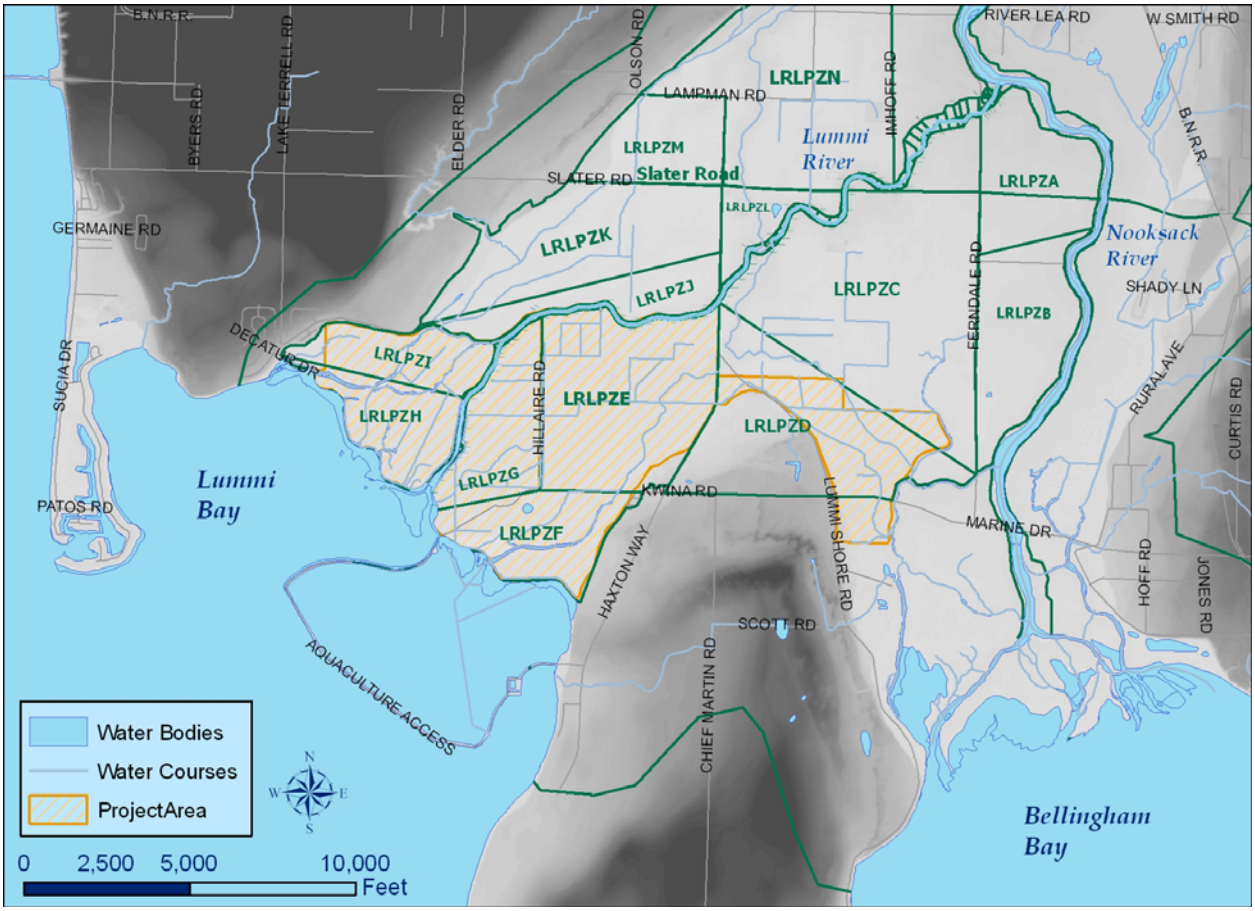

Figure 2-1. FEQ Model of the Project Area

2.2 Purpose of the Hydraulic Analysis

The purpose of the hydraulic evaluation was to determine how the restoration alternatives would affect water surface elevations in the delta. Because estuary restoration is a process that occurs through repeated inundation with saltwater, the model was used to predict inundation levels over a long period using actual tidal elevation data. The fraction of time inundated was computed by entering long-term, hourly tidal records into the FEQ model and preparing statistical summaries of the results.

For saltwater inundation analysis, the computational requirements of the long-term continuous simulations led the project team to build a sub-model of the lower Nooksack River system, using information pertinent to Lummi River and its floodplains. No overflow from the Nooksack River was simulated for the saltwater inundation analysis, because the overflow volume from the Nooksack River to the Lummi River is negligible when compared to the potential volume of daily tidal inundation.

The description of the Lummi River was refined for the analysis of levee breaches. Additional flow nodes (i.e., passages in the model to move water from the river to the floodplain) were included in the FEQ model to represent the flow interchange between the river and floodplain during tidal cycles.

For the freshwater analysis, the alternatives were evaluated by routing the 100-year design flood through the FEQ model of the lower Nooksack River system. The FEQ model inflow dataset for this design flood is based on a statistical analysis of the USGS gage data at Ferndale for the November 1990 flood event. During this event, the Nooksack River overflowed into the Lummi River and overtopped its levees to inundate some of the protected portions of the delta. Actual tidal records for this event formed the downstream boundary condition for the model. The restoration alternative components, such as breaching the Kwina Slough levee and breaching the Lummi River levees could potentially increase inundation levels during large flood events, and the FEQ model was used to quantify the extent of the rise in each portion of the Lummi River delta.

2.3 Data Sources and Comparisons

The two major data input sources to the FEQ model were tidal data and topography data. Before starting the hydraulic modeling, the project team compared the available data sources, as described below.

2.3.1 Tidal Data

The National Oceanographic Service (NOS) tidal gaging station at Cherry Point provides the best estimate of tidal elevations in Lummi Bay. Two different sources of Cherry Point tidal data were evaluated: the predicted values on the NOS web site and the predicted values computed by the Tides and Currents software package[1]. One advantage of the Tides and Currents software is that data can be exported very rapidly. Another advantage is the longer period of available data (in part because the Tides and Currents software predicts tidal elevations).

Before using the hourly data exported from Tides and Currents as input to the FEQ model for the saltwater inundation analysis, the Tides and Currents and NOS data were compared. Figure 2-2 shows the durations for each data source for the period from 1990 through 1995. The tidal durations are virtually identical for the two sources, indicating that the two sources would generate similar outputs from the FEQ model. Hourly tidal predictions exported from Tides and Currents for the period 1961 through 2000 were used as input to FEQ. The data were converted from the mean-lower-low-water (MLLW) datum to NGVD29 to match the vertical datum used to create the FEQ model[2].

[1] The Tides and Currents software package is produced by Nobeltec.

[2] For the Cherry Point station, the MLLW data were converted to the NGVD29 datum by subtracting 4.73 feet from the MLLW elevations. For example, a tide elevation of 8.73 ft MLLW would rise to (i.e., corresponds to) a land surface elevation of 4.00 feet NGVD29.

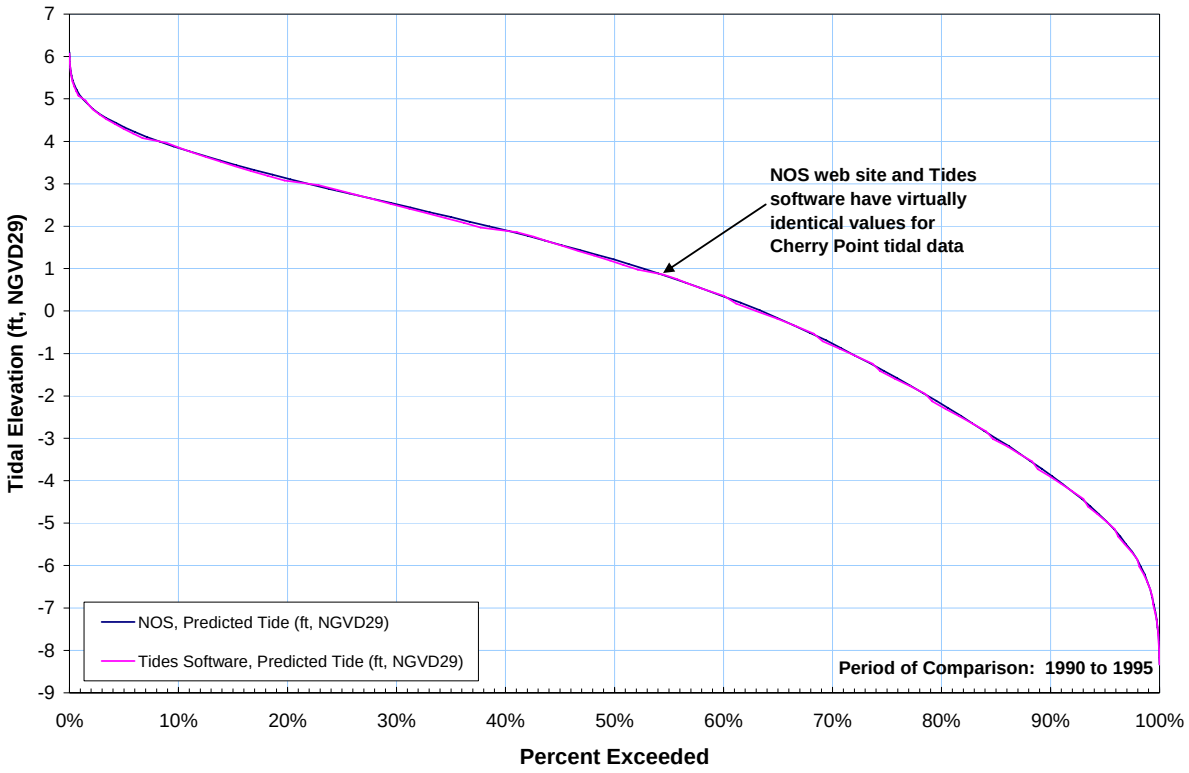

Figure 2-2. Comparison of Cherry Point Tidal Data: NOS vs. Tides and Currents Software

2.3.2 Topography Data

The existing FEQ model of the lower Nooksack River system was developed from Whatcom County topographic data, which was developed using aerial mapping methods. The project team compared a selection of the Whatcom County elevation data with the LiDAR-derived topography data available for this project. The purpose of the comparison was to identify any large discrepancies and generally assess the comparability of the two datasets.

General agreement between the two topographic datasets is very important, because the hydraulic evaluation uses both. For example, the FEQ model cross-sections and level-pool reservoir stage-storage-discharge tables are based on the Whatcom County topography data. The assessment of inundation impacts, such as determining whether roadways are overtopped and mapping the extent of inundation are based on the LiDAR topography data.

Two figures were prepared to illustrate the similarities and differences between the two topography datasets. Figure 2-3 shows the Whatcom County TIN elevations plotted against the LiDAR elevations. More than 7,500 locations were sampled to produce the plot. The large number of points clustered around the red line indicate a very close agreement between the datasets. Some of the scatter is attributable to the resolution of the datasets and different ability to pick up minor undulations in terrain. There is also a small bias between the two datasets that

is illustrated in Figure 2-4, which plots the difference between the sampled elevations and groups the results into half-foot bins. A value of 0 indicates the two datasets have precisely the same elevation for a particular location. For 39 percent of the sampled locations, the elevations agreed to within 0.5 feet. For 66 percent of the locations, the elevations agreed to within 1 foot. More than 81 percent of the elevations agreed to within 1.5 feet. The median elevation difference is 0.52 feet, with the LiDAR elevations generally lower than the Whatcom County elevations. The median difference of 6 inches should be considered small, especially given the difficulty of accurately measuring ground surface elevations over broad stretches of land. The agreement between the datasets is sufficiently strong for planning purposes.

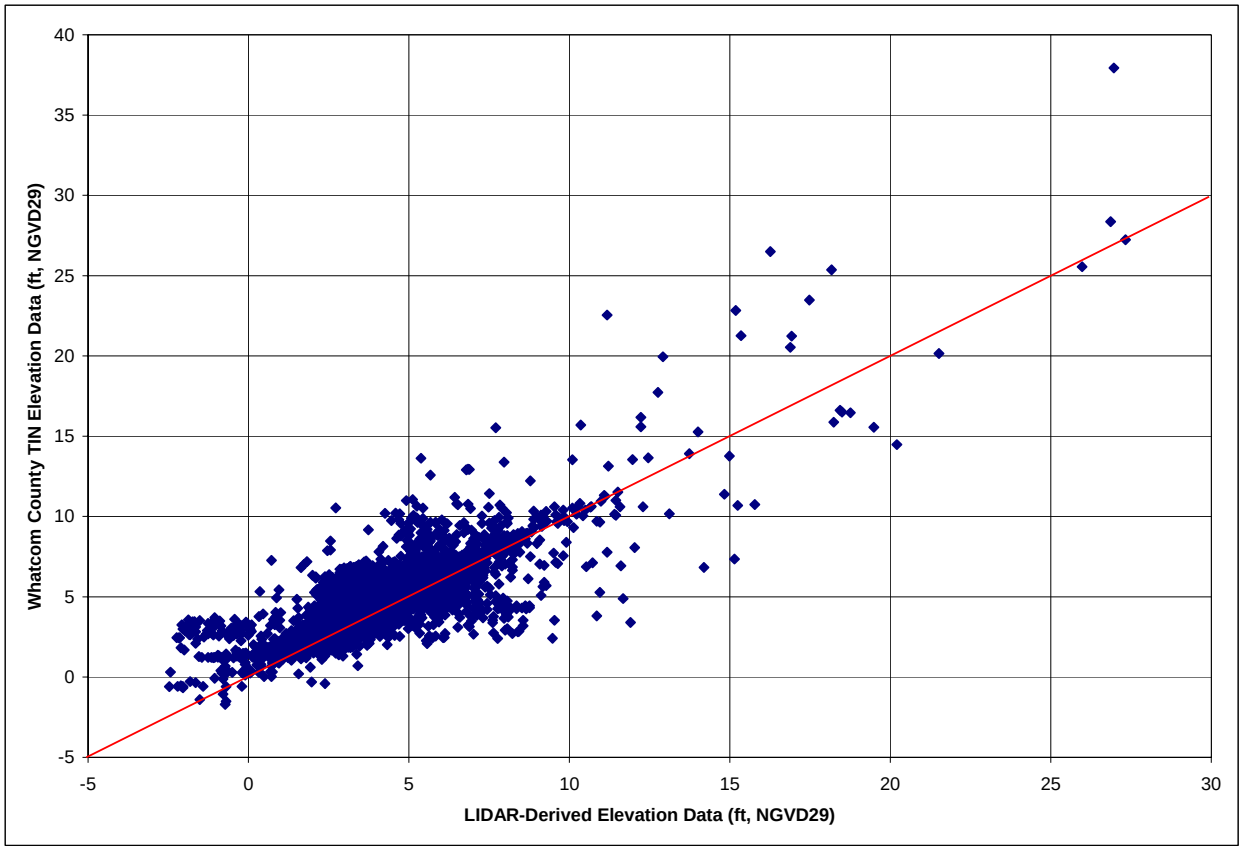

Figure 2-3. Scatter Plot Comparing LiDAR and Whatcom County Topography Data

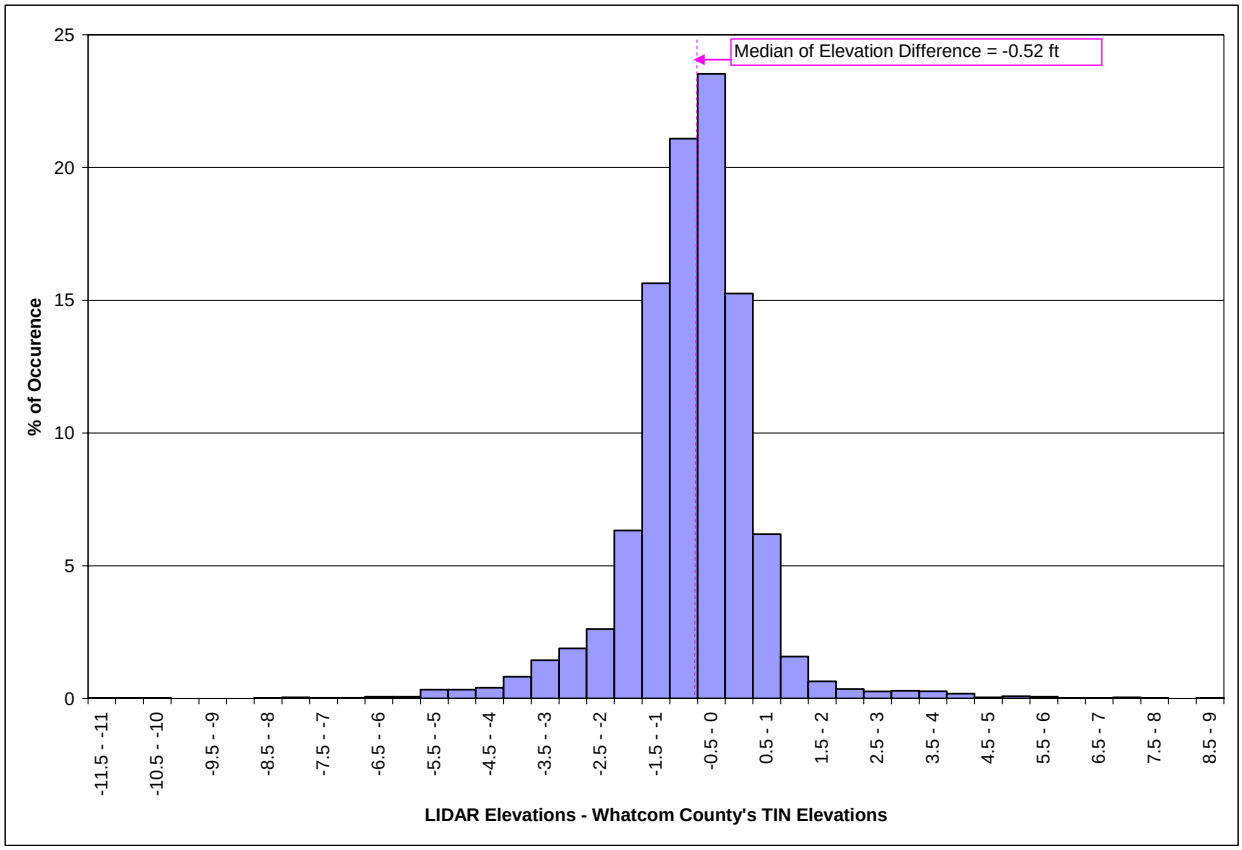

Figure 2-4. Comparison of LiDAR and Whatcom County Topography Data

Section 3 Restoration Alternatives Analysis and Modeling Results

The Lummi Department of Natural Resources (LNR) has proposed a series of restoration activities to help improve salmon habitat in the Nooksack River estuary. This section describes the proposed activities in detail and then examines the potential benefits and impacts by using an FEQ hydraulic model to estimate how the restoration activities would affect water surface elevations within the estuary and historic floodplain over a range of different conditions.

The historic estuary is currently protected by a sea wall and a dike at Lummi Bay, levees along the Lummi River, and tide gates at the mouths of Smuggler's Slough and the Lummi River's North Distributary. Together these structures separate the tidal waters of Lummi Bay from the historic estuary (Figure 3-1). LNR developed the proposed restoration activities into four separate alternatives that would (to differing degrees) remove or alter these protections to open a portion of the former estuary lands to the rise and fall of tidal waters. Periodic saltwater inundation should help support native salt marsh plant species and ecosystem function that will benefit salmon survival. A separate component of the restoration effort includes improving fish passage from the main stem of the Nooksack River to Lummi Bay, where the proposed habitat improvements would occur.

The hydraulic modeling analysis of the restoration alternatives identifies the potential benefits and impacts of the proposed restoration activities. Example benefits could include an expansion of tidal estuary lands and associated salmon habitat; example impacts could include the loss of agricultural lands and increased risk of flooding. A separate model was developed for each alternative to compute flow rates through new dike and levee openings and the resulting water surface elevations. Developing separate models allowed for a side-by-side comparison of the effects of the proposed restoration activities (i.e., weighing the relative benefits and impacts of the four alternatives).

To assess how the four restoration alternatives would perform over a range of conditions, the hydraulic modeling analysis included (1) long-term simulations of the full range of tidal conditions and (2) the simulation of a single large storm event. These are referred to, respectively, in the following sections as the *saltwater inundation analysis* and the *freshwater flooding analysis*. The results of the saltwater inundation analysis correspond to the likely long-term salt loading and the results of the freshwater flooding analysis reflect the potential change in flood risk that would be introduced by the restoration activities.

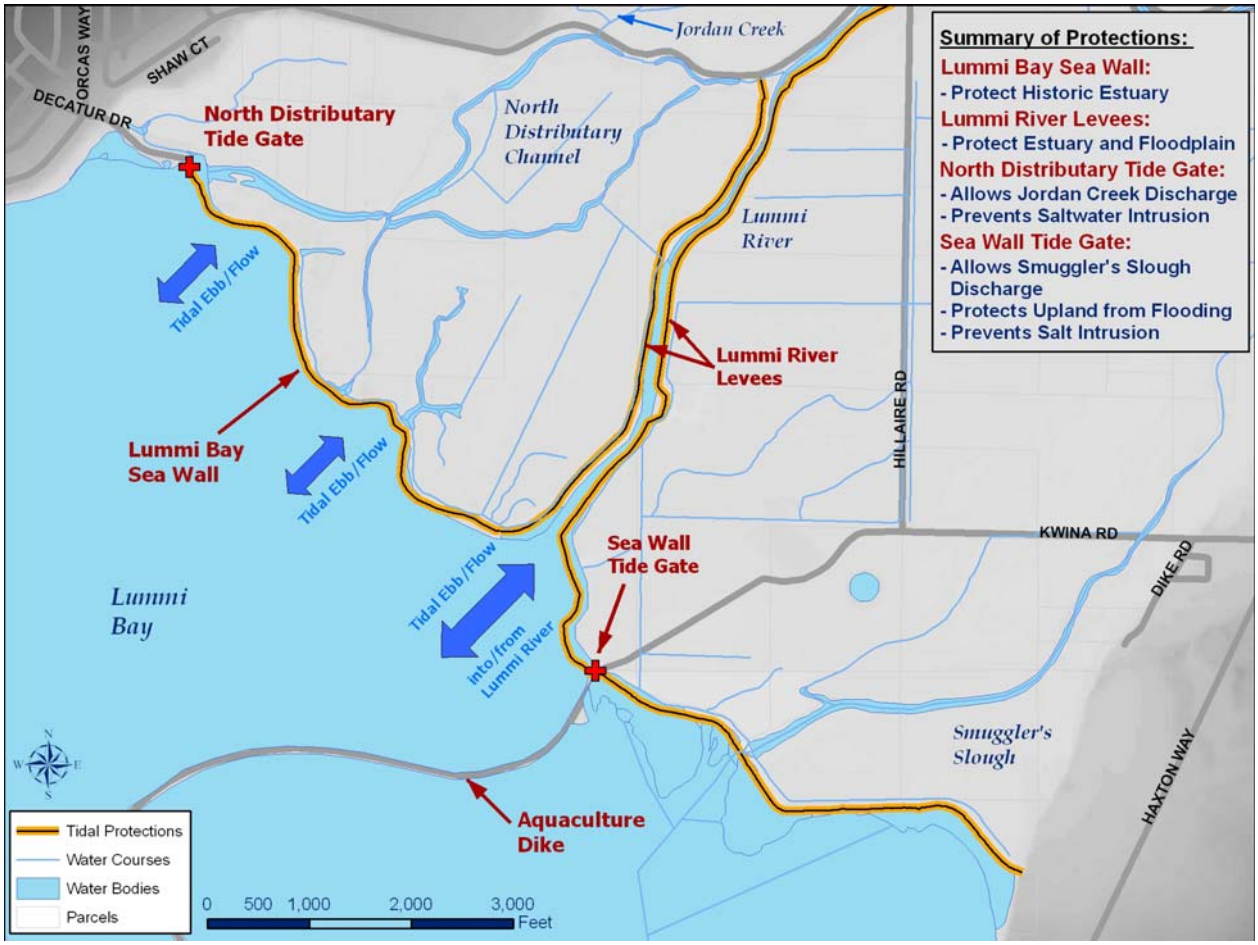

Figure 3-1. Tidal Protections Along Lummi Bay

3.1 Description of Proposed Restoration Activities

The alternatives developed by LNR include combinations of breaching or removing the sea wall, and Lummi River levees, along with adjustments to the tide gates, located at the mouth of Smuggler's Slough. The alternatives would involve different levels of construction and earthwork and would produce different levels of saltwater inundation. In concert with the specific breaching and removal alternatives, LNR plans restoration efforts near the Lummi River's North Distributary channel and near Kwina Slough that would be performed with any of the breaching and removal alternatives.

The following section describes the proposed restoration activities that would be common to all alternatives. After the description of the common elements, each of the four alternatives (with supporting graphics) is described.

3.1.1 Restoration Activities Common to All Alternatives

Allowing tidal waters into the historic estuary would require certain modifications to the hydraulic controls along Lummi Bay and the Lummi River that would occur with any of the alternatives. Figure 3-2 shows the proposed modifications. Table 3-1 describes the purpose of the modifications in greater detail.

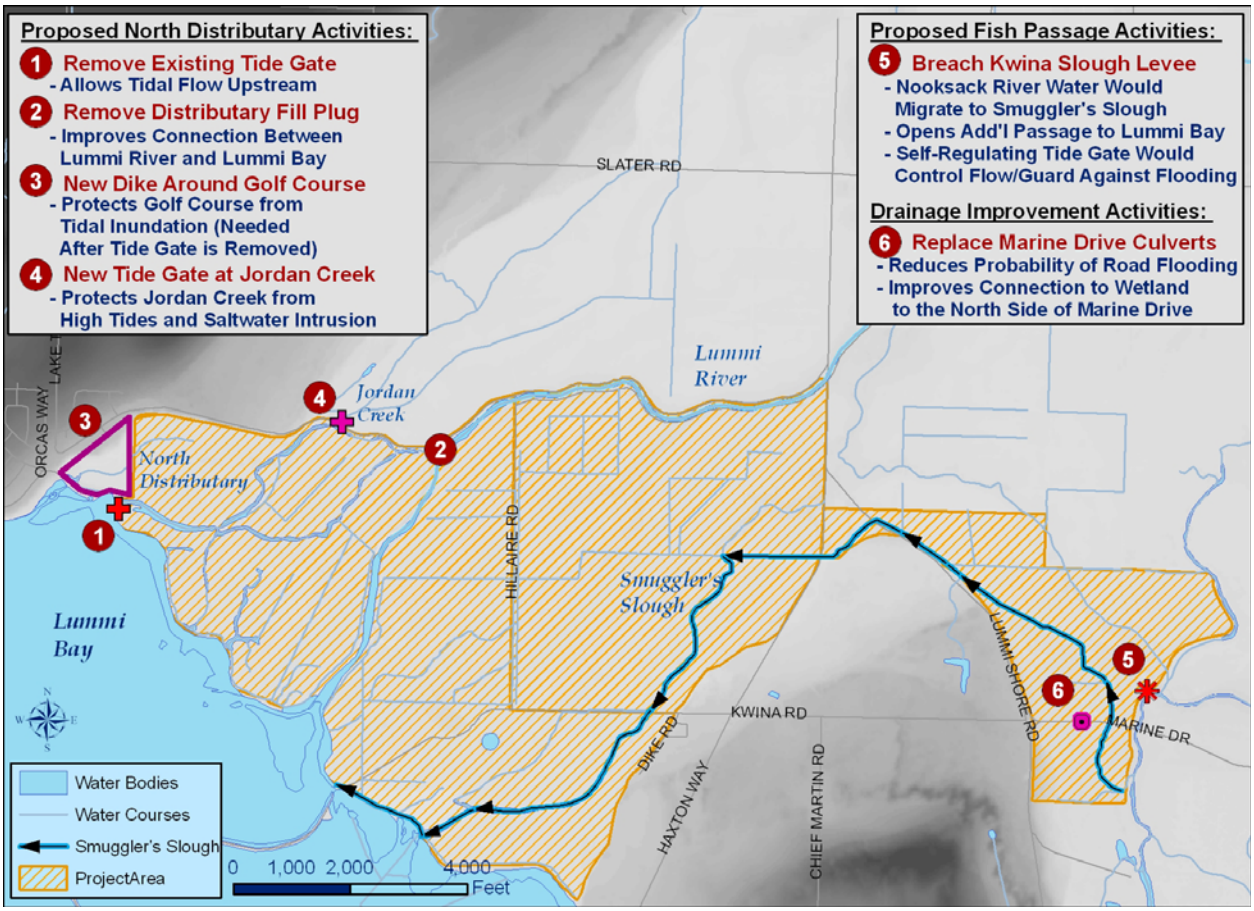

Figure 3-2. Project Area with Restoration Alternative Components Indicated

Table 3-1. Activities Common to All Restoration Alternatives

Purpose	Activities
MODIFICATIONS ALONG THE LUMMI RIVER NORTH DISTRIBUTARY	
Restoring Saltwater Flows to the North Distributary Channel	• Removing the Golf Course tide gate, which is located at the mouth of the Lummi River's North Distributary. Removing the tide gate would allow tidal water to flow into the distributary channel. • Removing the fill plug at the top of the Lummi River's North Distributary channel. Removing the fill plug would permit the free flow of water between the distributary channel and the Lummi River.
Protecting Resources near the North Distributary	• Constructing a dike around the south and east sides of the Sandy Point Golf Course (with the same elevation as the sea wall). The dike would protect the golf course from saltwater inundation resulting from the Golf Course tide gate removal and any sea wall breaching and levee removal activities. • Constructing a tide gate at the confluence of Jordan Creek and the Lummi River's North Distributary. The tide gate would protect Jordan Creek from salt water migration after the removal of the Golf Course tide gate.
MODIFICATIONS ALONG SMUGGLER'S SLOUGH	
Fish Passage Enhancement	• Creating a ten foot wide breach of the Kwina Slough levee near Marine Drive. The Kwina Slough carries water from the Nooksack River. Breaching the levee along the slough would allow water to flow to the west into Smuggler's Slough, improving fish passage potential from the Nooksack River into Lummi Bay. The additional freshwater could also enhance wetlands located near Smuggler's Slough.
Drainage Improvement/Wetland Enhancement	• Adding culverts under Marine Drive to the west of Kwina Slough. The addition of these culverts (replacing a culvert that is frequently blocked by beaver dams) would improve water movement from the wetland on the southern side of Marine Drive to the wetland on the northern half. The north side wetland may provide flow to Smuggler's Slough, which drains into Lummi Bay.
Protecting Low-Lying Land to the West of Smuggler's Slough	• The FEQ model assumes low-lying drainage ditches that discharge into the north-south running portion of Smuggler's Slough (to the west of the peninsula and north of Marine Drive) would be outfitted with flapper gates or other structures to prevent flooding to the west of Smuggler's Slough (see Figure 3-19).
ADDITIONAL MINOR DRAINAGE AND MODELING ASSUMPTIONS	
Additional Drainage Assumptions	• Hillaire Road and Kwina Road would become setback levees to prevent the migration of tidal waters into the more developed and/or agriculturally active lands to the east and north, if acquisition is not possible. • Any culverts under Hillaire Road and western portion of Kwina Road (west of the peninsula) would be fitted with flapper valves to prevent the upland migration of saltwater. The FEQ model includes the simplifying assumption that the road embankments would form an impermeable barrier to subsurface water movement. If fact, very small rates of infiltration would be possible but these rates would be too small to impact the saltwater inundation durations. • The FEQ model assumed tidal waters could move freely between the north and south sides of the Aquaculture Dike Access Road. During design phase of the project, the combined flow capacity of the channel behind the sea wall (south of the Lummi River) and the four culverts under the road should be examined to ensure adequate water movement throughout this portion of the delta.

3.1.2 Description of Four Restoration Alternatives

Four separate alternatives were developed by LNR to generate differing levels of tidal inundation in the historic estuary. These alternatives would function with the activities described in Table 3-1 above. All of the alternatives are designed to increase saltwater flushing (1) north of the Lummi River within the triangular-shaped lands between the river and North Red River Road and (2) south of the Lummi River within the lands bounded by Hillaire Road to the east and Kwina Road to the north and the peninsula high ground to the south (see Figure 3-3).

After implementing one of the proposed alternatives, the topographic boundaries holding back the further migration of saltwater to the north would be (1) the levee along North Red River Road and (2) the right bank levee on the Lummi River upstream of the Fill Plug. To the south of the river, the topographic boundaries would be (1) Hillaire Road, (2) the left bank levee on the Lummi River upstream of Hillaire Road, (3) Kwina Road and (4) the high ground of the Lummi peninsula. This analysis assumes that any existing culverts that cross these topographic boundaries would be retrofitted with flapper gates or similar devices to prevent tidal flow into upland areas while permitting upland areas to drain.

Alternative 1 Components:

Alternative 1 would remove the Lummi Bay sea wall and levees along both sides of the Lummi River (Figure 3-3). Due to the combined length of the sea wall, dike and levees, this alternative would involve more earthwork than the other alternatives being considered. The specific alternative components are listed below:

1. Remove entire Lummi Bay sea wall from mouth of the Lummi River ***north*** to the mouth of the North Distributary[3]
2. Remove the ***left bank and right bank*** Lummi River levees from the fill plug to the river's mouth
3. Remove the levee/sea wall component from mouth of the Lummi River south to the *sea wall tide gates*[4]

Removing the sea wall and levees would allow full inundation north and south of the Lummi River without any hydraulic bottlenecks that limited breaching might produce. Whenever the tides rise above the level of surrounding lands, tidal water would flow over the historic estuary. During the ebb tide, water would flow back into Lummi Bay or infiltrate to the surrounding soils.

Because this alternative would involve the most construction of any of the alternatives, it is a baseline against which other alternatives can be measured.

---

[3] There is currently a tide gate located at the mouth of the North Distributary. Removing this tide gate to allow saltwater flow into the North Distributary is one of the "common elements" described above that would be a part of all alternatives. The Sandy Point Golf Course would be protected by a new dike surrounding the south and east sides of the golf course property.

[4] This report uses the name "sea wall tide gates" to describe the tide gates at the mouth of Smuggler's Slough, immediately north of the Aquaculture Dike Access Road. This name was selected instead of "sea wall tide gates" to avoid any potential confusion with the gates that control tidal flows into and out of the Aquaculture production area.

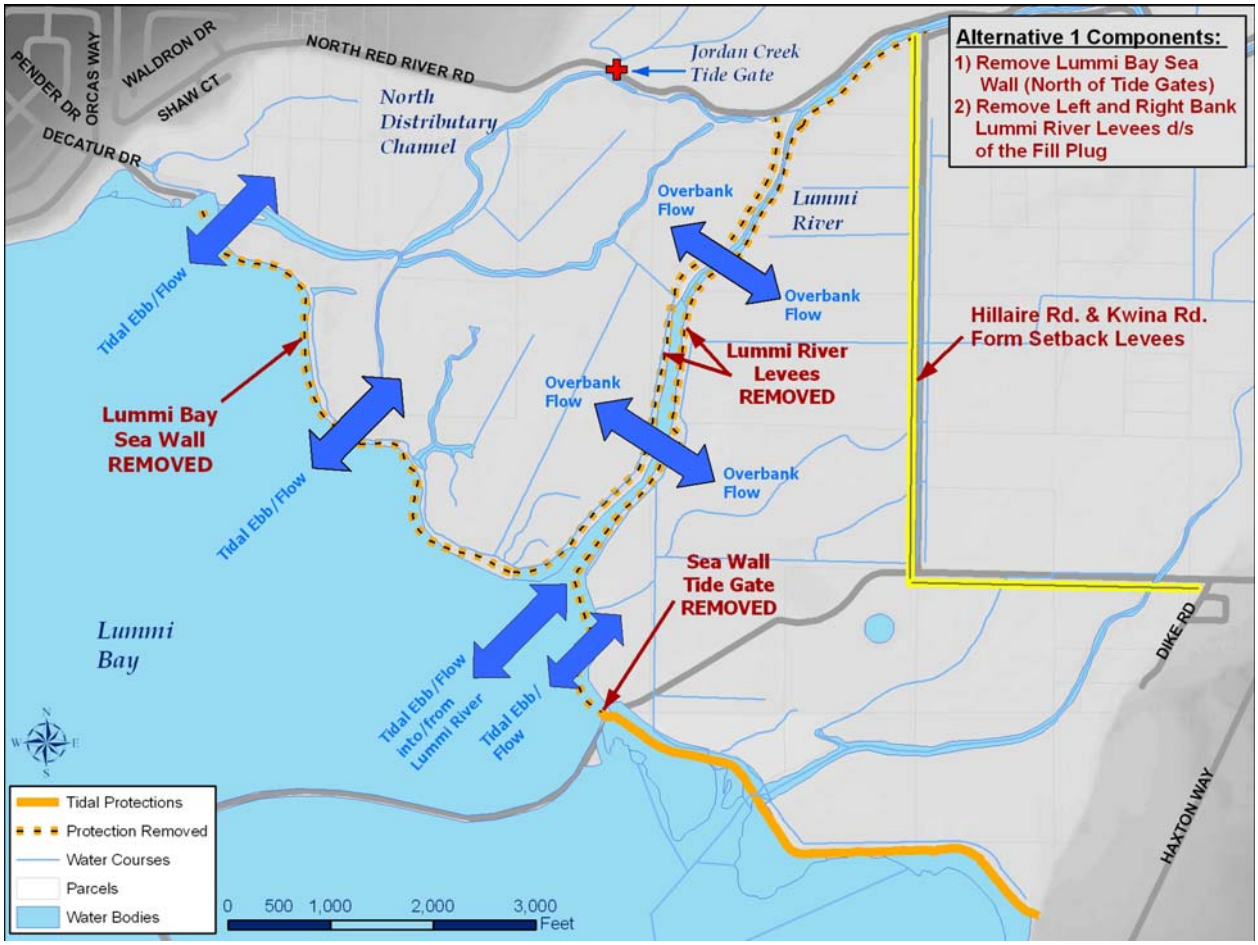

Figure 3-3. Components of Alternative 1

Alternative 2 Components:

Alternative 2 comprises two breaches in the Lummi Bay sea wall and the removal of the north bank Lummi River levee (downstream of the Distributary diversion) to inundate the area between the Lummi River and North Red River Road (Figure 3-4). South of the Lummi River, the sea wall tide gates would be removed to allow inundation and flushing of the lands behind the dike. The specific alternative components are listed below:

1. Breach the Lummi Bay sea wall in two locations: at the mouth of an historic slough and the low elevation area (assumed 50 foot wide breaches)
2. Remove the ***right bank*** Lummi River levee from the North Distributary fill plug to the river's mouth
3. Remove the sea wall tide gates, while leaving the existing box culverts open to tidal and upland flows

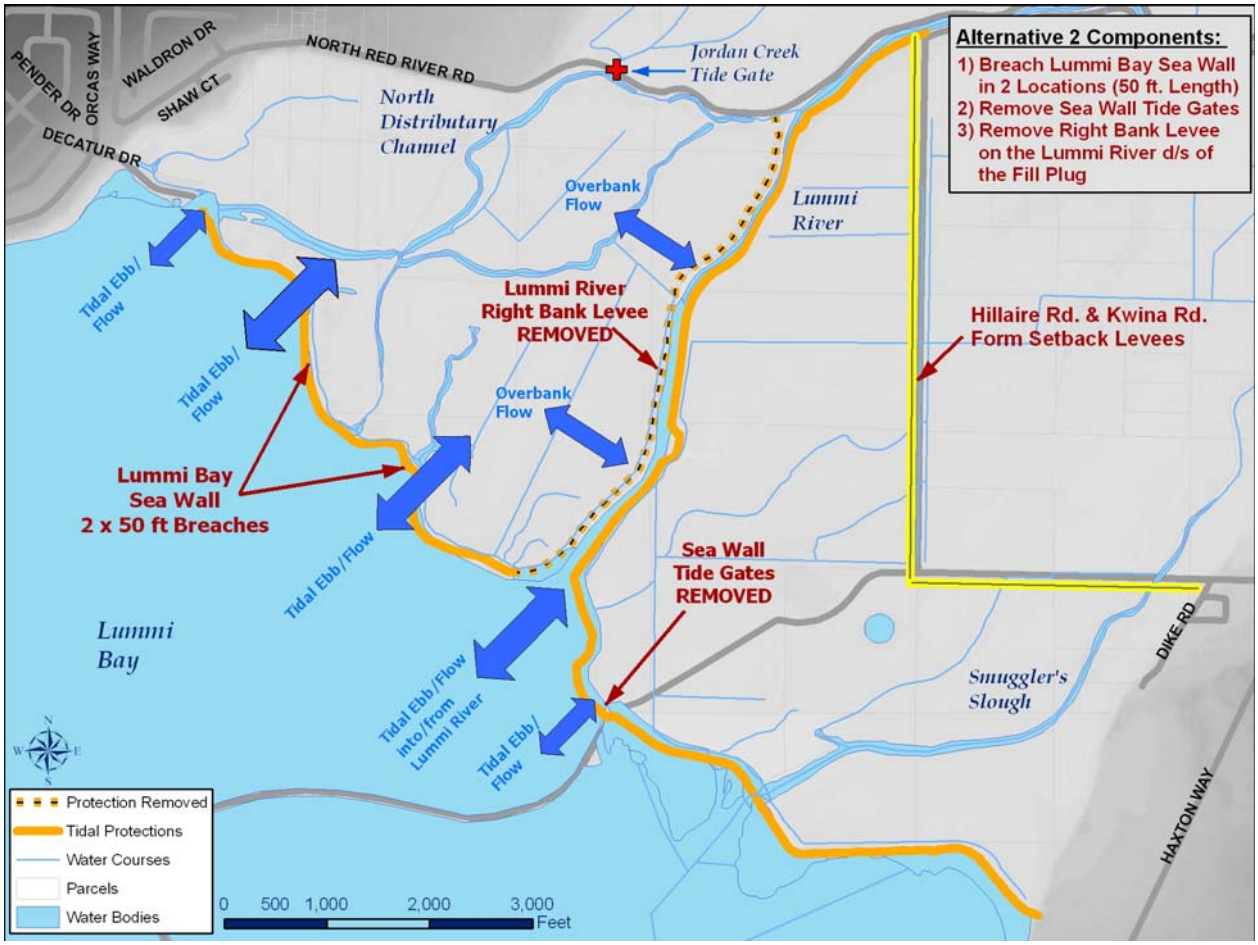

Figure 3-4. Components of Alternative 2

Alternative 2 contains two key differences from Alternative 1. First, the potential for inundation through the sea wall is limited to two 50 foot sections whereas Alternative 1 would remove approximately 4,000 feet of sea wall. Second, to the south of the Lummi River, Alternative 2 would funnel tidal waters through the five, 4 x 6 foot tide gates instead of flowing over the unprotected south bank of the Lummi River as in Alternative 1.

Alternative 3 Components:

Alternative 3 would breach the Lummi Bay sea wall in two locations and remove the sea wall tide gates – these two elements are the same as Alternative 2. Alternative 3 would also breach the Lummi River right bank levees in four locations instead of removing the levees as in Alternative 2 (Figure 3-5). The four breaches along the north bank of the Lummi River would allow tidal waters into the area between the Lummi River and the North Distributary channel, albeit with a limited area for rising and falling tides to enter and leave the estuary. The specific alternative components are listed below:

1. Breach the Lummi Bay sea wall in two locations: at the mouth of the historic slough and the low elevation area (assumed 50 foot wide breaches)
2. Breach the ***right bank*** Lummi River levee at four locations downstream of the North Distributary channel (assumed 50 foot wide breaches)
3. Remove the sea wall tide gates, while leaving the existing box culverts open to tidal and upland flows

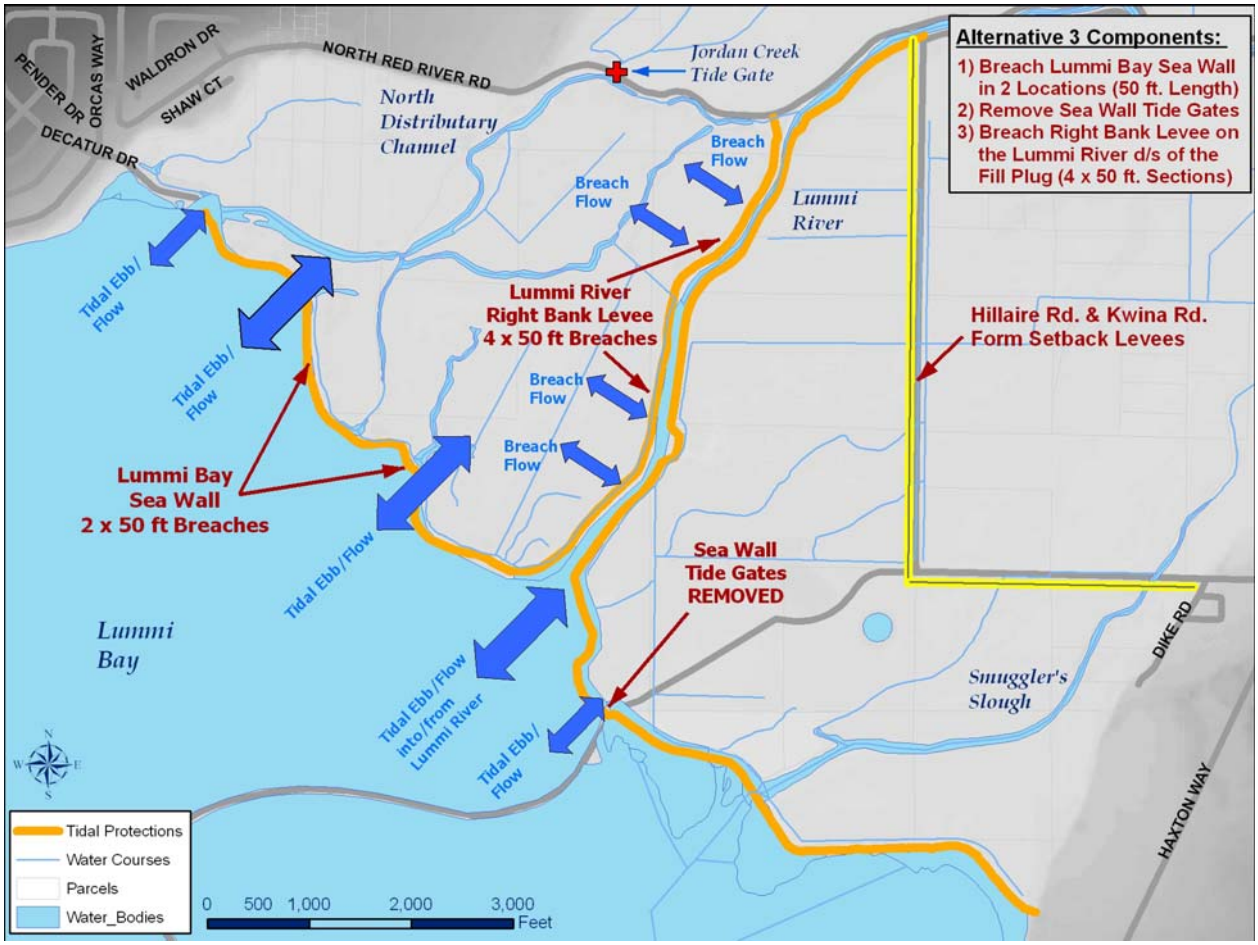

Figure 3-5. Components of Alternative 3

Alternative 4 Components:

This alternative takes a different approach to allowing tidal waters to enter the delta lands south of the Lummi River. Instead of simply removing the existing tide gates to allow free back-and-forth movement of tidal water, Alternative 4 would add self-regulating tide gates that permit free flow of water through the gates until the tides in Lummi Bay climb to a set elevation that causes the gates to close. Self-regulating tide gates provide the benefit of saltwater flows into the estuary combined with protection against unwanted levels of inundation.

This alternative could be combined with any of the restoration alternatives under consideration for the areas north of the Lummi River. In this analysis, Alternative 4 includes the Lummi River levee breaching approach described in Alternative 3. The specific alternative components are listed below:

1. Replace the existing flapper valves at the sea wall (south of the Lummi River) with self-regulating tide gates on each box culvert. For this analysis, the closure elevation was set to the crown of the box culverts, an elevation of 2.5 feet.
2. For areas north of the Lummi River, the Alternative 3 configuration – limited breaching of the sea wall and right bank levees – was used.

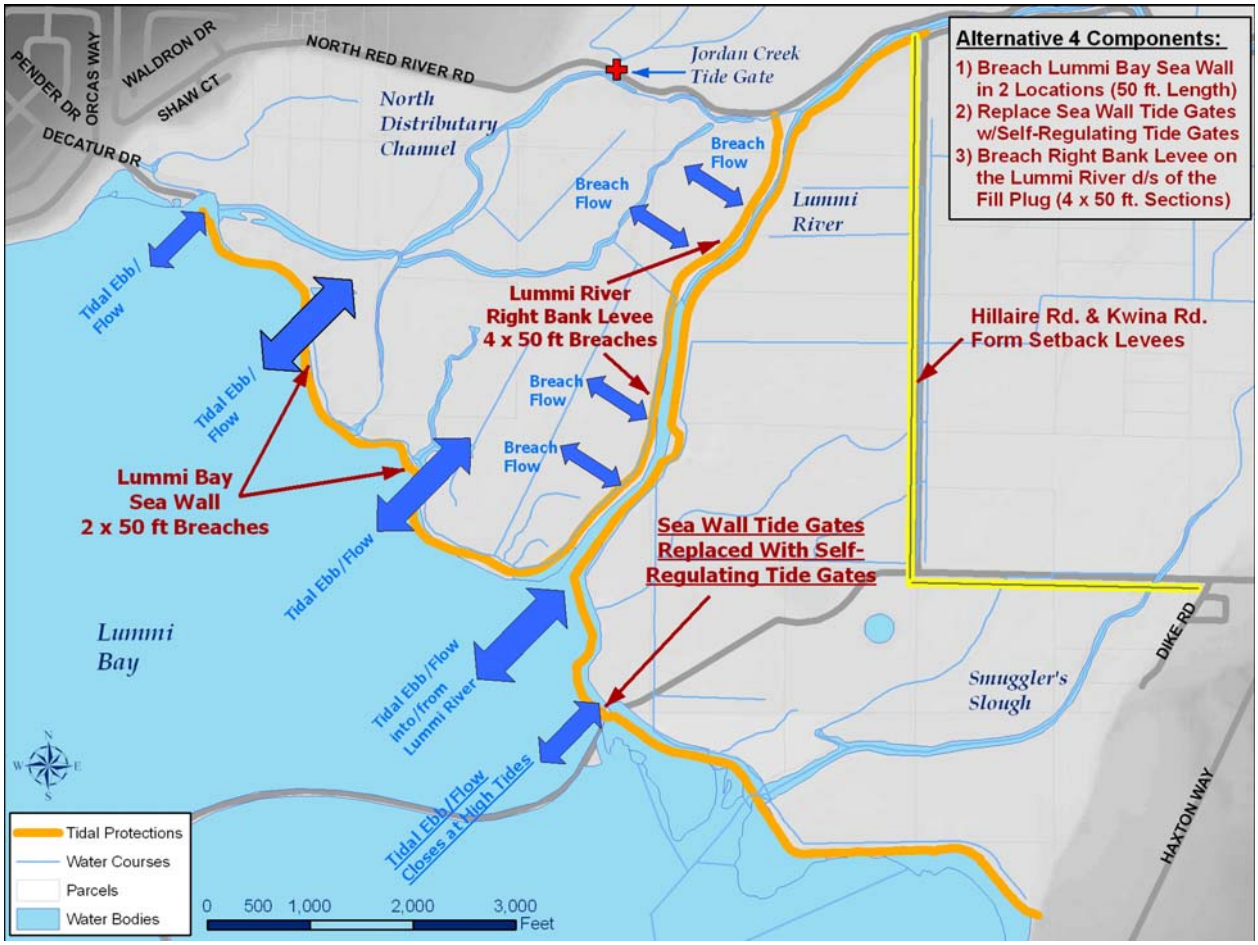

Figure 3-6. Components of Alternative 4

3.2 Saltwater Inundation Analysis

This section presents the results of the hydraulic modeling analysis of the four restoration alternatives. For each alternative, an FEQ model was run using 40 years of historical tidal data for the NOS Cherry Point station to simulate the rising and falling of tides, flow through sea wall and levee breaches and the inundation of estuary lands[5]. Duration statistics were computed for the 40 years of FEQ model hourly output to characterize the inundation extent and duration[6].

Mapping FEQ Modeling Results

For each of the alternatives modeled, the extent and duration of saltwater inundation were mapped and color-coded to distinguish areas with long periods of inundation from those with infrequent or short periods of inundation. The inundation statistics were computed by overlaying the FEQ modeling results on the LiDAR topography data (see Figure 3-7 to Figure 3-10).

The FEQ model divides the delta into a series of level-pool reservoirs. The saltwater inundation maps assume that any saltwater entering the delta will distribute itself according to local topography. In some cases, the results indicate areas with longer durations (shown in yellow) completely surrounded by areas with shorter durations (shown in green). The longer duration areas are localized low spots. After giving some consideration to filling the DEM to eliminate the longer inundation durations in localized low spots, the project team decided against it. Subsurface flow or narrow channels too small for the DEM to resolve could deliver into the localized low spots, and experience suggests these hollows will be wetter than surrounding higher elevation areas.

3.2.1 Alternative 1: Full Sea Wall and Levee Removal

The saltwater inundation modeling results are summarized in Figure 3-7. In the figure, red shaded areas indicate the longest inundation durations; blue shaded areas the shortest inundation durations. Table 3-2 lists a summary of key elevations relative to the height of existing roadways.

To the north of the Lummi River, the entire triangular region bounded by the river and the North Red River Road would be periodically inundated by tidal waters. Much of the area would be inundated at least 10 percent of the time. The highest predicted tide during the analysis period (from 1961 through 2000) is 6.25 feet (NGVD29), which is approximately 1.5 feet below the low-spot elevation of Red River Road, as inferred from the 2-meter LiDAR DEM.

---

[5] The long-term modeling assumed the flow in the Lummi River was entirely tidal and that no water was overflowing from the Nooksack River. Because the conversion to typical salt-tolerance estuary plant species is a mass-driven process (i.e., driven by frequent salt loading), neglecting periodic freshwater flows in the Lummi River is a reasonable simplification. The freshwater analysis described later in this section addresses the combined impacts of tidal inundation and freshwater flooding within the Nooksack and Lummi River delta.

[6] The duration analysis examined the FEQ model's time series output data to determine how often or for how long water surface elevations surpassed a given elevation.

To the south of the Lummi River, saltwater inundation would spread east to Hillaire Road and north to Kwina Road. The higher elevation lands to the south of Kwina Road would stop the advance of tidal waters to the south of Smuggler's Slough. ***During very high tides, water could spread across portions of the Aquaculture Dike Access Road, Hillaire Road and Kwina Road.*** The LiDAR DEM shows the low point of Hillaire Road is located approximately 1,900 feet north of the intersection with Kwina Road. The elevation inferred from the 2-meter LiDAR DEM is approximately 2.9 feet (NGVD29)[7].

Table 3-2. Alternative 1 Results: Inundation and Roadway Elevations

Roadway	Low Spot Elevation (NGVD29)	Predicted Max. Water Surface (NGVD29)	Roadway Overtopped?	Roadway Overtopped (% of time)
North of the Lummi River				
North Red River Road	7.7 ft	6.25 ft	No	0%
South of the Lummi River				
Aquaculture Dike Access Road	3.5 ft	6.25 ft	**Yes**	**13%**
Hillaire Road	2.9 ft	6.25 ft	**Yes**	**22%**
Kwina Road	3.7 ft	6.25 ft	**Yes**	**10%**

Summary of Alternative 1

Alternative 1 would create frequent inundation within the intended restoration areas, but during higher tides saltwater would overtop sections of Hillaire Road, Kwina Road and the Aquaculture Dike Access Road, in some cases by 2 to 3 feet (see Table 3-2 above). Overtopping Hillaire Road and Kwina Road would prevent traffic flow along these routes and would generate flooding into the more developed and active farmlands to the east of Hillaire Road and north of Kwina Road. Without addressing the potential overtopping of these roadways (e.g., by building a separate setback levee or elevating the road surface), this alternative is not feasible.

Assuming the roadway overtopping issue was resolved, the predicted level of inundation within the intended restoration area should be sufficient to support plant species typical of tidal salt marsh environment. The near daily saltwater inundation would make farming in these areas infeasible. Immediately beyond the target inundation area, LNR should ensure proper drainage to keep salt migration from affecting adjacent farm lands (see Section 3.2.6 for a recommended management and monitoring strategy).

[7] The Whatcom County survey data used to develop the FEQ model indicated a low-spot elevation of approximately 3.5 feet (NGVD29) along Hillaire Road and Kwina Road. The difference between the elevation data should be resolved during the design phase of the project.

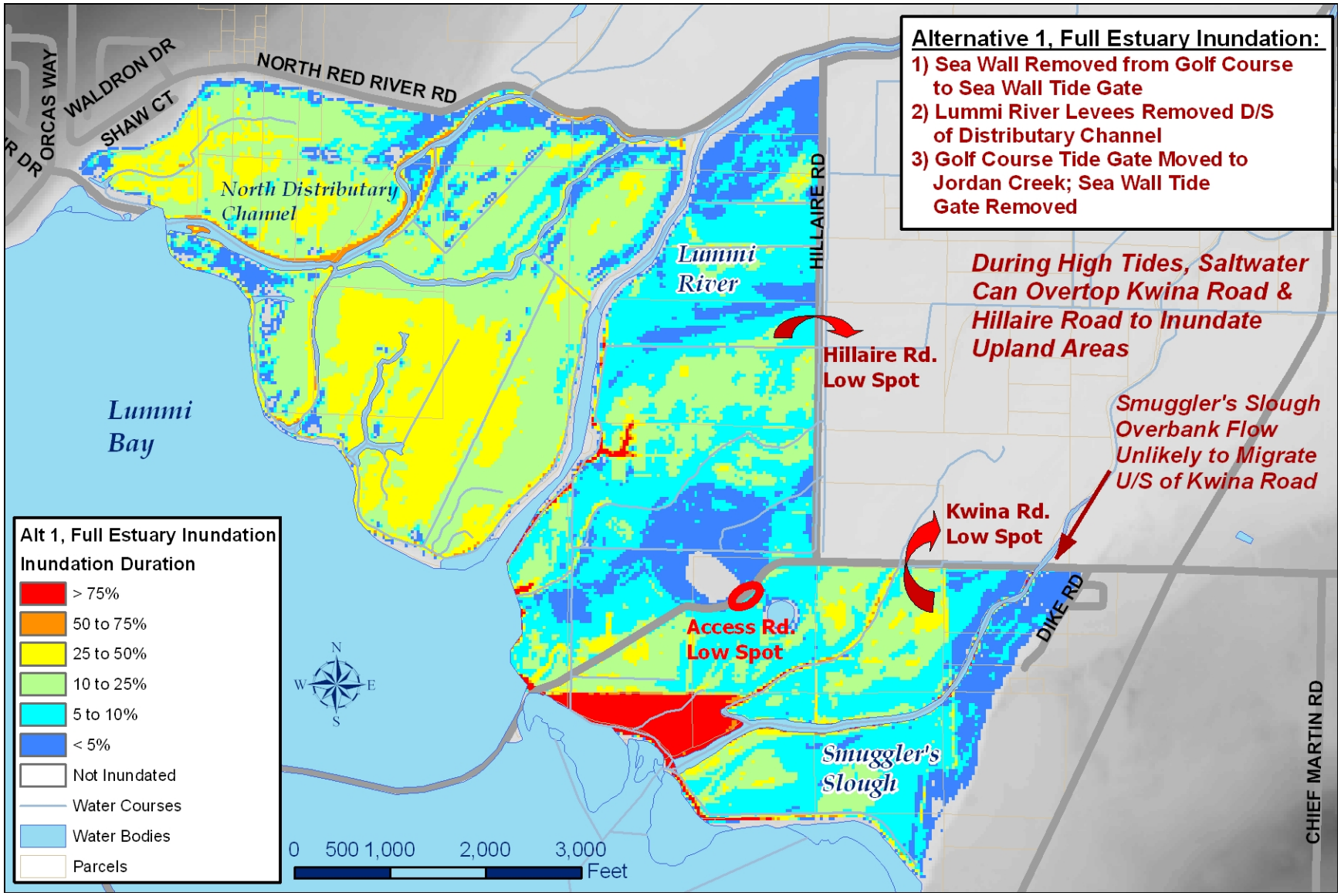

Figure 3-7. Alternative 1: Predicted Inundation Durations

3.2.2 Alternative 2: Seawall Breach and Right Bank Levee Removal

The saltwater inundation modeling results are summarized in Figure 3-8. The duration of inundation north of the Lummi River is the same as predicted inundation in Alternative 1. ***This means the combination of sea wall breaches and levee removal in Alternative 2 is just as effective as removing the entire sea wall and right bank levee.***

South of the Lummi River, removing the sea wall tide gates to open the five 4 x 6-foot box culverts to ebb and flow tidal waters would provide much the same inundation extent as Alternative 1. However, there are two key differences in the inundation durations:

1. The limited capacity of the open tide gates in Alternative 2 would result in lower water surface elevations (Table 3-3), although not low enough to prevent roadway overtopping. ***The FEQ model predicts the periodic overtopping of Hillaire Road, Kwina Road and the Aquaculture Dike Access Road***.

2. South of the Lummi River, some of the historic estuary lands would be inundated for longer periods under Alternative 2. The explanation for these results lies in the outflows during an ebb tide. The limited outflow area through the box culverts would limit the outflow rates as tides recede (relative to removing portions of the sea wall and south bank levee) and hold tidal waters over the delta for longer periods.

Table 3-3. Alternative 2 Results: Inundation and Roadway Elevations

Roadway	Low Spot Elevation (NGVD29)	Predicted Max. Water Surface (NGVD29)	Roadway Overtopped?	Roadway Overtopped (% of time)
North of the Lummi River				
North Red River Road	7.7 ft	6.25 ft	No	0%
South of the Lummi River				
Aquaculture Dike Access Road	3.5 ft	4.25 ft	**Yes**	**10%**
Hillaire Road	2.9 ft	4.25 ft	**Yes**	**25%**
Kwina Road	3.7 ft	4.25 ft	**Yes**	**5%**

Summary of Alternative 2

The extent of inundation and consequences for Alternative 2 are similar to those for Alternative 1. Alternative 2 would create frequent inundation within the intended restoration areas and during higher tides saltwater would overtop sections of Hillaire Road, Kwina Road and the Aquaculture Dike Access Road (see Table 3-3 above), although the frequency and volume of overtopping would be less than Alternative 1. Without addressing the potential overtopping of these roadways (e.g., by building a separate setback levee or elevating the road surface), this alternative is not feasible.

Similar to Alternative 1, this alternative should produce sufficient saltwater inundation to support plant species typical of tidal salt marsh environment. The near daily saltwater inundation would make farming in these areas infeasible. Adopting an upland salt management strategy should keep salt migration from affecting adjacent farm lands (see Section 3.2.6).

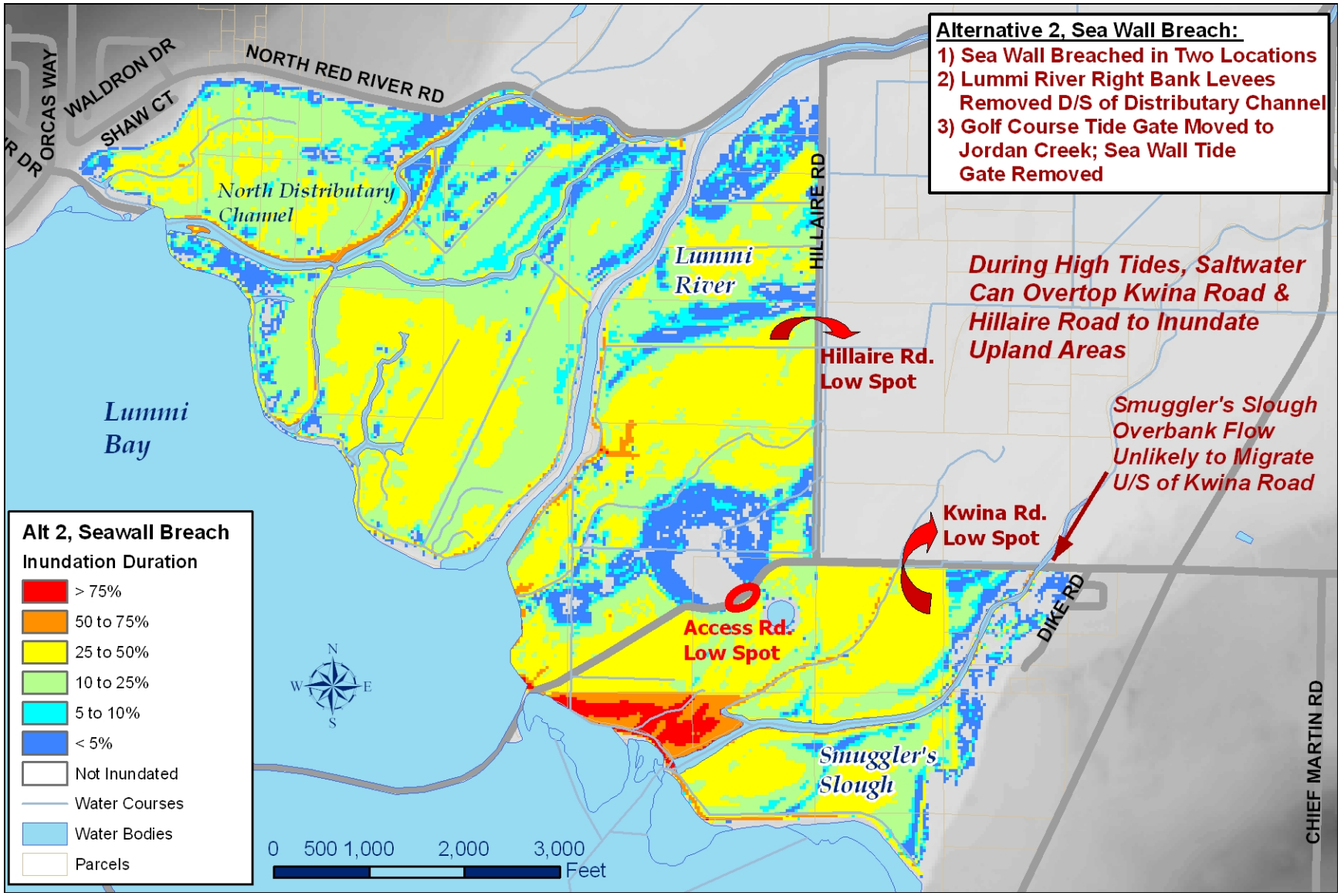

Figure 3-8. Alternative 2: Predicted Inundation Durations

3.2.3 Alternative 3: Limited Seawall and Levee Breaching

The hydraulic modeling results for Alternative 3 are summarized in Figure 3-9 and Table 3-4. North of the Lummi River, the predicted inundation durations are generally similar to Alternatives 1 and 2. A minor difference is that saltwater would inundate the delta for slightly longer durations than under Alternatives 1 or 2. The smaller openings presented by the sea wall and levee breaches would restrict tidal outflows during periods of receding tides[8], although the difference is small and unlikely to affect restoration goals differently than either Alternative 1 or 2. The more significant issue is that levee breaching requires far less construction than levee removal.

Table 3-4. Alternative 3 Results: Inundation and Roadway Elevations

Roadway	Low Spot Elevation (NGVD29)	Predicted Max. Water Surface (NGVD29)	Roadway Overtopped?	Roadway Overtopped (% of time)
North of the Lummi River				
North Red River Road	7.7 ft	6.25 ft	No	0%
South of the Lummi River				
Aquaculture Dike Access Road	3.5 ft	4.25 ft	**Yes**	**10%**
Hillaire Road	2.9 ft	4.25 ft	**Yes**	**25%**
Kwina Road	3.7 ft	4.25 ft	**Yes**	**5%**

Summary of Alternative 3

North of the Lummi River, this alternative would produce slightly longer inundation durations than Alternatives 1 and 2 and could be implemented at lower costs, because it would require less construction. For these reasons, the limited breaching approach should be preferred for the estuary lands north of the Lummi River.

South of the Lummi River, the composition of this alternative is the exactly same as Alternative 2. Roadways would be periodically overtopped, making this approach infeasible without incorporating additional levees to hold back the high tides.

[8] This effect is similar to the FEQ model predictions south of the Lummi River in Alternative 2. Smaller openings in the sea wall/dike/levees will trap saltwater over the delta for longer periods.

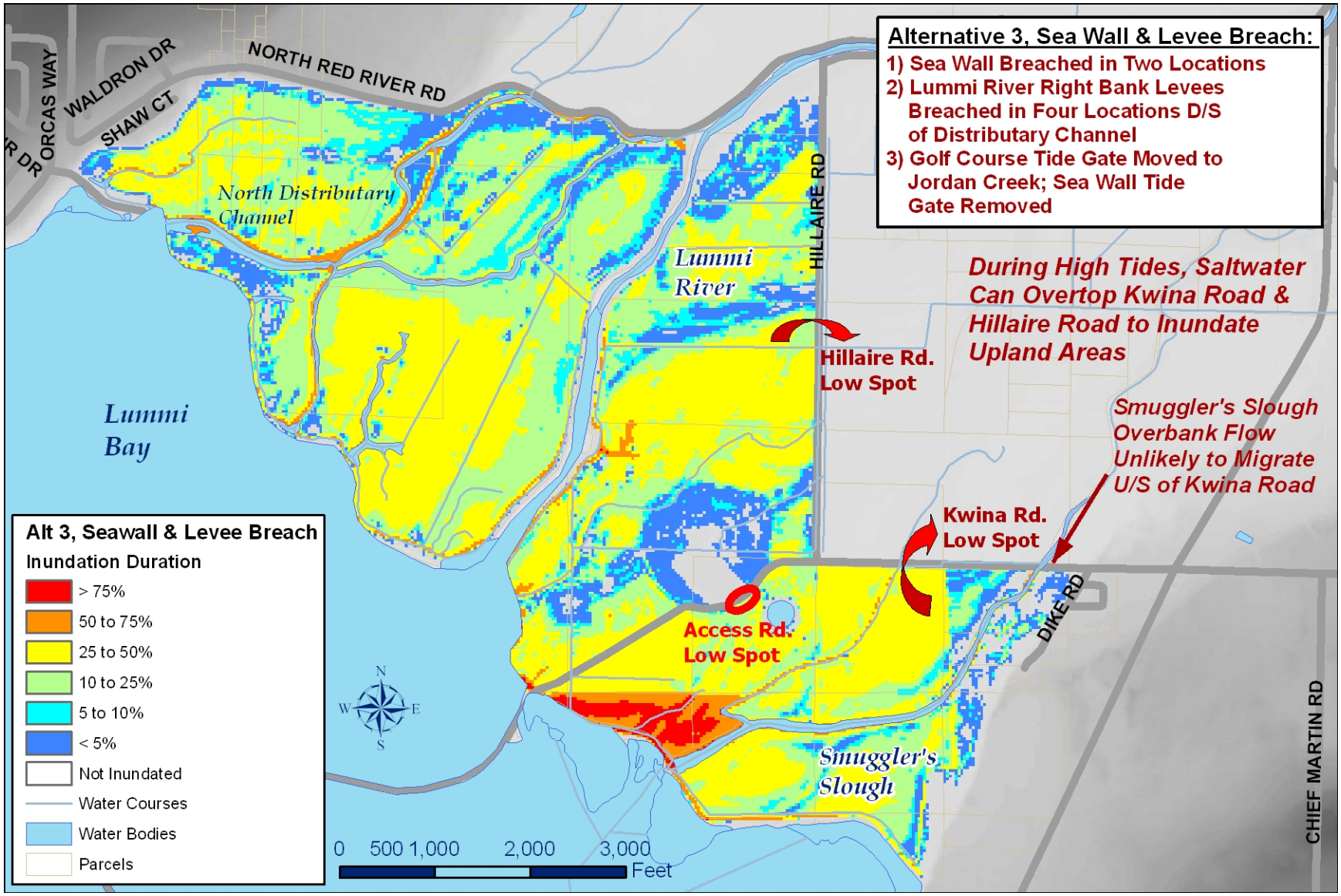

Figure 3-9. Alternative 3: Predicted Inundation Durations

3.2.4 Alternative 4: Contained Breaches and Passage Corridor

The installation of self-regulating tide gates at the sea wall (south of the Lummi River) with closure set elevations of 2.5 feet (NGVD29) would prevent the overtopping of roadways south of the Lummi River, but it would also limit the extent of saltwater inundation in the delta (see Figure 3-10 and Table 3-5). According to the long-term records for the Cherry Point tidal station, local tides surpass 2.5 feet (NGVD29) about 25 percent of the time. This means the self-regulating tide gate would be closed about one-quarter of the time – a substantial difference from Alternatives 2 and 3, which would leave the box culverts open to tidal flow at all times. Setting the closure elevation any higher would result in periodic overtopping Kwina Road, based on the low-spot elevations inferred from the LiDAR DEM.

This alternative could be modified to include road raising along Kwina Road with a higher closure set-elevation on the self-regulating tide gates. Anther possible modification would remove some but not all of the flapper valves from the existing sea wall. This option would limit tidal inflows more than Alternative 3 but would allow a greater extent of inundation than the self-regulating tide gates simulation in Alternative 4.

Table 3-5. Alternative 4 Results: Inundation and Roadway Elevations

Roadway	Low Spot Elevation (NGVD29)	Predicted Max. Water Surface (NGVD29)	Roadway Overtopped?	Roadway Overtopped (% of time)
North of the Lummi River				
North Red River Road	7.7 ft	6.25 ft	No	0%
South of the Lummi River				
Aquaculture Dike Access Road	3.5 ft	2.7 ft	**No**	**0%**
Hillaire Road	2.9 ft	2.7 ft	**No**	**0%**
Kwina Road	3.7 ft	2.7 ft	**No**	**0%**

Summary of Alternative 4

Unlike the other alternatives evaluated, Alternative 4 would not submerge portions of Hillaire Road and Kwina Road during very high tides. This difference makes Alternative 4 more feasible and straightforward to implement than the others.

South of the Lummi River, the extent of saltwater inundation is considerably less than the other alternatives. However, regular introduction and flushing of saltwater into large portions of the lands behind the sea wall should allow salt marsh vegetation to develop, particularly in the vicinity of Smuggler's Slough. While the inundation durations are relatively low through much of the area to the south of the Lummi River, saltwater inundation would touch almost every parcel (see Figure 3-10). Farming to the west of Hillaire Road and south of Kwina Road will probably not be feasible without the construction of new drainage facilities to help flush out saltwater.

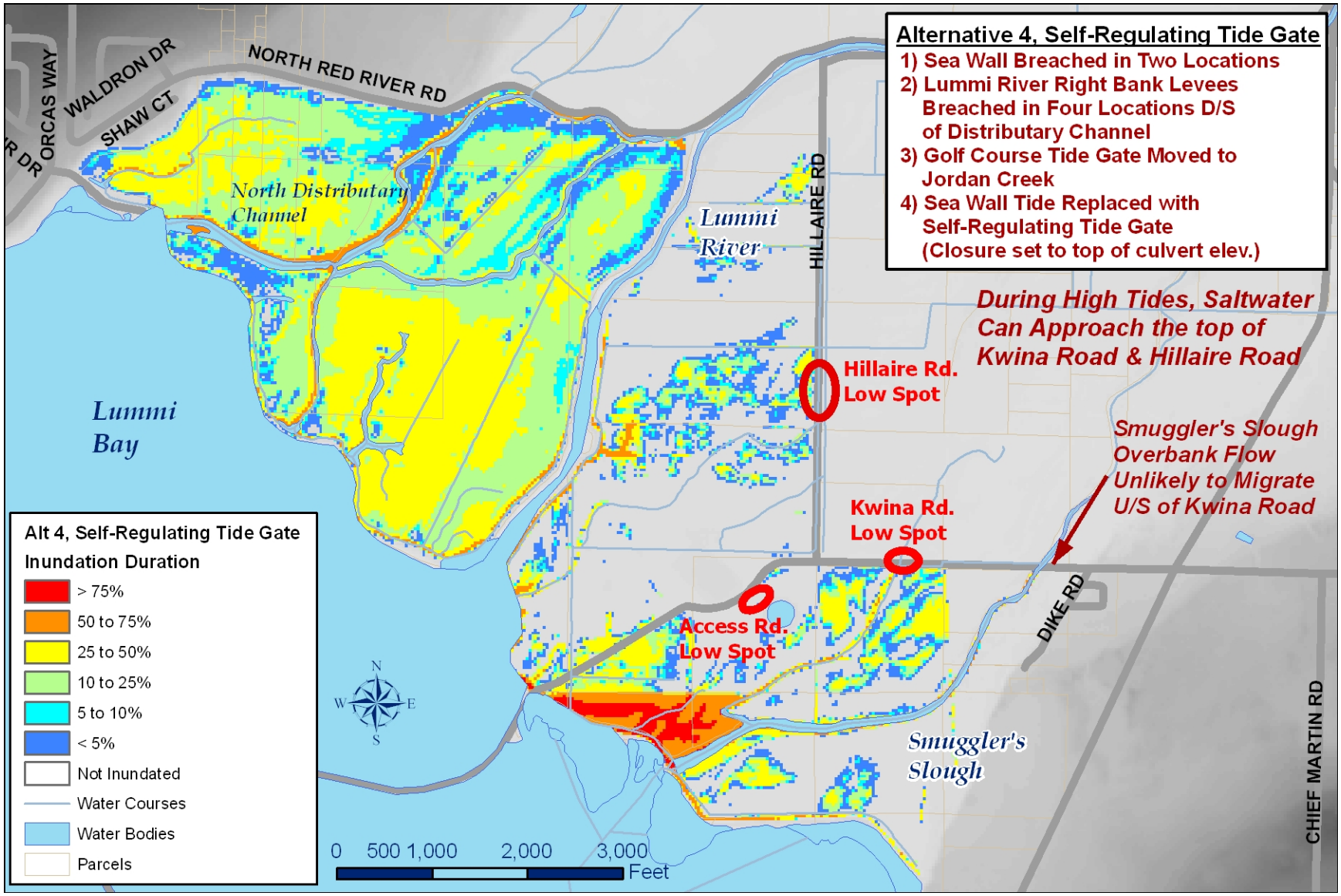

Figure 3-10. Alternative 4: Predicted Inundation Durations

3.2.5 Summary of Saltwater Inundation Analysis

The saltwater inundation analysis used historical tide data, high-resolution LiDAR topography data and a fully-dynamic hydraulic model to estimate the extent and duration of saltwater inundation associated with four separate restoration alternatives. The modeling results were also examined to determine if any local roadways were likely to be overtopped during very high tides. Table 3-6 lists a summary of modeling results.

Table 3-6. Summary of Saltwater Inundation Hydraulic Modeling Results

	Alternative 1	**Alternative 2**	**Alternative 3**	**Alternative 4**
Inundation North of the Lummi River	Extensive	Extensive	Extensive	Extensive
Inundation South of Lummi River	Extensive	Extensive	Extensive	Less Extensive
Roadway Submergence				
North Red River Road	No	No	No	No
Aquaculture Dike Access Road	Yes	Yes	Yes	No
Hillaire Road	Yes	Yes	Yes	No
Kwina Road	Yes	Yes	Yes	No

To the north of the Lummi River, any of the alternatives would produce extensive saltwater inundation and all tidal waters would be contained within the project area by the embankment at North Red River Road. Alternative 3 would generate this level of inundation with only limited breaching of the Lummi Bay sea wall and right bank Lummi River levee. ***Because it requires the least earthwork to produce the desired level of inundation, Alternative 3 should be the preferred alternative for inundating the portion of the project area to the north of the Lummi River.***

The selection of a preferred estuary restoration alternative for the area to the south of the Lummi River is more complex. Alternative 4 is the only approach that would not overtop portions of Hillaire Road and Kwina Road. However, this alternative would generate less new salt marsh habitat than the other alternatives (although the new habitat would probably be located in the vicinity of Smuggler's Slough).

Any of the alternatives would deliver enough saltwater to the historic estuary lands to the north of the Lummi River (below the start of the North Distributary channel) and to the south of the river (on the bayside of Hillaire Road and Kwina Road) to preclude active farming in these areas.

3.2.6 Managing Salinity Migration

On the bayside of Hillaire Road, Kwina Road and North Red River Road, LNR could expect a build-up in salinity concentrations that would preclude any agricultural production for any of the alternatives examined. The local vegetation would over time convert to salt tolerant species typical for salt marsh and estuary lands. This conversion of vegetation types is a primary goal of the restoration project – to reestablish portions of the historic estuary to better support salmon migration and to develop habitat supportive of the salmon life cycle.

While the introduction of saltwater into portions of the delta is desirable, restoration activities could allow sodium to migrate beyond intended boundaries of the restored estuary. For example, LNR could expect slow rates of seepage through the embankments beneath Hillaire Road, Kwina Road and North Red River Road whenever the tidal waters are higher than the upland groundwater and/or ditch water (see Figure 3-11). Saltwater could also migrate upstream within the Smuggler's Slough channel during high tides, backing up into the roadside ditches to the north of Kwina Road and the east of Hillaire Road. Saltwater in these ditches could migrate into the soils beneath adjacent agricultural lands.

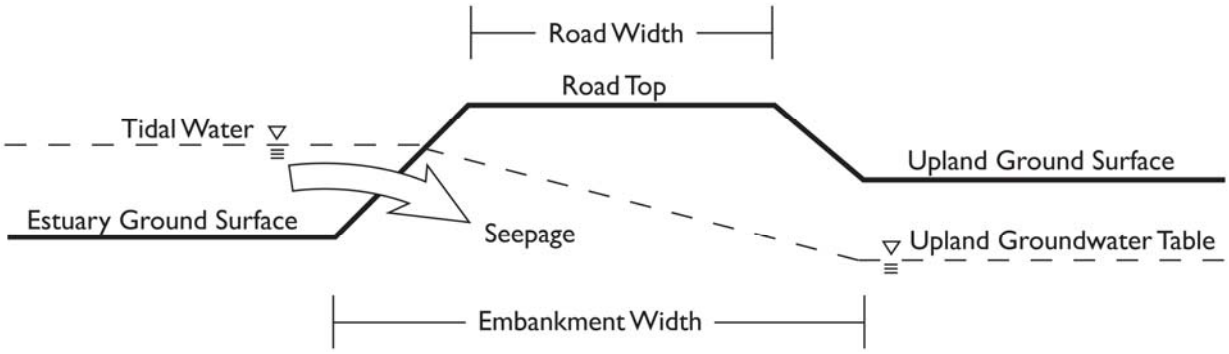

Figure 3-11. Illustration of Potential Saltwater Seepage Through a Road Embankment

During the design and construction phases of the estuary restoration project, LNR should proactively address saltwater intrusion risk. Recommended activities include:

1) Installing flapper valves or other hydraulic controls that prevent saltwater from backing up into drainage ditches that run along active farmland. This issue will be most prevalent along the west side (right bank) of Smuggler's Slough.

2) Ensuring the drainage ditches located on the upland side of Hillaire Road and Kwina Road function properly to flush out any saline groundwater intrusion. The rate of any saline groundwater seepage through the roadway embankments should be low compared with the rate of freshwater captured and conveyed by these ditches.

After implementing a restoration plan, LNR could install monitoring stations to detect any salinity build-up and respond with appropriate adaptive measures. For example, LNR could:

1) Monitor the groundwater flow and electrical conductivity (proxy for salinity) in soils on the upland side of road embankments, particularly on the north side of North Red River Road. If the ditches along the east (upland) side of Hillaire Road and north (upland) side of Kwina Road are consistently stagnant, LNR could also monitor in these locations.

2) Developing an adaptive management plan that responds to any significant increases in soil salinity levels. One element of the adaptive management plan could include maintenance of drainage ditches or ensure proper function.

3.3 Freshwater Flooding Analysis

The saltwater inundation analysis described in the previous section was performed to map the potential expansion of the Nooksack and Lummi River estuary. The saltwater inundation analysis described the potential inundation lands (i.e., the benefit) and identified the potential for high tides to impact local roadways. This *freshwater flooding analysis* examines the potential for these alternatives, along with the proposed breaching of the Kwina Slough and corresponding increase in flows through Smuggler's Slough, to increase the floodwater elevation and extent within the historic estuary and other parts of the project area.

The proposed restoration activities near Lummi Bay could affect floodplain inundation because portions of the delta would be inundated by tide waters thereby reducing the available surface water storage volume. The proposed breach in Kwina Slough could affect flood elevations by delivering more freshwater into Smuggler's Slough and the adjacent floodplain. The lower Nooksack River system FEQ model was modified to examine both of these issues. The following section describes the modeling analysis in greater detail.

3.3.1 Hydraulic Model Setup of 100-Year Design Flood

To evaluate the freshwater flooding extent, the 100-year design flood was routed through an FEQ model of the lower Nooksack River, Lummi River and adjacent floodplains.

The FEQ model was setup as follows:

- The November 1990 flood event, as derived from the USGS Ferndale gaging station was routed through the FEQ model. For the Nooksack River system, this is considered the 100-year design flood. During this event, water surface elevations are high enough to spill over into the uppermost portion of the Lummi River and overtop main stem levees.

- The actual Bellingham Bay and Cherry Point tidal data recorded during November 1990 were used as the downstream boundary condition for the FEQ model.

- The Lummi delta was divided into numerous level pool reservoirs that represent different portions of the Nooksack River and Lummi River floodplain (see Figure 3-12)[9]. The

[9] Several of the level pool reservoirs shown in Figure 3-12 are combined within the FEQ model to ensure the pools are separated by topographic boundaries, such as levees and road embankments. Level pool reservoirs C and D were combined, F and G were combined, H and I were combined, and J and K were combined.

level pool reservoir boundaries correspond to topographic boundaries within the delta, such as road embankments. The FEQ model allows water to spill from one level pool reservoir to adjacent reservoirs.

- A self-regulating tide gate was included at the proposed Kwina Slough breach. Self-regulating tide gates are designed to remain open until waters in front of the gate (i.e., water in Kwina Slough) reach a set elevation at which point the gate closes rapidly. This type of gate permits the interchange of tidal flows across the gate, but also protects downstream areas from flooding. Table 3-7 lists the geometry of the proposed breach. Two separate closure settings were modeled to determine how the self-regulating tide gate settings would affect floodwater elevations.

- The existing conditions and four restoration alternatives were modeled to estimate how the proposed restoration activities would affect the flood elevations and extent during a very large storm. The existing conditions simulation plus the four alternatives and two self-regulating gate settings simulations resulted in a total of nine different FEQ model simulations.

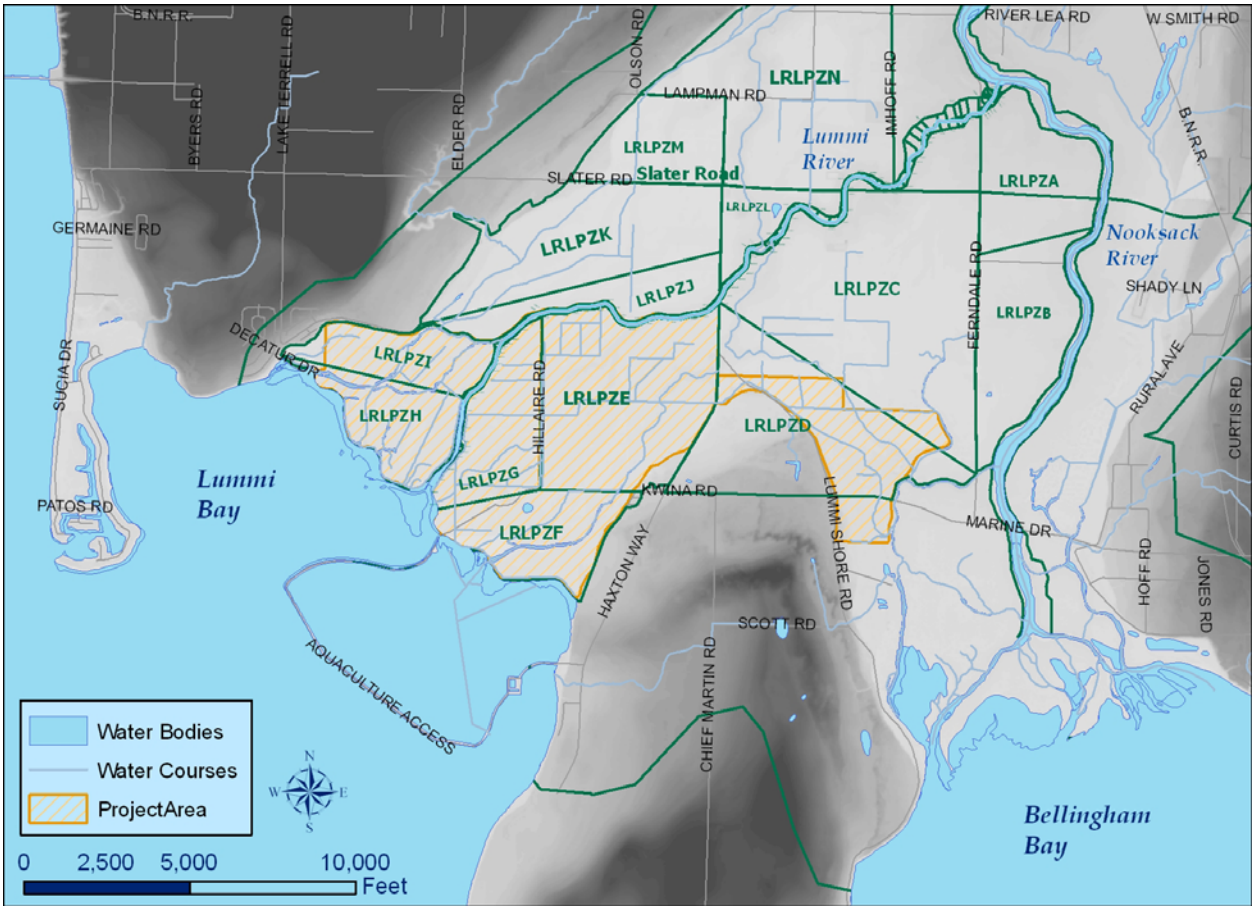

Figure 3-12. FEQ Model of the Project Area

Table 3-7. Proposed Kwina Slough Breach Geometry and Gate Settings

Proposed Breach Geometry (all elevation in NGVD29)	
Invert Elevation	3.2 feet
Width	10 feet
Height	~13 feet
Proposed Self-Regulating Tide Gate Settings	
Gate Width	10 feet
Proposed Closure Set Elevation	6.7 or 7.7 feet
Corresponding Maximum Opening	3.5 or 4.5 feet

3.3.2 Freshwater Flooding Modeling Results

The FEQ model was modified to represent each of the four restoration alternatives. These alternatives along with the existing condition (i.e., the base case) were modeled, as described above. Table 3-8 lists the predicted maximum water surface elevations in different portions of the delta for each alternative, as well as the elevations of key roadways.

Along the right bank of the Lummi River, the restoration alternatives would produce no flood elevation rise, except for the area between the Lummi River and North Red River Road (see LRP HI in Figure 3-12), which would be exposed to the rise and fall of the tides. Along the left bank of the Lummi River, flood waters would rise near Lummi Bay and in the vicinity of Smuggler's Slough (see LRP FG and CD in Figure 3-12). The following subsections describe the predicted flood inundation for the existing conditions and various alternatives in greater detail.

Flood Extent for Existing Conditions (Base Case)

The lower Nooksack River system is prone to flooding during large flow events. According to the predictions of the existing conditions model, portions of the delta would become inundated during the 100-year flood event, including some portions of the project area (Figure 3-13). The flooded areas are concentrated along the eastern portion of the project area to the north of Smuggler's Slough. Flooding is also predicted along the right bank of the Lummi River in the Jordan Creek floodplain, which is outside of the project area.

Flood Extent for Alternatives 1 – 3

Implementing Alternative 1, 2 or 3 along with the proposed Kwina Slough breach would increase the level of flood inundation during the 100-year flood. Figure 3-14 and Figure 3-15 show that flood waters would extend along the left bank of Smuggler's Slough, overtop Hillaire Road and Kwina Road, and spread east of Hillaire Road and north of Kwina Road along the right bank of Smuggler's Slough.

The similar levels of inundation shown in Figure 3-14 and Figure 3-15 suggests the closure elevation for the proposed self-regulating tide gate at the Kwina Slough breach would have little effect on the flood inundation. For these alternatives, the upland movement of tidal waters from Lummi Bay and the resulting backwater effect on Smuggler's Slough would play a significant

role in the spread of floodwaters across the delta (in particular across Hillaire Road and Kwina Road), throughout the project area and beyond.

Along the right bank of the Lummi River, implementing Alternative 1, 2 or 3 would increase the flood stage in the triangular-shaped area bounded by the Lummi River and the North Red River Road, but the predicted maximum elevation would remain below the top of the roadway embankment.

Flood Extent for Alternative 4

Figure 3-16 and Figure 3-17 show the predicted flood extent for Alternative 4 with the self-regulating tide gate closure set for 6.7 feet and 7.7 feet, respectively. The portions of the delta flooded after implementing Alternative 4 would be similar to existing conditions, although the inundation in the vicinity of Smuggler's Slough would extend farther to the north and west.

Closer to Lummi Bay, flood levels would be elevated but the predicted high water marks would be lower than existing roadway elevations. The proposed self-regulating tide gates at the sea wall would restrict the inflow of tidal waters near the mouth of Smuggler's Slough. Floodwaters would not overtop Hillaire Road and Kwina Road.

Setting the Kwina Slough breach tide gate to close when the slough waters reach an elevation of 6.7 feet would reduce the flood stage by 0.4 feet (see Table 3-8) when compared with setting the closure elevation at 7.7 feet. This difference does not have a great impact on the extent of flooding but the lower flood stage could be important near Haxton Way. According to the survey data, the minimum elevation along Haxton way is approximately 5.5 feet, which is less than 0.3 feet above the maximum predicted flood elevation, if the tide gate closure were set at 7.7 feet. Using the lower closure setting would preserve about 0.4 feet of freeboard at the roadway.

3.3.3 Summary of Freshwater Flooding Analysis

Similar to the saltwater inundation analysis, the freshwater flooding analysis suggests Alternative 1 – 3 could inundate large areas of the project area, including many that are actively farmed. Alternative 4 would generate much smaller increases in the level of freshwater flooding. According to the FEQ model, the flood elevation rise would be limited to level pool reservoir LPR CD (see Figure 3-12), which is bounded by Marine Drive (south), the Lummi River (north), Haxton Way (west) and Ferndale Road (east). Setting the self-regulating tide gate closure elevation lower than 6.7 feet could potentially limit the flood rise further without impacting the potential for fish passage along Smuggler's Slough.

Table 3-8. Summary of Freshwater flooding for the 100-Year Design Flood (elevations in NGVD29)

Level Pool Reservoir (LPR)	Base	Alt 1-3 SRT @ 6.7	Alt 1-3 SRT @ 7.7	Alt4 SRT @ 6.7	Alt4 SRT @ 7.7 ft	Simulation Notes
Lummi River Left Bank Floodplain						
LPR A	4.91 ft	4.91 ft	4.91 ft	4.91 ft	4.91 ft	**No Rise.** Slater Road between Nooksack River and Lummi River lowest elevation at 12.05 ft (to LPR B).
LPR B	5.70 ft	5.70 ft	5.70 ft	5.70 ft	5.70 ft	**No Rise.** Ferndale Road lowest elevation at 5.52 ft (to LPR CD). Ongoing road raising project should prevent this road from overtopping in future.
LPR CD	4.16 ft	4.85 ft	5.24 ft	4.85 ft	5.24 ft	**Water Rises.** Haxton Way lowest elevation at 5.52 ft. Water rises near top of road. LPR CD drains to LPR E.
LPR E	3.90 ft	3.90 ft	3.90 ft	3.90 ft	3.90 ft	**No Rise or Minimal Rise.** Lummi staff currently observes surface ponding during a range of storm intensities, largely driven by local drainage..
LPR FG	-0.70 ft	4.02 ft	4.02 ft	2.73 ft	2.73 ft	**Water Rises.** Drains to Lummi Bay.
Lummi River Right Bank Floodplain						
LPR N	7.22 ft	7.22 ft	7.22 ft	7.22 ft	7.22 ft	**No Rise.** Lampman Rd and Haxton Way north of Slater lowest elevation at 4.75 ft (to LPR M), Slater Rd. east of Haxton Way lowest elevation at 6.90 ft (to LPR L).
LPR L	6.02 ft	6.04 ft	6.04 ft	6.04 ft	6.04 ft	**Minimal Rise.** Haxton Way south of Slater Road and north of the Lummi River lowest elevation at 5.30 ft (to LPR JK).
LPR M	7.21 ft	7.21 ft	7.21 ft	7.21 ft	7.21 ft	**No Rise.** Slater Road west of Haxton Way lowest elevation at 6.53 ft (to LPR JK).
LPR JK	6.02 ft	6.04 ft	6.04 ft	6.04 ft	6.04 ft	**No Rise.** North Red River Road lowest elevation at 7.73 ft.
LPR HI	2.78 ft	5.46 ft	5.46 ft	5.46 ft	5.46 ft	**Water Rises.** North Red River Road not overtopped. Reservoir drains to Lummi Bay.

Table Header Notes:
Base = existing conditions;
Alt 3 (6.7) = Alternative 3 with Kwina Slough SRT closed at elevation 6.7 feet; no tide gates at Aquaculture Dike Access Road
Alt 3 (7.7) = Alternative 3 with Kwina Slough SRT closed at elevation of 7.7 feet; no tide gates at Aquaculture Dike Access Road
Alt 4 (6.7) = Alternative 4 with Kwina Slough SRT closed at elevation 6.7 feet; SRT at Aquaculture Dike Access Road closes at elevation of 2.5 feet
Alt 4 (7.7) = Alternative 4 with Kwina Slough SRT closed at elevation of 7.7 feet; SRT at Aquaculture Dike Access Road closes at elevation of 2.5 feet

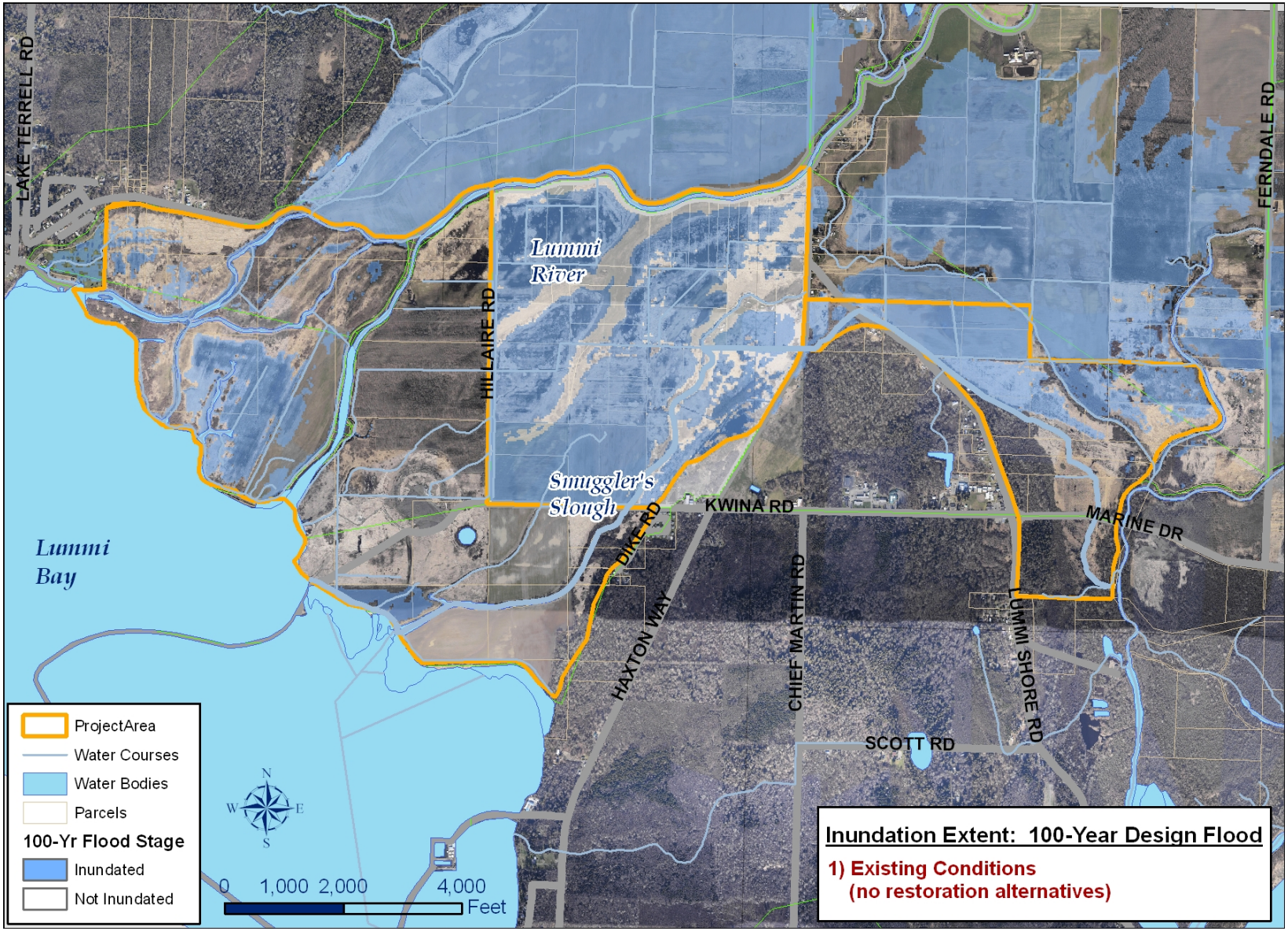

Figure 3-13. Predicted Inundation for the 100-Year Design Flood, Existing Conditions

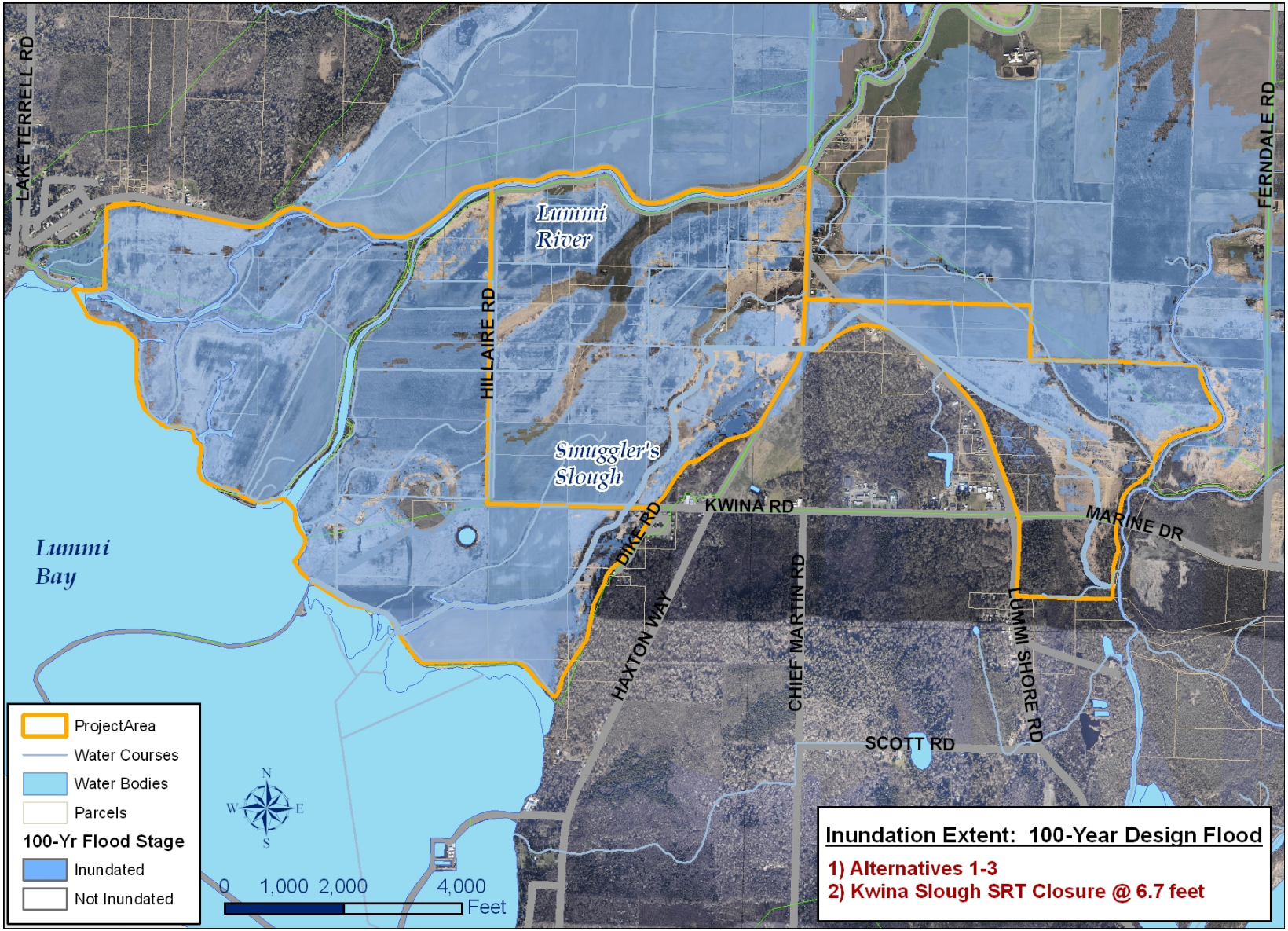

Figure 3-14. Predicted Inundation for the 100-Year Design Flood, Alts. 1-3 + Kwina Slough SRT Closure @ 6.7 ft.

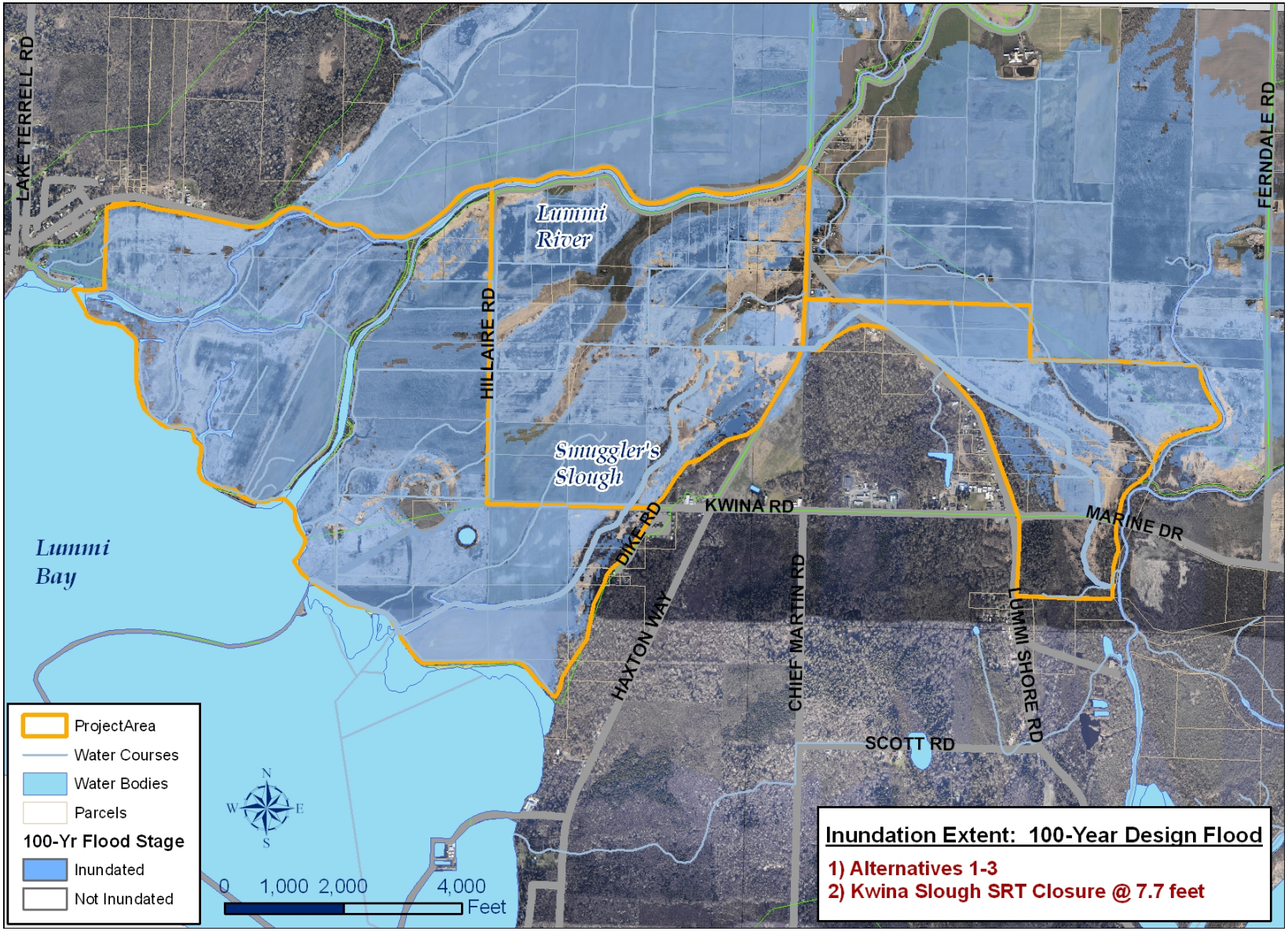

Figure 3-15. Predicted Inundation for the 100-Year Design Flood, Alts. 1-3 + Kwina Slough SRT Closure @ 7.7 ft.

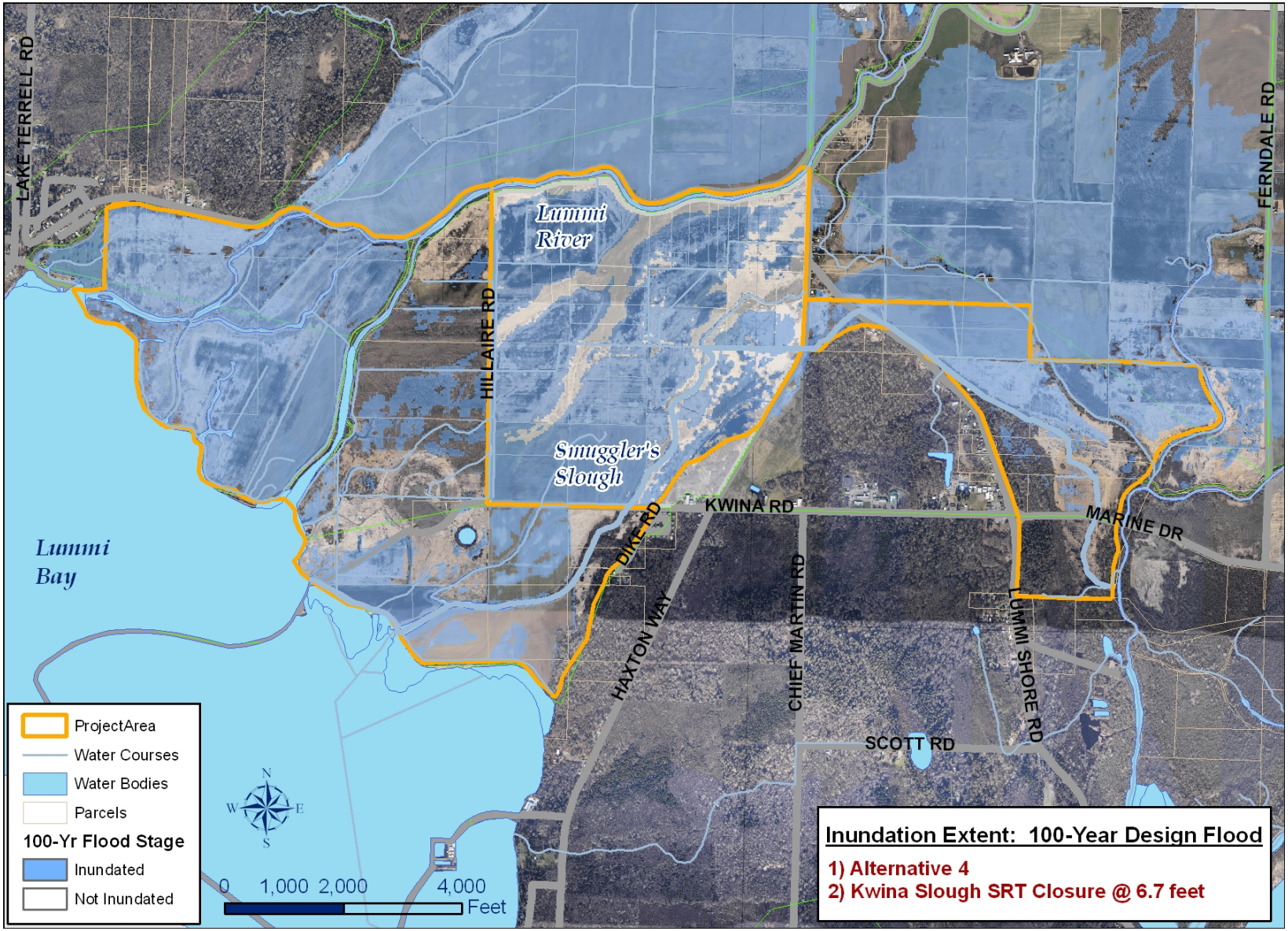

Figure 3-16. Predicted Inundation for the 100-Year Design Flood, Alt. 4 + Kwina Slough SRT Closure @ 6.7 ft.

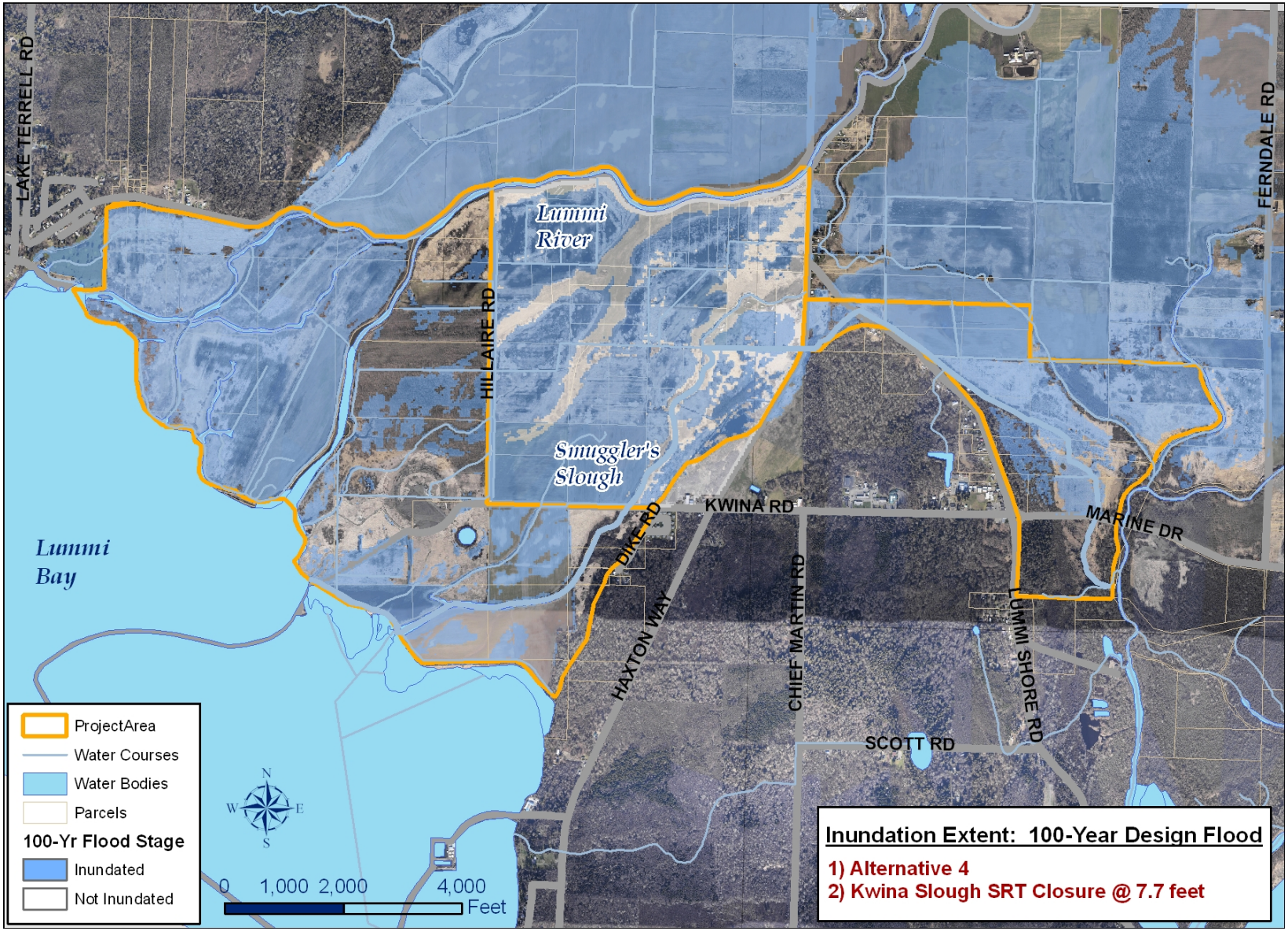

Figure 3-17. Predicted Inundation for the 100-Year Design Flood, Alt. 4 + Kwina Slough SRT Closure @ 7.7 ft.

3.3.4 Evaluation of Water Levels in Smuggler's Slough

Breaching Kwina Slough would increase flow rates in Smuggler's Slough. The higher flow rates bring the potential to enhance a local freshwater wetland but they also bring the potential to create backflow into drainage ditches that run alongside low-lying fields adjacent to Smuggler's Slough. Backing water into these low-lying ditches to flood surrounding fields should be a more pressing issue than overtopping the berms along Smuggler's Slough. The project team examined the Smuggler's Slough channel using detailed topographic information to address these two issues.

Potential Wetland Enhancement

The consistently higher flow rates through Smuggler's Slough could provide an opportunity to enhance a wetland area located near the right bank of Smuggler's slough, near the north tip of the peninsula (Figure 3-18). The project team examined potential inflow and outflow alignments and the surrounding berm elevation to determine the feasibility of moving water from Smuggler's Slough into the wetland.

An examination of the local topography suggests Smuggler's Slough flows could be used to augment the wetland. The site has two potential side channels that could connect the slough to the wetland. Equally important, the wetland is surrounded by a continuous ring of higher ground that would retain the diverted flows within the wetland instead of running out to adjacent properties. During the design phase of the larger restoration project, LNR could include channel modifications to enhance the interchange of flows between the slough and wetland.

Managing Backflow into Drainage Ditches

There are several ditches that drain the low-lying fields to the west of Smuggler's Slough near Kwina Road. Carrying more water in Smuggler's Slough could raise the water surface elevation and create backflow into these drainage ditches and potentially overtop the ditches to inundate surrounding lands.

Figure 3-19 shows the locations of ditches entering Smuggler's Slough. The design phase of the project should include a field survey of Smuggler's Slough to identify all ditches that could potentially backup and increase the flood risk to the west of Smuggler's Slough.

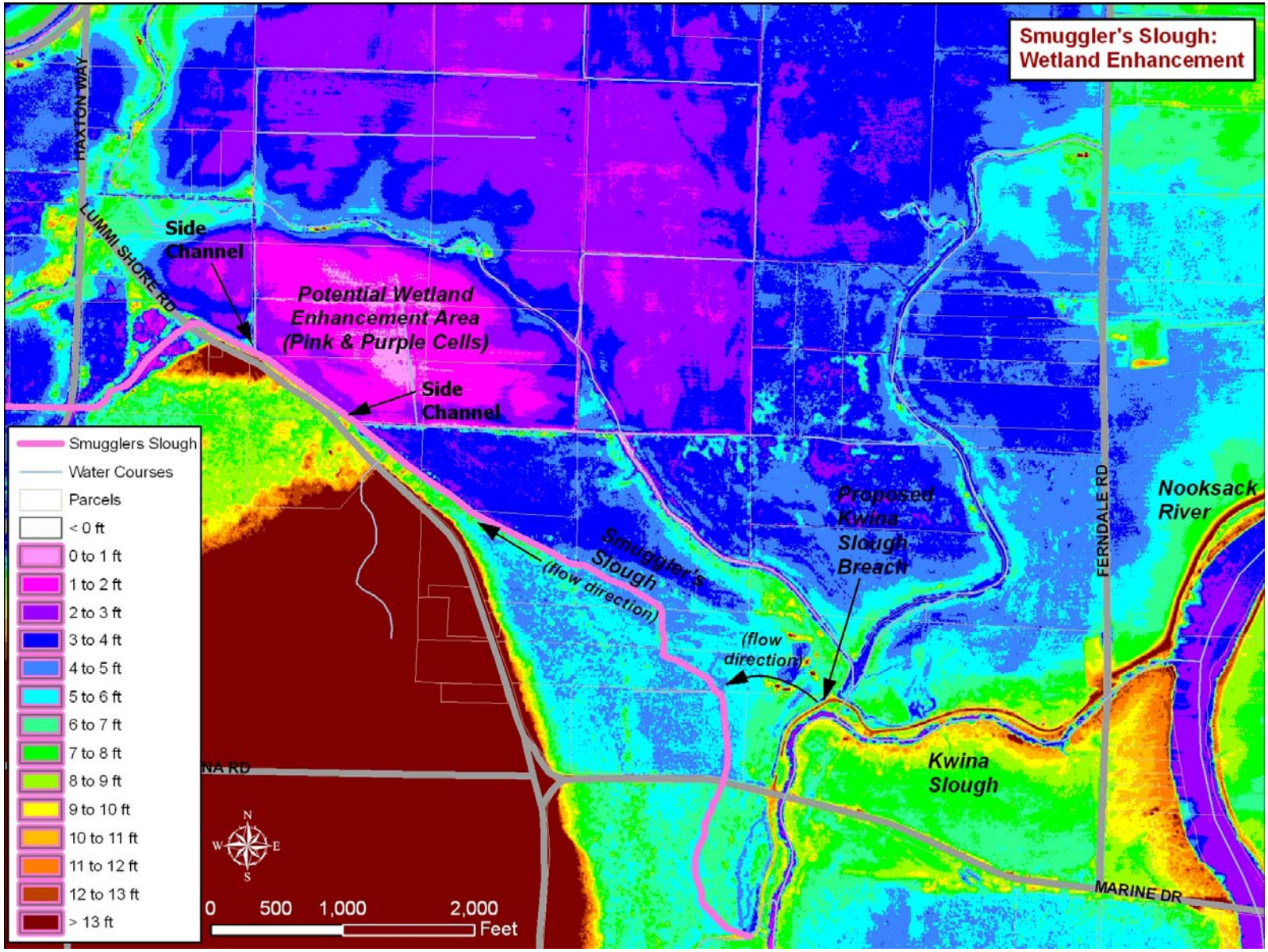

Figure 3-18. Delineation of Proposed Wetland Enhancement Project near Smuggler's Slough

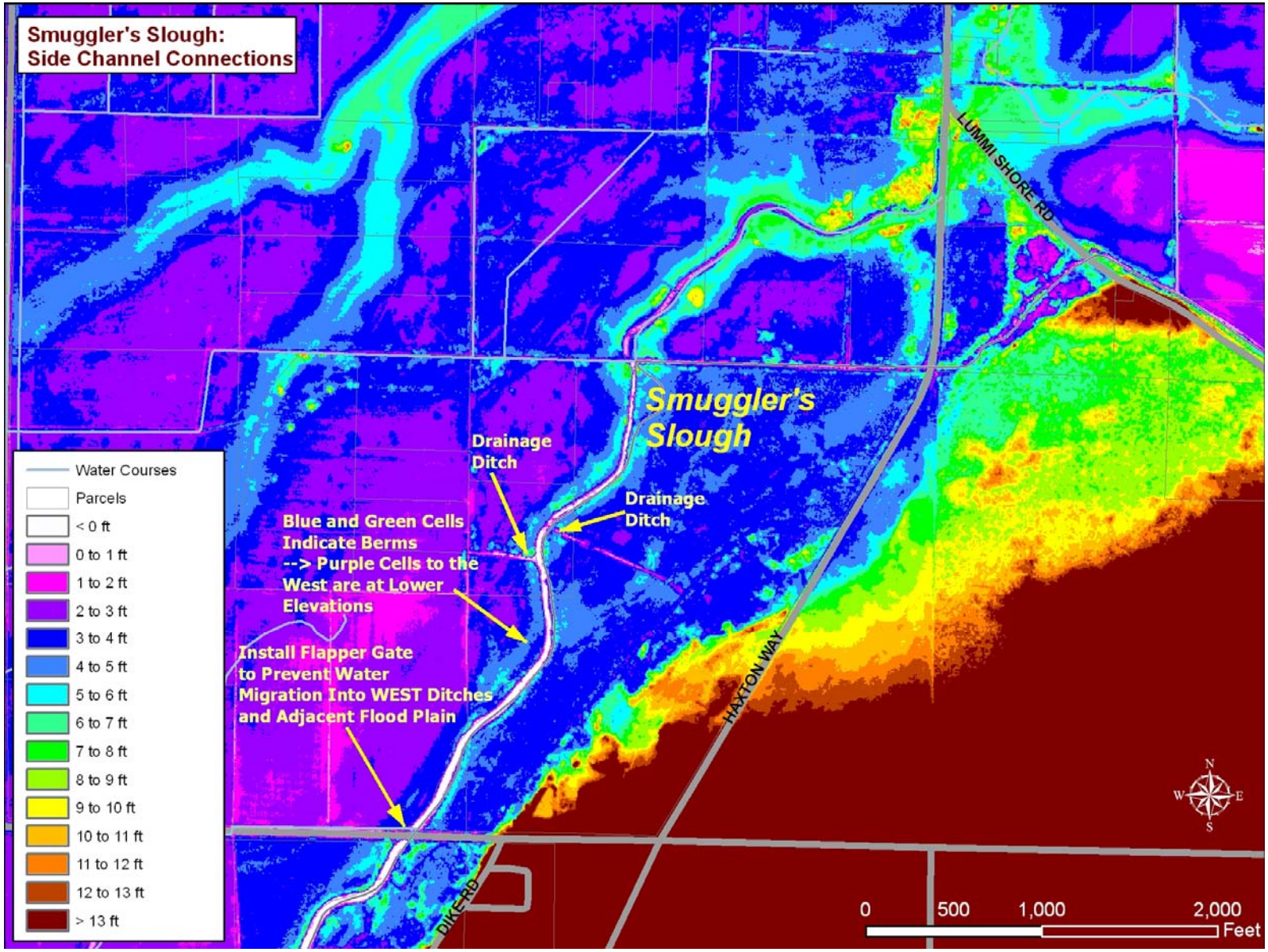

Figure 3-19. Smuggler's Slough Drainage Ditch Connections in the Vicinity of Low Lands

Section 4 Conclusions and Recommendations

The restoration activities examined in this report present an opportunity to reconnect portions of the historic estuary to the tidal waters of Lummi Bay and to improve fish passage from the Nooksack River to Lummi Bay. These activities could help increase the amount of viable salmon habitat in the Nooksack and Lummi River delta and help restore depleted salmon stocks.

Saltwater marshes are among the most productive ecosystems in the world[10]. The restoration of a saltwater marsh within the project area could provide largely positive effects to Chinook and other anadromous fish by enhancing the following components of ecosystem function:

- Annual gross and net productivity is high within a salt marsh habitat. The high productivity is due to tidal nutrient import while the abundance of water offsets the stresses posed by salinity, fluctuating temperatures the cycle of wetting and drying.

- A salt marsh is a major producer of detritus for both the salt marsh system and the adjacent estuary. Detritus and shelter found along the marsh edges provide important nursery areas for many fish and shellfish species. The decomposition of detritus helps provide a food source for consumers.

- Leaves and stems of vegetation serve as surface area for the growth of epiphytic algae and other epibiotic organisms. This enhances the productivity of the marsh.

- The rise and fall of tides can help export detritus and associated food sources to areas adjacent to the salt marsh for the benefit of juvenile salmon.

Summary of Restoration Alternatives and Results

The restoration activities are described fully in Section 3.1 and summarized briefly here:

> *Alternative 1*: Remove the Lummi Bay sea wall (north of Aquaculture Dike Access Road) and Lummi River levees downstream of the North Distributary channel. This approach would produce the largest openings for tidal waters to inundate the land surface and then recede.
>
> *Alternative 2:* Breach the Lummi Bay sea wall and remove Lummi River north bank levee; remove the tide gates from the sea wall (south of the Lummi River). This alternative would also open areas to the north and south of the Lummi River to tidal inundation, but the openings would be smaller than in Alternative 1.
>
> *Alternative 3:* Breach the Lummi Bay sea wall and breach the north bank Lummi River levee; remove the tide gates from the sea wall (south of the Lummi River). This

[10] The discussion of the ecological benefits of salt marsh habitat is based on the discussion by W.J. Mitsch and J.G. Gosselink in their book *Wetlands*, published in 1993 by Van Nostrand Reinhold, New York, NY.

alternative would further reduce the openings for tidal interchange north of the Lummi River. South of the Lummi River, this alternative is the same as Alternative 2.

Alternative 4: Breach the Lummi Bay sea wall and breach the north bank Lummi River levee (same as Alternative 3 north of the Lummi River); replace existing sea wall tide gates with self-regulating tide gates. The self-regulating tide gates would close against high tides to protect upland areas.

All Alternatives would include a breach in Kwina Slough to deliver freshwater from the Nooksack River to Lummi Bay via Smuggler's Slough and the removal of the North Distributary channel tide gate and fill plug (with new protections for the Sandy Point Golf Course and Jordan Creek).

This study evaluated the hydraulic aspects of the four proposed restoration alternatives by using a hydraulic model to estimate, for each alternative, the extent and duration of tidal inundation and the potential increase in the 100-year flood stage. The water surface elevations predicted during high tides (saltwater inundation analysis) and during the 100-year flood (freshwater flooding analysis) were mapped and compared to the elevations of key structures, such as local roadways and levees to identify any additional impacts associated with the alternatives.

The saltwater inundation analysis is summarized as follows (see Table 4-1):

- **North of the Lummi River,** any of the alternatives would produce extensive tidal inundation to the north of the Lummi River, in the triangular-shaped area bounded by the river (south), North Red River Road (north) and Lummi Bay (west). Tidal waters would not overtop the key structure within the inundation area – the embankment at North Red River Road.

- **South of the Lummi River**, only the self-regulating tide gate alternative (Alternative 4) would prevent Hillaire Road and Kwina Road from being overtopped during high tides. Removing the sea wall (north of the Aquaculture Dike Access Road) or simply removing the sea wall's tide gates would allow high tides to submerge these roadways and inundate areas to the east.

- **Salinity Impacts on Agriculture:** On the bayside of Hillaire Road, Kwina Road and North Red River Road, LNR could expect a build-up in salinity concentrations that would preclude any agricultural production for any of the alternatives examined. The local vegetation would over time convert to salt tolerance species typical for salt marsh and estuary lands. To protect against further, unintended, salinity migration, LNR should implement the strategies described in earlier in this report (see Section 3.2.6).

Table 4-1. Summary of Saltwater Inundation Hydraulic Modeling Results

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Inundation North of the Lummi River	Extensive	Extensive	Extensive	Extensive
Inundation South of Lummi River	Extensive	Extensive	Extensive	Less Extensive
Roadway Submergence				
North Red River Road	No	No	No	No
Aquaculture Dike Access Road	Yes	Yes	Yes	No
Hillaire Road	Yes	Yes	Yes	No
Kwina Road	Yes	Yes	Yes	No

The freshwater flooding analysis is summarized as follows:

- **North of the Lummi River,** the restoration alternatives would have a negligible impact on flood elevations. The only portion of the project area that would experience higher floodwaters (relative to existing conditions) would be within the triangular area to the south of North Red River Road, along the North Distributary channel, but the predicted 100-year flood elevation would be contained by the North Red River Road embankment.

- **South of the Lummi River,** Alternatives 1 – 3 would widely expand the predicted 100-year flood's inundation area. A portion of the additional inundation would be attributable to high tides overtopping Hillaire Road and Kwina Road and a portion would be attributable to the higher flows within Smuggler's Slough. The sea wall self-regulating tide gates included in Alternative 4 would eliminate much of the increase in flood elevations. The closure setting at the Kwina Slough breach is also important. The hydraulic modeling simulations showed that setting the gate to close when Kwina Slough waters reach an elevation of 6.7 feet produces lower flood elevations than closing the gates when upstream waters reach an elevation of 7.7 feet. During the design phase of the project, LNR could optimize the design of the Kwina Slough breach and tide gate settings to accomplish the dual goals of improving fish passage via Smuggler's Slough and minimizing any additional flood risk associated with the breaching activity.

Roadmap for Designing and Implementing a Restoration Strategy:

The hydraulic modeling evaluation identified the relative benefits and impacts of the proposed restoration alternatives. Of the alternatives proposed, Alternative 4 provides the most promising combination of potential habitat improvements while limiting adverse impacts. As LNR

proceeds with the design and implementation of restoration activities, certain aspects of the project must be more fully defined, such as:

- *The total property acquisition requirements*
- *The estimated cost for designing and constructing the selected restoration activities*
- *The permitting requirements and permitting schedule*

LNR should also address the following questions to help identify the key criteria for the optimal restoration design:

- *What is an acceptable level of freeboard between the predicted high tides and the roadway elevation, particularly for emergency evacuation routes?*
- *Could LNR construct new channels within and between the predicted inundation areas for Alternative 4 to help enhance the accessibility of any new habitat for fish?*
- *Would raising Hillaire Road, Kwina Road and the Aquaculture Dike Access Road be a viable approach to expanding the area of inundation (Alternative 1 – 3 versus Alternative 4)?*
- *Should the design project include hydraulic modifications along Smuggler's Slough to encourage the enhancement of the freshwater wetland located adjacent to the slough, near Lummi Shore Road?*
- *How will the modification of hydraulic aspects of the restoration activities within the Nooksack and Lummi River delta combine with landscaping/planting activities to promote the development of salt tolerant plant species that will augment existing salmon habitat?*