EBEY ISLAND HABITAT RESTORATION FEASIBILITY STUDY

Draft Report

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Washington Department of Fish and Wildlife

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TABLE OF CONTENTS

1.0 INTRODUCTION 1

2.0 DESIRED PROJECT OUTCOMES 5
- 2.1 ECOLOGICAL GOALS 5
  - 2.1.1 Restore ecosystems 5
  - 2.1.2 Contribute to recovery of listed Chinook populations 5
  - 2.1.3 Benefit other salmonids 5
  - 2.1.4 Provide habitat for birds and other wildlife 6
- 2.2 SOCIETAL GOALS 6
  - 2.2.1 Address Societal Concerns 6
  - 2.2.2 Benefits Should Outweigh Costs 7

3.0 STAKEHOLDER INVOLVEMENT 7
- 3.1 ENGAGEMENT STRATEGY 7
- 3.2 STAKEHOLDER ADVISORY COMMITTEE 8
- 3.3 PUBLIC COMMUNICATIONS 9
- 3.4 INDIVIDUAL COMMUNICATIONS 9

4.0 EXISTING CONDITIONS 9
- 4.1 SOCIAL CONDITIONS 9
  - 4.1.1 WDFW Mission 9
  - 4.1.2 Diking District #1 9
  - 4.1.3 Agriculture 13
  - 4.1.4 Ownership 13
  - 4.1.5 Land Outside of Dikes 13
  - 4.1.6 Transportation and Utilities 14
- 4.2 ECOLOGICAL CONDITIONS 14
  - 4.2.1 Wetlands 14
  - 4.2.2 Vegetation 14
  - 4.2.3 Fish 18
  - 4.2.4 Birds 18
  - 4.2.5 Amphibians and Reptiles 19
  - 4.2.6 Mammals 19
- 4.3 PHYSICAL CONDITIONS 19
  - 4.3.1 Dikes and Levees 19
  - 4.3.2 Drainage 23
  - 4.3.3 Soils 24
  - 4.3.4 Flooding 24
  - 4.3.5 Elevations (Subsidence) 30
  - 4.3.6 Water quality 30

5.0 HABITAT RESTORATION ALTERNATIVES 30
- 5.1 CONCEPTUAL ALTERNATIVES 31
  - 5.1.1 Specification of Conceptual Alternatives 31
  - 5.1.2 Evaluation and Ranking of Conceptual Alternatives 65
  - 5.1.3 Scoring Process 69
- 5.2 PREFERRED ALTERNATIVES 73
  - 5.2.1 Selection and Refinement of Preferred Alternatives 73
  - 5.2.2 Hydrodynamic Modeling of Preferred Alternatives 76

5.2.3 Design Considerations 111
5.2.4 Ecological Effects of Preferred Alternatives 112
5.2.5 Fish habitat value in muted tidal systems 117

6.0 CONCLUSIONS AND RECOMMENDED NEXT STEPS 131

7.0 REFERENCES 135

TABLES

Table 1 Project Team and Advisory Committee members. 2
Table 2 14 alternatives developed, along with a brief description of each. Figure 9 through Figure 22 depict these alternatives. 36
Table 3 Agricultural Productivity Scoring Method 67
Table 4 Criteria Scoring Scheme and Raw Normalized Scores 71
Table 5 Results of the Pairwise Comparison & Resulting Decision Factor Ranks 73
Table 6 Predicted tidal prism changes and potential channel dimension changes in response to restoration alternatives. 111
Table 7 Summary of quantities and suggested construction budget for preferred alternatives. 112
Table 8 Selected species and observed elevations in estuary. 117
Table 9 Summary of IVA Scores for Preferred Alternatives 123
Table 10 Habitat and Fish Production Estimates for Preferred Alternatives. 130

FIGURES

Figure 1 WDFW and other government-owned property, shown on a 2009 aerial photograph. .. 3
Figure 2 Diking District #1 map, showing perimeter dike, ditch system, tide gates, and pump station. 11
Figure 3 Photo of a depression in a pasture used as a hunting area, with cattle and SR 2 visible in the background. 15
Figure 4 SR 2 and the City of Everett water pipelines along the lower end of Deadwater Slough, within Diking District #1. 16
Figure 5 Diking District #1 dike, with Ebey Slough on the left. The view is looking south toward at the eastern portion of the project area, with the heavily forested area visible in the backround in the right half of the photo. The dike here is graveled to provide year-round access to the Olympic Pipe Line corridor. 21
Figure 6 Diking District #1 pump station, with outlets visible in the center of the photo, penetrating the dike. Deadwater Slough is tidally influenced in the foreground. 25
Figure 7 Diking District #1 tide gates discharging water into the tidally influenced portion of Deadwater Slough during a low tide. One of the outlet pipes from the pump station is visible at the lower left corner of the photo. 27
Figure 8 Channel spanning log jam in Ebey Slough at the eastbound SR 2 crossing. Some of the rows of pilings that support the highway are visible in the photo. These pilings caused the log jam to start. Circa 2003. Credit: A.G. Alexander. 33
Figure 9 Alternative A 37
Figure 10 Alternative B 39
Figure 11 Alternative C 41

Figure 12 Alternative D 43
Figure 13 Alternative E 45
Figure 14 Alternative F 47
Figure 15 Alternative G 49
Figure 16 Alternative H 51
Figure 17 Alternative I 53
Figure 18 Alternative J 55
Figure 19 Alternative K 57
Figure 20 Alternative L 59
Figure 21 Alternative M 61
Figure 22 Alternative N 63
Figure 23 North Tip Ebey Island 77
Figure 24 Fully Tidal Water Levels, Dry Season, Ebey Slough 81
Figure 25 Fully Tidal Water Levels, Dry Season, Ebey Slough 83
Figure 26 Muted Tidal Water Levels, Dry Season 87
Figure 27 Muted Tidal Water Levels, Wet Season 89
Figure 28 Peak Water Levels, January 2002, Snohomish River 93
Figure 29 Peak Water Levels, January 2002, Ebey Slough 95
Figure 30 Peak Water Levels, 5-Year Discharge, Snohomish River 97
Figure 31 Peak Water Levels, 5-Year Discharge, Ebey Slough 99
Figure 32 Q100 Peak Water Levels - Snohomish River, January 2002 103
Figure 33 Peak Water Levels, 100-Year Discharge, Ebey Slough 105
Figure 34 Conceptual example of the effects of dike removal, setback or modification on juvenile salmonids and associated habitat (adapted from Clancy et al. 2009). 113

APPENDICES

Appendix A Preliminary Geotechnical Report
Appendix B Criteria Considered But Not Used In The Evaluation
Appendix C Potentially Useful Criteria
Appendix D Hydrodynamic Modeling and Geomorphic Analysis

EBEY ISLAND HABITAT RESTORATION FEASIBILITY STUDY

1.0 INTRODUCTION

The Ebey Island Habitat Restoration Feasibility Study was designed to evaluate the technical and social feasibility of restoring high quality, tidally influenced aquatic habitat on 1,237 acres of land owned and managed by the Washington Department of Fish and Wildlife on Ebey Island. The 3,940-acre island is bounded by the mainstem Snohomish River on the west and Ebey Slough on the east. The WDFW property is located just south of the State Route 2 (SR 2) trestle bridge that spans the Snohomish River floodplain between Everett and Snohomish, Washington (Figure 1).

Fish and wildlife managers have identified the restoration of tidally influenced habitat in the Snohomish River estuary as a priority for Chinook salmon recovery in the basin. If properly implemented, habitat restoration is an effective tool for boosting the survival and productivity of depressed salmon populations. However, habitat restoration is an expensive proposition, especially in urban and agricultural areas, and therefore requires careful planning and shepherding of resources. Many projects fail to reach their objectives due to technical infeasibility, cost, and lack of public support. For this reason, before significant monies are expended, it is prudent to carefully consider whether a restoration effort is likely to produce the desired outcome, and what steps can be taken to maximize the probability of success.

With the assistance and guidance of a stakeholder Advisory Committee (Table 1), the WDFW determined that the restoration of the Ebey Island site should commence with a feasibility study that explored a range of restoration alternatives, highlighted opportunities and constraints associated with each alternative, and addressed critical uncertainties and gaps in knowledge before committing additional time and money to designing, permitting, and implementing the project. WDFW also recognized that the feasibility study would be most effective if they involved key stakeholders, local residents, and other individuals who are familiar with Ebey Island or whose interests would be directly affected by the agency's actions. The involvement of diverse interest groups and knowledgeable people at an early stage of the feasibility assessment was recommended as a way of tapping into local expertise, identifying potential pitfalls, reconciling differences of opinion, and shoring up support for one or more restoration options that might conceivably further the goals of the agency.

The Ebey Island Habitat Restoration Feasibility Study commenced in February 2010 with the solicitation of proposals and the hiring of a contractor, AMEC Earth and Environmental, Inc. AMEC

Table 1 Project Team and Advisory Committee members.

Project Team			
WDFW		**Consulting Team**	
Name	**Role**	**Name**	**Organization**
Richard Tveten	Project Director	Cleve Steward	Project Manager
Doug Hennick	Fish and Wildlife Biologist	Ryan Bartelheimer	Habitat Engineer
John Garrett	Wildlife Area Manager	Jim Dransfield	Geotechnical Engineer
Belinda Schuster	Asst. Wildlife Area Mgr	Dan Evans	Facilitator
Annette Hoffman	Fish Program Manager	Walker Stanovsky	Administrator
Kye Iris	Property Acquisitions	Tad Schwager	Fisheries Biologist
Russell Link	Program Manager	Cliff Strong	Planner
Ruth Millner	District wildlife biologist	Matt Brennan	ESA PWA, Hydrologist
Advisory Committee			
Name	**Organization**	**Name**	**Organization**
Everett Alexander	Diking District #1	Ryan Hembree	Snohomish County Agriculture Coordinator
Cory Armstrong-Hoss	YMCA of Snohomish County	Janne Kaje	King County Snoqualmie-Skykomish Watershed
Barney Bagwell	Diking District #1	Chuck Lobdell	Ducks Unlimited
Phil Cunningham	Diking District #1	Tom Nowak	Adjacent landowner
Jason Anderson	Stilly-Snohomish Fisheries Task Force	Monty Marti	Snohomish Conservation District
Mike Blackbird	Pilchuck Audubon Society	Kurt Nelson	Tulalip Tribes
Brian Bookey	Snohomish County Ag. Advisory Board	Graeme Peters	Ducks Unlimited
Maria Calvi	Tulalip Tribes	Casey Rice	NOAA Fisheries
Andrew Corbin	WSU Snohomish County Extension	Mark Sadler	City of Everett
John Engel	Snohomish County Public Works	Sharon Swan	Sno County Parks and Recreation
Kate Halstead	Snohomish Valley Tilth	Micah Wait	Wild Fish Conservancy
Nick Harper	Cascade Land Conservancy		

was joined by subcontractors ESA PWA (formerly Philip Williams and Associates) and Dan Evans Consulting. Working with the project Advisory Committee, the WDFW-AMEC team developed a process that involved formulating goals for the project, compiling existing information, identifying a suite of potential restoration alternatives, and evaluating and scoring the alternatives using a wide array of technical, ecological, and socioeconomic criteria. The highest ranking conceptual alternatives – that is, those that were predicted to yield the greatest ecological and societal benefits – were selected for further in-depth hydrological modeling and geomorphological analysis. The modeling effort enabled project ecologists, engineers and planners to evaluate the physical and ecological response of the system, and to modify the preferred alternatives to achieve a broad range of benefits.

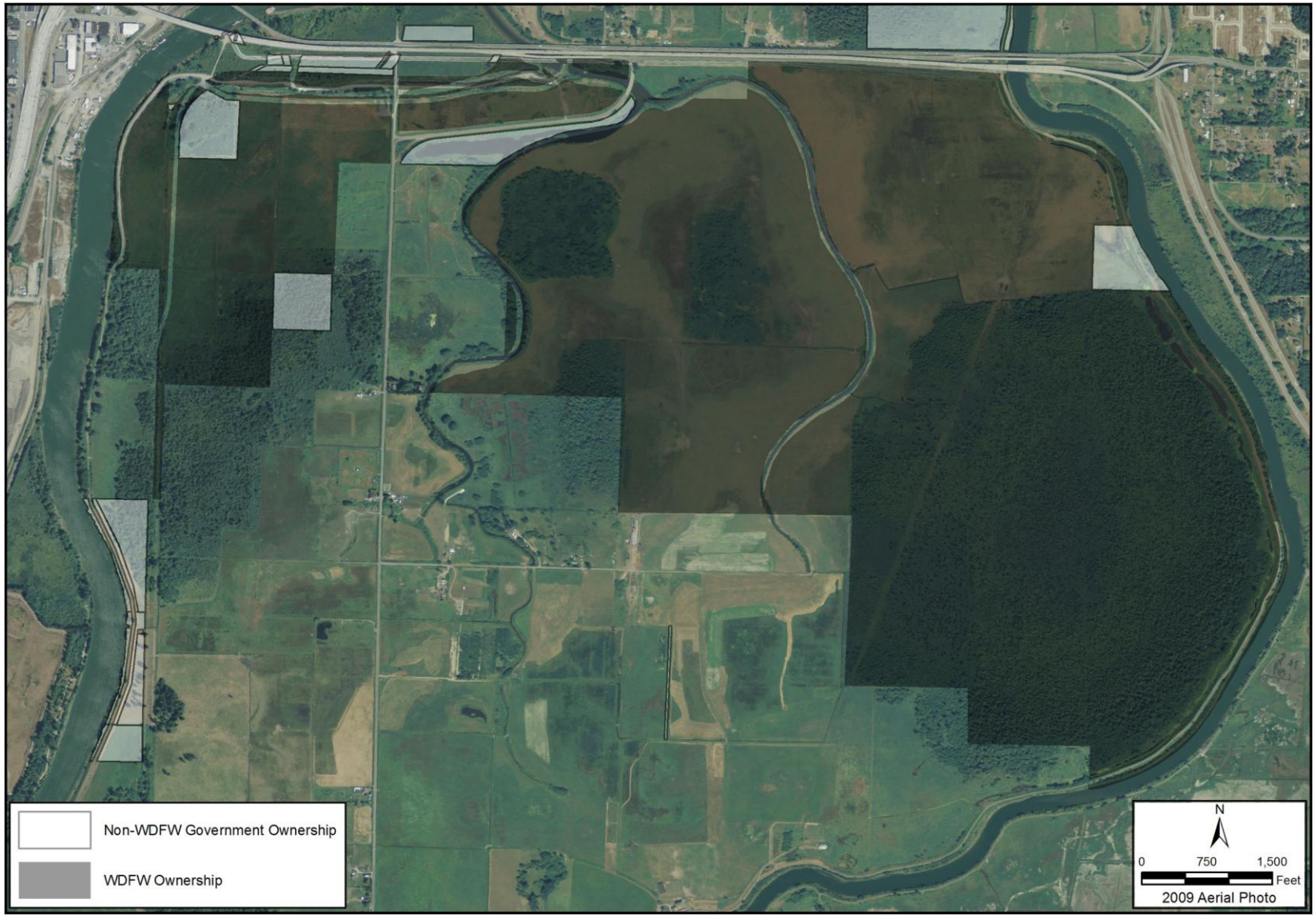


Figure 1 WDFW and other government-owned property, shown on a 2009 aerial photograph.

This report describes the evaluative process and the preliminary results and recommendations of the Ebey Island Habitat Restoration Feasibility Study. It is hoped that this effort will enable project proponents to secure addition funding and generate support among stakeholders to implement the recommended actions if WDFW decides to pursue them.

2.0 DESIRED PROJECT OUTCOMES

The overarching goals of the Ebey Island habitat restoration project can be broadly divided into ecological and societal categories. The potential for the Ebey Island project to simultaneously maximize both ecological and societal goals is low. Successfully agreeing on a plan and moving forward with the design and implementation of a preferred habitat restoration alternative will require compromise.

2.1 ECOLOGICAL GOALS

2.1.1 Restore ecosystems

The primary ecological goal is to restore freshwater tidal marsh habitat and biological communities. These include a complex suite of aquatic and terrestrial plants, invertebrates, amphibians, birds and fish. The complexity of their myriad interactions makes it difficult, if not impossible, to recreate an ecosystem by managing only a small subset of species. Therefore, ecosystem restoration efforts typically focus on reestablishing the physical processes that provide the template for an ecosystem. On Ebey Island, this means restoring the natural fluvial and tidal processes that would result in the type of habitat characteristic of nearby undisturbed areas.

2.1.2 Contribute to recovery of listed Chinook populations

Another major ecological goal of the Ebey Island Restoration Project is to provide habitat conditions that will contribute to the recovery of salmon populations listed under the Endangered Species Act (ESA), particularly Puget Sound Chinook salmon. A high proportion of juvenile Chinook salmon undergo a lengthy rearing stage in the Snohomish estuary, which makes them especially sensitive to the diking and other anthropogenic modifications to the Snohomish River delta over the last 150 years (Beamer and Larson 2004).

Focusing on one species seems contradictory to the goal of restoring whole ecosystems. However, Chinook are important not only because of their legal status, but also because as a keystone species, they are essential components of healthy Puget Sound river systems.

2.1.3 Benefit other salmonids

Several other species of salmon also use the lower Snohomish River to varying degrees. Coho salmon use the freshwater tidal, off-channel, and floodplain areas for rearing. Pink, chum, and

sockeye salmon migrate through the estuary to spawn in reaches farther upstream, and consequently their juveniles migrate back through the estuary to marine waters. Bull trout, which are also listed under the ESA, exhibit several life history strategies. The anadromous life history uses the lower Snohomish River for refuge and foraging.

This project, if designed appropriately to improve the habitat components and processes that benefit Chinook salmon, will also benefit a wide range of other fish species.

2.1.4 Provide habitat for birds and other wildlife

Protecting and conserving other wildlife species, including non-commercial species, is an important goal of WDFW. Ebey Island has the potential to provide a large area of high quality habitat for migratory waterfowl, raptors, and resident bird species. Therefore, the restoration of habitat types other than fish habitat is also a project goal.

2.2 Societal Goals

2.2.1 Address Societal Concerns

Ebey Island has supported farms and recreational uses since it was diked and drained in the first half of the 20th century. Local residents, especially those whose families have farmed on Ebey Island for many years, are understandably concerned that the restoration envisioned by WDFW would increase the risk of flooding and impair their ability to make a living as farmers. The general lack of information and opportunity for parties to dialogue in the past has heightened the ongoing need to address these issues in a collaborative setting.

Ebey Island is at the epicenter of an ongoing vigorous debate between agriculture and environmental interests in Snohomish County. Even if it is technically feasible to restore tidal processes on a portion of the WDFW-owned land on Ebey Island, the project will move forward only if the proposed actions are supported by a critical mass of stakeholders, including the agricultural community. The success of the Ebey Island Restoration Project hinges on the development of a carefully balanced design and implementation plan that accommodates a broad range of societal values.

Project implementation will also be constrained by potential direct and indirect effects on neighbors and surrounding land uses. As a neighbor and as a government agency, WDFW intends to be receptive to input from stakeholders to the extent practicable. WDFW also must comply with existing agreements and permit requirements that pertain to dike realignment or other modifications to the existing infrastructure.

2.2.2 Benefits Should Outweigh Costs

Construction and maintenance costs largely dictate the feasibility of any proposed project design. Costs for the construction components of the proposed alternatives are calculated elsewhere in this report. While the costs (and benefits) alone do not decide the feasibility, they form the basis for critical decision making.

3.0 STAKEHOLDER INVOLVEMENT

WDFW recognizes that the diverse community in and around Ebey Island comprises individuals and interest groups with equally diverse, and sometimes contentious, views of habitat restoration. An important objective of the Ebey Island Habitat Restoration Feasibility Study was to convene an Advisory Committee representing these diverse interests to help define key issues, provide meaningful feedback on proposed alternatives, and deliberate in the selection of preferred habitat restoration alternatives. The goal was to facilitate dialogue and the exchange of information so that people's concerns and ideas would be heard, and ultimately, to generate support for the project. Hopefully, the result was a fair, well-informed process and technical proposal that balances agricultural, recreational, and restoration interests and provides a sound basis for future decisions and actions.

3.1 ENGAGEMENT STRATEGY

The following objectives guided the public outreach and stakeholder engagement efforts:

- **Inform**: Facilitate understanding of the Feasibility Study's intent, process (including opportunities for review and comment at each stage), alternatives, and the recommendation of preferred alternatives.
- **Support Collaboration**: Build rapport among participants and the project team and develop a productive, collaborative dynamic.
- **Engage**: Invite the public, stakeholders, and directly affected individuals to review, evaluate, and comment on Feasibility Study information and initial findings, alternatives, and recommendations.
- **Integrate**: Monitor basin-wide efforts to address the tension between agricultural and restoration interests. Evaluate opportunities to learn and benefit from these efforts, avoid pitfalls, and use Ebey Island as a positive template or example.

Visual and descriptive materials presented to the Advisory Committee include:

1. Concise project description and list of project contacts

2. Detailed project description and overview, including maps, schedule, and Advisory Committee list
3. Handouts of ongoing project-related materials, including ecological indicators, evaluation criteria, and map-based overviews of alternatives at all stages
4. Detailed summary notes for Advisory Committee meetings
5. Summary of draft findings and conclusions
6. Draft and Final Feasibility Study Report

3.2 Stakeholder Advisory Committee

Stakeholder engagement was conducted primarily through the Ebey Island Restoration Feasibility Study Advisory Committee, composed of over 20 individuals representing a broad and balanced set of interested parties, including farmers, fish and wildlife advocates, community leaders, recreational group representatives, diking and drainage groups, and others (Table 1). The Advisory Committee met five times over the course of the 12 month feasibility study.

Ebey Island has been an important agricultural area in the past, and some areas are still farmed today. The island therefore represents a unique opportunity to implement a habitat restoration project sensitive to the needs of the agricultural community. The project team explored opportunities to benefit both salmon and farmers by exchanging strategically located WDFW-owned land that has good agriculture capacity, yet modest habitat potential, with privately-owned land that can be restored to highly productive habitat. While it may not be possible to fully adhere to the “no net loss of agricultural land” policy advocated by the Snohomish County Agricultural Advisory Board, the project can serve as an example of how to effectively involve and protect the interests of local farmers and open space advocates.

Because of the Ebey Island Restoration Project’s relationship to the broader ag-restoration conversation underway in the Snohomish basin, the Advisory Committee includes members of the County’s Agriculture Advisory Board, and the emerging Sustainable Lands Strategy. In addition, project team members participated in these processes to ascertain issues, problems, and opportunities that are likely to arise, as well as to inform the broader discussion about any lessons learned or helpful strategies that may be gleaned from the Ebey Island Restoration Feasibility Study.

Advisory Committee meetings and members were especially helpful in gathering relevant information, understanding stakeholder sensitivities and perspectives, developing the optimal mix of project design elements, and serving as a sounding board for the project team to use in developing Feasibility Study recommendations.

The final Advisory Committee meeting is on March 15, 2011, to which the public will be invited. WDFW has invited all interested parties to read this draft report, attend the meeting, and voice their questions and comments about the project. This input, along with that of Advisory Committee members, will be acknowledged and, as appropriate, incorporated into the final feasibility study report.

3.3 Public Communications

The WDFW has continuously updated a publicly accessible project website with Advisory Committee meeting notes, project documents, and updated process and schedule information (http://wdfw.wa.gov/lands/wildlife_areas/snoqualmie/restoration_study.php).

3.4 Individual Communications

The individuals with the most direct stake in the project are, of course, local landowners and others who have a direct and substantial connection to the project. Adjacent landowners—public and private—were contacted by the project team. In addition, letters to Ebey Island residents and landowners were sent out to describe the project, invite their participation in public or personal meetings, and comment on project findings, alternatives, and recommendations.

4.0 EXISTING CONDITIONS

4.1 Social Conditions

4.1.1 WDFW Mission

As a state agency, the WDFW is charged with protecting, restoring and enhancing fish and wildlife and their habitats, and providing the public with recreational and commercial opportunities to use the State's fish and wildlife resources on a sustained basis. The Ebey Island project is designed to balance these goals within a habitat restoration context. The various alternatives proposed for Ebey Island all aimed at restoring and enhancing fish and wildlife habitat, but at the same time, they also promoted opportunities for recreational and/or commercial use. The WDFW is a public agency and therefore attempts to set and implement policy in a way that is sensitive to the needs and interests of different user groups. Depending on local circumstances, these considerations can serve as either an impetus or hindrance to implementing habitat restoration projects.

4.1.2 Diking District #1

Diking District #1 was formed to provide drainage and flood protection to the landowners within its boundary. The district infrastructure consists of about 13 miles of perimeter dikes and 42 miles of drainage ditches within the diked area. Diking districts typically obtain easements to guarantee access and the ability to operate and maintain its system of dikes and ditches. This means that any proposed actions to modify Diking District #1 ditches or dikes would require their approval (Figure 2). Diking

District #1 commissioners have been engaged throughout this process. When considering modifying the WDFW properties to improve habitat for salmon, the district has expressed these general concerns:

- The integrity of the dike system
- The function of the drainage system
- The time it takes the district to fill up in an overtopping flood
- The land base for their assessments

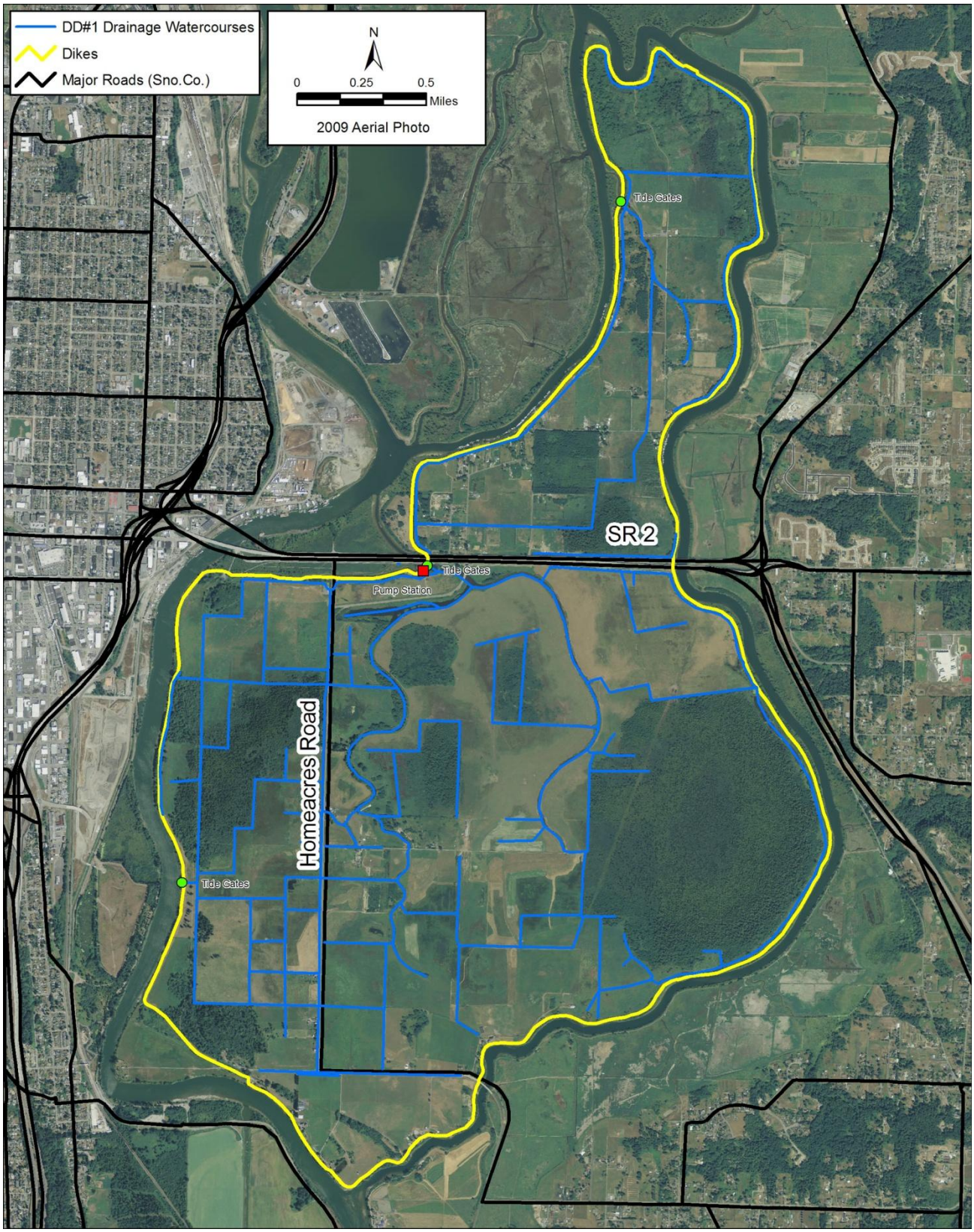


Figure 2 Diking District #1 map, showing perimeter dike, ditch system, tide gates, and pump station.

4.1.3 Agriculture

Aerial photos dating as far back as 1938 are available for this area. The photos reveal that the main river and slough channels have not migrated laterally. Inside the island, however, one can see evidence of historic sloughs and channels within the island that are not immediately evident looking at current aerial photos. A look at elevation data collected by NOAA Fisheries in 2009 seems to confirm that these historic channel locations are still evident by the presence of minor depressions where the channel centerlines used to be and slightly elevated areas adjacent to where the channels were. Everett Alexander recounted that several decades ago, at high tide, it was possible to take a canoe from the southern end of the island all the way to the mouth of Deadwater Slough. Since then, much of the southern end of branches of Deadwater slough have been regraded and the connection to tidal waters cut off by the dike system. It is also clear that by 1938, portions of the island had been cleared and put into agricultural production, while much of it had yet to be cleared.

Existing land uses on Ebey Island include rural residential and agriculture. The primary agricultural use is grazing. Waterfowl hunting, both on and off WDFW's property, occurs on some of the pasture areas during the winter. Figure 3 shows a duck blind located within a pasture.

4.1.4 Ownership

Washington Department of Fish and Wildlife owns about 1,237 acres on Ebey Island, south of Highway 2. There are a few other public entities that own much smaller areas of land on the island. The remaining land is privately owned. The emphasis of this feasibility study is to explore options for fish habitat restoration on WDFW-owned land, and to consider what adjacent and/or nearby properties would be the most logical to consider purchasing to create a better project. A map of the government-owned properties is shown in Figure 2.

4.1.5 Land Outside of Dikes

The interior of Ebey Island is flat, although the land is higher at the southern, upstream end of the island, compared to the northern end of the island. There is a farm at the south-western corner of the island called Getchell Ranch, which is mostly located outside of the existing dike. Everett Alexander indicated that his grandparents did not want their farm to be part of the diking district when it was formed. It is interesting to note that this location, as well as other ground outside of the dikes, is much higher than the areas within the dikes. The other location where there is a significant amount of land outside of the dike is at the western center portion of the island, in the vicinity of SR 2.

4.1.6 Transportation and Utilities

US Highway 2 crosses through the middle of Ebey Island in the east-west direction. Homeacres Road provides access to the interior of the island from the south. There are several roads within the island that provide local access.

Major utility transmission corridors also exist on the island, including two City of Everett waterline corridors and an Olympic Pipe Line Company petroleum pipeline corridor. Local power and water distribution corridors also exist on the island to serve the local residents and farms. Figure 4 shows SR 2 and the City of Everett pipelines where they abut Deadwater Slough, in the vicinity of the Diking District #1 pump station.

4.2 ECOLOGICAL CONDITIONS

Ebey Island is located in the Forested Riverine Tidal (FRT) ecological zone of the Snohomish River Estuary (Haas and Collins 2001). While water levels in the main channels fluctuate on a semi-diurnal basis due to tidal effects, salinity is rarely greater than 5 ppt. The island has been extensively diked to allow agricultural development, effectively eliminating the possibility of tidal flooding. The only examples of historic conditions nearby are Otter Island, which has never been diked, and the southern portion of Spencer Island where the dike was intentionally breached restore tidal processes. Two blind slough networks, Deadman Slough north of Hwy 2 and Deadwater Slough south of Hwy 2, serve as the primary drainage networks for the island and both prevent tidal inundation by tide gates.

4.2.1 Wetlands

Significant portions of Ebey Island are currently covered by various types of wetlands. The largest forested wetland, 520 acres along Ebey Slough, has been owned by WDFW for many years and is densely forested with Sitka spruce, Western red cedar, lodgepole pine, and red alder. Other areas of forested wetland are patchily distributed, primarily along the west side of the island along the mainstem, and on the northern tip of the island. In addition, fallow agricultural fields, grazed wet meadows, tidal emergent and scrub-shrub habitats all provide some value to wildlife (City of Everett 1997).

4.2.2 Vegetation

A list of the dominant plant species found in the tidal and non-tidal freshwater zones of the estuary is reproduced here from SEWIP (City of Everett 1997):

- Aquatic Bed Emergent, Tidal: *Callitriche heterophylla* (water chickweed), *Nuphar luteum* (yellow pond lily).

Figure 3 Photo of a depression in a pasture used as a hunting area, with cattle and SR 2 visible in the background.

Figure 4 SR 2 and the City of Everett water pipelines along the lower end of Deadwater Slough, within Diking District #1.

- Palustrine Emergent, Tidal: *Lysichiton americanum* (skunk cabbage), *Phalaris arundinacea* (reed canary grass), *Carex obnupta* (slough sedge), *Typha latifolia* (common cattail), *Caltha palustris* (yellow marsh-marigold), *Athyrium felix-femina* (lady fern), *Alisma plantago-aquatica* (broadleaf water plantain), *Sagittaria latifolia* (duck potato), *Oenanthe sarmentosa* (water parsley), *Veronica spp.* (speedwell), *Polystichum munitum* (sword fern).
- Palustrine Scrub-Shrub, Tidal: *Cornus sericea* (red-osier dogwood), *Rosa nutkana* (Nootka rose), *Physocarpus capitatus* (Pacific ninebark), *Malus fusca* (crabapple), *Rubus spectabilis* (salmonberry), *Spiraea douglasii* (hardhack spirea).
- Palustrine Forested, Tidal: *Salix lasiandra* (Pacific willow), *Salix scouleriana* (Scouler's willow), *Picea sitchensis* (Sitka spruce), *Populus trichocarpa* (black cottonwood), *Thuja plicata* (western red cedar), *Alnus rubra* (red alder), *Rhamnus purshiana* (cascara).
- Palustrine Aquatic Bed, Non Tidal: *Potamogeton spp.* (pondweed), *Myriophyllum spicatum* (Eurasian water milfoil), *Lemna minor* (duckweed).
- Palustrine Emergent, Non-Tidal: *Lysichiton americanum* (skunk cabbage), *Carex deweyana* (Dewey's sedge)*, Carex obnupta* (slough sedge), *Typha latifolia* (common cattail), *Sparganium spp.* (burreed), *Athyrium felix-femina* (lady fern), *Alisma plantago-aquatica* (broadleaf water plantain), *Oenanthe sarmentosa* (water parsley), *Veronica spp.*(speedwell), *Iris pseudacorus* (yellow iris), *Tolmiea menziesii* (piggyback plant), *Juncus ensifolius* (dagger-leaf rush)*, Impatiens noli-tangere* (yellow touch-me-not), *Eleocharis spp* (spikerush)*, Glyceria spp.* (mannagrass), *Urtica dioica* (stinging nettle), *Solanum dulcamara* (bittersweet nightshade).
- Palustrine Emergent Non-Tidal On Agricultural Lands: *Phalaris arundinacea* (reed canary grass), *Festuca spp*. (fescue), *Holcus lanatus* (common velvetgrass), *Agropyron spp.* (wheatgrass)*, Alopecurus spp.* (foxtail), *Juncus effusus,* (soft rush)*, Dactylis glomerata* (orchard grass)*, Agrostis spp* (bentgrass), *Poa spp.* (bluegrass), Gly*Epilobium angustifolium* (fireweed)*, Melilotis alba* (white sweet clover), *Ranunculus repens (*creeping buttercup*), Phleum pratense* (timothy)*, Cirsium arvense* (Canadian thistle)*, Cirsium vulgare* (bull thistle), *Polygonum sp.* (knotweed), *Chenopodium album* (lambs quarters).
- Palustrine Scrub-Shrub, Non-Tidal: *Cornus sericea* (red-osier dogwood), *Rosa nutkana* (Nootka rose), *Lonicera involucrata* (black twinberry), *Physocarpus capitatus* (Pacific ninebark), *Oemleria cerasiformis* (Indian plum), *Spirea douglasii* (hardhack spirea), *Salix sp*p (willow), *Malus fusca* (crabapple), *Sambucus racemosa* (red elderberry), *Rubus procerus* (Himalayan blackberry).
- Palustrine Forested, Non-Tidal: *Salix lasiandra* (Pacific willow), *Salix scouleriana* (Scouler's willow), *Picea sitchensis* (Sitka spruce), *Populus tricocarpa* (black cottonwood), *Thuja plicata*

(western red cedar), *Alnus rubra* (red alder), *Pinus contorta* (lodgepole pine), *Acer macrophyllum* (big-leafed maple).

4.2.3 Fish

The Ebey Island project area does not currently contain tidal channels or areas of consistently ponded water that serve as fish habitat. Drainage ditches and canals and a remnant reach of Deadwater Slough are the only areas that might contain enough water to support fish during certain times of the year, however access to these areas are prevented by a pump station and water quality is very poor (WRIA 7 LFA Report 2020).

Deadman Slough, on the northern tip of Ebey Island was found to contain some juvenile chum and coho salmon, but abundance was between 10 to 100 times less than in the same slough outside of the tide gate (Tonnes 2006). Other species that may use Ebey Island sloughs and ditches include threespine stickleback, starry flounder and peamouth chub.

Numerous fish species reside or migrate through the lower Snohomish River, including eight salmonids (Chinook, coho, chum, pink, sockeye, cutthroat, steelhead, and bull trout) and estuarine species.

Fish sampling in conjunction with the Spencer Island restoration/dike breach, in the same estuarine zone as Ebey Island) found catches predominately consisting of chum, Chinook and coho salmon, threespine stickleback and peamouth chub, and to a lesser degree, pink salmon, cutthroat and steelhead trout, bluegill, starry flounder, staghorn and prickly sculpins (Tanner et al 2002).

4.2.4 Birds

Existing conditions on Ebey Island provide a diverse assemblage of habitats for a wide array of birds, including migrating waterfowl, overwintering shore birds, raptors, and passerines. The following species have been observed using habitat on Ebey Island: wood duck, gadwall, yellowthroat, green-winged teal, canvasback, cedar waxwing, dunlin, Canada geese, brant, trumpeter swan, northern harrier, red-tailed hawk, bald eagle, roughlegged hawk, peregrine falcon, great blue heron, kingfisher, great horned owl, osprey, tree and barn swallows, song sparrows, downy woodpecker, pileated woodpecker, red-winged blackbird, killdeer, Swainson's thrush, and rufous-sided towhee (City of Everett 1997). Western sandpiper are known to use the restored southern portion of Spencer Island nearby (City of Everett and Pentec Environmental 2001).

Agricultural fields and pastures provide overwintering habitat for dabbling ducks and trumpeter swans (City of Everett and Pentec Environmental 2001). A field in the center of Ebey Island is leased by a hunting club. Flooding at that site is managed by the farmer to provide optimal waterfowl habitat.

In the Skagit and Stillaguamish River deltas, Slater (2004) found that dabbling duck species (mallard, American wigeon, Northern pintail, and green-winged teal) used both emergent marsh and agricultural fields but densities were higher in emergent marsh. Shorebirds prefer low vegetated marsh and intertidal mudflat habitat compared to agricultural lands. Geese and swans, on the other hand, appeared to prefer vegetated agricultural habitats to estuarine marsh.

4.2.5 Amphibians and Reptiles

Amphibians and reptiles are generally found in protected, non-tidal, freshwater aquatic habitats such as ponds, emergent wetlands, and ditches. Species common around the lower Snohomish River include Pacific tree frog, northern red-legged frog, bullfrog, and common garter snake (City of Everett 1997).

4.2.6 Mammals

Several species of mammals have been known to use Ebey Island, particularly the forested habitats. Deer, river otter, beaver, muskrat, mink, long-tailed weasel, porcupine and raccoon are all commonly sighted (City of Everett 1997) across the island.

4.3 Physical Conditions

4.3.1 Dikes and Levees

The district commissioners have said that they think that the existing perimeter location of the dikes is where the most suitable soils are to support a full-height flood dike. They have commented that they think that the interior soils are too soft to support a full height set-back dike. A review of available sub-surface investigations was completed by AMEC's geotechnical engineers and additional subsurface samples were taken. Their conclusion is that construction of full height dikes are possible, but would require special design and construction methods to create suitable dikes. Figure 5 shows the dike along Ebey Slough near SR 2.

Diking District #1 entered into an agreement about 20 years ago with all the other diking, drainage, and flood control districts in the vicinity, as well as a number of agencies, to establish an approach for creating the dike and levee profiles that would provide uniform flood protection for the districts. In the portion of the Snohomish River that is dominated by river flooding, the desired levee elevation is one foot above the 5 year flood level. The dikes on Ebey Island have been overtopped a few times in the last few decades. Downstream, the dike elevations are set to minimize the chance of flooding from tides and storm surges. The southern half of the island is subject to river flooding, while the northern half is more susceptible to flooding from tides and storm surges. Diking District #1 is also in a unique situation, compared to most of the other districts, in that there are no adjacent upland areas. Egress

Figure 5 **Diking District #1 dike, with Ebey Slough on the left. The view is looking south toward at the eastern portion of the project area, with the heavily forested area visible in the backround in the right half of the photo. The dike here is graveled to provide year-round access to the Olympic Pipe Line corridor.**

from the district is by SR 2 and Homeacres Road. The district commissioners have indicated that it is important not to create a situation where the amount of time that residents have to flee the island safely is reduced.

The commissioners have also described efforts to repair dike breaches and erosion at the toe of the dikes in recent years. They have indicated that it is becoming increasingly difficult to affordably complete the repairs because of wetland regulations and limitations on placing rock riprap, in favor of using other materials, especially large woody debris, along with bio-engineering techniques. The commissioners have expressed an interest in considering a project that would create a setback dike to calve off the northern part of the island for fish habitat. They have indicated that the trade-off of having less dike to maintain in an area that is difficult to access would likely be worth the relatively minor loss of assessed land within the district. The focus of this project is to look for opportunities for fish habitat improvement on WDFW-owned land, with consideration for what other areas, particularly adjacent land, would provide opportunities to greatly improve a potential project, either by increasing the potential habitat value or by creating cost savings.

4.3.2 Drainage

Because the ground surface of Ebey Island has subsided below water levels in the adjacent channels, the island is drained by a system of drainage channels which gather water from the island and convey it to one-way tide gates where water is passed off the island. A pump station is co-located with the tide gates on Deadwater Slough to supplement the gravity drainage. This part of the drainage system provides most of the drainage for the island. During periods when precipitation rates and water levels in the adjacent channels are lower, sufficient volumes of water can be drained from the island on each low tide using only gravity. However, when precipitation increases the volume of water delivered to the island and water levels in the adjacent channel rise through a combination of tidal conditions and riverine discharge, water must be removed by pumping to prevent standing water on the island. Elements of the drainage system include (pers. comm., Diking District #1 commissioners):

- A 4-foot diameter culvert and with a one-way tide gate on the west side of the district, about 7,000 feet south of SR 2. Its bottom invert is exposed when water levels in the Snohomish River fall to approximately mean lower low water (MLLW, a “zero” tide).
- A 4-foot diameter culvert and with a one-way tide gate on the west side of the district, about 7,000 feet north of SR 2. Its bottom invert is exposed when water levels in the Snohomish River fall to approximately mean lower low water (MLLW, a “zero” tide).
- Two approximately 5-foot diameter culverts and two approximately 7-foot diameter culverts, all with one-way tide gates, convey flow off the island through the lower portion of Deadwater Slough. These culverts have inverts at approximately two feet below MLLW (Figure 6).

- There are three pumps at the pump station on Deadwater Slough Figure 7 shows a photo of these pump outlets. The pumps are apparently mounted low enough that they could nearly pump Deadwater Slough dry. The pump specifications are:
  - 16” discharge, about 40 hp electric motor, axial flow pump
  - 20” discharge, about 60 hp motor, submersible pump
  - 20” discharge, about 100 hp motor, axial flow pump

Pumps are turned on when there is water over the low areas of Homeacres Road. Pumps are also typically used toward the end of February when low tide levels increase as a result of increased riverine discharge. One or more pumps are used as needed through the rest of winter and early spring. Pumping typically ends before June. Although the pumps have automatic controls, they are typically operated manually in response to observed changes in water levels.

4.3.3 Soils

The soils on the island are considered prime agricultural soils when drained and protected from flooding, as determined by the USDA Natural Resources Conservation District. The practical limitations for agriculture on the island and within the project area are related to the depth of the water table from the soil surface. Not much high intensity agriculture is currently practiced here, so the diking district has chosen to limit the use of the pump system. The commissioners have indicated that in the past, landowners have grown crops, such as corn, that required a lower water table. The diking district used the pumps to provide that drainage, and continue to assert that their pump system is capable of providing the drainage needed to support these crops in the future.

AMEC evaluated available existing soil logs from nearby road and utility projects to evaluate the potential limitations for constructing new dikes on the island. Additional explorations were also performed in the project area. See Appendix A for the preliminary geotechnical report.

4.3.4 Flooding

The entire project area and all of Ebey Island are within the mapped 100-year floodplain. As mentioned in section 4.3.1, Dikes and Levees, the Snohomish River and Ebey Slough can be expected to overtop the levees south of Highway 2 periodically during large floods. There are only two roads that provide egress from the island. These are Highway 2 and Homeacres Road. After the overtopping starts, there is a very limited amount of time that residents have to leave the island before the water becomes too deep for them to drive out. Most of the houses on the island have their living areas elevated significantly above the ground elevation. However, the higher the water gets within the district, the greater the damage to structures and belongings. Proposed alternatives to create full or

Figure 6 **Diking District #1 pump station, with outlets visible in the center of the photo, penetrating the dike. Deadwater Slough is tidally influenced in the foreground.**

Figure 7 **Diking District #1 tide gates discharging water into the tidally influenced portion of Deadwater Slough during a low tide. One of the outlet pipes from the pump station is visible at the lower left corner of the photo.**

muted tidal conditions within the boundary of the district will result in flood waters rising faster because of the reduction in flood storage capacity. This reduction in flood storage capacity can likely be mitigated wholly or in part by adding flood gates at the downstream end of the flood water receiving areas. Flood gates work similarly to a tide gate by allowing water to leave the district when the water level in the district is higher than the water level on the outboard side of the flood gate. Flood gates are typically installed above the existing ground surface and are designed to minimize the amount of water impounded within an area during a flood and to allow most of the flood water to rapidly leave the district as the water levels in the river and sloughs subside.

The eastbound SR 2 bridge over Ebey Slough is supported by multiple rows of pilings, which has created log jams in previous floods, as shown in Figure 8.

Applications to Snohomish County for flood hazard permits generally will need to include a “zero rise” analysis, and it is prudent to forecast the expected change in the 100-year flood elevation that a project would cause, even if the analysis is not required. It is not likely that Diking District #1 or other nearby districts would be in favor of any action that increased the expected water levels during a flood large enough to cause overtopping of their dikes and levees.

Applications to Snohomish County for flood hazard permits generally will need to include a “zero-rise” analysis. It would be prudent to forecast the expected change in the 100-year flood elevation that a project would cause, even if the analysis will not be required The basic premise is that proposed activities must result in “no-rise” of the 100-year flood level, compared to the existing conditions. To meet this requirement, and to get at the desire to improve the flood protection for the diking district, structures that release flood water after an overtopping event should be considered to provide an improved ability to drain water out of the district after a major flood event. An added benefit of this type of structure is that it greatly reduces the possibility of stranding fish within the dike system, which would be a concern primarily on the properties not within the project footprint. It would also greatly reduce the probability of a dike breach, which would have financial, social, economic, and environmental implications.

Full-height setback dikes allow more flow through the adjacent channel. However, when the dikes overtop, there is less flood water storage inside of the dike system, which results in the water level rising faster than it did previously. During a 100-year flood, the dikes would likely overtop long enough to completely fill the district, with the downstream dike on Ebey Island acting as a spillway to let floodwaters out. In the case of a full restoration of all the WDFW properties to full tidal influence, floodgates may need to be considered to allow flood water that overtops the dike system to flow out so that the level of inundation of the properties on the southern part of Ebey Island is minimized.

4.3.5 Elevations (Subsidence)

Considerable subsidence to the ground surface elevation has occurred behind dikes and levees on the Snohomish River due to soil compaction, organic matter decomposition, and the reduction in sediment deposition. Otter Island, which has never been diked and likely represents an approximate natural marsh elevation, is on average +13 ft MLLW (City of Everett 1997). Most of the land in the northwest corner of the project area is between 4 and 8 ft MLLW and in the northeast corner it is between 3 and 6 ft MLLW, indicating considerable subsidence has occurred. In the SEWIP (1997) study, an elevation of +7 ft MLLW (4.75 ft NAVD) was considered the lower limit for vegetated marsh to establish and species diversity increased significantly above +12 ft MLLW. Restored areas below this elevation were expected to become intertidal mudflat at least until sediment accretion raised the marsh surface to sufficient height.

4.3.6 Water quality

The lower Snohomish River has a long history of poor water quality due to industrial effluent (WRIA 7 LFA Report 2002), and continues to be plagued by high temperatures, turbidity, fecal coliform counts, and pollutant levels (organic and metal), and low dissolved oxygen concentrations and pH. In 1998, it was included on the 303(d) list of impaired waterbodies in Washington State.

Deadwater Slough is the large two-branched slough that serves as the trunk of the drainage system for the diking district. The presence of the tide gates and dry conditions during summer, have led to stagnant water conditions and poor water quality. High water temperatures and low dissolved oxygen have been cited in other documents as the leading water quality problems in this slough.

5.0 HABITAT RESTORATION ALTERNATIVES

A 3-stage process was used to identify and screen a preliminary set of restoration alternatives, evaluate the feasibility of the most promising alternatives, and select, model, and conduct an in-depth assessment and public vetting of a single preferred alternative. The tiered approach represented a logical framework and process by which various candidate alternatives were screened and winnowed down by the AMEC team and the Advisory Committee to two preferred alternatives based on increasingly detailed design and technical and social performance criteria. The various data, analytical tools and methods developed to support the evaluation process are described below.

The first stage in the design, evaluation and selection process consisted of identifying 14 conceptual alternatives that warranted further consideration based on available information, including a preliminary site assessment and input received from landowners, stakeholders and experts. The

ecological, social and economic feasibility of these alternatives was evaluated relative to an extensive set of technical and social feasibility criteria in the second stage of the process, and 2 leading alternatives were selected for further analysis. Section 5.2.2.5 describes how these alternatives were refined, hydrodynamically modeled, and subjected to further analysis in the third stage of the alternatives development process.

5.1 Conceptual Alternatives

5.1.1 Specification of Conceptual Alternatives

Conceptual alternatives were developed with the goal of providing significant fish habitat improvement, compared with existing conditions. The alternatives were placed primarily on the properties currently owned by WDFW and landowners known to be supportive of the concept of improving habitat for fish and wildlife. In one case, permission to include private property was denied by the landowner. The conceptual alternatives were developed to avoid this property as much as possible. A few alternatives would require additional property acquisitions where the landowners were not contacted. The conceptual alternatives focused on possible land use configurations across the available property and the infrastructure that would be needed to support the changes in use. It is interesting to note that the infrastructure that needs to be added for a full tidal restoration is for the purpose of allowing other adjacent and nearby land uses to continue, whereas the infrastructure that needs to be added for a muted tidal restoration is generally needed to allow for the formation of the new habitat.

Figure 8 **Channel spanning log jam in Ebey Slough at the eastbound SR 2 crossing. Some of the rows of pilings that support the highway are visible in the photo. These pilings caused the log jam to start. Circa 2003. Credit: A.G. Alexander.**

The conceptual alternatives, summarized in Table 2, were crafted based upon a careful study of the available information, including the various input offered by the stakeholders. All of the alternatives were crafted to provide an increase in the amount of fish habitat. Input from the fish biologists suggested that multiple connections between the river or slough and the restored area are better than a single connection, more juvenile salmonids outmigrate down the Snohomish River than Ebey Slough, full tidal restoration is better than muted tidal restoration, and the best new habitat is that which restores natural riverine and estuarine processes as much as possible.

Input was sought from the diking district to look for areas where deficiencies in their diking or drainage infrastructure could present an opportunity to improve habitat and improve the situation for the district. Most of the problem sections of dike are away from the project area. However, there remains ongoing concern about the section of dike just upstream of SR 2 because of the history of logjams forming there. Additional input from the diking district included identifying areas within WDFW ownership that would least impact the ongoing farming operations. The diking district also suggested a project in the northern-most portion of the island that would create full tidal restoration and eliminate a problem area of dike for them. This alternative is discussed later in this report.

WDFW and stakeholders have expressed a desire to provide more opportunities to improve the recreational uses of the property, including boating, hunting, bird watching, and trail walking. All of these uses are secondary to the main categories of land use that include full tidal restoration, muted tidal restoration, and managed lands. Therefore, the conceptual alternatives do not explicitly propose recreational use areas or features because they can be overlain on a proposed project once it has been more fully formed and because at this stage, each alternative has an equivalent potential for recreational uses. Additionally, the managed lands category can include areas drained and used for agriculture, wetlands, and walking wetlands. Walking wetlands is a concept whereby an area is fully capable of supporting agriculture, but is managed in such a way as to alter the water table of sub-sections of the site to create wetland features that are moved to a different portion of the site each year, usually to promote use by waterfowl. These choices are all possibilities within the areas labeled in the alternatives as managed drained.

Table 2 14 alternatives developed, along with a brief description of each. Figure 9 through Figure 22 depict these alternatives.

Alternative	Description
A	Full tidal restoration on WDFW-owned land with a minimum of additional acquisitions. Full tidal connections to Ebey Slough and connector to Snohomish River.
B	Muted tidal restoration on WDFW-owned land with a minimum of additional acquisitions. Tidal connections to Ebey Slough and connector to Snohomish River via regulated tide gate(s).
C	Full tidal restoration on WDFW-owned land with additional acquisitions. Full tidal connections to Ebey Slough and connector to Snohomish River. Requires elevating Homeacres Road and the installation of pump stations and flood gates to support ongoing uses outside of project area.
D	Full tidal restoration on extreme west and east portions of WDFW-owned land with a minimum of additional acquisitions. Full tidal connections to Ebey Slough and connector to Snohomish River. East-central portion of WDFW property proposed as muted tidal area to improve the flood water conveyance through the island during an overtopping event and to displace less flood water to reduce the rate of flood water rise compared to Alternative C.
E	Full tidal restoration on western portions of WDFW-owned land with additional acquisitions. Full tidal connections to connector to Snohomish River. Area east of the east branch of Deadwater Slough to be restored as a muted-tidal area. Central portion of the property unchanged to allow water conveyance through the island during an overtopping event.
F	Full tidal restoration on extreme west portion of WDFW-owned land with no additional acquisitions. Full tidal connection to connector to Snohomish River. East-central portion of WDFW property proposed as managed wet area with no tidal connection. Area between the branches of Deadwater Slough enhanced as a wetland.
G	Full tidal restoration on extreme northwest portion of WDFW-owned land with a minimum of additional acquisitions. Full tidal connections to Ebey Slough. East-central portion of WDFW property proposed as muted tidal area. Southeast and northwest portions of the property proposed for wetland enhancement.
H	Full tidal restoration on extreme west and east portions of WDFW-owned land with a minimum of additional acquisitions. Full tidal connections to Ebey Slough and connector to Snohomish River. Central portion of WDFW property proposed as muted tidal area. Area adjacent to east for of Deadwater Slough left open to allow flood water conveyance through the island during an overtopping event.
I	Full tidal restoration on extreme and east portion of WDFW-owned land with a minimum of additional acquisitions. Full tidal connection to Ebey Slough. East-central portion of WDFW property proposed as muted tidal area. Central portion of the project left alone to allow flood water conveyance through the island during an overtopping event.
J	Full tidal restoration on easterrn half of WDFW-owned land with a minimum of additional acquisitions. Full tidal connection to Ebey Slough and to connector to Snohomish River. Western portion of WDFW property proposed as managed drained area. This area is shown in a possible "walking wetland" configuration. Central portion of the project left alone to allow flood water conveyance through the island during an overtopping event.
K	Full tidal restoration on western portions of WDFW-owned land with additional acquisitions. Full tidal connections to connector to Snohomish River. Area east of the east branch of Deadwater Slough to be restored as a muted-tidal area, along with a portion of the eastern branch of Deadwater Slough. Central portion of the property unchanged.
L	Muted tidal restoration on western and northeastern portions of WDFW-owned land with no additional acquisitions. The muted tidal restoration areas shown were the areas where the diking district commissioners thought restoration would have the least impact to the adjacent and nearby landowners.
M	Full tidal restoration east of the petroleum pipelines. Muted tidal restoration on western and northeastern portions of WDFW-owned land with no additional acquisitions. The muted tidal restoration areas shown were the areas where the diking district commissioners thought restoration would have the least impact to the adjacent and nearby landowners.
N	Muted tidal restoration on western and northeastern portions of WDFW-owned land with no additional acquisitions. The muted tidal restoration areas shown were the areas where the diking district commissioners thought restoration would have the least impact to the adjacent and nearby landowners. This alternative shows the conceptual layout of chinampas-style elevated agricultural areas, surrounded by sloughs.

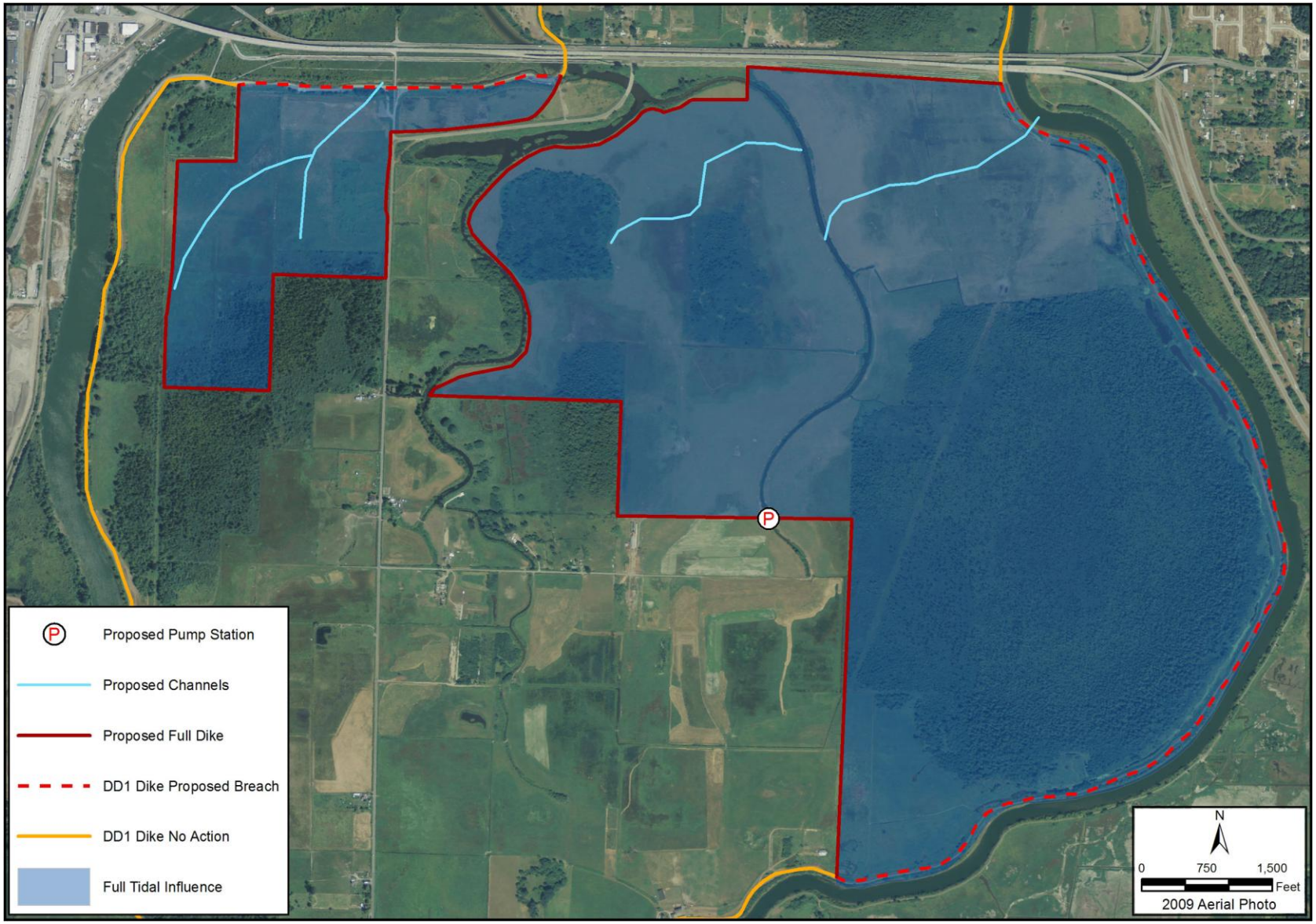


Figure 9 Alternative A

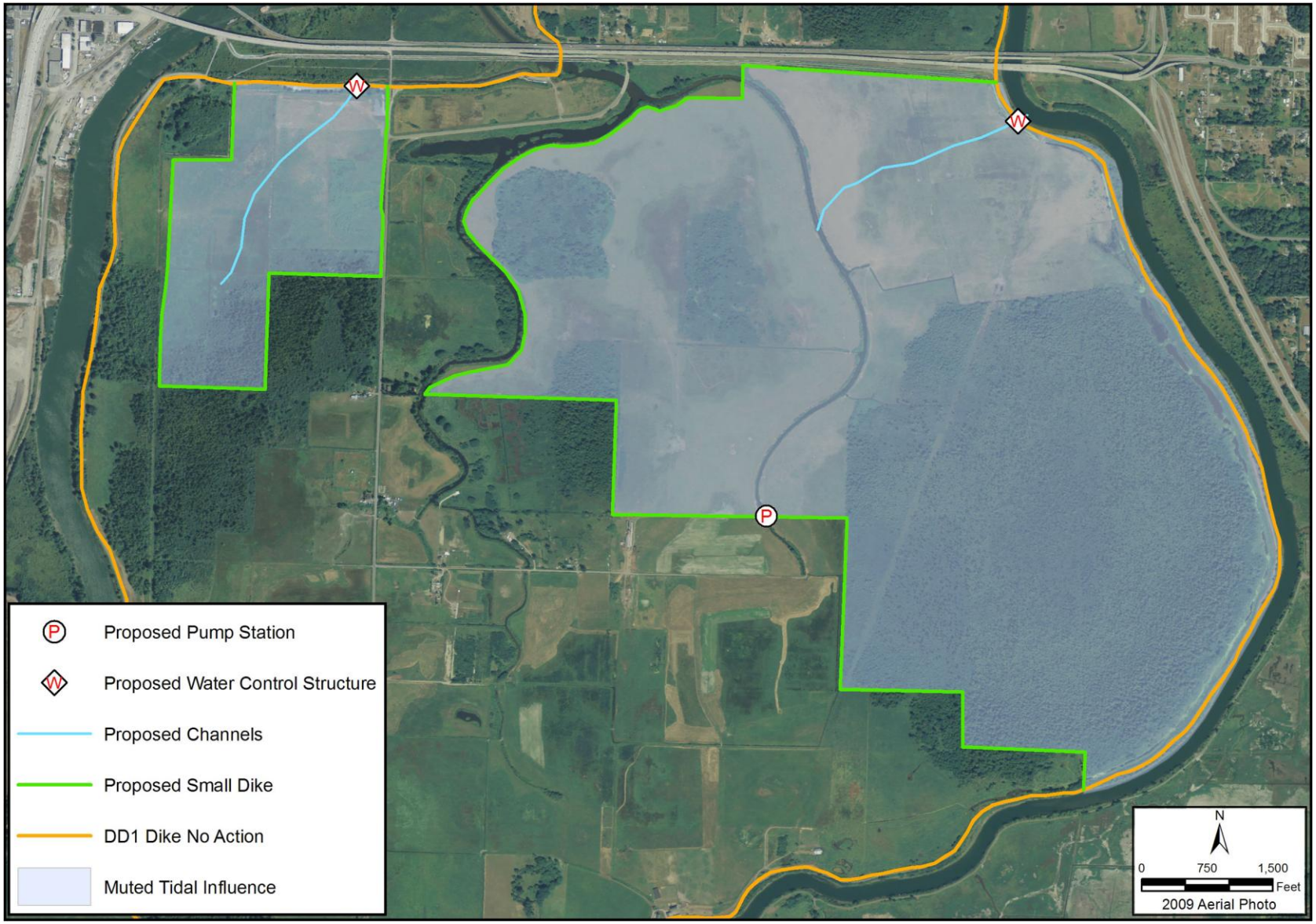


Figure 10 Alternative B

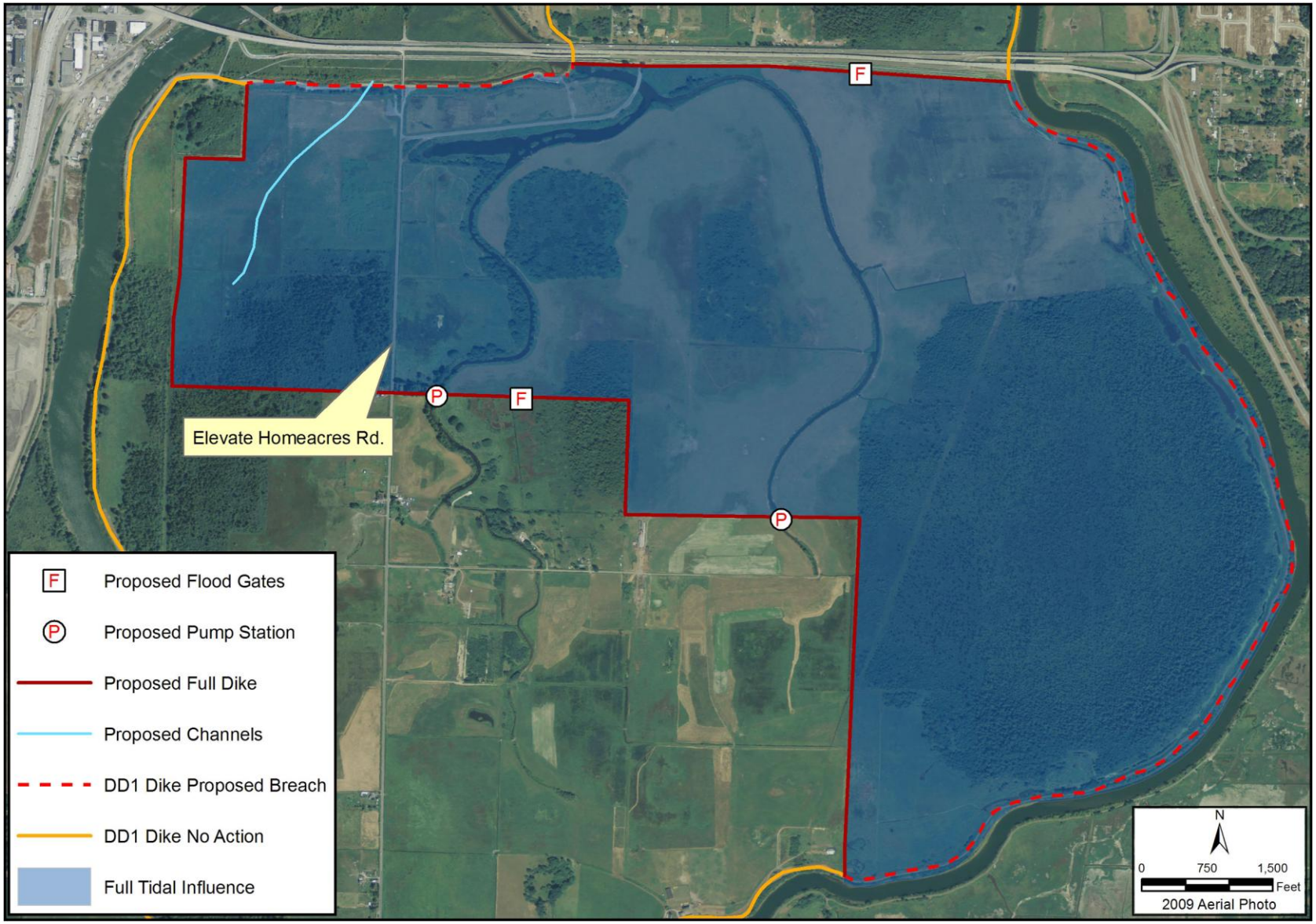


Figure 11 Alternative C

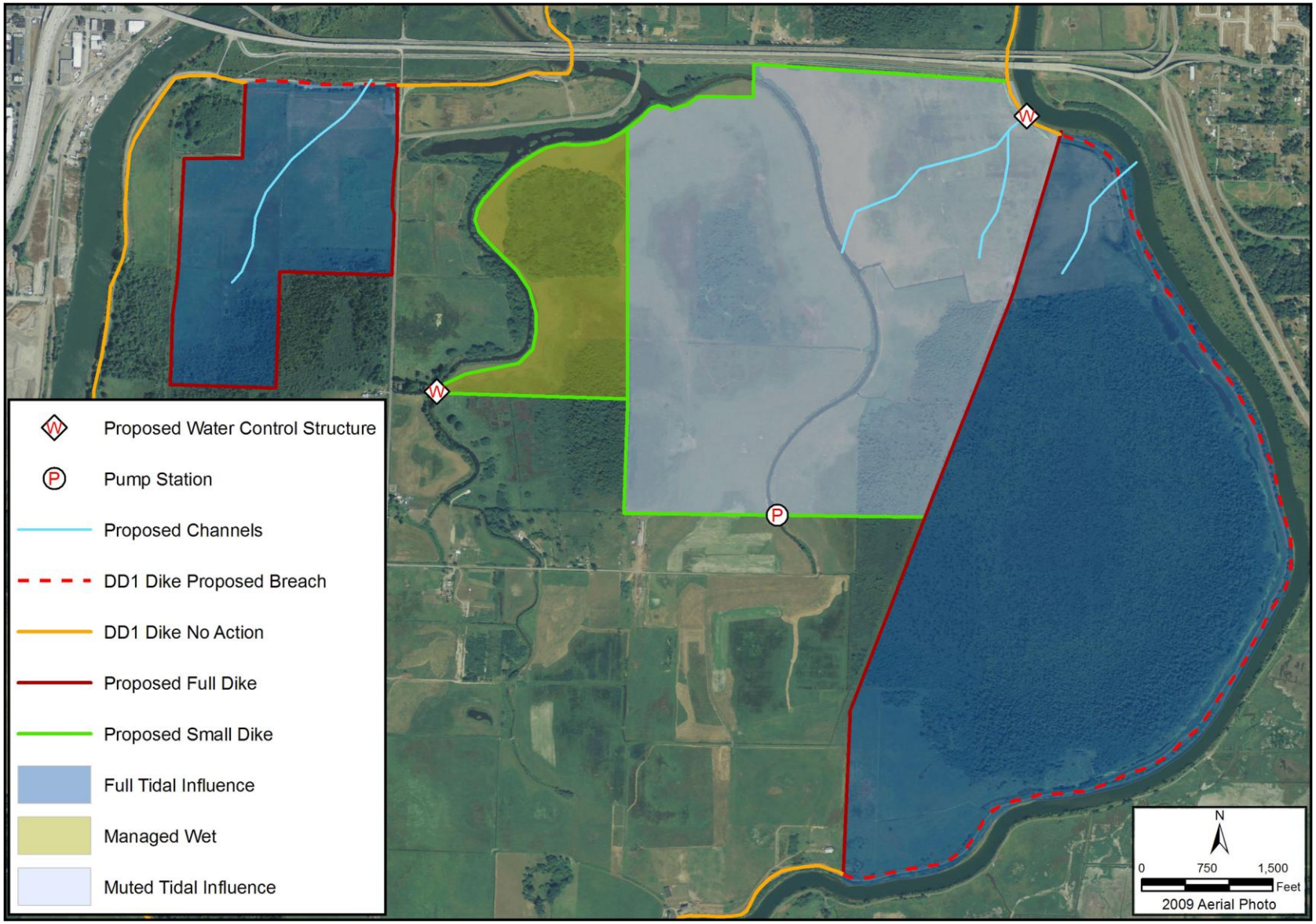


Figure 12 Alternative D

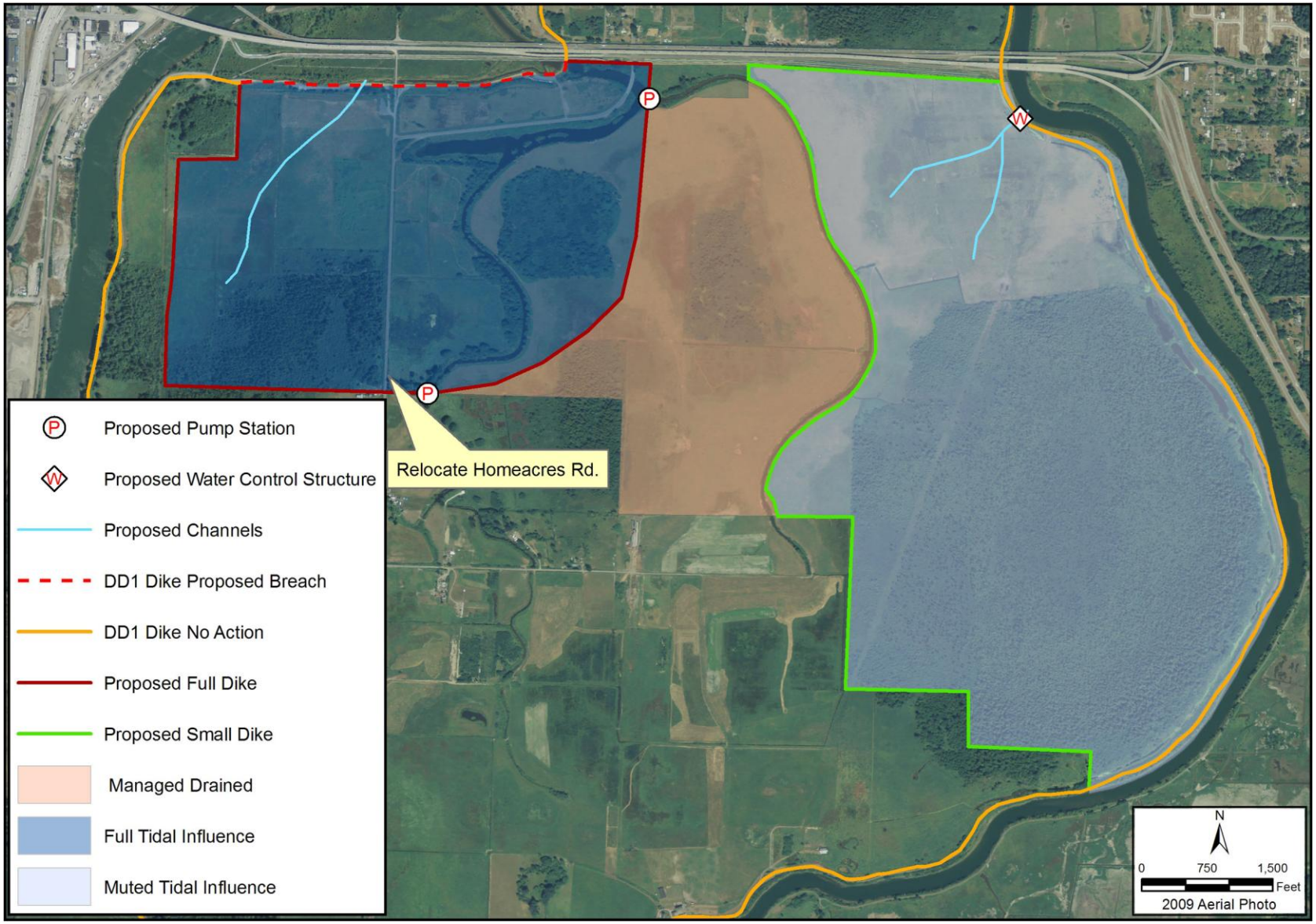


Figure 13 Alternative E

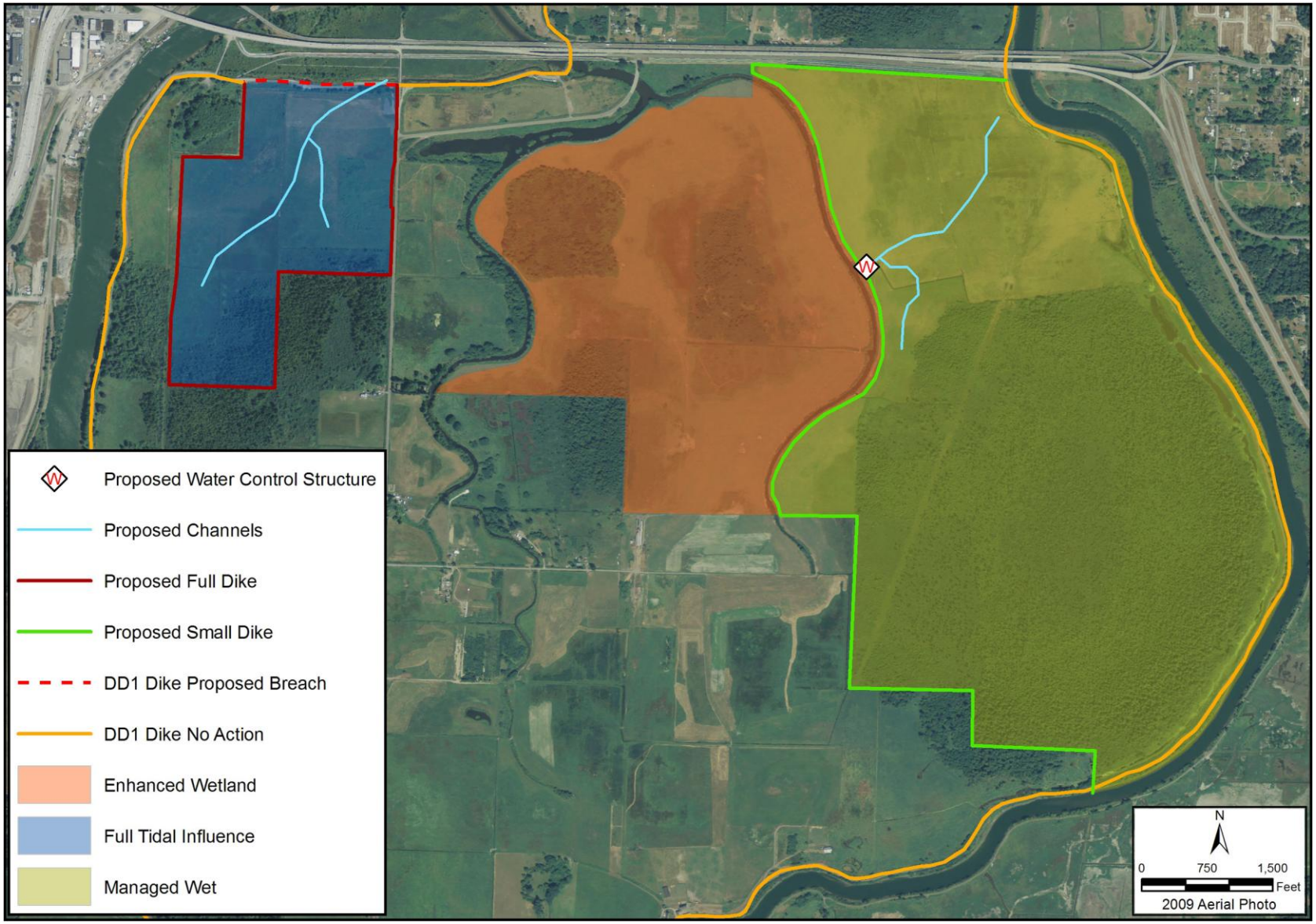


Figure 14 Alternative F

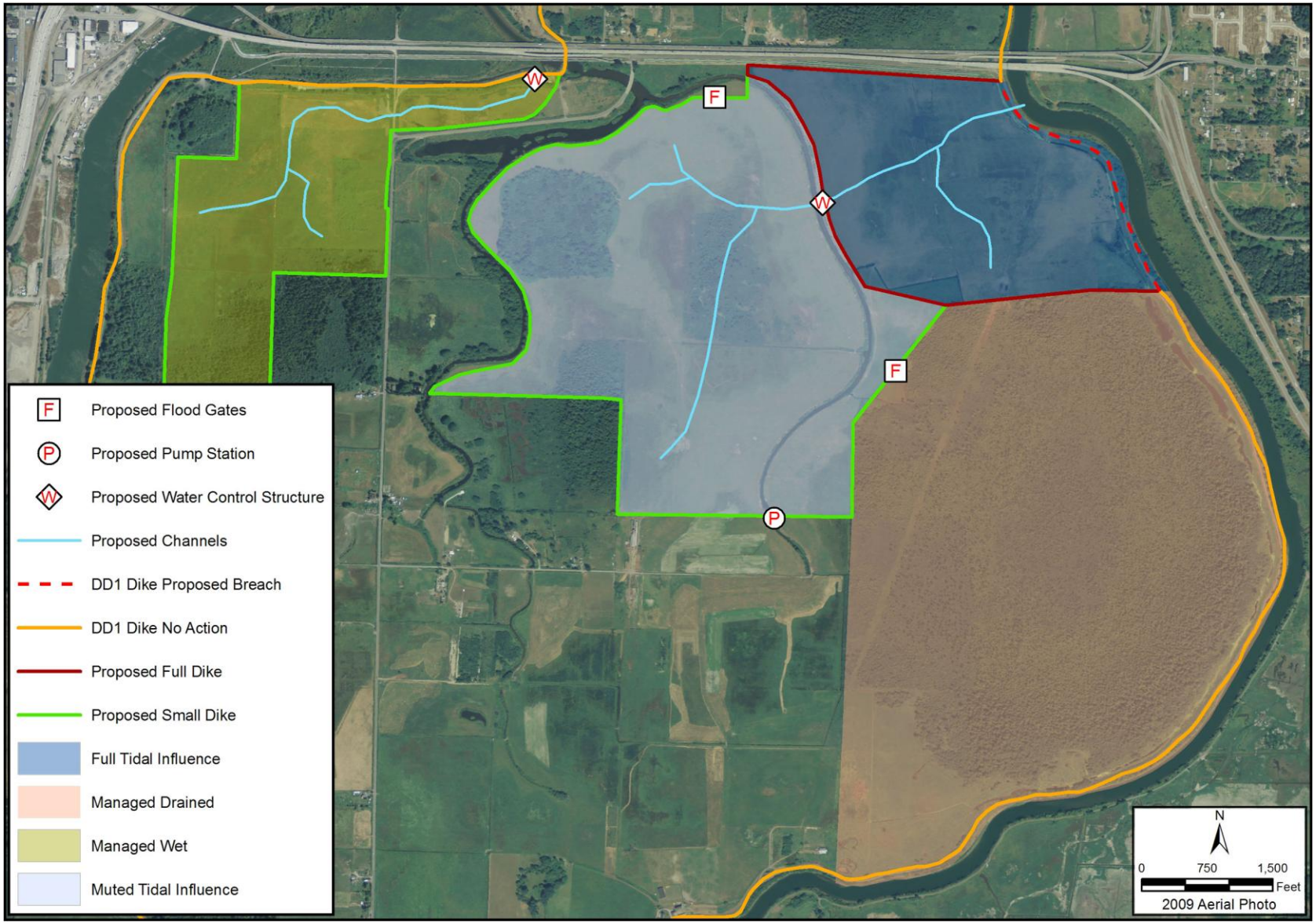


Figure 15 Alternative G

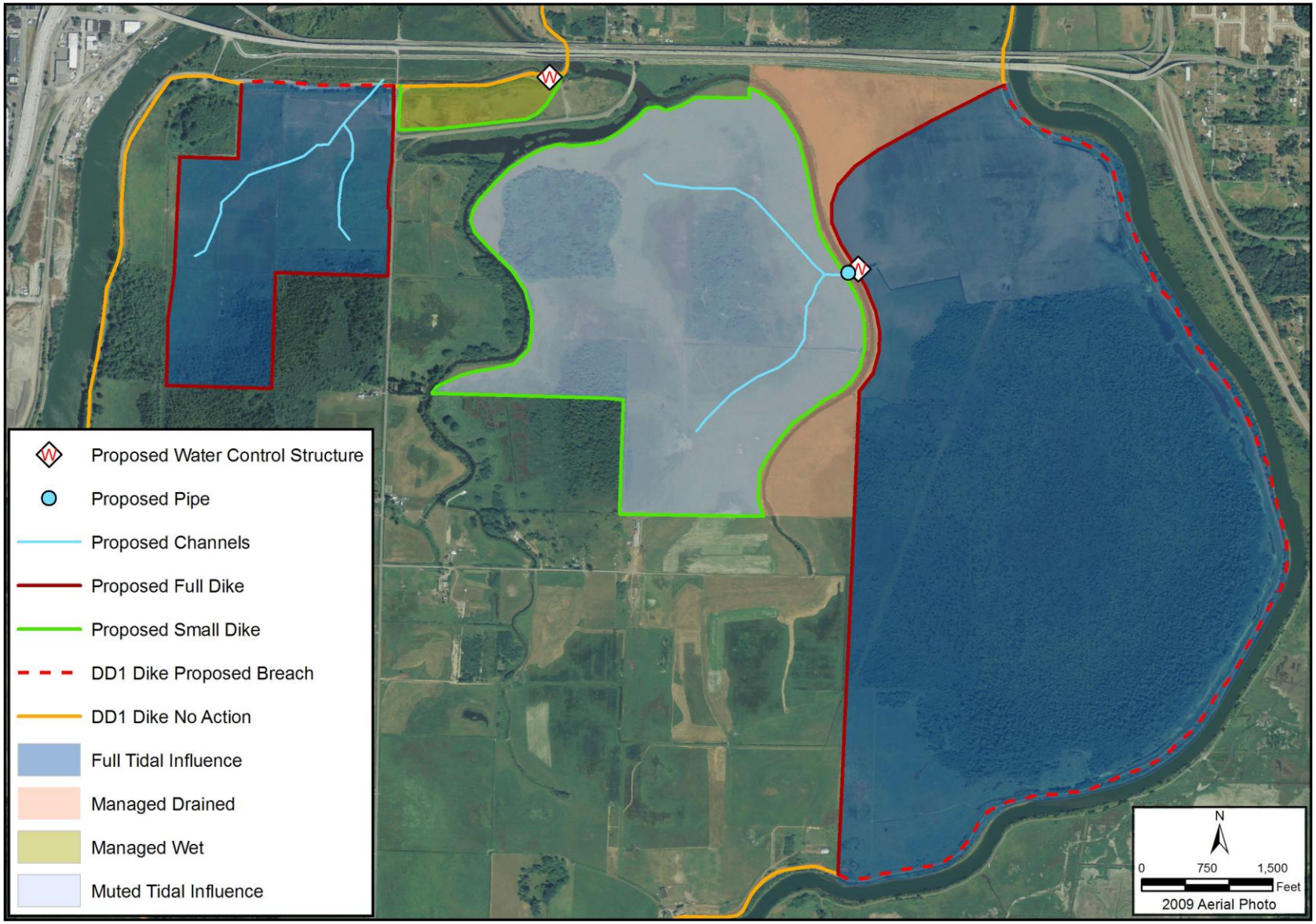


Figure 16 Alternative H

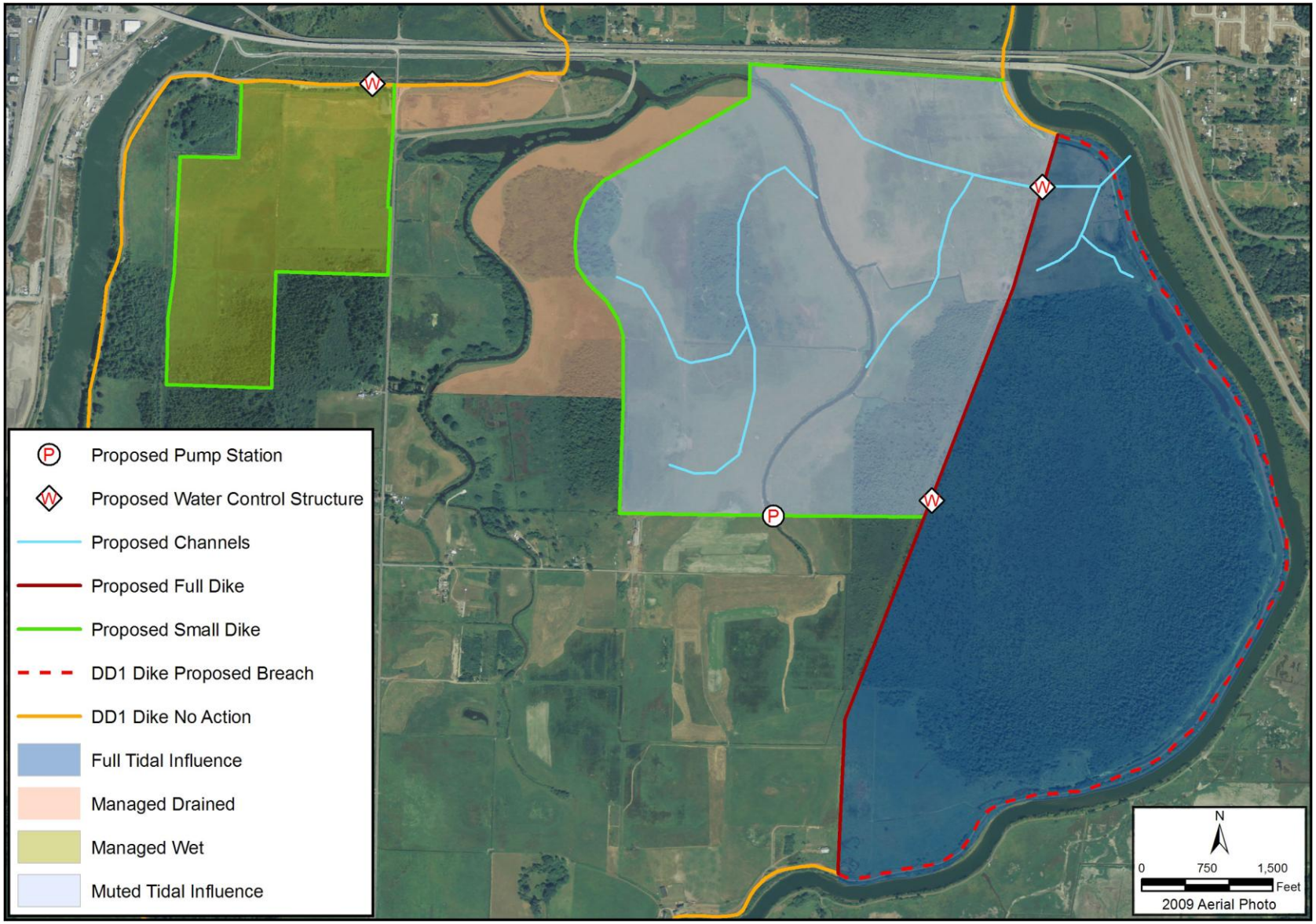


Figure 17 Alternative I

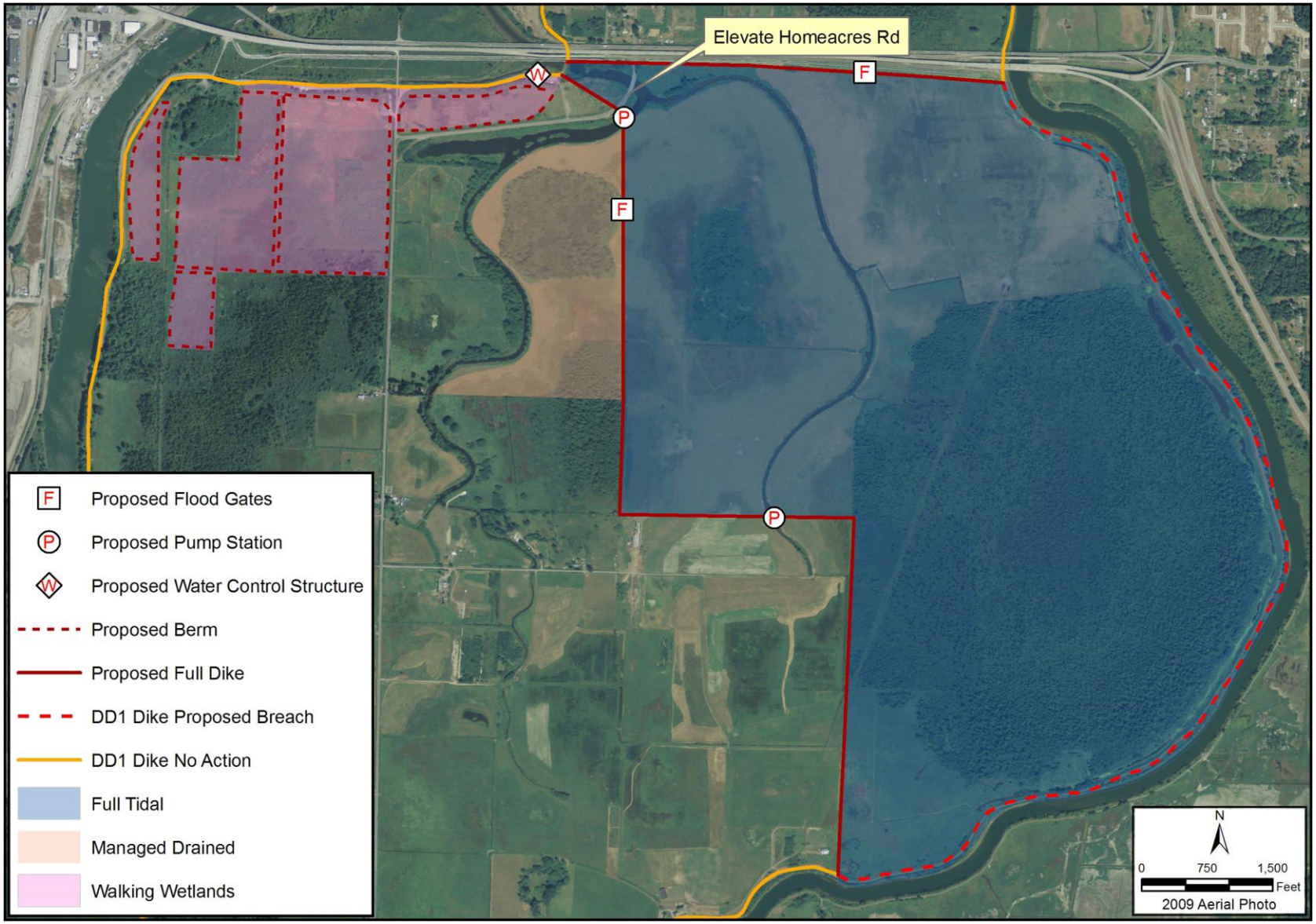


Figure 18 Alternative J

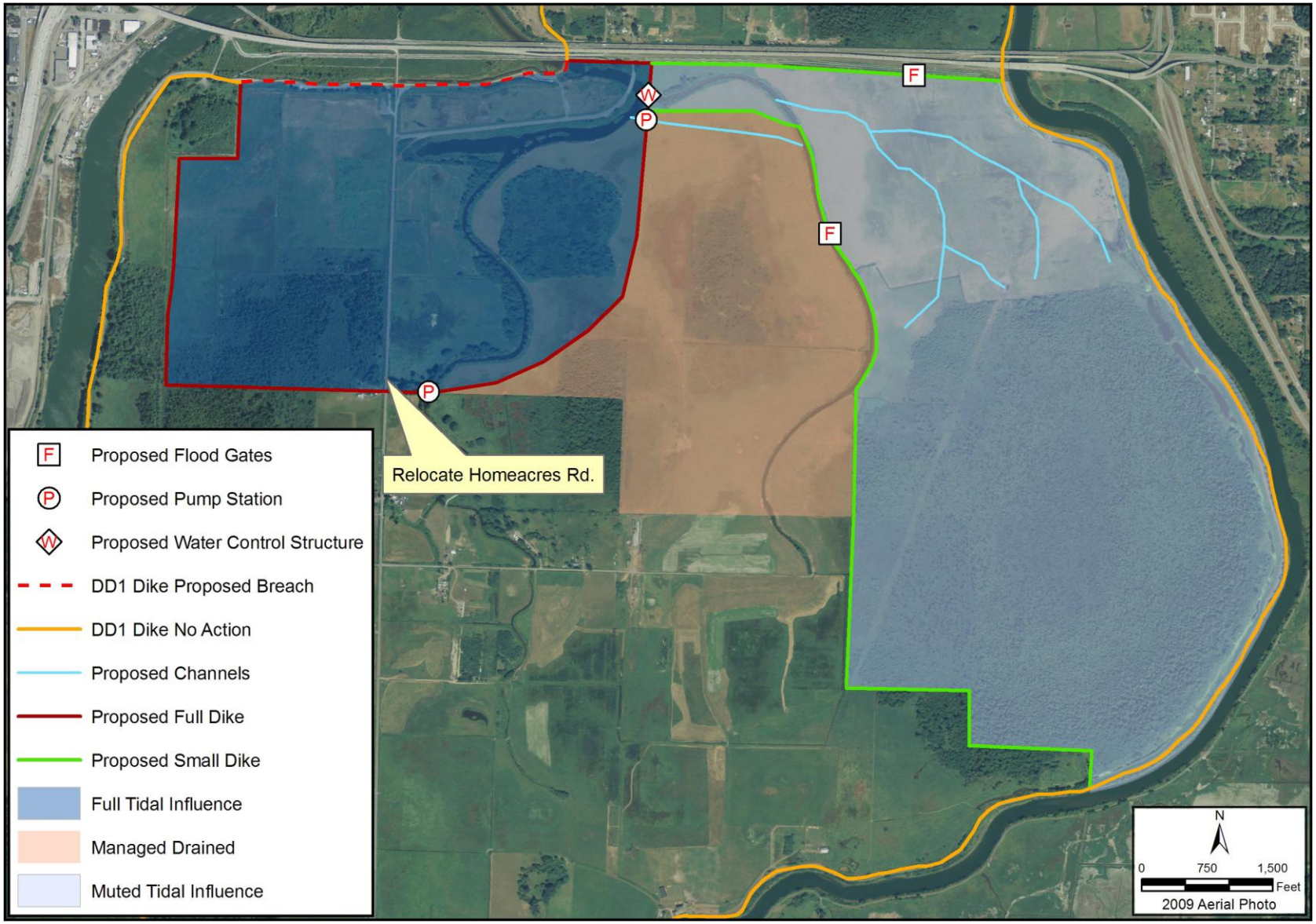


Figure 19 Alternative K

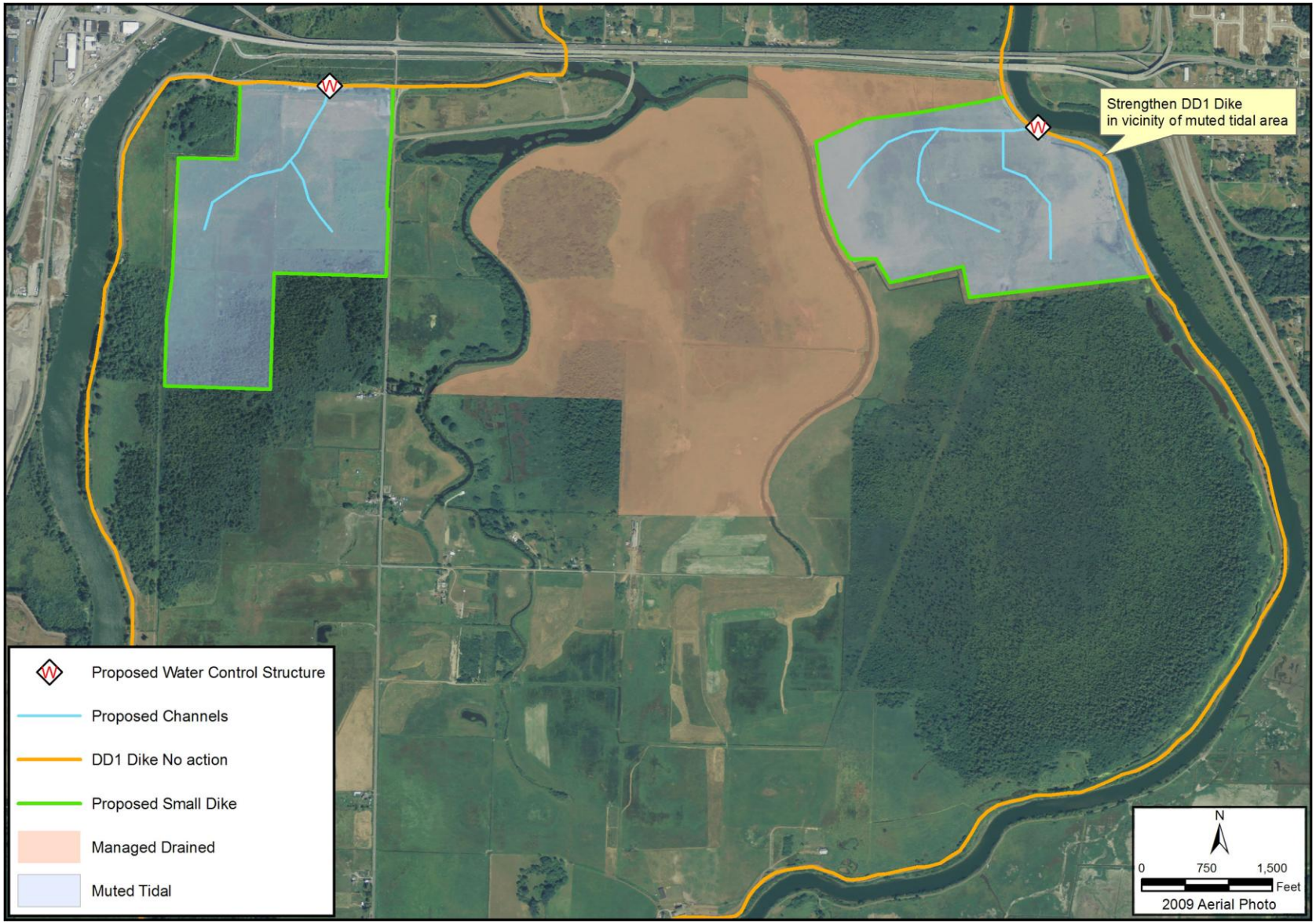


Figure 20 Alternative L

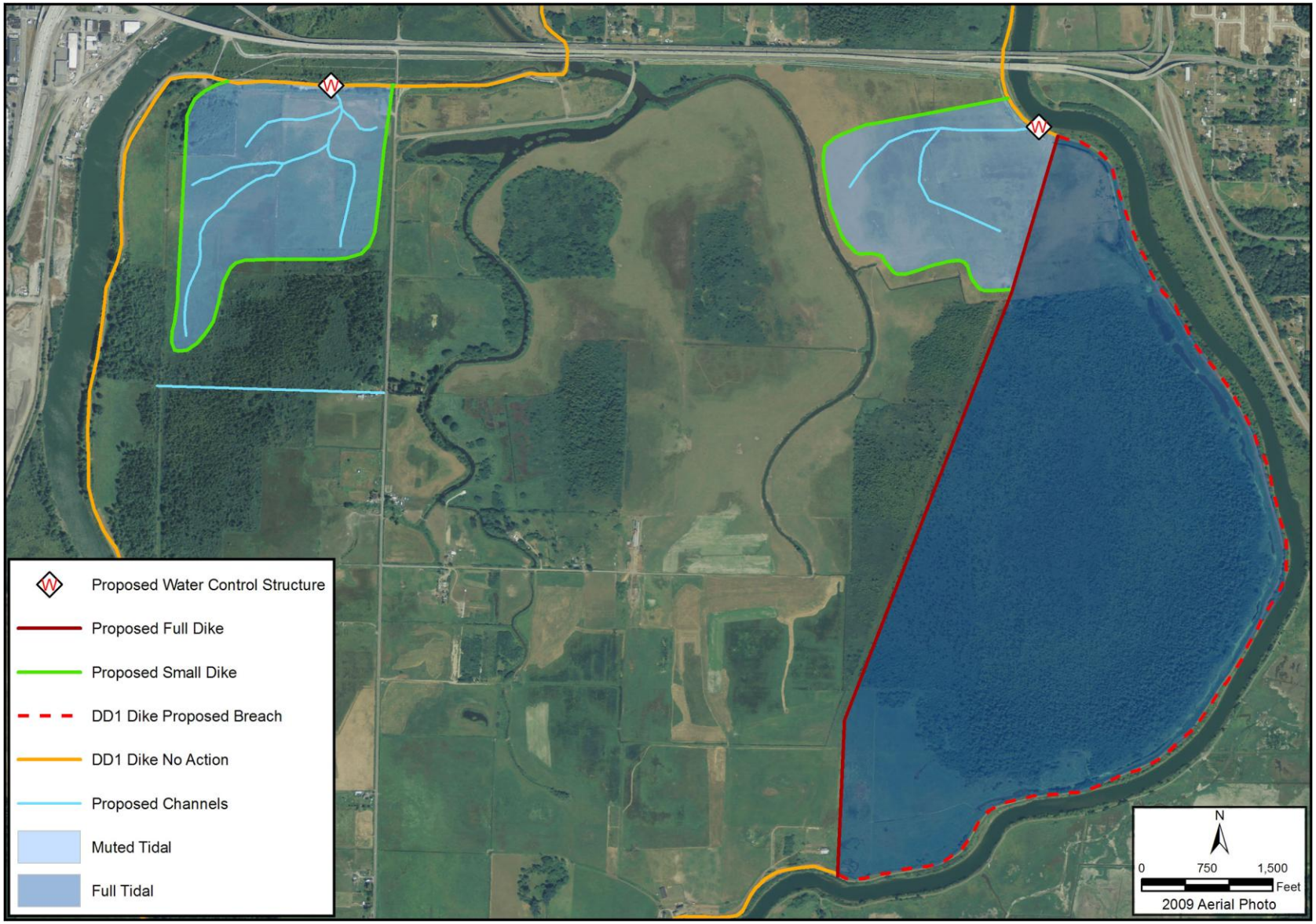


Figure 21 Alternative M

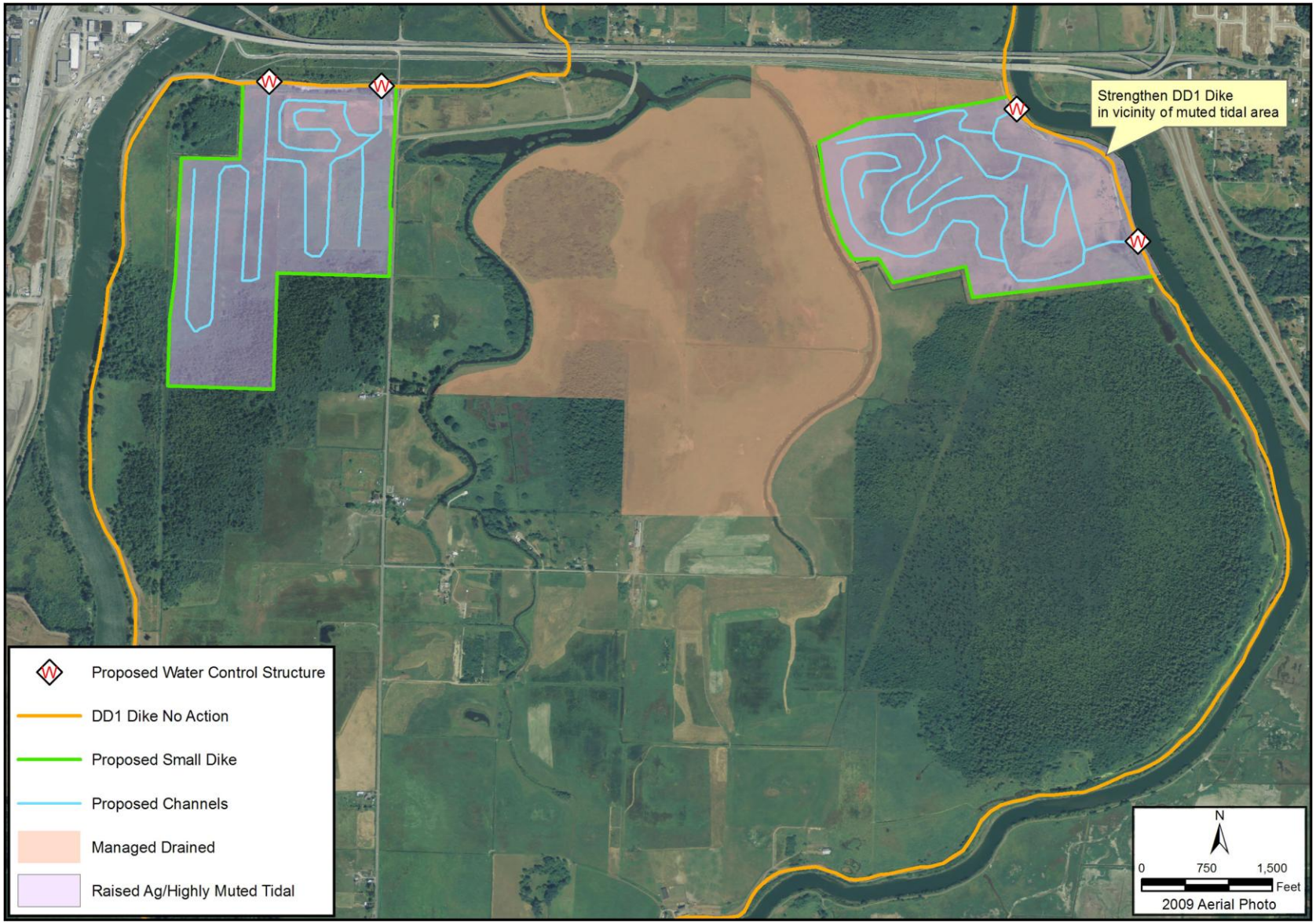


Figure 22 Alternative N

5.1.2 Evaluation and Ranking of Conceptual Alternatives

This section introduces the method and process used to evaluate the technical and social feasibility of the conceptual alternatives, and based on the results of this process, to identify a subset of alternatives for further analysis.

The method used to narrow and prioritize the range of alternatives was adapted from Felice and Franz (Felice & Franz, 1980). This method provides a straightforward procedure to efficiently score and rank the conceptual restoration alternatives, and meets this project's need for a relatively simple and systematic procedure to objectively rank-order potential restoration alternatives projects needed to improve salmon habitat while accommodating other social and recreational values.

The process followed in this study includes the following steps:

- Step One: Develop a draft list of potential evaluation criteria. Define scoring method. Review these with key stakeholders involved in fisheries, agriculture, and recreation in the project area. Amend the criteria and scoring method based on stakeholder feedback.
- Step Two: Collect, map, and compile pertinent data and metrics.
- Step Three: Score the various alternatives based on their metrics.
- Step Four: Normalize the scores to a 0 – 4-point basis.
- Step Five: Rank the identified criteria using a pairwise comparison procedure (Souder, 1975) as described in Section 5.1.3.2 of this report.
- Step Six: Calculate a weight for each decision factor based on the ranks determined in Step Three. Decision factor weights are calculated by the rank total being divided by the rank number (Baker & Moore, 1969).
- Step Seven: Calculate a final score for each alternative based on metrics and decision weighting factor.
- Step Eight: Evaluate the resulting score and identify the highest rated alternatives for further engineering analysis.

5.1.2.1 Application of Criteria and Scoring Metrics

In trying to assess how best to evaluate the potential effects of different conceptual alternatives on fish, agricultural, social, and recreational resources, many criteria were originally considered. A draft list of 47 potential criteria was developed. Through evaluation and discussion with the Advisory Committee many were determined to not be useful, either due to lack of data, the lack of meaningful differentiating measurements, or because it was determined that the criterion shouldn't play a role in

deciding what is appropriate in rating an alternative (e.g., cost). Some of these individual criteria were combined into one, single-subject criteria, as explained below. Additionally, while some of the criteria considered might be useful in prioritizing which properties to buy for future restoration within a watershed, they were found not to be determinative with such a small, homogenous area.

Regarding cost considerations, WDFW staff decided that cost should not play a role in determining what the best alternative is. The reasons are: 1) They wanted to know what alternatives worked best from a technical perspective (i.e., which ones provided the most and best habitat for salmon restoration) regardless of cost; and 2) Since this is a long-term plan (20-50+ years), no one knows what monies might be available in the future. This is not to say that costs will not ultimately play a role in determining what, if anything, is built ultimately; they just felt that cost should not play a role in figuring out the best alternative(s). Once this is determined from a purely technical standpoint, then costs can be introduced at the point of project selection, funding, and design. Undoubtedly, someone will ask which alternative gives “the biggest bang for our bucks.”

A list of criteria originally considered, but subsequently not used, is provided in Appendix B. Additionally, Appendix C contains a list of criteria that were found to be potentially useful for distinguishing between the final two alternatives (for which more intensive study was done), or at the very least, as something to consider (but not used as distinguishing criteria amongst all preliminary alternatives). The main reason was the cost of performing such analyses. Focusing such analyses on a smaller subset of alternatives saved limited resources.

5.1.2.2 Criteria Used in Narrowing the Alternatives

The following are the final criteria used to choose amongst the 14 original alternative restoration scenarios to pare them down to the final two. In order to try to provide equity amongst the main competing issues many of the metrics of the original draft criteria were combined, and reduced to formulae for ease in creating replicable results.

As shown below, four of the final criteria were reduced to formulae, with quantifiable variables. These include Value to Fish, Agricultural Productivity, Economic Effects on the Diking District, and Impacts on Road System. For these, the metrics were developed from measurements derived from data that had been entered into a GIS program.

The criterion Impacts on Utilities was a little more subjective, relying on perceptions of scale of the utility facilities and difficulty/ease of relocating or flood proofing them.

For the criterion Effects on Recreational Opportunities it was determined that since there are no readily measurable formal facilities, we would simply rank the alternatives based on whether there

would be a positive, neutral, or negative effect on each of the activities using a -1, 0, or 1 score. These were then totaled for each of the alternatives.

Value to Fish

Concept: To account for area of restored areas, tidal processes, connectivity to the riverine processes, fish access, and connectivity to the mainstem, a "bio score" formula was created:

$$\sum(A_i \times T_i \times R_i \times M_i)$$

Where:

i =	Parcels	the number of different parcels that comprise each scenario
A =	Area	The area (acres) within each proposed parcel
T =	Tidal Processes	The degree to which the full tidal amplitude is restored. Full = 1; Muted = 0.5
R =	River Connectivity	Connectivity to natural riverine processes and the ease of access for fish (size and location of dike breach).
M =	Mainstem	Access to the site from the mainstem or from Ebey Slough. Mainstem = 1; Ebey = 0.8

Potential Agricultural Productivity

Concept: To account for potential agricultural acreage, function, contiguity, and infrastructure requirements a formula was created:

Table 3 Agricultural Productivity Scoring Method

	Description	Calculation
Step 1	Total agricultural acreage in alternative	Sum of forage and fallow acreage encompassed by each alternative, excluding managed drained
Step 2	Unaffected agricultural acreage (relative to 617 acres)	617 - Step 1
Step 3	Fraction of Enhanced Wet, Managed Wet, and Walking Wet acreage usable for agriculture annually	$\sum_i F_i \, Area_i$ i=sector of enhanced wet, managed wet, or walking wet; Values of F: 0.35=Enhanced Wet, 0.45=Managed Wet, 0.6=Walking Wet
Step 4	Total agricultural acreage available including usable Enhanced Wet and Walking Wet	Step 2 + Step 3
Step 5	Infrastructure requirements	D x Step 4; Values of D: 1=unaffected, 0.75=pump station relocated and draining to muted tidal, 0.5=pump station relocated and draining to full tidal
Step 6 (Final Score)	Contiguity of remaining agricultural parcels within WDFW property	C x Step 5; Values of C:1=unaffected, 1/(remaining agricultural sectors)=large portions, 0.25=isolated parcels

Economic Effects on Diking District

Concept: Flood prevention infrastructure (dikes, et al.) are expensive to build and maintain. The smaller the system to the greatest amount of acres served, the more economical it is for the Diking District. Thus, a measurement of the ratio of dike length to acres of agriculture land protected (i.e., land left within the Diking District and/or assessed for their services) was used as an overall indicator of the Diking District's ability to continue providing this service.

Impacts on Utilities

Concept: Are utilities and other infrastructure present? If so, can they be feasibly moved or flood proofed? Doing so could add substantial cost to the project. If not, this would narrow the alternatives. The major utility facilities include the Olympic Pipeline and the City of Everett's water transmission line; minor ones include electrical lines, communications lines, and stormwater systems. The alternatives were developed to avoid impacts to the greatest extent possible, though a few still had potential impacts. Scores were assigned based on relative difficulty of relocation and/or flood proofing.

Impacts on Road System

Concept: After restoration, the road system will still need to work and not be flooded. There may be a need to replace roads, build bridges, etc., which would greatly increase the cost of the project. However, in some instances it may be cheaper to move a road than build a long dike to protect an existing road. Any project will also need to maintain access to private property, new and existing dikes, flood control infrastructure, etc, but such mitigation can be designed into any of the final project alternatives.

As a simple measure of impacts, it was decided to use a measurement of the length of arterial or arterial collector roads and bike paths that would be affected by any of the alternatives.

Effects on Recreational Opportunities

Concept: Are any of the properties currently used for fishing, hunting, boating, hiking/walking, or bird watching? Would any existing recreational opportunities be lost due to project implementation? Are any added? Which properties have the most potential for recreational uses?

It turned out that there are no formal recreational facilities within the project boundaries, though many informal facilities (hiking along the tops of dikes, bird watching from non-formalized sites, bike riding, etc.). Standard measurements of recreational Levels of Service are typically derived from measurements of formal facilities (number of play fields, acres of designated parkland, number of restrooms, number of parking stalls, etc.).

5.1.3 Scoring Process

The preliminary alternatives were scored by the core project team based on the formulae described above, almost a purely mathematical exercise. These scores were then normalized (as described in Section 5.1.3.1), a pairwise comparison of the criteria performed to as to obtain weights for the criteria (Section 5.1.3.2), and then weights were applied to the scores (Section 5.1.3.3) to obtain final scores of the preliminary alternatives. These scores were then reviewed by the Advisory Committee (Section 5.1.3.4)

It should be noted that different people might rank decision factors differently based upon individual goals and objectives. In this study nine members of the core project team, each with differing backgrounds, expertise and goals, participated in this exercise.

5.1.3.1 Normalizing the Scores

Analysis and measurement of each of the above final criteria resulted in a score for that particular criterion. However, because of the differences in metrics, formula, and method of assessment, individual criterion scores had various ranges (e.g., 4.6 to 1,213 for value to fish, 0 to 393 for agricultural productivity). In order to compare apples to apples each score was normalized to a 1 – 4 point system based on their quartiles. Results are shown in Table 4.

5.1.3.2 Pairwise Comparison and Ranking of Decision Factors

The six major decision factors identified and defined in Section 5.1.2.2 were ranked using the pairwise comparison chart developed by Souder (Souder, 1975). This process provides a ranking of the relative importance of each decision factor. The mechanics of the pairwise comparison require the construction of an n x n matrix, where n is the total number of decision factors. The decision factors are listed as column and row headings on the matrix as shown in Table 5. In a systematic order, all column headings are compared with each row heading so that all pairs of decision factors are individually compared. When a column heading is determined to be more important than a row heading, a “1” is placed in the square of the matrix where the row and column intersect. When a column heading is determined to be less important than a row heading, the cell is left blank. For example, if Value to Fish (column 1) is considered more important than, say, Agricultural Productivity (row B), a “1” would be entered where column 1 intersects row B; if Value to Fish is considered less important than, say Economic Effects on Diking District, then the cell at the intersection of column 1 and row 3 would be left blank.

After all the paired comparisons are completed, the rank for each decision factor is determined by summing the total number of “1’s” for each column. The decision factor with the highest number of

“1's” is given a rank of “1,” the next highest is given a rank of “2,” etc. until all of the column decision factors have been ranked.

The pairwise comparison chart requires that the relative importance of each decision factor be consistently determined. Conflicts will reveal themselves at the end of the process as decision factors of equal rank, indicating that the relative importance of the decision factors has been evaluated inconsistently. This forces a reassessment of the decision factor(s) to verify that only one factor in each pair is considered of greater importance.

Table 5 shows the results of the pairwise comparison and decision factor ranks.

5.1.3.3 Decision Factor Weights

Once the decision factors were ranked using the pairwise comparison chart, a decision factor weight was calculated for each decision factor by dividing the rank total by the rank number. For example, in Table 4 decision factors are ranked 1 to 6. The rank total = 1 + 2 + 3 + 4 + 5 + 6 = 21. The decision factor weight for the highest ranked factor, which has a rank of 1, is 21/1 or 21. The weights for each decision factor in Table 5 are shown in the row at the bottom of the table. Decision factor weights used in the study range from 3.5 to 21.

The procedure used to calculate the decision factor weights emphasizes the value of the highest ranked decision factor and reduces the range of values when the number of decision factor ranks is fewer. This procedure addresses the goal of using a method that focuses on determining the relative importance of the identified decision factors.

5.1.3.4 Stakeholder Review of Criteria

As previously explained, each of the above steps was presented to the Advisory Committee for review and discussion. This included a presentation of all the original draft evaluation criteria, the discussion of which helped pare down the list to the final ones. Concerns about them included “too many,” “not measurable,” and “too skewed toward one major issue over another.”

The Committee also reviewed the results of the pairwise comparisons and resulting decision ranking scores. Concerns here mainly centered on taking umbrage with only the Project Team being involved in this step and not the full Committee (mainly concern that the results would be skewed to WDFW’s objectives). This concern seemed to be alleviated once the results were shown, since the top scoring ones were the ones that several Committee members intuitively thought should come out on top.

Table 4 Criteria Scoring Scheme and Raw Normalized Scores

Decision Factors	Measurement	Deal Breaker	Scoring Scheme: 1 (lowest)	2	3	4 (highest)	Alternatives' Raw Normalized Scores: A	B	C	D	E	F	G	H	I	J	K	L	M	N
Value to Fish	Based on formula accounting for area of restored areas, tidal processes, connectivity to the riverine processes, fish access, and connectivity to the mainstem.		Mathematical score normalized to a 4 point system	Mathematical score normalized to a 4 point system	Mathematical score normalized to a 4 point system	Mathematical score normalized to a 4 point system	3.2	1.2	4.0	2.1	1.4	1.1	1.3	2.4	2.0	2.9	1.4	1.1	2.0	1.0
Agricultural Productivity	Based on formula accounting for agricultural acreage, function, contiguity, and impacts to DD1		Mathematical score normalized to a 4 point system	Mathematical score normalized to a 4 point system	Mathematical score normalized to a 4 point system	Mathematical score normalized to a 4 point system	1	1	1	2	3	3	2	2	2	2	3	4	4	4
Economic Effects on Diking District	What effects will the project have on the Diking District's ability to maintain its flood protection infrastructure? Changes can be measured as a change in ratio of length of dikes to land protected from flooding.	Ratio such that the district is no longer economically viable	Mathematical score normalized to a 4 point system	Mathematical score normalized to a 4 point system	Mathematical score normalized to a 4 point system	Mathematical score normalized to a 4 point system	1	4	1	2	2	3	3	2	3	2	2	4	3	4
Impacts on Utilities	Will the project have significant impacts on existing utility infrastructure?	Major utilities are present that cannot be relocated, maintained, or flood-proofed	Major utilities are present that would be extremely difficult to relocate, maintain, or flood-proof	Major utilities are present that would be moderately difficult to relocate, maintain, or flood-proof	Minor utility infrastructure present, which can easily be relocated, maintained, and/or flood-proofed	No utility infrastructure present	1	2	1	2	2	2	1	1	2	1	2	2	2	2
Impacts on Road System	What effects will the project have on roads?	Project will cause a state highway to need to be relocated	Comparison of relative effects on roads and bike trails, based on length affected	Comparison of relative effects on roads and bike trails, based on length affected	Comparison of relative effects on roads and bike trails, based on length affected	Comparison of relative effects on roads and bike trails, based on length affected	3	4	1	4	1	4	3	4	4	2	1	4	4	4
Effects on Recreational Opportunities[1]	Overall, will the project have positive, negative, or neutral effects on fishing, hunting, boating, hiking/walking, or bird watching opportunities?		Score based on analysis of effects on each of the mentioned recreational activities	Score based on analysis of effects on each of the mentioned recreational activities	Score based on analysis of effects on each of the mentioned recreational activities	Score based on analysis of effects on each of the mentioned recreational activities	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Score							**13.2**	**16.2**	**12.0**	**16.1**	**13.4**	**17.1**	**14.3**	**15.4**	**17.0**	**13.9**	**13.4**	**19.1**	**19.0**	**19.0**

1 Since there are no formal, readily measurable recreational facilities, and any of the recreational activities/facilities could (and would) be built and formalized into any of the alternatives, all scores turned out equal.

Table 5 Results of the Pairwise Comparison & Resulting Decision Factor Ranks

Decision Factors	Value to Fish	Agricultural Productivity	Economic Effects on Diking District	Impacts on Utilities	Impacts on Road System	Affects on Recreational Opportunities	Sum of Ranking
Value to Fish	0	1	2	2	1	1	
Agricultural Productivity	8	0	5	4	3	5	
Economic Effects on Diking District	6	3	0	4	1	3	
Impacts on Utilities	6	4	5	0	2	6	
Impacts on Road System	7	5	8	6	0	6	
Effects on Recreational Opportunities	7	3	6	3	4	0	
Total number of times factor checked	34	16	26	19	11	21	
Rank (highest number checked = #1 rank)	1	5	2	4	6	3	21
Weighted Decision Factor (sum of all ranks and divide by the rank of the specific decision factor)	**21.00**	**4.20**	**10.50**	**5.25**	**3.50**	**7.00**	

5.2 PREFERRED ALTERNATIVES

5.2.1 Selection and Refinement of Preferred Alternatives

After the top two alternatives were selected, they were refined by creating realistic dike alignments, habitat areas, basic channels needed for habitat or drainage, and infrastructure needed to support the alternative. This information was used to generate quantity estimates, cost estimates, habitat benefit estimates, and was used in the modeling process. Additionally, earlier input from the diking district created the addition of an option to restore the north tip of Ebey Island to full tidal conditions.

5.2.1.1 Key features and objectives

Alternative C, otherwise known as the long-term alternative, features full set-back dikes that bisect the island and the drainage district to maximize the amount of area that would be restored to full tidal conditions. The primary goal of this alternative is to create an environment where the natural riverine and tidal processes would take over the restored area to create and maintain suitable fish habitat. This alternative would allow for passive recreation in the form of wildlife viewing and walking along the setback dike, as well as more active recreation such as canoeing and kayaking in the restored tidal area. Connections are proposed both to the Snohomish River and Ebey Slough. Available research indicates that the highest fish usage in restoration sites generally occurs where there are multiple connections between the main water body and the restored habitat area. The water control structures

and dikes that are proposed as part of this alternative are for the purpose of allowing existing uses in the rest of the diking district to continue. The infrastructure required would be substantial. Additionally, the current practice of leasing out part of the WDFW-owned property for agricultural uses would not be possible.

Alternative M, otherwise known as the near-term alternative, features short interior dikes in the northwest and northeast portions of the WDFW-owned land, to allow muted tidal exchange in these areas. Self-regulated tide gates and these dikes together would be required to allow for the creation of muted tidal areas within the island and the diking district. Muted tidal restoration areas are designed to provide some of the fish habitat benefits of full tidal restoration in areas where full tidal restoration is not feasible, practical, or desirable. The main limitation for fish habitat is the impeded ability of fish to volitionally pass from the main water body into the restored habitat area, and vice-versa. The lack of full tidal exchange would not allow the site to be subject to the full force of the natural processes. This alternative would not affect the adjacent and nearby properties and their owners as much as Alternative C. The district and its infrastructure would remain intact, and agricultural and recreational uses on the WDFW-owned properties could continue.

The near-term alternative also includes a full tidal restoration area east of the Olympic Pipe Line corridor. To facilitate this, a full height setback dike would be created just east of the pipelines, and the existing dike east of this new dike would be breached in one or more locations and likely be lowered or removed near the breaches. Starter channels should be formed to encourage the evolution of this area to happen faster than if tidal action alone was used to form new channels.

5.2.1.2 Constraints and opportunities

The Olympic Pipe Line Company operates a pipeline system that runs in a corridor from Ferndale, Washington to Portland, Oregon. Olympic Pipeline ships 4.4 billion gallons of fuel a year, as of 2008, and is the sole supplier of jet fuel to Sea-Tac Airport. This pipeline corridor runs generally in the north-south direction in the eastern part of the WDFW-owned land on Ebey Island. Company representatives indicated that accessing the pipeline corridor is challenging for them because of the soft soils and wet conditions. While no official response to the proposed alternatives has been received, company officials assert that having full tidal conditions in the pipeline corridor would make it nearly impossible to perform their necessary maintenance and inspections. They also suggested that it is possible that muted tidal conditions within the pipeline corridor would be acceptable if the operation of the self-regulated tide gates could be changed seasonally to allow for scheduled maintenance and inspections during the summer, and at other times to perform unscheduled maintenance and inspections. While not discussed with the company representatives, it may be worth discussing the possibility of creating a short dike on the pipeline corridor to serve as the boundary of

muted tidal conditions and improve the company's ability to access the pipeline corridor. None of the chosen alternatives consider this dike alignment.

The City of Everett has multiple large potable water pipelines that cross Ebey Island in the east-west direction. Two such pipelines are located parallel to and south of US Highway 2. A City of Everett representative indicated that their main concern is the ability to have unrestricted access at any point on their pipeline corridor. Full tidal or muted tidal conditions would not be acceptable. The two main alternatives are both located south of these pipelines, and do not involve changing conditions within this pipeline corridor. The City of Everett has other water pipelines on Ebey Island. There is a major pipeline corridor that runs east-west toward the southern end of the island, outside of the area considered by this feasibility study. There is also a smaller pipeline corridor that parallels Homeacres Road, but is not currently being used. This pipeline corridor would be affected by the long-term alternative.

A preliminary geotechnical report was completed for this project. Data from previous advance borings for transportation and utility projects was gathered. To supplement the available data, advance borings were done on WDFW property, away from areas where previous borings had been completed. The full report is included as Appendix A. The conclusion is that the construction of new interior dikes is feasible from an engineering perspective. However, the soils in the project area are soft enough to require special design and construction considerations. In order to properly design new dikes, it was recommended to advance borings along the centerline of a proposed dike alignment, collecting data in the field and soil samples for laboratory analysis. The results of the field data and laboratory analysis would allow slope stability, seepage, and settlement design elements to be addressed. The possible use of soil material that would be excavated for the creation of channels or other habitat features could also be evaluated to determine the feasibility of its re-use.

The long-term alternative is predicted to create much better fish habitat than the near-term alternative, but it would have the greatest negative impact on the rest of the diking district and the other landowners within the district. This alternative would split the district into two parts, greatly reduce the amount of land within the district, and drastically change how quickly and completely flood waters would fill the upstream, southern part of the district. Home Acres road, power lines, and other utilities would need to be flood proofed or re-routed. Full tidal restoration projects considered in this feasibility study each require a significant new setback dike to be constructed. The cost to install these dikes could be reduced or the habitat gains significantly improved by acquiring additional property. It would be advisable for the district to have a disaster recovery plan in place to determine how they would respond to a major dike breach or other significant loss of integrity of their flood control and drainage system. As the severity of the problem increases, the viability of the district decreases. The discussion has to take place before a disaster to take away the emotions and fear that would come in the

aftermath of such a situation to enable the district and its constituents to make a decision of what to do after a major failure of infrastructure. There are ongoing threats to the integrity of the exterior dikes. These threats occur in multiple spots around the perimeter dike. It is advisable to consider calving off a portion of the district for fish habitat and at the same time, getting rid of a problem section of dike, compared to continuing to battle the same problem dike into the future.

5.2.1.3 North Tip of Ebey Island

The North Tip Option would create full tidal conditions in the northern, downstream, tip of the island. A full setback dike would be created, a short section of new ditch would be needed, and a new tide gate would be created to allow the diking district to continue to provide flood protection and drainage within the district, as shown in Figure 23. Breaches would be created in the portion of the dike outside of the new setback dike and starter channels created to allow for the relatively rapid evolution of the site to conditions that would allow for natural processes to take over to improve habitat for fish. The diking district indicated that this option would remove a fairly minor amount of land from their district, but would relieve them from the responsibilities of maintaining about 14,000 feet of problematic dikes. This option was suggested by the district as a “win-win” situation for them and for the fish.

WDFW does not own property in this location, but this option was considered a valid extension of the feasibility study. Snohomish County owns the northern-most portion of the island. Property from a few private landowners would need to be acquired to make this option happen.

5.2.2 Hydrodynamic Modeling of Preferred Alternatives

Hydrodynamic models of existing conditions and the proposed alternatives were developed and applied to address the following questions:

- What are the likely hydrologic characteristics of habitat in the restored areas?
- What hydraulic structure is likely to meet both habitat and flood/drainage design criteria?
- How will alternatives affect water levels during overtopping flood events on developed areas of Ebey Island and adjacent land?

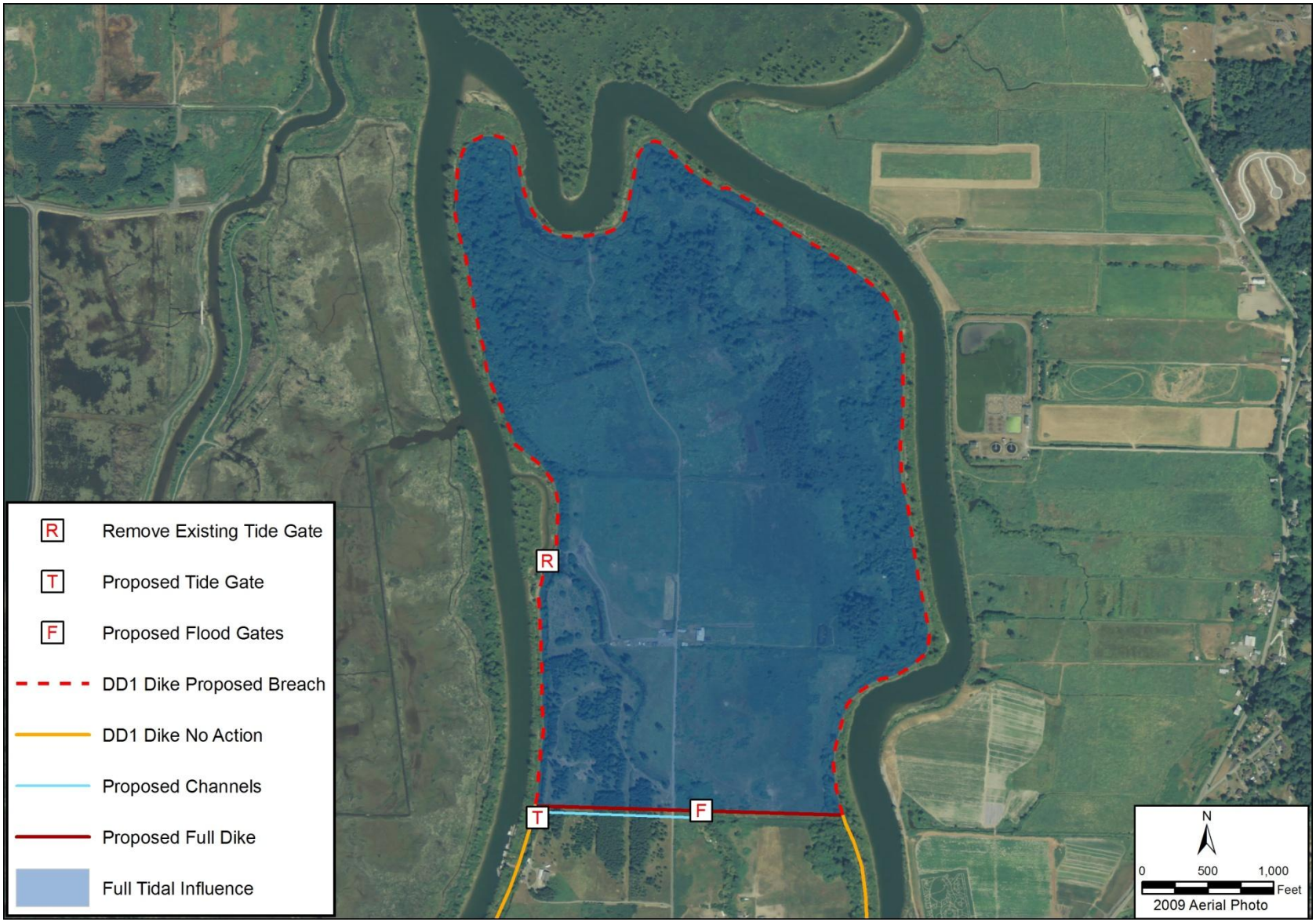


Figure 23 North Tip Ebey Island

- How might the alternatives affect geomorphic conditions within the project site and in adjacent channels?

After briefly summarizing the relevant site hydrology and modeling approach, this section presents the results of this modeling and analysis and discusses the implications for the restoration alternatives.

5.2.2.1 Modeling Approach

The primary tool used to evaluate the hydraulic response of the project site and adjacent channels to the restoration alternatives was the existing UNET model of the Snohomish Estuary. This model was developed by the U.S. Army Corps of Engineers and applied to the Snohomish Estuary for FEMA flood insurance study (FEMA, 2001; FEMA, 2005). UNET is an unsteady, one-dimensional model that can represent a network of channels and storage areas. The Snohomish Estuary domain includes the river from just downstream of the City of Monroe to the mouth of its distributary channels where they enter Possession Sound. Significant areas of overbank storage were represented in the model as stage-storage nodes. Geometry in the existing UNET model was derived from a prior FEQ model of the Snohomish River and updated with additional data when available. More recent LiDAR data was used as a source for land surface elevations on Ebey Island (Puget Sound LiDAR Consortium, 2010). The model's key boundary conditions are specified time series of river discharge at the upstream end and tidally varying water levels at the downstream end. Figure 24 shows the topography of the south portion of the island, compared to the tidal datums.

Water level management in the muted tidal areas will require hydraulic structures that can be configured with gates that open and close as a function of water level. Since the UNET model does not have the capability to represent hydraulic structures with operating rules, an additional HEC-RAS model was developed to assess conditions within the muted tidal areas. HEC-RAS, whose unsteady computation engine is actually based on UNET, provides all the features of UNET and the capability to model hydraulic structure operations. The HEC-RAS model is nested within the full UNET as the domain for each muted tidal area only includes the muted tidal area itself, a short stretch of outboard channel and the hydraulic structure linking these two. UNET predictions of water levels in the outboard channels immediately outside the muted tidal areas were used to force the HEC-RAS model.

Additional details about both the UNET and the HEC-RAS models can be found in Appendix D.

5.2.2.2 Restored Tidal Habitat Hydrology

Under existing conditions, none of the project site is inundated with tidal exchange because of the dikes and hydraulic control structures which are maintained by the Diking District. The restoration alternatives would re-connect portions or all of the project area to the outboard channels, causing

water levels to fluctuate with the tides. This re-connection supports the project habitat objectives both by creating tidal habitat and by providing access for organisms, particularly salmonids, to access this habitat. This section interprets the model results to characterize the full tidal and muted tidal habitat in the proposed restoration alternatives.

Water Levels – Full Tidal Restoration

Water levels in the fully tidal regions of the Near Term Alternative and the Long Term Alternative are predicted to nearly match the tide range under existing conditions. Figure 25 shows water levels from all three conditions during three days of August from the WY2002 model scenario. This time period demonstrates water level response when riverine discharge is low and, consequently, the largest tidal range. Predicted water levels are nearly identical for the two restoration alternatives. At high tides, restoration water levels are up to 0.5 ft lower than existing conditions; at low tides, restoration water levels are up to 1 ft higher than existing conditions. This predicted reduction in tide range, or tidal damping, occurs because the restoration increases the volume of water exchanged on each tide via channels that have established equilibrium dimensions for conveying lower flow. Because the model geometry uses existing channel dimensions and Ebey Island bed elevations, these predictions probably represent an upper bound on the potential tidal damping. Geomorphic changes in response to restoration, in the form of channel scour and accretion on Ebey Island's intertidal areas, are likely to reverse tidal damping, as discussed in Section 5.2.2.5. Channel scour, which enlarges channel dimensions, would increase conveyance to the site while accretion would reduce the intertidal volume. Observations at implemented restoration projects confirm this trajectory of the largest tidal damping immediately after tidal re-connection, followed by increases in tide range as channels scour and accretion occurs in intertidal areas (Williams and Orr, 2002).

Because of the subsided ground surface of Ebey Island, portions of the project area that are exposed to full tidal exchange will be intertidal: inundated at high tide and drained at low tide. Most of the project area is below mean tide elevation and therefore will be covered with at least four feet of water more than half the time. The implications for habitat of these inundation characteristics are discussed in Section 5.2.4.

Water Levels – Muted Tidal Restoration

Target water levels

The Near Term Alternative proposes that portions of the project area be restored to muted tidal conditions by constructing a lower setback dike within the existing perimeter dikes and then connecting the areas to the outboard channels with hydraulic structures. The hydraulic structures would be configured to obtain target water levels within the restored areas. For this feasibility study,

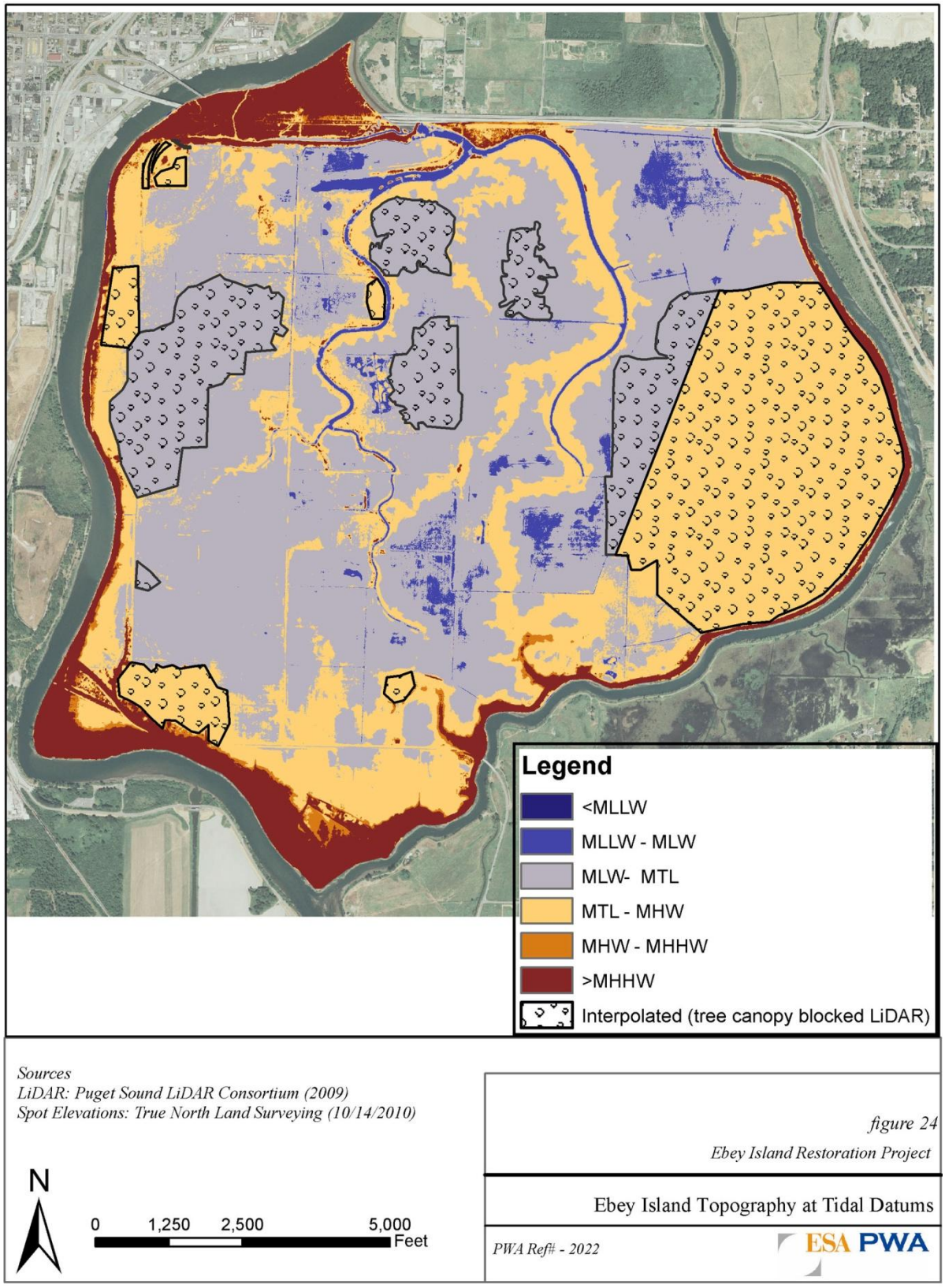
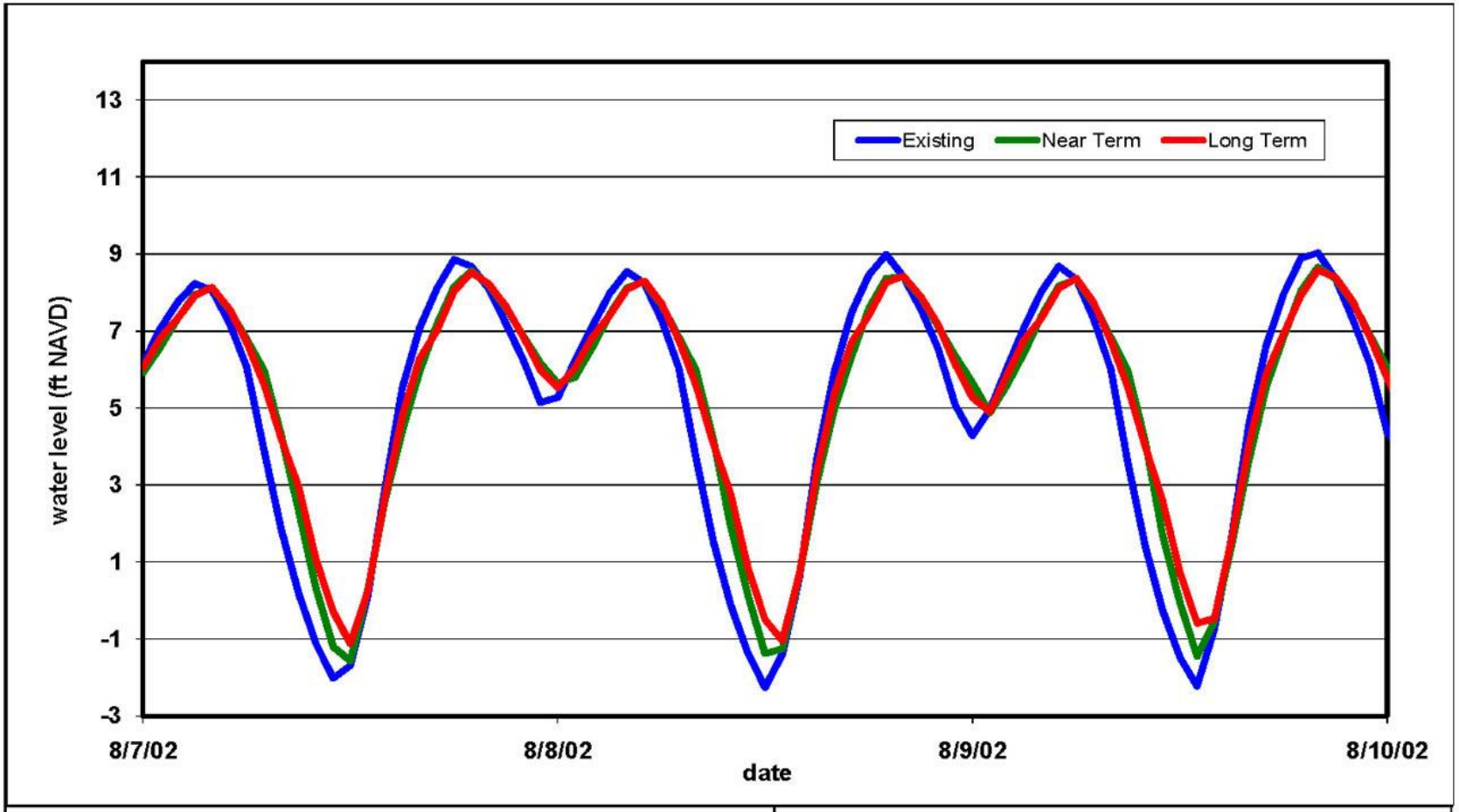


Figure 24 Fully Tidal Water Levels, Dry Season, Ebey Slough



Sources: UNET model results

figure 25

Ebey Island Restortation Project

Fully Tidal Water Levels, Dry Season, Ebey Slough

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Figure 25 Fully Tidal Water Levels, Dry Season, Ebey Slough

the target water levels were selected to sustain vegetated intertidal habitat and to promote bed accretion while also limiting water levels that pose a flood risk to adjacent Ebey Island properties. For the east muted area, a target high water level of 2.5 ft NAVD was selected and for the west muted area, which has higher bed elevations, a target high water level of 4 ft NAVD was selected.

Mature vegetated tidal marshplain typically occurs in the Snohomish estuary at elevations at or just above MHHW. Examples of this are the portions of Ebey Island outside the perimeter dikes (the southwest corner and the western portion of the island adjacent to Highway 2) and nearby, undiked Otter Island. However, at this point in the tide range, the inundation period is limited, which decreases the capacity of tidal flow to convey and deposit sediment, as well as carve tidal channels (Williams and Orr, 2002). Therefore, the target high water level was selected for each muted restoration area such that the areas' typical bed elevations would be inundated by one half to one foot of water. This will extend the inundation period, increasing the delivery of sediment to the marsh plain (Williams et al., 2002) and promote the formation of tidal channels. Even though this tidal regime will inundate the bed for longer periods than mature marshplain, vegetation should still be able to colonize the site, further promoting sediment to settle out from the tides and also adding organic material to augment total bed accretion <confirm vegetation colonization with ecologic assessment>. In subsequent phases of restoration design, water levels in the muted tidal areas can be further tuned to encourage colonization for target vegetation species based on ongoing monitoring of nearby restoration sites which are also subsided relative to the tides, e.g. Spencer Island.

The muted tidal areas will require setback dikes to prevent flooding of adjacent Ebey Island properties. Because the target high water levels are four feet or less than average outboard water levels and the hydraulic structures can be configured to block extreme water levels, the setback dikes can be significantly lower than the existing perimeter dikes.

Modeling assessment

To assess the temporal variation in water levels in response to outboard water levels, a HEC-RAS model was developed for each muted tidal area. Each model included a reach of the outboard channel linked to the muted area by a hydraulic structure with a gate that opens and closes as a function of outboard water level. The gate was set to close when the water level in the outboard channel exceeded the target high water level for the muted tidal area and re-open when water levels dropped below this elevation. Outboard water levels from WY2002 were predicted by the UNET model and used as boundary conditions for the muted tidal area models. Additional details about these models can be found in Appendix D.

Modeled time series of dry season water levels within the muted tidal restoration areas are shown in Figure 26. During this period, when riverine discharge is less than 5,000 ft^3/s, the outboard tides have

their greatest range because low tides are not significantly elevated by riverine discharge. Since the tide range within the muted tidal areas is constrained on the upper end by the target high water level, this period is when the muted tidal areas experience the largest tide range. For the eastern muted area, which has lower bed elevations and hence a lower target water level, the tide range during this period is approximately two feet during neap tides and up to 4.5 feet during spring tides (Figure 26a). Because the higher low tide in each day is typically above the target high water level, the water levels within the muted tidal area only have one high tide and one low tide per day for much of the spring-neap cycle instead of the twice-a-day tides in the outboard channel. Inside the muted areas, water levels persist near the high water target for approximately 18 hours of each day; the decline to low tide and subsequent recovery occupy the other 6 hours of the day. During several days of neap tides when both outboard low tides drop below the target high water level, water levels fluctuate twice per day in the muted areas, but maintain constant water levels near the target high water level for nearly three quarters of each day. Bed elevations in the western muted area are approximately 1.5 ft higher, so the target high water level and tide range are larger by a similar amount (Figure 26b)The timing of inundation (diurnal on most days, semidiurnal for several neap tides) is also similar in the west muted tidal area to the east area.

During the wet season (November through July), riverine discharge increases as a result of rainfall and/or snowmelt. This flow through the estuary elevates water levels, particularly low tides. When flow exceeds approximately 20,000 ft^3/s, the minimum outboard water level does not drop below the target high water level for the east muted area, so the hydraulic structure does not open. An example of this response during a high flow event in January 2002 is shown in Figure 27. The peak flow during this event is 56,000 ft^3/s, slightly less than the 2-year event. Because of the elevated outboard water levels, the structure stays closed and water levels within the muted area stay constant for approximately six days. For the WY2002 scenario, the east muted area's hydraulic structure remained closed for more than a day on 13 occasions. The longest closure lasted twelve days and occurred in late May and early June during the peak discharge associated with snowmelt. Because of its higher bed elevation and higher target water level, the west muted area's hydraulic structure stays closed only when discharge exceeds approximately 30,000 ft^3/s. Therefore, for the WY2002 hindcast, the west muted tidal area would be subject to only six multi-day closures. The longest closure is predicted to have lasted for six days.

Hydraulic structure operations attempt to balance among several constraints. For purposes of this feasibility study, only WY2002, which had flows close to mean values, was tested. Future analysis should consider a broader range of hydrologic conditions such as drought years and wet years. Based on a wider range of hydrologic conditions, the operation procedures for the hydraulic structure can be

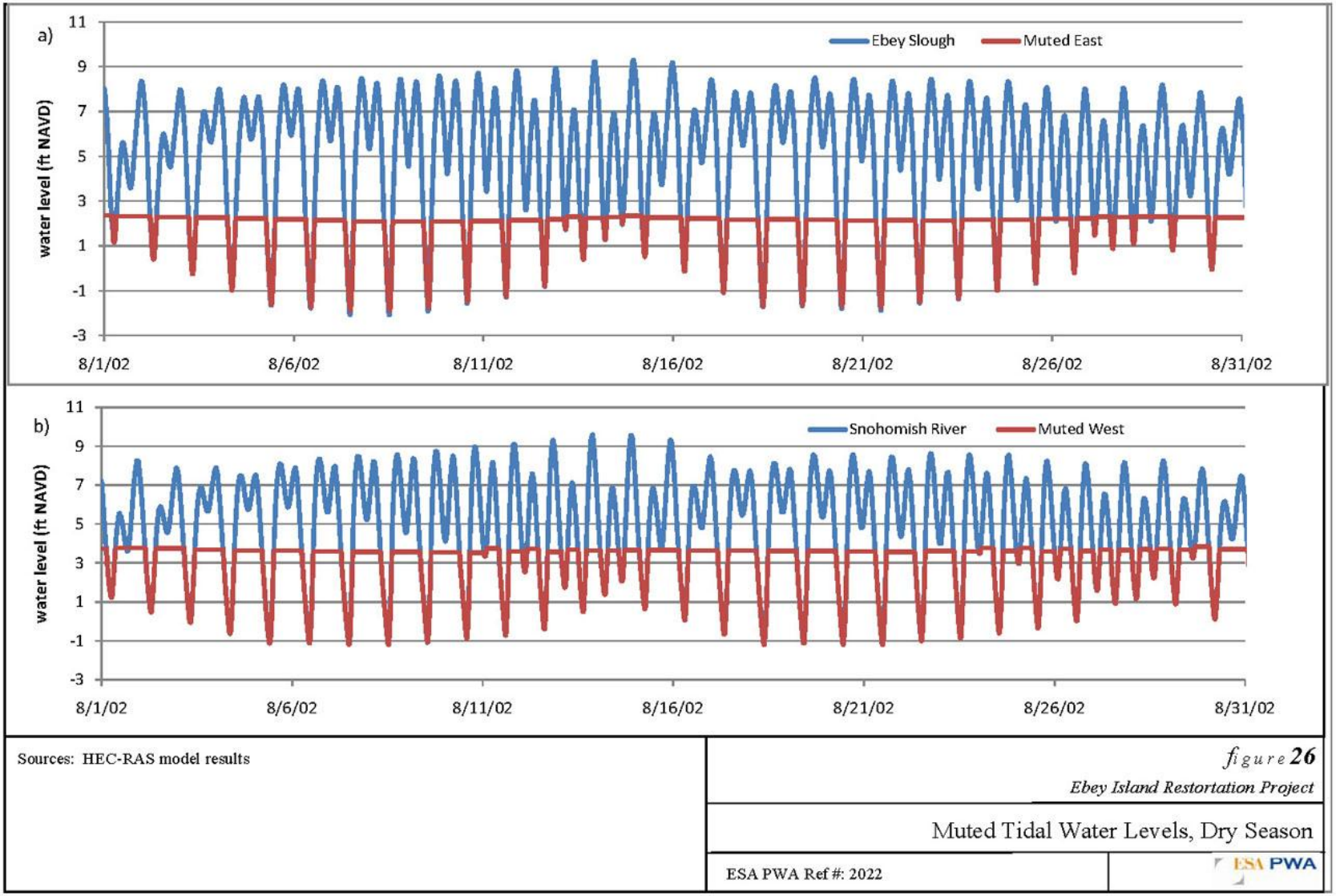


Figure 26 Muted Tidal Water Levels, Dry Season

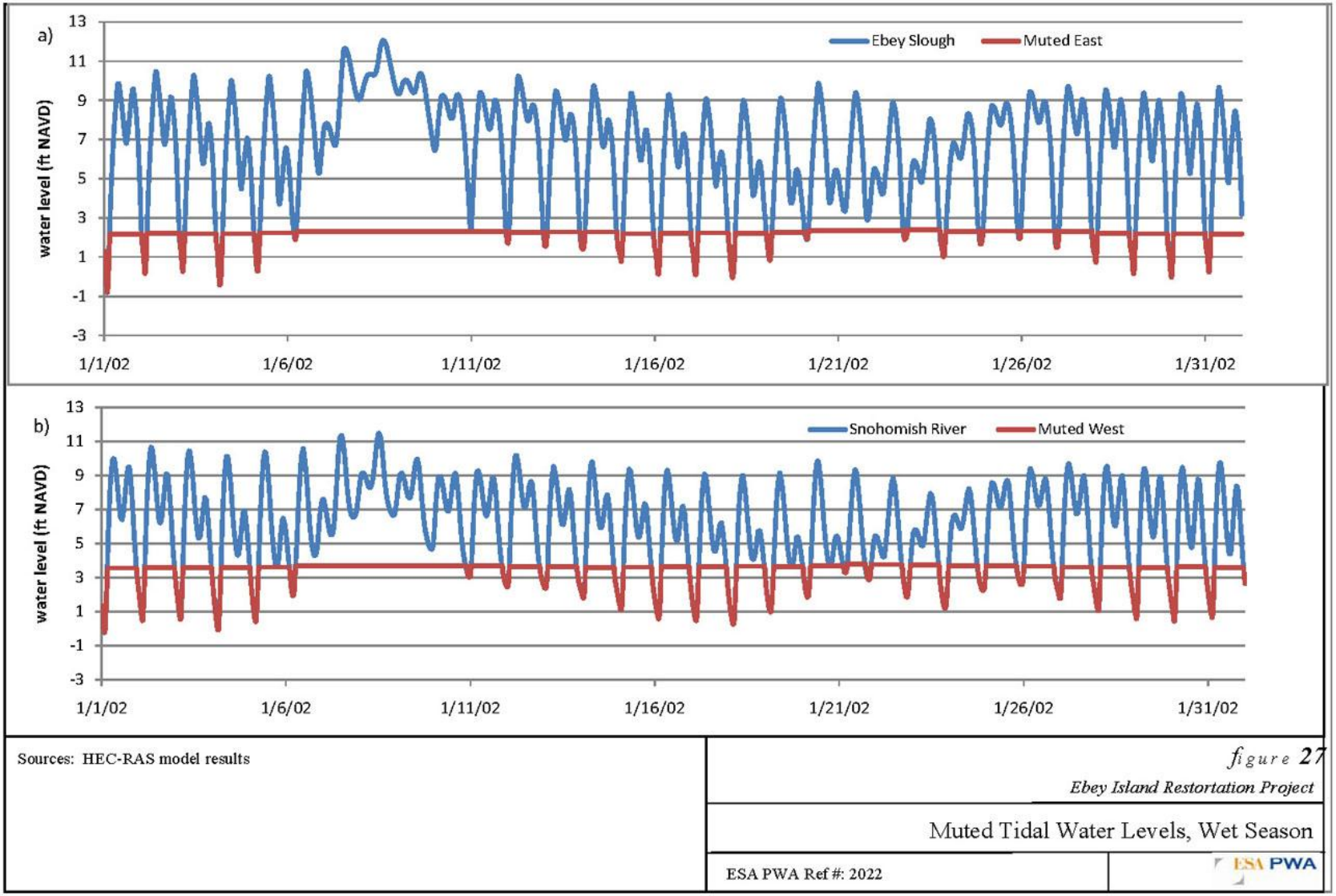


Figure 27 Muted Tidal Water Levels, Wet Season

optimized to better balance between the criteria for habitat, water quality, and flood risk. Note that the modeling did not include direct precipitation onto the muted tidal areas.

Sizing of hydraulic structures

In addition to predicting the potential habitat conditions, the modeling was used to assess the size and vertical placement of the hydraulic structure required to adequately connect each muted tidal area to its outboard channel. For this initial assessment, the performance criteria for the structures was providing sufficient conveyance capacity to obtain nearly the full tidal range between the outboard channel low water levels and the target high water level. Based on several model iterations and sensitivity analysis, the culvert dimensions found to just meet this criteria was a box culvert six feet high by twelve feet wide with its bottom or invert elevation at -3.5 ft NAVD. To account for the development of a tidal channel network within the muted tidal areas, this sizing was done with additional storage volume added to the existing geometry of the muted tidal areas. The structures' invert elevation was set approximately 2 feet below the lowest water levels in the adjacent channels to ensure adequate flow depths and drainage capacity even at the lowest tides. An assessment of the ecologic implications of this structure can be found in 5.2.4. Subsequent planning stages will need to refine the design of the hydraulic structures to optimize the design for fish access, flood hazard management, and cost.

5.2.2.3 Flooding Assessment

The proposed restoration alternatives include changes to the existing perimeter dike which will impact the water levels during flood events both on and adjacent to the project site. The UNET model of the Snohomish, which is the model used in FEMA's flood study of the Snohomish estuary, was applied to estimate potential changes to peak water levels resulting from restoration. Three flood scenarios were executed: a hindcast of the annual maximum flood event from January 2002 (representative of a typical year), and two extreme riverine discharge events derived from statistical analysis of basin hydrology: the 5-year riverine flood and the 100-year flood.

January 2002 annual peak discharge

The riverine discharge event which occurred during January 6-10, 2002 is representative of the mean annual peak discharge. Peak discharge during this event was 56,000 ft^3/s, which just below the estimated 2-year discharge of 64,000 ft^3/s (FEMA, 2001). This discharge was coincident with an observed 10.7 ft NAVD high tide at the mouth of the estuary. This water level is approximately 2 feet greater than MHHW and 0.7 ft less than the 2-year tidal water level.

The peak January 2002 water levels predicted for existing conditions and the two restoration alternatives are shown for the Snohomish River main stem (Figure 28) and Ebey Slough (Figure 29). No levee overtopping was observed during January 2002 or was predicted by the model of existing

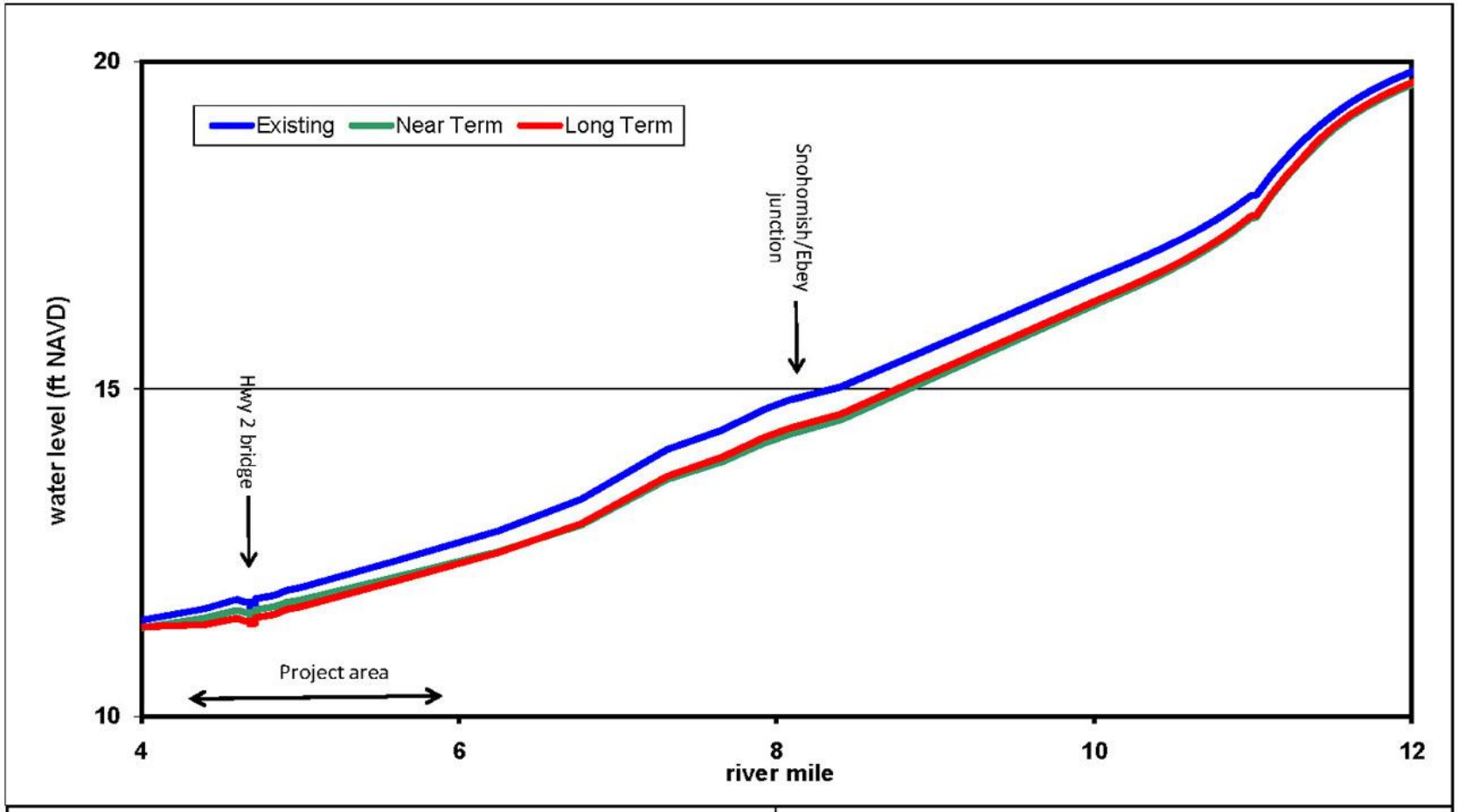
conditions. Since the alternatives reduced peak water levels along both channels, no overtopping is predicted for the alternatives. The largest decrease in peak water levels of about one foot occurs in Ebey Slough under the Near Term Alternative. This decrease occurs in the stretch of the slough bordering the full restored region where the restored area provides both additional flood conveyance and storage. Near Term peak water levels are reduced on the main stem even though there are no significant changes to this reach's geometry because the additional conveyance capacity of Ebey Slough reduces flood discharge in the main stem. Changes to peak water levels under the Long Term Alternative are also lower than existing conditions and typically within 0.1 ft of the Near Term Alternative peak water levels. For a portion of Ebey Slough, the predicted Long Term peak water level is about 0.5 higher than the Near Term. Part of this difference may be attributed to different formulations of the full tidal area for the two alternatives.

Limited Overtopping

To assess impacts of flood events which cause limited dike overtopping, existing conditions and the alternatives were modeled with discharge event peaking at 92,000 ft^3/s and coinciding with high tides of 10.7 ft NAVD. Based on frequency analysis, this river discharge is approximately the 5-year event (FEMA, 2001) and the high tide is approximately the 2-year return period (USACE, 2002).

Nominally, the 5-year event is not supposed to overtop the Ebey Island dikes in accordance with completion of the Snohomish River Comprehensive Flood Control Management Plan for Diking District 1 (Snohomish County, 1991 and Snohomish County, 2011). However, when these discharge and tidal conditions were applied to existing conditions, the UNET model predicts overtopping into Ebey Island. This discrepancy between the management plan and the current study's modeling results may be attributed to differences between hydraulic models (the 1991 management plan's use of the FEQ model versus the current study's use of FEMA's UNET model) and/or the implemented dike crest profile, which, by design, has a low point on Ebey Slough that is lower than the management plan's target crest elevation.

The peak 5-year discharge water levels predicted for existing conditions and the two restoration alternatives are shown for the Snohomish River main stem (Figure 30) and Ebey Slough (Figure 31). The largest decrease in peak water levels of a little more than one foot occurs in Ebey Slough under the Near Term Alternative. This decrease occurs in the stretch of the slough bordering the full restored region where the restored area provides both additional flood conveyance and storage. In addition, water from this reach overtops onto Ebey Island. Just upstream of the Highway 2 bridge, peak Near Term water levels exceed existing conditions by about four tenths of a foot and continue to



Sources: UNET model predictions

figure 28

Ebey Island Restortation Project

Peak Water Levels, January 2002, Snohomish River

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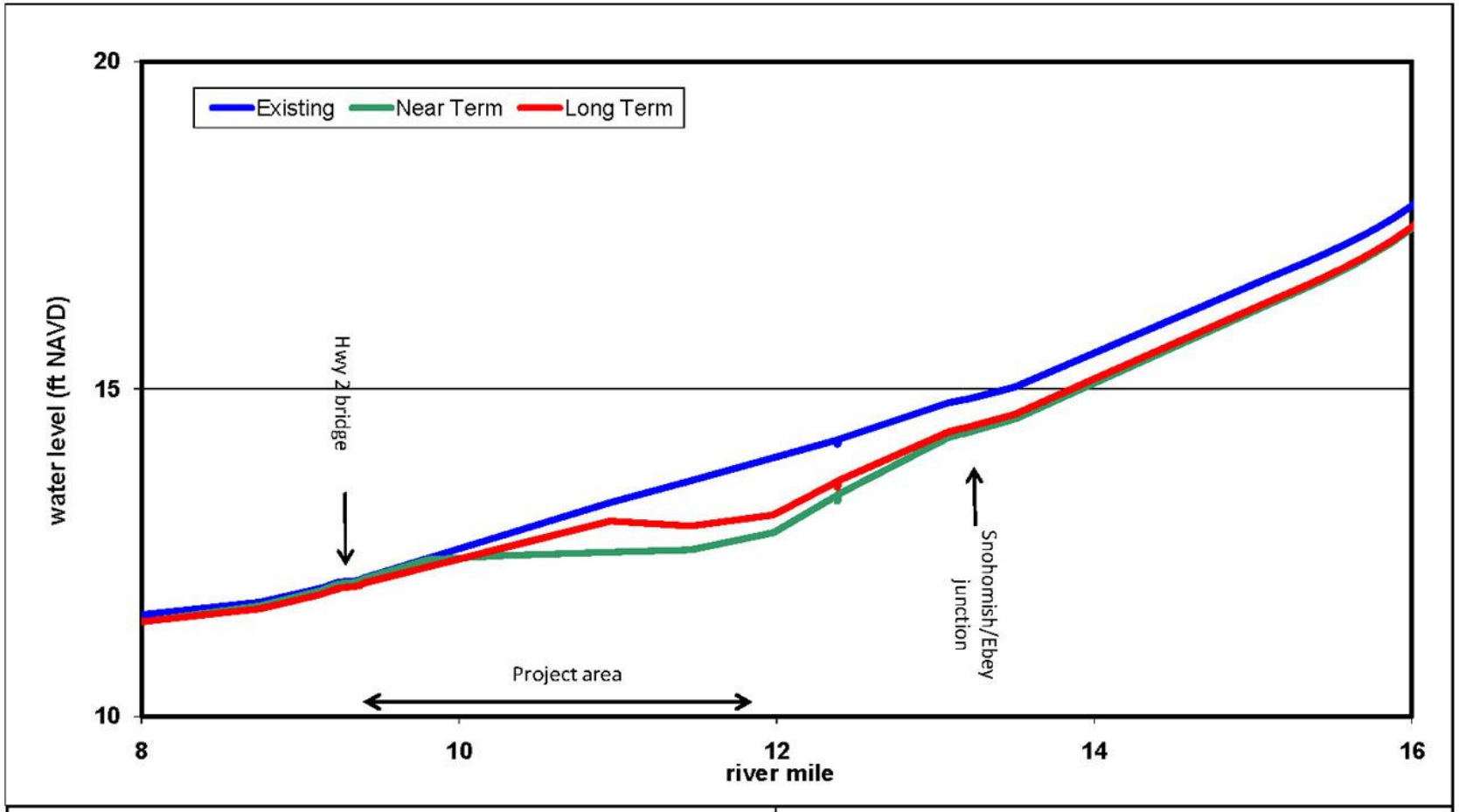
ESA PWA

Figure 28 Peak Water Levels, January 2002, Snohomish River



Sources: UNET model predictions

figure 29

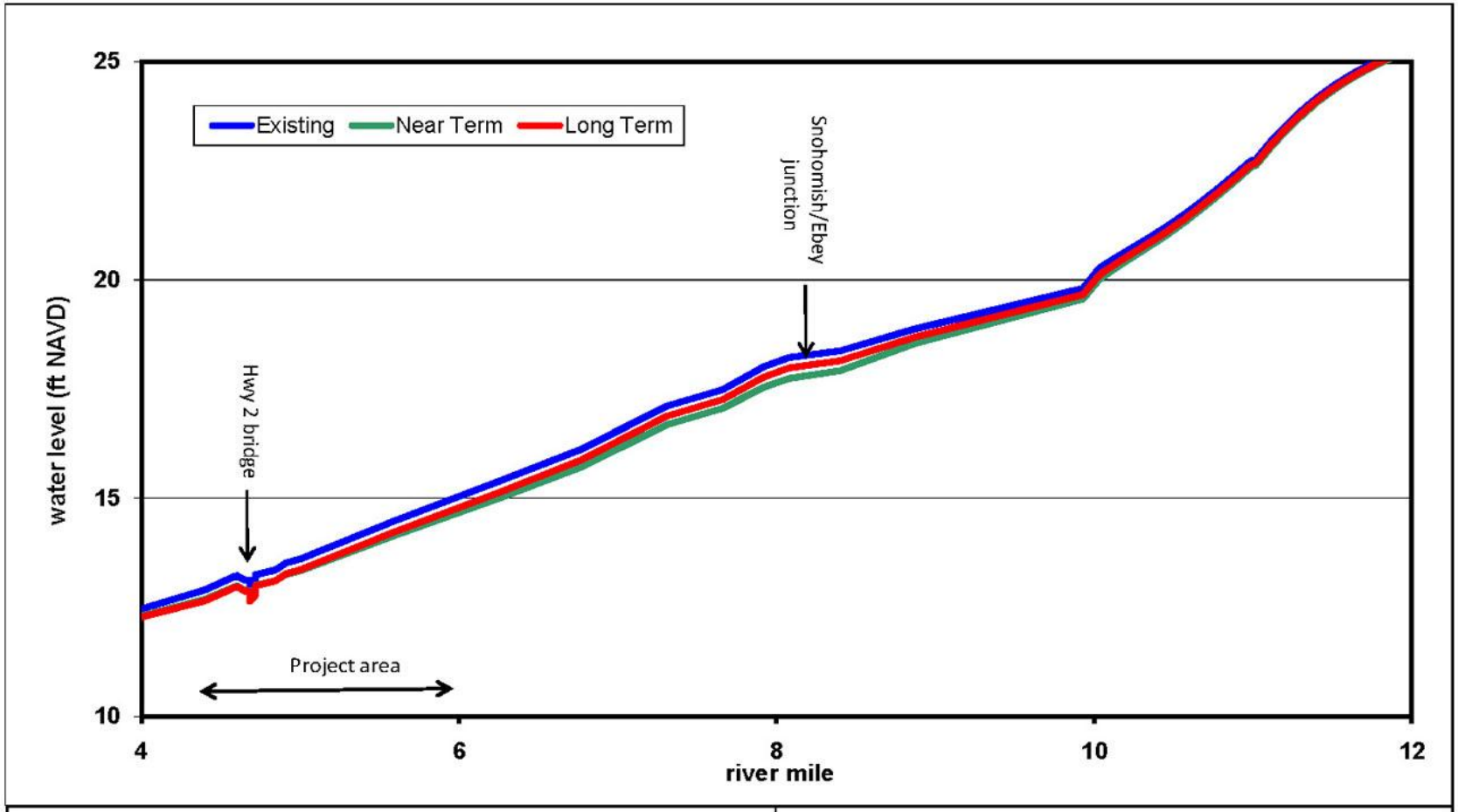
Ebey Island Restortation Project

Peak Water Levels, January 2002, Ebey Slough

ESA PWA Ref #: 2022

ESA PWA

Figure 29 Peak Water Levels, January 2002, Ebey Slough



Sources: UNET model predictions

figure 30

Ebey Island Restortation Project

Peak Water Levels, 5-Year Discharge, Snohomish River

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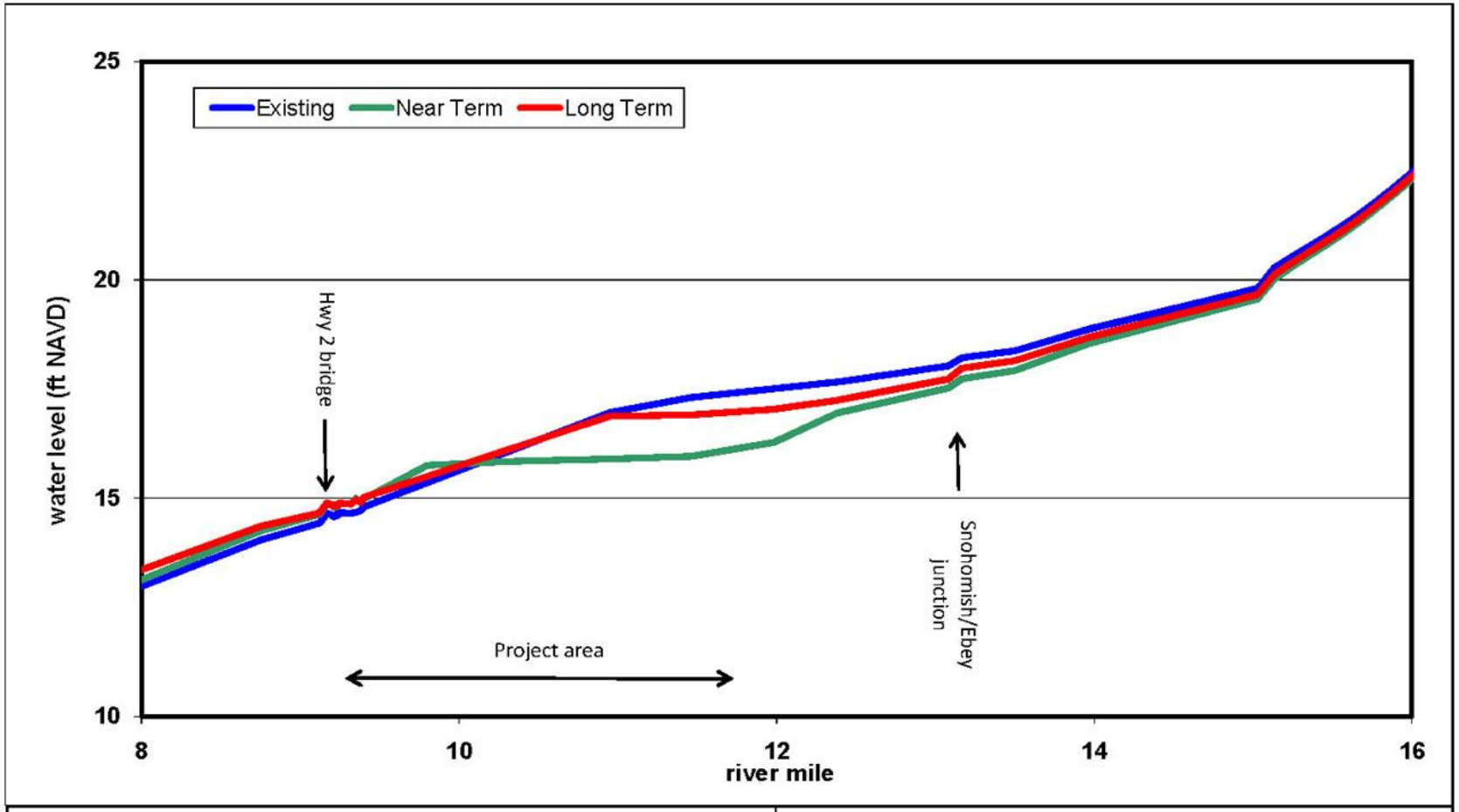
ESA PWA

Figure 30 Peak Water Levels, 5-Year Discharge, Snohomish River



Sources: UNET model predictions

figure 31

Ebey Island Restortation Project

Peak Water Levels, 5-Year Discharge, Ebey Slough

ESA PWA Ref #: 2022

ESA PWA

Figure 31 Peak Water Levels, 5-Year Discharge, Ebey Slough

be about two tenths of a foot higher downstream of Highway 2. Changes to Ebey Slough peak water levels under the Long Term Alternative follow a similar pattern of being lower than existing conditions along much of south Ebey Island, but then increasing slightly above existing conditions starting from just upstream of the Highway 2 bridge. For the portion of Ebey Slough between river mile 10 and river mile 12, the predicted Long Term peak water level is about 0.5 higher than the Near Term. Part of this difference may be attributed to different formulations of the full tidal area for the two alternatives.

Near Term peak water levels are reduced on the main stem (Figure 30) even though there are no significant changes to this reach's geometry because the additional conveyance capacity of Ebey Slough reduces flood discharge in the main stem.

Most of the overtopping onto Ebey Island that occurs under these discharge conditions is limited to the low point on the Ebey Slough dikes. Since the Near Term Alternative translates the existing crest elevation onto the new dike and outboard water levels are similar, the overtopping rate into Ebey Island would be similar between existing conditions and the Near Term Alternative. For the Long Term Alternative, which splits the island into two perimeter dikes, no overtopping is predicted for the southern perimeter dike. Overtopping is predicted for the northern perimeter dike. The total volume of this overtopping is less than the total volume predicted to overtop under existing conditions, but since the storage volume of the north perimeter dike is less than the storage volume of the entire island, increased water depths are predicted inside the Long Term Alternative's north perimeter dike as compared to existing conditions. Most of the flow into the north perimeter dike occurs from the full tidal area over the new cross dike. This new dike could be designed with a higher crest elevation, but doing so would increase predicted 100-year water levels, as discussed in Section 6.4.2.3 below.

Extensive Overtopping (100-year Discharge)

Hydrologic analysis as part of the FEMA study estimated the 100-year riverine discharge to be 204,000 ft^3/s at Monroe (FEMA, 2005). This discharge was evaluated with a constant water level at the mouth of the estuary of 1 ft above MHHW or 9.9 ft NAVD. Under these conditions, the entire river valley is predicted to be inundated, such that most of the levees are overtopped. The November 1990 flood event, which inundated Ebey Island under more than 10 ft of water (Snohomish County, 1991), was approximately the 30-year event (FEMA, 2001).

Estimates of peak water levels for existing conditions and the two restoration alternatives are shown for the Snohomish main stem (Figure 32) and Ebey Slough (Figure 33).

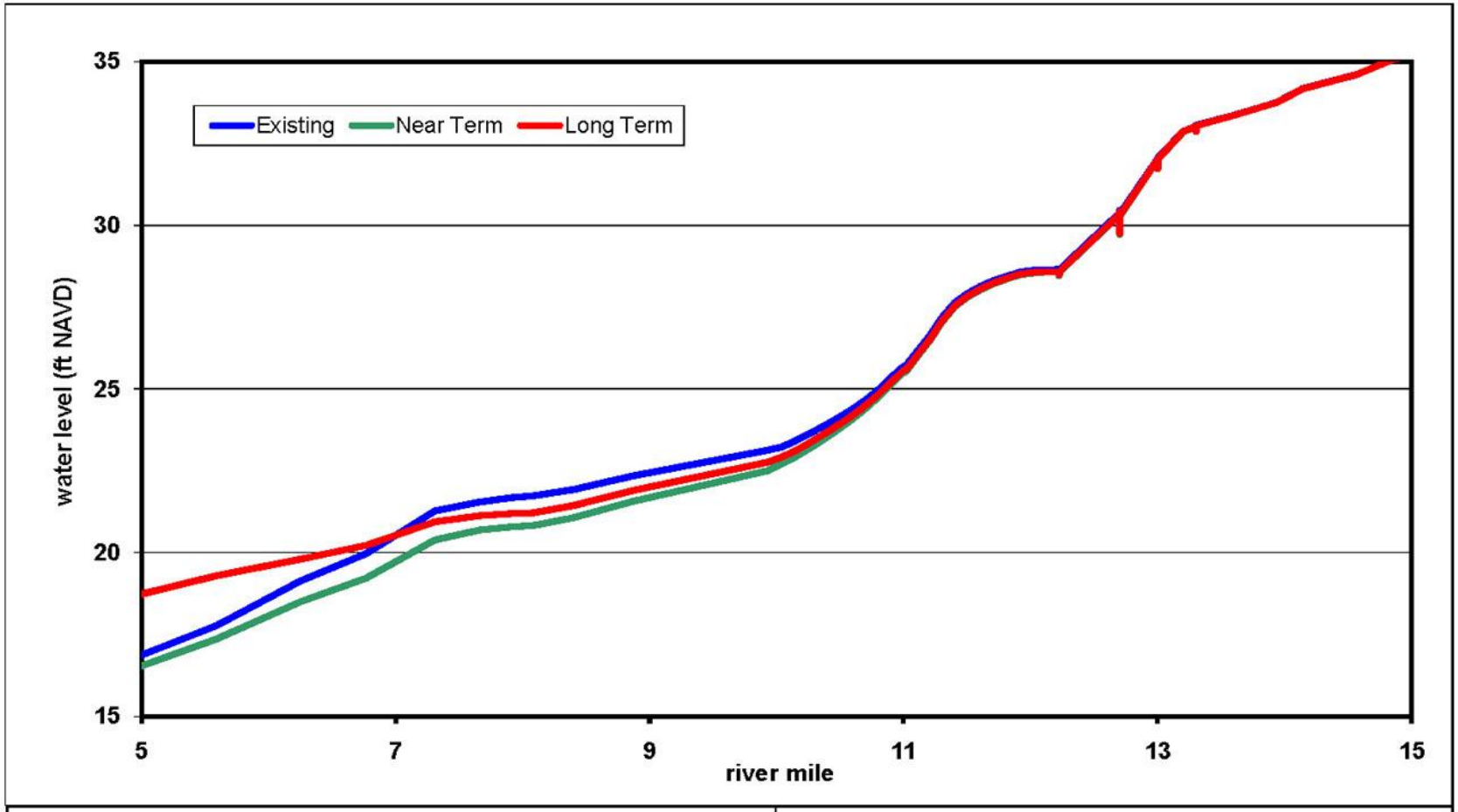
For the Near Term Alternative, the model predicts a reduction in peak water levels all along main stem, with largest decrease of nearly one foot at the junction with Ebey Slough (Figure 33). The reduction in main stem water levels occurs because the model predicts that more water is diverted

into Ebey Slough than under existing conditions. The additional water flows into Ebey Slough because adding the full tidal area as floodplain improves the Slough's conveyance capacity. Even with the additional water flowing into Ebey Slough, Near Term peak water levels are predicted to be nearly two feet lower in the upstream two miles of Ebey Slough (Figure 33). Just before the Highway 2 bridge, the distance between the levees narrows to its existing width; this narrowing, combined with the flow constriction at the bridge itself, cause water to back up and exceed existing conditions water levels by approximately 0.4 ft.

In the upstream portion of Ebey Slough, the Long Term Alternative decreases peak water levels by nearly a half foot (Figure 33). Further downstream, the water levels are predicted to increase by up to three quarters of a foot, then decline back below existing conditions downstream of the Highway 2 bridge. The Snohomish main stem also experiences a decrease of several tenths of a foot along the south end of Ebey Island. Peak water levels then increase to a maximum of one foot higher than peak water levels predicted for existing conditions.

In general, the new cross dikes proposed as part of the Long Term Alternative increase flow resistance during very large flood events with extensive overtopping, thereby raising predicted peak water levels. The decrease in both channels just downstream of the channel junction, followed by an increase downstream suggests that the proposed cross dike to the north of the restoration area plays a more significant role in peak water levels than the south cross dike. The north cross dike affects the flowpath of floodwaters that pass through the northern part of Ebey Island. Its crest elevation was set to 14.7 ft NAVD, which is similar to elevations where it joins the existing dikes. In contrast, a large fraction of the flood flow bypasses the proposed south cross dike, flowing through the main stem and Ebey Slough. Hence, overall conveyance capacity is not as strongly influenced by the south cross dike.

For the Long Term alternative, note that water is predicted to begin overtopping onto the developed portion of south Ebey Island later than existing conditions. The low point in the current perimeter dike, which provides the initial flood pathway for existing conditions, is not part of Long Term Alternative's dike that surrounds the developed portion of south Ebey Island. As a result, water levels need to rise higher before overtopping, providing a delay in flooding during which evacuation could occur from the south island. The northern diked portion of Long Term Alternative is overtopped in a similar timeframe as existing conditions.



Sources: UNET model predictions for WY2002

figure 32

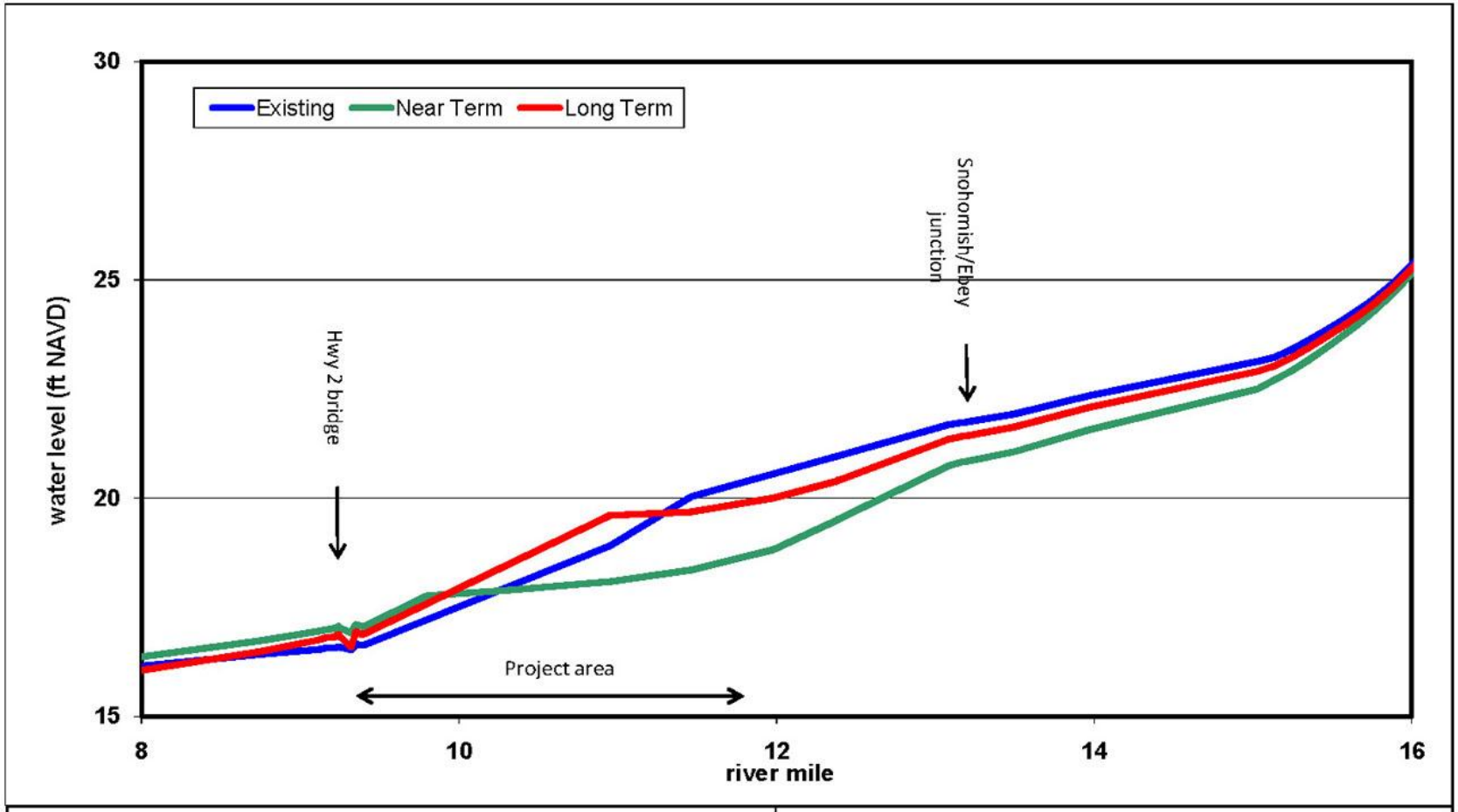
Ebey Island Restortation Project

Q100 Peak Water Levels - Snohomish River, January 2002

ESA PWA Ref #: 2022

ESA PWA

Figure 32 Q100 Peak Water Levels - Snohomish River, January 2002



Sources: UNET model predictions

figure 33

Ebey Island Restortation Project

Peak Water Levels, 100-Year Discharge, Ebey Slough

ESA PWA Ref #: 2022

ESA PWA

Figure 33 Peak Water Levels, 100-Year Discharge, Ebey Slough

5.2.2.4 North Tip Option

The option of including full tidal restoration on the northern tip of Ebey Island was assessed with the UNET model for its potential impact on peak water levels during the 100-year riverine discharge event. Predicted peak water levels with the north tip were nearly identical to the peak water levels predict for Long Term conditions (Figure 32 and Figure 33). The largest differences, which were less than 0.1 ft, occurred in Steamboat Slough to the west of northern Ebey Island and in the connecting channel between Steamboat Slough and Ebey Slough to the north of Ebey Island. The new cross dike required to separate the north tip restoration from the rest of Ebey Island appears to have little impact on the flow when its crest elevation is 13.7 ft NAVD. This crest elevation is similar to the crest elevation of the junction between the new cross dike and the existing dike and also one foot below the elevation of the proposed cross dike adjacent to Highway 2.

5.2.2.5 Geomorphic Assessment of Preferred Alternatives

The restoration design includes several elements whose design will influence the site's geomorphic evolution after restoration is implemented, including breaching, dike lowering, and tidal channels. Below are guidelines to inform the design of these elements to facilitate site evolution towards mature vegetated habitat. Also discussed below is the potential for the restoration to cause off-site scour.

Breach Sizing and Dike Lowering

The full tidal areas will be re-connected with the outboard channels by breaching and lowering the perimeter dikes. Breaches refer to incisions through the dike which are deep enough to convey water at all phases of the tide, providing a pathway for channels to penetrate into the site. Lowering refers to reducing the elevation of the dike crest such that flow can exchange with the site during a portion of the tide range. In general, the restored area will evolve more quickly towards mature habitat in equilibrium with physical processes if breaching and lowering is sufficient to reconnect the site to full tidal and riverine influence. Better hydraulic connectivity facilitates tidal channel development, bed accretion, fish access, food chain exchange, and recruitment of large woody debris.

An estimate of the breach size for the full tidal restoration areas can be calculated from the top width of Deadwater Slough and hydraulic geometry scaling factors. Hydraulic geometry refers to the observation that the dimensions of tidal channels are often found to develop an equilibrium condition that is a function of tidal hydraulics, specifically the diurnal tidal prism[1] (Williams et al. 2002). Quantifying the relationship between tidal prism and channel dimensions requires field observations. Such observations are lacking for Puget Sound, so the more extensive data set from San Francisco Bay (Williams et al. 2002) was used. This data set was adjusted to account for the larger tide ranges found in Puget Sound (ESA PWA, 2010).

1 Average volume of water that flow through a channel cross section on the largest tide of each day.

The top width of the mouth Deadwater Slough has been relatively stable since it was first quantified on the historic map of 1869. Hence, its 170 ft top width serves as the best reference for breach sizing for full tidal connectivity from the west side of the island to the Snohomish main stem. Since no depth data is available for Deadwater Slough prior to diking, the hydraulic geometry relationships can be use to infer a corresponding depth of -6 ft NAVD. We initially recommend a breach of this size, trapezoidal in cross section with side slopes of 3H:1V. Because of subsidence on the site, the initial tidal prism will be larger than for a mature marsh of the same area, which is the condition upon which the hydraulic geometry analysis is based. Therefore, a breach this size is likely to scour at the outset, creating a more natural shape. It will then trend back toward the original dimensions as the interior bed elevation evolves.

Since no historic channels information is available for the full tidal portion of the Near Term Alternative, the Deadwater Slough information can be scaled down according to the acreage of the Near Term fully tidal area, the acreage of the Deadwater Slough drainage area, and a hydraulic geometry factor. This yields an estimated top width of 120 feet at MHHW. The corresponding depth is -4 ft NAVD. These dimensions form the basis for designing a similar trapezoidal breach that would follow a similar evolution as for the Deadwater Slough and the Long Term Alternative discussed above.

Dike lowering provides better hydraulic connectivity between the restoration site and the outboard channels. On either side of the main breaches, for a distance of one to two breach widths, we recommend lowering the dike to the existing grade of the island's interior. This ensures full connectivity at the breaches and provides some latitude for natural lateral migration of the breach. Because of the infrastructure close to the location where Deadwater Slough intersects the levee, a design which only employs levee lowering to the west and protects infrastructure to the east may be required. Further away from the breaches, we recommend lowering the dike to MHHW. This lowered dike will allow higher waters to exchange as sheet flow between the site and the outboard channels. A lowered elevation at MHHW balances between levee removal and construction practicality. This elevation is consistent with the expected long term elevation, as indicated by marshplain elevations at reference sites. The total length of the dike to be lowered needs to be weighed against costs (e.g. the need to balance cut and fill onsite) and benefits (degree of hydraulic connectivity) in future design stages. Minor breaks in the dike down to the island's existing grade and coinciding with historic drainage channels (when these can be identified), would provide additional lower-tide drainage across the dike and help create a range of channel sizes in the restored site. These minor breaks are expected to scour to some degree, but not to become major breaches.

Tidal Channels in Restored Areas

The restoration design should facilitate the development of dendritc networks of tidal channels within the restored areas. These networks convey tides and suspended sediment into the interior of the sites, convey nutrients and primary production off the site, and provide habitat diversity. For the muted tidal areas and full tidal area of the Near Term Alternative, this network can be encouraged by excavating starter channels. Starter channels extend the main channel that enters the restoration site through a breach or structure and includes the addition of one to three smaller starter channels that branch from the main channel. For the additional full tidal area proposed for the western portion of the island under the Long Term Alternative, the existing network provided by Deadwater Slough should be sufficient. Because of the relatively large tidal exchange initially entering the site, this network will erode and expand to create a more extensive network of marsh channels. The linear drainage channels which currently exist on the site should be filled both to reduce fish stranding in unconnected reaches and to prevent the drainage ditches from capturing flow from the dendritic network.

Bed Elevation Evolution

Perimeter dikes built around Ebey Island have resulted in subsidence of the site, with the ground surface elevations now well below typical marshplain elevation (Figure 24). Currently, the ground surface elevation over much of the project area is between 2 and 6 ft NAVD, as compared to typical marshplain elevations, which at least MHHW or approximately 9 ft NAVD. Re-connecting the restored areas to the adjacent channels is expected to result in accretion of the existing ground surface as suspended sediment is transported onto the site and deposits. This sediment will be carried onto the site with flood tides and at higher concentrations during riverine flood events. When wetlands vegetation colonizes the site, it will provide an additional source of organic material to supplement the mineral sediment accretion rate.

Limited observations from other locations in the Snohomish Estuary provide an indication of potential accretion rates at the Ebey Island restoration site. Observations from cores collected in a marsh at the downstream end of Ebey Slough indicate long term accretion rates of approximately 0.4 inches/year (USACE, 2002). Monitoring five years after breaching of a small restoration site also located on the downstream end Ebey Slough indicated that the site had accreted a rate of about 1.2 inches/yr in its first five years (Jones & Stokes, 1999). Several other restoration sites in the lower Snohomish Estuary have been breached since 2000 and may provide additional insight into site evolution, but sources of observed accretion rates from these sites are not known at this time.

The accretion rates from these other locations in the Snohomish Estuary suggest that the highest ground on Ebey Island, which is approximately 3 feet below MHHW, would take at least take three decades to reach MHHW. Lower regions of the island, which are 6 feet or more below MHHW, would take a century or more to reach MHHW. These estimate are based on accretion rates when mean sea

level was rising at a relatively modest 1 mm/yr. With the expected acceleration of sea level rise, MHHW would be shifting upward as much as ten times faster (Mote et al. 2008), which would extent the time for the bed to reach MHHW.

The Corps maintains a settling basin on the Snohomish main stem just downstream of the project site to trap silt before it deposits in the Port of Everett. This site experiences several feet of deposition per year, and is dredged every few years in installments of several hundred thousand cubic yards (USACE, 2004). These accretion rates are not directly applicable to predicting accretion within the restored area because a substantial portion of the deposition in the settling basin may be bed load, which is not readily transported into off-channel locations, except perhaps during riverine flood events. Even if sediment from this settling basin is not transported to the restoration site by natural processes, it may be a viable source for dredged sediment that is mechanically transported to the restoration site and place there to augment the existing bed elevation. Previous testing of the settling basin has qualified its sediment for beneficial use (USACE, 2004). Further study of the viability of dredge material reuse on Ebey Island is recommended; issues to be addressed would include available volumes, suitability as a substrate for wetlands vegetation (grain size, contamination), engineering feasibility, and costs.

Off-site Scour

The proposed restoration will increase the tidal flow in the outboard channels as these channels will convey the additional water that exchanges with the restored areas on each tide. This increase in tidal flow may cause scour and enlarge the outboard channels since tidal channels are often found to develop an equilibrium dimension that is a function of the diurnal tidal prism, as described above in Section 5.2.2.2[2] (Williams et al. 2002). Observations from San Francisco Bay (Williams et al. 2002), which are then adjusted to account for the larger tide ranges found in Puget Sound (ESA PWA, 2010), can be used to evaluate the potential for scour resulting from the increased tidal prism associated with restoration.

Estimates of potential changes to tidal prism (from the UNET model) and channel width and depth (from the hydraulic geometry relationships) are shown in Table 6. The tidal prism estimates are extracted from the model just downstream of the restoration areas to capture the region likely to have the largest impact. Only relative changes in channel dimension are show to emphasize that this is an estimate of the likely upper bound of channel scour, not a prediction for a particular location. Note that the channel dimensions do not scale linearly with the tidal prism because the assumed hydraulic geometry relationship is nonlinear[3]. Larger changes are predicted for Ebey Slough since the relative change in tidal prism is larger in the slough as compared to the main stem. The potential changes in

2 Average volume of water that flow through a channel cross section on the largest tide of each day.
[3] Of the form $y=ax^b$ (as opposed to the linear form $y=ax+b$)

channel width are shown, but would be constrained by the dikes. To balance this restriction on widening, deeper scour in the channels may occur. Since the predicted tidal prisms are for the existing bed elevations, the estimate corresponds to the period right after restoration. If accretion increases the bed elevations in the restored areas, the tidal prism will decrease and, correspondingly, the pressure for the outboard channels to enlarge to the extent shown below.

To develop an better understanding of the potential for restoration to scour the outboard channels, we suggest an estuary-wide review of evolution of channel dimensions over time. Several sources of bathymetric data were integrated into the model used for the FIS (FEMA, 2001). This data could be compared with side scan bathymetry data collected in 2006 (Yang and Khangaokar, 2007). Of particular interest is the channel response in the vicinity of Snohomish Estuary restoration sites breached in the last decade.

Table 6 Predicted tidal prism changes and potential channel dimension changes in response to restoration alternatives.

	Existing	Near Term	Long Term
Snohomish River			
Tidal prism (ac-ft)	5,702	5,886	8,094
Tidal prism (% change)	—	3%	30%
Potential % increase, channel depth	—	3%	6%
Potential % increase, channel width	—	2%	15%
Ebey Slough			
Tidal prism (ac-ft)	2,115	3,274	3,348
Tidal prism (% change)	—	55%	58%
Potential % increase, channel depth	—	11%	12%
Potential % increase, channel width	—	27%	28%

5.2.3 Design Considerations

5.2.3.1 Estimated Quantities and Costs

Planning level budgets for the two chosen alternatives and the North Tip option were created. The costs were estimated using available data and experience with similar projects. There are a number of uncertainties with the quantities of materials that would be needed for these projects. Quantity estimates were created for the construction of dikes, breaching of dikes, construction of starter channels, creation of ditches, addition of tide gates, addition of self-regulated tide gates, and addition of flood gates. Estimated unit costs were used to come up with a planning level construction budget. The costs of permits, land acquisition, utility work, and the like were not included.

Table 7 summarizes the quantities of various features for the two preferred alternatives and the North Tip Option, along with planning level construction budgets for each. The costs to design, permit,

acquire additional property, relocate or floodproof utilities or roads, and mitigate for any environmental impacts have not been estimated.

Table 7 Summary of quantities and suggested construction budget for preferred alternatives.

	New Habitat: Muted Tidal (ac)	New Habitat: Full Tidal (ac)	New Dike Length Needed: Short Height (ft)	New Dike Length Needed: Full Height (ft)	Number of Water Control Structures Needed	Dike Eligible for Breaching or Lowering (ft)	Suggested Construction Budget
Near-Term Alternative							
1. West Muted Tidal Area	114		8,150		1	0	$1,490,000
2. East Muted Tidal Area	96		5,630		1	0	$1,170,000
3. East Full Tidal Area		574		8,930	0	12,640	$14,010,000
Near-Term Alternative	**210**	**574**	**13,780**	**8,930**	**2**	**12,640**	**$16,670,000**
Long-term Alternative		**1,500**		**22,000**	**4**	**17,300**	**$33,840,000**
North Tip Option		**300**		**2,400**	**2**	**14,300**	**$3,990,000**

5.2.4 Ecological Effects of Preferred Alternatives

The Snohomish estuary is traversed by juvenile and adult salmonids representing seven different species, including ESA-listed Chinook salmon *(Oncorhynchus tshawytscha),* steelhead (*O. mykiss),* and Dolly Varden *(Sa/ve/inus ma/ma).* All of these species are important from ecological, cultural and economic standpoints. The restored Ebey Island site is expected to provide high quality, accessible habitat that would be used extensively by juvenile (subyearling and yearling) Chinook salmon during their protracted downstream migrations each spring and early summer and, to a lesser extent, by upstream-bound adults in the late summer and fall. Estuarine sloughs and tidal marshes are highly productive areas that provide important acclimation, feeding, and refuge functions for salmonids, as well as non-salmonid species such as Peamouth chub *(Mylocheifus caurinus),* which are common throughout the Snohomish estuary. Growth and survival rates are generally high for all fish species in estuaries.

Figure 34 presents the general effects of dike removal or modification on estuarine components and processes, and their combined effect on juvenile salmon movements (access), growth and survival (predator avoidance) in newly accessible restored habitats. The arrows indicate the pathways through which responses are expected to occur (the darker the line, the stronger the relationship).

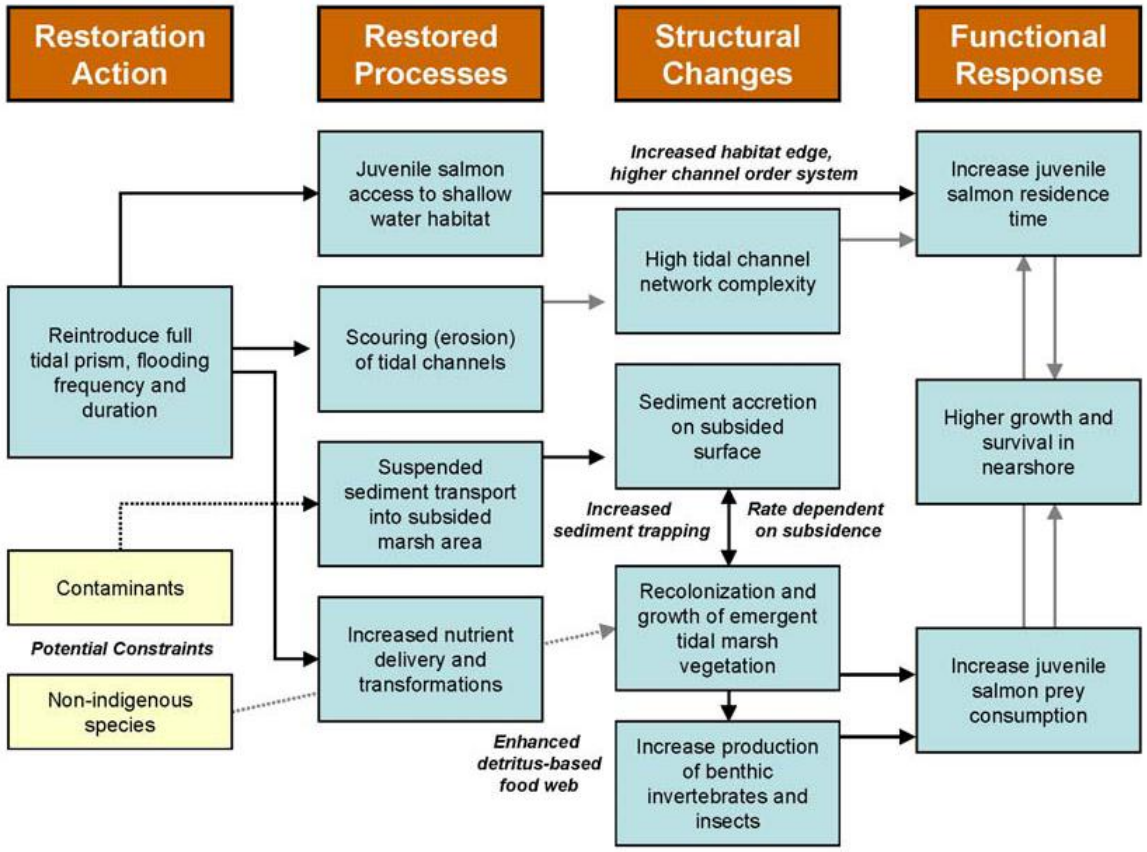


Figure 34 Conceptual example of the effects of dike removal, setback or modification on juvenile salmonids and associated habitat (adapted from Clancy et al. 2009).

The estuarine processes that would be restored by these alternatives include tidal hydrology, delivery and routing of sediment and LWD, nutrient cycling, and establishment and maintenance of a complex network of drainage channels. Some of the more important structural changes expected are sediment accretion, salt marsh vegetation recolonization, tidal channel network expansion, increased production of benthic and salt marsh invertebrates, among others.

The near-term and long-term alternatives would restore, in varying degrees, the natural estuarine processes and components that are typical of healthy ecosystems. Restoration of muted tidal and full tidal conditions in areas behind the existing dikes, and provision for passage into these areas via tide gates, would ensure that they are accessible to downstream migrating fish.

We developed a conceptual model similar to the one described above to evaluate the potential ecological benefits of restoring the Ebey Island site under the two preferred alternatives. Anticipated

benefits to fish resources were derived from model-predicted estimates of wetted surface area, combined with indices of hydraulic connectivity (i.e., accessibility) and habitat quality based on modeled hydraulic characteristics within the restored area. Juvenile salmonid densities vary according to habitat type, as defined by water depth and velocity, temperature, salinity, dissolved oxygen, substrate, cover, and other parameters that affect habitat quality. We evaluated the suitability of habitat expected to result from implementation of near- and long-term alternatives on the basis of its physical characteristics, weighted by estimates of juvenile density obtained in similar habitats in the lower Snohomish River estuary. This information was incorporated into the alternatives effects analysis and the evaluation and design process.

5.2.4.1 Restoration of the Snohomish Estuary

Prior to anthropogenic modifications, Haas and Collins (2001) estimate the Snohomish River Delta contained approximately 3,950 hectares of tidal marsh habitat (not including lower intertidal/subtidal mudflat. Sixty six percent (2,607 ha) of this tidal marsh habitat was located around Ebey Island within the freshwater portion of the estuary, also referred to as the Forested Riverine/Tidal (FRT) zone. Today, only 600 hectares of total marsh remain, and the FRT zone has lost 95 percent (only 130 ha remain) of its historic area, primarily due to diking and conversion to agricultural uses. Only 25% of the blind tidal sloughs remain intact throughout the Snohomish River Delta and channel margins along the distributary sloughs and main channels have been significantly modified by extensive diking. Based on the amount of rearing habitat available for juvenile Chinook and coho salmon, the authors estimated historic capacity at approximately 2.6 million Chinook smolts, whereas current conditions accommodate only 1.0 to 1.6 million Chinook smolts.

In more recent years, and particularly with the listing of Chinook salmon as threatened under the Endangered Species Act (NMFS 1999; Good et al 2005), estuarine tidal marshes have become the focus for habitat restoration. The following projects are a few examples of tidal marsh restoration in the Pacific Northwest.

In the Snohomish River Delta dikes have been breached intentionally and unintentionally. The Snohomish River Basin Salmon Conservation Plan (2005) lists a dozen projects that have been implemented or are in the planning phase.

One of these projects is the Qwuloolt site, 300+ acres in the emergent/forest transition zone near Marysville, WA that was purchased by the Tulalip Tribes. In partnership with NOAA Fisheries, the Tribes have been developing a restoration design to breach the existing dikes and restore full tidal conditions across the marsh (Minick 2004).

In the oligohaline portion of the estuary near Ebey Island, tidal restoration occurred at the south end of Spencer Island in 1994. Dikes were breached in two places to reconnect tidal and fluvial processes to 23.7 ha (Cordell et al 2001; Tanner et al 2002). Spencer Island is located directly across Steamboat Slough from the northern end of Ebey Island and offers an example of what full tidal restoration might look like on Ebey Island. Many of the other restoration projects, such as those on Smith Island along Union Slough, are located lower in the estuary where salinities are higher.

A great deal of restoration work and biological recovery monitoring has occurred in the Skagit River delta where many of the same conflicts between land uses arise (Beamer et al 2005). Wiley Slough (Hinton et al 2005), Fisher Slough (Beamer et al 2010), and Deepwater Slough (Beamer et al 2006) are all useful examples of restoration design processes, implementation, and biological monitoring programs. Research conducted at these sites contributes to our understanding of fish use of restored sites and the effectiveness of removing and modifying tide gates.

The restoration of freshwater tidal marsh habitat and fish passage at tide gates are common concerns around the Puget Sound, in the Lower Columbia River Estuary, and in Oregon (Simenstad and Thom 1996, Charland 1998, Giannico and Souder 2004, Hering et al 2006, Poirier et al 2009).

5.2.4.2 Critical Uncertainties

Restoration Design Details

Predicting the ecological benefits that will accrue as a result of a restoration project is difficult because the processes and successional nature of site evolution are inherently uncertain. The Ebey Island restoration project is still in the feasibility stage and therefore many of the design details have not yet been determined. These details, especially pertaining to the type of water control structures, the controlled height of water in muted tide areas, and the amount of grading and excavating that will be used to create starter channels, all play an important role in achieving ecological benefits. The quantification of ecological benefits presented in this report are uncertain and only predict future site conditions to extent possible given the feasibility level of design detail.

Tide Gates

Tide gate designs have been creatively modified in recent years to improve water quality and fish passage in estuarine settings (Giannico and Souder 2005). Studies of juvenile fish distribution in the vicinity of traditional and modified tide gates show clear benefits to using either side-hinged or self-regulating tide gates (refs.). Unfortunately, it is rare that tide gates function identically across a range of sites and thus it is difficult to quantify the improved level of access. These design specifics will greatly impact the ability of fish to access a muted tide area, and it will be important to define these specifics clearly before further refining this ecological effects analysis.

Water Temperatures

Any type of tide gate, by definition, will impound water for some amount of time. If water is trapped in a shallow pool behind the dike for too long, air temperature and solar radiation will raise the water temperature. In the near term alternative presented in this report, the muted tide areas flush at least once per day over most of the year. We assume this frequency of exchange is sufficient to keep the temperature of the water within the muted tide site equal to the water temperature in the mainstem/slough. However, a formal analysis has not been conducted and the lower Snohomish has been identified as having high water temperatures in the later summer low flow period. The spring outmigration period has generally cooler air temperatures, but higher river stages result in the gate being closed for longer periods of time.

Rates of Sediment Accretion and Community Succession

As noted above, subsidence has occurred across Ebey Island and will be an important factor in determining the affect of restored tidal processes on biological communities. This is not a unique problem; many other tidal marsh restoration projects have addressed this issue by assuming that restored fluvial and tidal processes will provide sediment inputs that, over time, will build up the marsh surface elevation and allow vascular plants to colonize.

The rate of accretion is primarily determined by the sediment budget for the river, and secondarily by the velocity and volume of flows across the restored site. In the Pacific Northwest, these rates are widely variable in different systems: 0.36 centimeters per year in Salmon Creek Estuary (Frenkel and Morlan 1990) and 4.80 centimeters per year in Puyallap River Estuary (Simenstad 1995).

There are fewer examples with which to predict sediment accretion rates in a muted tide system, but they will likely be much slower than in an area of full tidal influence because perimeter of the marsh has no connection to the sediment sources transported by the river (except through the culvert), and the tidal prism is greatly reduced. (Frenkel and Morlan 1990). Perimeter dikes will also prevent natural recruitment of large wood pieces that act as nurse logs and help expedite the establishment of emergent marsh vegetation (Hood 2007).

Wetland researchers have found that most intertidal vascular emergent species occur primarily between Mean Lower High Water (+9.39 ft. in Snohomish Estuary) and Mean Higher High Water (11.11 ft. in Snohomish Estuary) (Lewis 1982)(Table 8).

Table 8 Selected species and observed elevations in estuary.

Selected Species and Observed Elevations in Estuary

Elevation Above MLLW in Feet	Dominant Plant Species	Habitat Type	Wetland Complex Number
+ 5.9 MLLW	Marine Algae, Diatoms (Mudflat)	Intertidal Mudflat	19, 171 Entrance Mudflats
+ 6.9 MLLW	*Carex lyngbyei*	Emergent Intertidal Salt Marsh	133, 134, 135, 18 Quilceda, N. Ebey, W. Smith
+ 9.9 MLLW	*Carex lyngbyei*	Emergent Brackish Intertidal Marsh	144, 138 Mid Ebey and Spencer
+ 8.8 MLLW	*Scirpus acutus*	Emergent Intertidal Salt Marsh	132 Quilceda
+ 7.9 MLLW	*Scirpus acutus*	Emergent Intertidal Brackish Marsh	148 Mid Ebey
+ 8.9 MLLW	*Typha latifolia*	Emergent Intertidal Brackish Marsh	144 Mid Ebey
+ 11.9 MLLW	*Typha latifolia*	Emerg/SS/Forest Intertidal Brackish & Freshwater Marsh	105 Otter Island
+ 11.9 MLLW	*Lonicera involucrata*	Scrub-shrub Inter-tidal Brackish Marsh	141 Mid Ebey
+ 12.9	*Lonicera involucrata*	Scrub-shrub Inter-tidal Brackish Marsh	137 South Spencer

Source: SEWIP Wetland Complex Inventories and COE 1973 Flooding Map for Snohomish Estuary

5.2.5 Fish habitat value in muted tidal systems

All of the issues and unknowns described above lead to difficulty in predicting whether it is possible to mimic optimal fish habitat within the muted tidal systems proposed at Ebey Island. While many of the habitat conditions that are known to be of value to juvenile salmon and other native species can be incorporated as design criteria, compromises are inevitably made to accommodate other types of criteria and key attributes or ecological interactions cease to function. Despite all that is known about fish use of estuarine tidal marsh habitat, it is still a daunting challenge to engineer optimal habitat in a system that does not allow natural processes to run their course, and to predict the use and value of this habitat for any given species.

5.2.5.1 Methods to Quantify Ecological Benefits

The basic method for predicting fish use of a restored area involves simply multiplying the expected usable habitat area by an average density of fish. To increase the level of certainty, fish density and habitat type data should be compiled from field studies that are as comparable as possible.

Habitat area can be defined in many different ways: marsh area, channel surface area, channel volume, linear feet of channel, etc. Whichever unit of measure is chosen will need to correlate with the units of fish density values. In this report, we define usable habitat area as the length of the

anticipated dendritic tidal channels, multiplied by an average distance from the bank that represents the edge habitat typically used by juvenile Chinook salmon. The expected length of dendritic channels is estimated using several different geomorphic principles and observed allometric relationships.

Fish density values are derived by multiplying the daily average density of juveniles over the course of the outmigration period by the average residence time in the marsh. Therefore, fish density represents the number of fish that would pass through a given acre of usable habitat in a given year.

This method is used most appropriately for areas where full tidal restoration is proposed. For areas where muted tidal ranges are proposed, this method is combined with further analyses that describe anticipated habitat conditions and fish access potential in these areas.

Usable Habitat Area

The amount of habitat that would be made accessible to fish under different alternatives is difficult to predict with certainty, but can be estimated using a few basic approaches. One is by using established allometric relationships that correlate the size of a marsh system to the number and order of its drainage channel network. The tidal prism of a marsh system, which represents the volume of water exchanged across the site over a standard tidal exchange, can be used to predict the morphology of these channels.

These relationships have been quantified based on observations of tidal marsh systems in the San Francisco Bay, California (PWA 1995) and the Skagit River Delta, Washington (Hood 2007b), and can be used to reasonably represent processes in the Snohomish River Estuary (M. Brennan, personal communication). Ideally, this analysis would be based on formulas developed specifically for the Snohomish River, which would allow for local calibration; however, because these formulas have not been developed, we rely on the geomorphic relationships developed in the systems mentioned above. The biggest source of uncertainty in applying these models to the Ebey Island restoration alternatives stems from not knowing whether these relationships hold true in muted tidal areas. In these areas, the tidal prism is substantially reduced and tidal flushing occurs less frequently (diurnal instead of semi-diurnal).

The Skagit River System Cooperative (SRSC) compiled a database of geomorphic attributes that has been used to understand the relationship between the total acreage of a tidal marsh, either natural or restored, and the proportion of area that is covered by tidal channels (Beamer et al 2005). Adapting these formulae to the restored acreages proposed on Ebey Island provides one method for estimating the channel area that would be available to rearing fish. The North Fork Skagit River Delta regression equation is:

$$y = 0.0018x^{1.80}$$

and the South Fork equation is:

$$y = 0.006x^{1.48}$$

where y is the total channel area (hectares), and x is the marsh island area (hectares). It is important to note that the largest areas of marsh that were included in this analysis were on the order of 70 hectares. No marshes of a size comparable to the Ebey Island long term alternative (greater than 490 hectares) were available for sampling. Nevertheless, we predicted the area of tidal channel in each of the Ebey Island restoration alternatives by applying both of the Skagit equations and averaging the results. In the near term alternative, we predict a total of **29.0 ha** of channel to be either created or formed naturally across the restored full tidal and muted tidal areas. In the long term alternative, we predict **131.5** ha of channel to develop over time (Table 10).

Coats et al (1995) compiled similar geomorphic data from tidal marshes in San Francisco Bay that can also be applied to the Snohomish River Delta to develop an alternative estimate of the drainage order and usable habitat for a given size marsh. Coats et al (1995) report a simpler rule for predicting the drainage density, or the length of total channel per marsh surface area. On average 0.01 to 0.02 feet of channel is found for every square foot of marsh area. This is equivalent to 328 to 656 lineal meters of channel per hectare. For this analysis, we assume an intermediary value of 0.015 lineal feet per square foot, or 492 m/ha. This value is used to represent both the equilibrium morphology of a marsh restored entirely by natural processes, and the design criteria for marshes systems that are "jump-started" by construction/excavation.

Using this relationship, the Ebey Island restoration near term alternative would result in 155,964 meters of channel (114,144 meters in the full tidal area and 41,820 meters in the muted areas), and the long term alternative would result in 298,644 meters of channel.

These channel networks are made up of a range of channel orders, especially in the large marsh sites. On the small end of the range, first order channels may be no wider than a ditch, whereas the large fourth and fifth order channels may be tens of meters across. Assuming an average channel width of 5 meters, this would result in **78.0 ha** and **149.3 ha** of channel habitat in the near and long term alternatives, respectively.

An even simpler approach to predicting channel area in tidal marsh habitat used by Bartz et al (2006) and based on prior analysis of the Snohomish River Estuary (Haas and Collins 2001), was to multiply the land area within a given habitat zone by a certain percentage. In blind tidal channel areas within

the FRT, usable habitat area was calculated simply as 3.0% of the total area. Using this approach, and assuming the Ebey Island restoration alternatives create only blind tidal channel networks, the near term scenario would create **9.5 ha** and the long term scenario would create **18.2 ha**.

Due to the great disparity in the results from these alternative methods, we chose to use the intermediary values from the Beamer et al (2005) model. These equations were developed specifically to assist in calculating fish benefits. In addition, these equations capture the fundamental idea that larger sites produce a great benefit per hectare than smaller sites.

Distinction between full tidal marsh and muted tidal areas

Estimates of usable habitat area that have been developed above focus exclusively on the habitat quantity that might be made available under different restoration alternatives. Unfortunately, the ability to predict the quality and the accessibility of this habitat is limited, especially in the areas where muted tides are proposed. Specific details regarding what these areas will look like, what hydrology and habitat features will be present, and what types of communities will reestablish, all contribute to the quality of habitat and the ability of these restored areas to benefit juvenile salmonids that rear in the estuary.

Fish Densities

We compiled a variety of reported juvenile Chinook salmon density values from the literature, which when multiplied by the predicted channel areas in each area would allow a rough estimation of the number of smolts that would benefit from restoration. In general, there is very limited data available on typical juvenile Chinook salmon densities in Snohomish River tidal marshes, especially in the freshwater portion of the estuary. Sampling is problematic: very few sites still exist because of extensive diking, funding is limited, and the population dynamics (especially life history, behavior and carrying capacity) are not well understood, which make interpreting results difficult.

We found that many of the past efforts to quantify the effects of habitat alteration on Chinook populations relied on fish density numbers from tidal marshes in other systems. Bartz et al (2006) provided a list of habitat-specific fish density values that they used to populate their model. Based on an average from several sources in the Fraser and Skagit Rivers, they estimated that FRT habitats could support **1,400** (SD=1,510) Chinook smolts per hectare.

Haas and Collins (2001) applied an average production capacity of **2,857** Chinook smolts per usable hectare of blind tidal channel. This value was also derived from field work in the Skagit River (Hayman et al 1996).

Both Bartz et al (2006) and Haas and Collins (2001) applied higher juvenile Chinook densities to habitats zones lower in the estuary: 1,410 and 4,200 per hectare in estuarine emergent marsh and estuarine scrub-shrub, respectively (Bartz et al 2006); and 21,916 per hectare in both estuarine emergent marsh and emergent/forested transition zones, respectively (Beamer et al 1999 as cited in Haas and Collins 2001).

More recent work in the Skagit River has established a method for predicting the carrying capacity/density of a given site based on its location within the tidal marsh system, also known as the "landscape connectivity" (Beamer et al 2005). A numerical score for landscape connectivity is derived as a function of the distance and the number of bifurcations from the mainstem. Then this score is used as a surrogate for habitat value and accessibility. In the Skagit River delta, sites with high landscape connectivity average **11,200** juvenile Chinook per hectare of blind tidal channel over the outmigration season. While freshwater sites higher in the delta system naturally have higher connectivity because of fewer bifurcations, this value may be skewed by exceptionally high number of Chinook found in the brackish sites.

Two other key insights from the Skagit system are useful to consider when predicting the benefits of habitat restoration in the Snohomish River. First, the density of juvenile Chinook salmon observed in blind tidal channels was density dependent: data was collected over multiple years when the total number of smolts ranged from 800,000 to 7.1 million; during this time the average number of fish per hectare ranged from under 2,000 to over 14,000. Second, as the total number of smolts increased, residence time in the delta habitat decreased. We assume these characteristics are also true of Snohomish River stocks (with total smolt production estimated at 1.0 - 1.6 million (Haas and Collins 2001)); but the similarity of these dynamics between regions, and the plasticity of life-history strategies within populations over time is not well understood. Until a more thorough understanding of the Snohomish River Chinook population dynamics and juvenile behavior is attained and local values are made available, then it will be impossible to refine estimates of expected restoration benefits.

Some of the discrepancy between these carrying capacity estimates may reflect the fact that it is not simply measured in the field, but rather calculated from field data based on several assumptions. Sampling the number of smolts in blind tidal marsh habitat first requires a correction for capture efficiency (Hayman et al 1996); then the average number of smolts captured on a given day is multiplied by the length of the outmigration season, approximately 150 days (Beamer and Greene 2005); and divided by an average residence time of 25 to 35 days (Healy 1980 and Beamer et al 2000, respectively. These extra steps introduce a high degree of uncertainty to each capacity estimate and variability between studies.

Given the wide range of reported values for the smolt production potential of freshwater blind tidal channel habitat, we applied a high (10,000 smolts/ha) and a low (2,000 smolts/ha) estimate to the anticipated amount of usable habitat area created by the near term and long term tidal restoration scenarios.

Other Metrics

SEWIP Salmon Overlay

A planning process to identify and rank potential mitigation and/or restoration sites in the greater Snohomish River Estuary was undertaken a decade ago (City of Everett and Pentec Environmental 1997, 2001). First, the ecological functions of wetland and tidal areas across the estuary were evaluated using an “indicator value assessment” model (IVA). This IVA score is used to represent the relative current or future ecological value of each acre of land within a given area. This score is then multiplied by the acreage of a given site to determine the relative value of a specific project. The scoring process was initially completed for wetland function (1997), and subsequently modified to be used for predicting fish habitat function (2001)(Table 9).

Five of the top 25 potential sites that were evaluated in the SEWIP report overlap with the current project area being considered by WDFW: the central area around Deadwater Slough; the northwest corner along the mainstem; the northeast corner along Ebey Slough; the eastern forested portion along Ebey Slough; and the northern tip of Ebey Island. The boundaries of these areas do not match with those proposed in the currently proposed alternatives, and therefore the acreage calculations are not comparable, but the maximum IVA scores indicate the relative restoration value of these locations.

Based on their analysis, the northern tip of Ebey Island had the highest maximum IVA score (103.7), followed by the northeast corner (70.4), the eastern side (62.1), Deadwater Slough (58.0), and the northwest corner (40.3). The minimum IVA scores, which were calculated assuming only the dike was breached and no other habitat enhancement work was performed, for the northeast and northwest corners were 25.6 and 27.3, respectively.

If we apply the maximum IVA scores to the acres proposed for full tidal restoration under the current alternatives, and use the minimum IVA scores to the acres proposed for muted tides (not the way it was intended to be used), we can generate a relative score with which to evaluate the fish habitat restoration potential of each location.

The top 25 sites promoted in the SEWIP model summed to a maximum IVA restoration potential of 413,608 IVA-acres (City of Everett and Pentec Environmental 2001). Using this modified approach to the IVA model, the near term alternative with the addition of the north tip option would yield benefits equivalent to the long term alternative. Implementation of either would realize over 17% of the total

IVA-acre potential. The long term alternative plus the north tip option would meet 25% of the total potential.

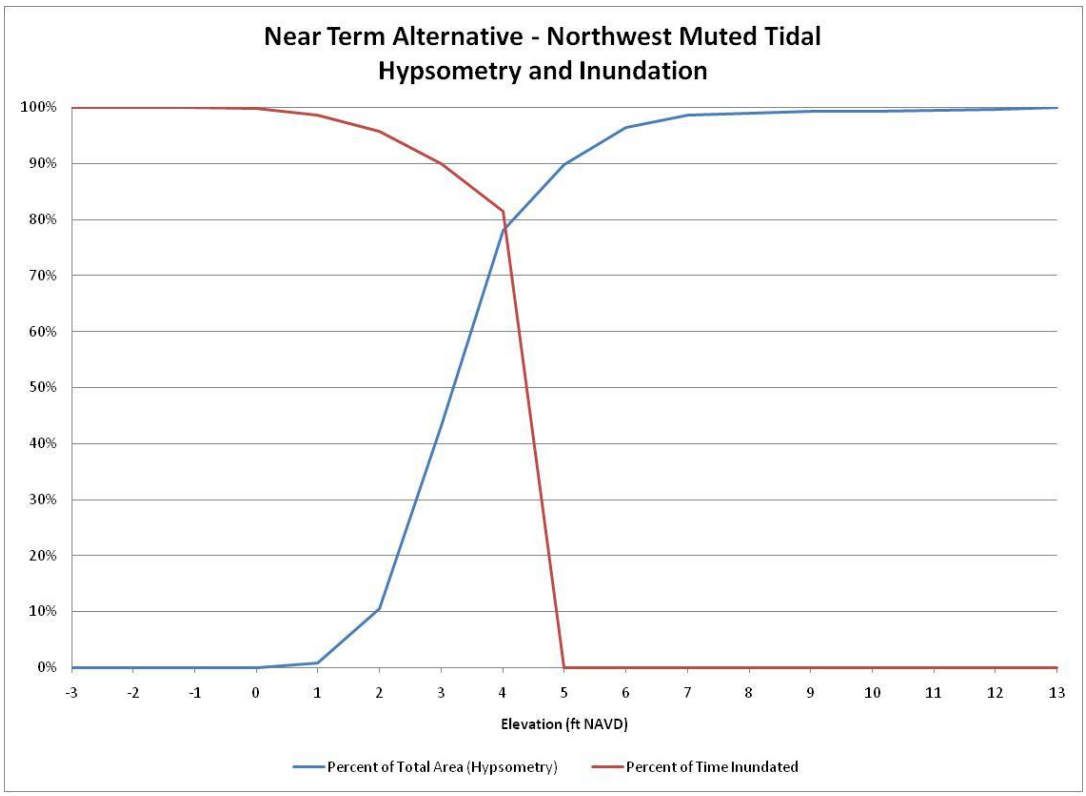
Table 9 Summary of IVA Scores for Preferred Alternatives

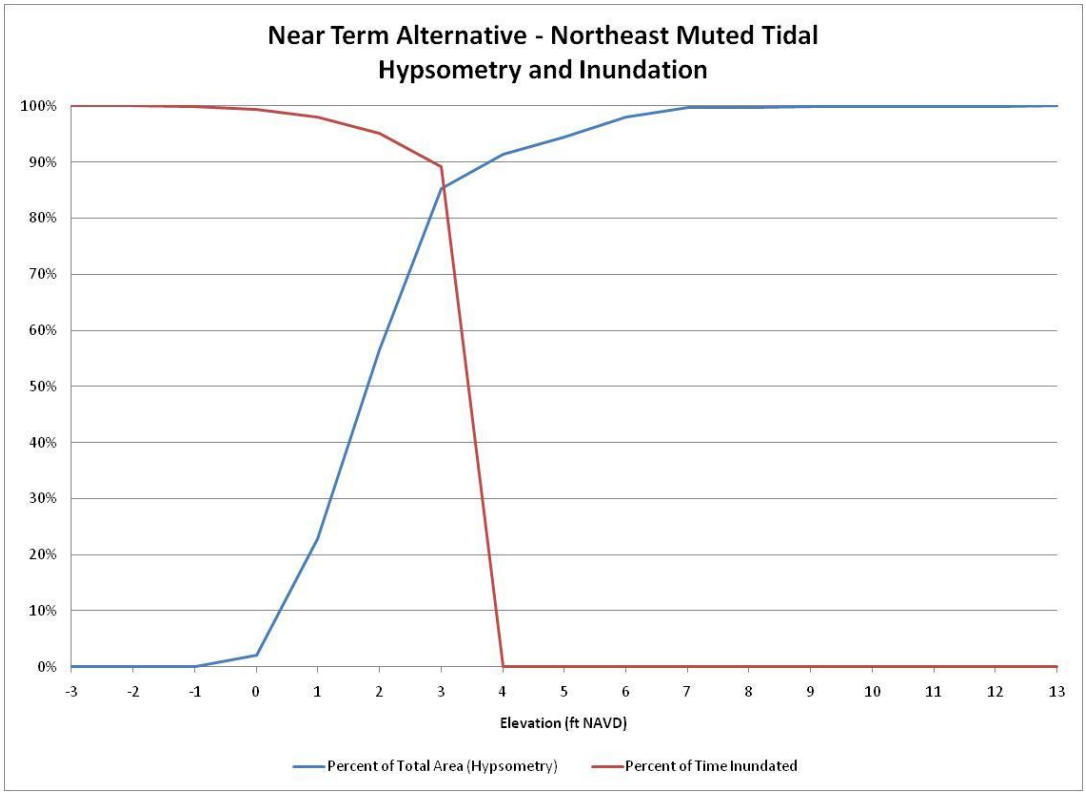
Site	Min IVA Score	Max IVA Score	Acres	Relative Value
NW Corner - Muted Tidal	27.3	40.3	121	3,303.3
NE Corner - Muted Tidal	25.6	70.4	124	3,174.4
E Side - Full Tidal	62.1	62.1	552	34,279.2
Central - Managed Drained	29.8	58.0	400	0.0
Near Term Subtotal				**40,756.9**
Long Term - Full Tidal		59.4	1213	72,052.2
Long Term Subtotal				**72,052.2**
N Tip	66.2	103.7	303	31,421.1
Option Subtotal				**31,421.1**

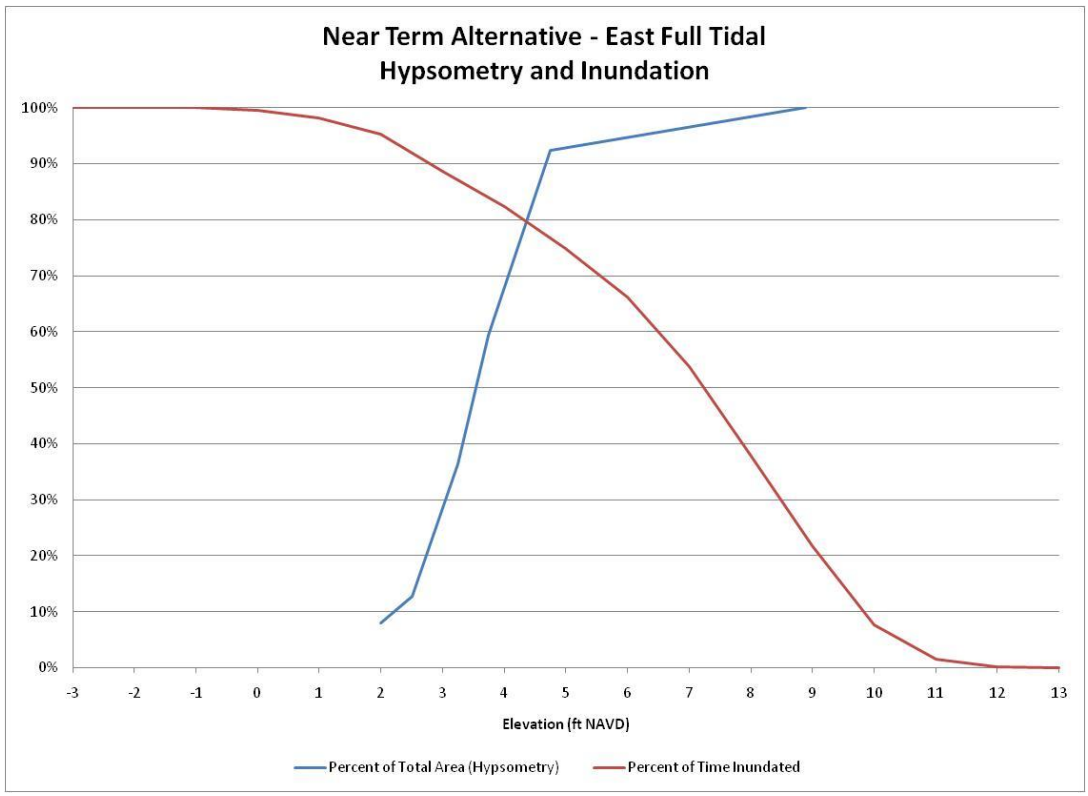
Inundation Frequency

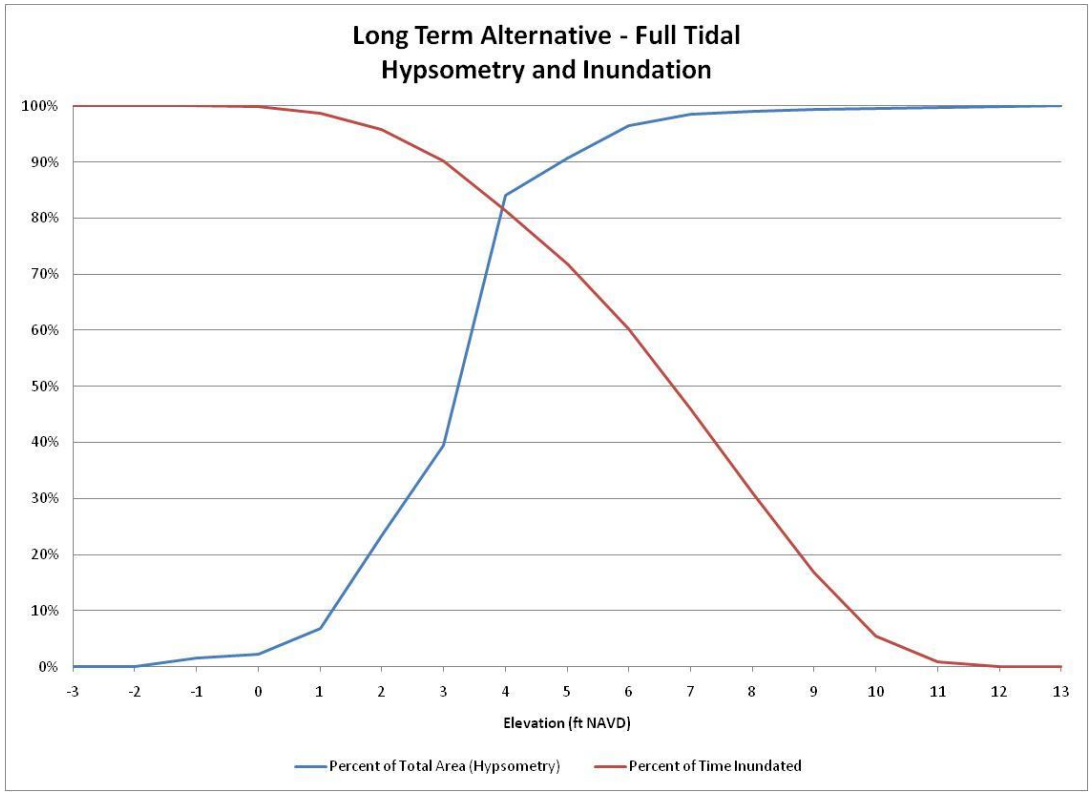
Water surface elevation data (at 10 minute intervals) from the Snohomish River during Water Year (WY) 2002 were used as an example of the anticipated fluctuations of river stage over the course of a normal year. We used these data to model inundation frequency across the sites proposed for full tidal restoration. For the muted tidal areas, we used water level elevation model output provided by ESA PWA based on the same WY 2002 data. The time series of water levels were summarized in a frequency distribution and compared to the current site elevations to predict the extent of land that would be flooded for a given percentage of time. This analysis was based on current site elevations and did not account for any habitat design features involving earthwork (channel excavation or marsh island creation) or the long term changes that will likely occur at the site (sediment accretion and scouring).

We found that in both the muted tide scenarios and the full tidal scenarios approximately 80% of the land area would be flooded 80 to 90% of the time (Appx x). The main difference is the depth to which these sites flood. In the full tidal areas of both the near and long term alternatives, the depth of the water across the site will vary continually, but 85% of the area will be inundated at a depth of at least 3 feet 40-45% of the time. In the muted tidal areas, only 1-2% of the land area will ever be flooded to a depth of 3 feet. Over time the ground surface elevation of the full tidal areas is expected to build up due to sediment accretion.


Near Term Alternative - Northwest Muted Tidal
Hypsometry and Inundation
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Elevation (ft NAVD)
Percent of Total Area (Hypsometry)
Percent of Time Inundated


Near Term Alternative - Northeast Muted Tidal
Hypsometry and Inundation
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Elevation (ft NAVD)
Percent of Total Area (Hypsometry)
Percent of Time Inundated


Near Term Alternative - East Full Tidal
Hypsometry and Inundation
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Elevation (ft NAVD)
Percent of Total Area (Hypsometry)
Percent of Time Inundated


Long Term Alternative - Full Tidal
Hypsometry and Inundation
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Elevation (ft NAVD)
Percent of Total Area (Hypsometry)
Percent of Time Inundated

Vegetation elevation distribution

Emergent marsh begins to establish at approximately +7 ft MLLW (City of Everett and Pentec 1997), below which mudflat habitat is predicted. This elevation corresponds to 4.75 ft NAVD. According to our analysis of the water level data on the mainstem, this elevation would be inundated approximately 75% of the time. In the near term muted tidal areas, none of the land is inundated 75% of the time; 78% and 85% of the area in the northwest and northeast areas, respectively are flooded over 80% of the time, and the rest is not flooded at all. Roughly 85% of the land in the long term alternative is lower than this inundation threshold.

Bird habitat / general guild preferences and amount of acres of each

Bird habitat on Ebey Island would change as a result of the proposed near or long term restoration alternatives. In the near term alternative, the managed drained portion in the center of the island would retain its current habitat value and would be expected to be used by geese and swans, passerine species, and raptors. The northeast and northwest muted tidal areas, which would be inundated at a shallow depth for a significant portion of time, would reallocate this wetland habitat from scrub-shrub wetland to mudflat bordered by emergent marsh. The increased frequency of flooding and low vegetation would greatly increase the use by waterfowl and shorebirds. Depending on the proportion of time the area is inundated, these areas may look similar to lentic habitats, which would attract a different composition of species.

The areas in which full tidal inundation is restored in the near term and long term alternative would, especially in the first several years, revert to mudflat habitat. While some shorebirds may use these new areas, they are generally found in higher densities in brackish mudflat areas due to the distribution of preferred prey.

The effect of tidal inundation on the spruce forest on the east side of the island is not well understood. Ground surface elevation data from this area is lacking, and our ability to predict whether these trees would survive or not is limited. Undoubtedly, this area currently represents unique habitat – it is the largest remaining stand of Sitka spruce in the Snohomish estuary and is utilized by a wide variety of bird and mammal species. If the perimeter dike is removed and the area becomes exposed to the fluvial and tidal processes it is likely that this habitat will change significantly and may cease to function in an optimal way for the more terrestrial species.

Fish Access to Site

To this point, our analysis has ignored the question of whether fish will be able to access the restored site. This is an important issue, particularly in the proposed muted tide systems that will rely on water control structures to modulate water level elevation behind the dikes. The response of outmigrating juvenile salmon to tide gates is still relatively unknown (Giannico and Souder, 2005). Despite recent

studies of passage success, and fine scale distribution of fish above and below tide gates, (there is little conclusive evidence regarding the degree to which fish are deterred from migrating into and out of tidal marsh habitat and what the implications of deterrence or delay might be in terms of fitness and survival. Fish passage requirements developed for culverts at stream crossings focus primarily on upstream adult passage.

Full tidal restoration

For the areas of full tidal restoration that are proposed in the near term and long term alternatives for Ebey Island, we assume that access to the site will be equivalent to a natural system. The full habitat opportunity resulting from restoration would be realized.

SRT and other tide gate alternatives

In the muted tidal areas, fish will not have unimpeded access to the site. Even if high quality habitat conditions were to be created in the muted areas, the habitat may not be fully utilized because of impeded access. The existing perimeter dike would remain in place, which means fish would only be able to gain access to the site through the culvert and tide gate structure. At low tide, the ability to access the restore marsh area and blind tidal channel network may not be much different than in a natural system, since the fish would only be able to enter through the wetted channel anyway. However, at high tide, where fish would normally be able to enter the inundated marsh across an extensive perimeter, the water control structures in the muted system will limit access to the habitat.

Research at the Elkhorn Slough National Estuarine Research Preserve has been done to study the plant and animal presence within areas of minimal, muted, and full tidal influence (Ritter 2006). Researchers there have concluded that full tidal exchange sites generally support the greatest number of species, but that the sites with muted or minimal tidal exchange harbor unique species and some threatened species. Overall, the mosaic of different habitats, ranging from minimal to muted to full tidal exchange, increased the overall biodiversity in the slough. Restoration projects in the Snohomish River estuary should therefore be viewed with the potential to benefit a variety of plants, fish, and other wildlife.

Bass reported that many researchers have studied the effect of tide gates on chemical and physical processes, but that no research describing their effects on fish movement and behavior had been published in peer-reviewed journals to date (Bass 2010). His research concluded that there were differences in frequency of Coho movement upstream and downstream through a top-hinged, side-hinged, and non-gated channel. While his studies did not include SRTs, his research included one or more leaky gates. He recommended that his work be considered a case study and the findings should not be assumed to be transferrable due to the great diversity of tide gate installations in use. He also recommended further research

While it is clear that fish access into and out of muted tidal systems will be limited compared to full tidal systems, this effect was not quantified because of the lack of relevant studies.

Percent time Open/Close

Output from the hydrologic modeling work - primarily a time series of water velocities through the tide gate for water year 2002 - was used to calculate the percent of time that the tide gate would be open and thus passable by fish in a given year.

The specific design criteria of the self-regulating tide gate unit have not been fully identified. In the meantime, we used basic criteria to illustrate the effect that a generic SRT tide gate would have on fish access. In reality, there are several design techniques that could potentially be employed to improve fish access. These are discussed elsewhere in the report.

To perform this calculation, we assumed that whenever the water level on the outside of the gate (either in the mainstem Snohomish River or Ebey Slough for the West and East muted tidal areas, respectively) is lower than or equal to the water level inside the gate, then the gate would be open and water would flow out of the site. When the water level outside the gate is higher than the water level inside the gate, the gate will remain open and water will flow back in until a certain water level is reached inside the gate. At this point, the gate will close and prevent fish from entering or exiting the site.

If the muted tidal system on the East side of Ebey Island closes when water level elevation reaches 2.5 ft (NAVD), then the gate is open only 12.0% of the year. On the West side of Ebey Island, if the gate closes when outside water level reaches 4.0 ft (NAVD), then the gate is open 23.7% of the year.

If only the outmigration period (March 1 through June 15) is used for the calculation, the East gate would be open for **11.0%** of the time, and the West gate would be open for **23.0%** of the time.

Modeled velocities through gate

Simply because the gate is open does not necessarily mean that fish will be able to volitional pass through the culvert into or out of the marsh. Juvenile salmon are generally weak swimmers due to their small size. The head pressure differential and the size of the culvert opening both affect the velocity of the water passing through the culvert. In Oregon, state guidelines for volitional passage through culverts by juvenile salmonids recommend that flows be limited to no greater than 2 feet per second (Stahl 2006). NMFS has not developed guidelines specifically for tide gates but recommends average velocities of less than 1 foot per second for juvenile passage through culverts (NMFS 2008).

The amount of time that both the tide gate was open and velocities through the culvert were below 2 ft/s was only 4.6% of the year (**6.2%** during outmigration) for the East tide gate and 13.8% of the year (**16.0%** during outmigration) for the West tide gate.

Of course it is possible that juvenile salmonids and other fish could pass through the gate, in one direction or another, if they allow themselves to be sucked through in the direction of the high velocity flow. In this case, we calculate the percentage of time a fish could enter the muted tidal marsh separately from when it could exit the tidal marsh. At the East tide gate, fish could swim or be swept IN to the area 5.4% of the year, and OUT of the area 6.3% of the year. During the outmigration time period this would be 4.8% and 5.8% in and out, respectively. At the West tide gate, fish could swim or be swept in to the area 9.5% and out of the area 13.6% of the time. During outmigration, this would be 9.2% and 12.9% in and out, respectively.

Design modifications to the tide gates and dikes, such as small orifices and “pet-doors,” could greatly increase the potential for fish access. These features allow a small volume of water to continually enter the site at a rate low enough to avoid substantial changes to the water level elevation across the site (Giannico and Souder 2005).

Thresholds for access?

Clearly access to a tidal marsh is limited by the presence of tide gates. But when using this information to quantify this effect, the question becomes: how much time does a fish require to get through? If juvenile Chinook salmon migrate downstream and seek tidal marsh habitat, how long will they wait at the mouth of a channel to gain access before moving on? A better understanding of outmigrant behavioral patterns is needed to appropriately quantify the impact of temporary blockages to juvenile fish passage.

One way to calculate the reduced habitat capacity of a muted tidal marsh is to discount the number of fish that would be expected to use the same area under fully restored conditions by the percentage of time access is available. This is a rather simplistic approach that does not consider any time thresholds for passage nor does it consider modified ecological setting behind the perimeter dikes.

5.2.5.2 Results of Ecological Effects Analysis

Area × Density × Access Calculations

To summarize the potential benefits to Chinook salmon of restoration on Ebey Island, we combined the values for usable habitat area, smolt capacity, and site accessibility that were discussed above and calculated the annual number of smolts that would be produced by the near and long term alternatives, and the north tip option (Table 10). Under the near term alternative, we predict that the proposed land use changes would provide rearing habitat for approximately an additional 53,000 to

264,000 juvenile Chinook per year. Full implementation of the long term alternative could provide habitat for roughly 263,000 to 1.32 million juvenile Chinook salmon. The option to restore the north tip of Ebey Island could provide habitat for 17,000 to 87,000 smolts.

Table 10 Habitat and Fish Production Estimates for Preferred Alternatives.

Alternative	Sub-Area	Total Area		Channel Habitat	Access	Juvenile Chinook Capacity	
		(acres)	(hectares)	(hectares)		High	Low
Near Term	NW Muted	114	46	1.76	23%	4,050	810
	NE Muted	96	39	1.33	11%	1,461	292
	E Full	574	232	25.86	100%	258,596	51,719
	Center Drained	400	162	0.00	0%	0	0
Total		1184	479	28.95		**264,108**	**52,822**
Long Term	Full Tidal	1500	607	131.52	100%	**1,315,241**	**263,048**
Option	North tip	300	121	8.73	100%	**87,262**	**17,452**

Other Species

Of all the salmon species, coho salmon will benefit the most from muted tidal areas. Low velocity, off-channel areas such as oxbows and beaver ponds provide optimal habitat for rearing coho, as long as water quality (temperature, dissolved oxygen, etc.) and food supply remain adequate. Coho, like Chinook salmon, will also benefit from the restoration of full tidal freshwater areas.

The proposed restoration alternatives will likely lead to a shift in the bird species assemblages that use the area because the habitat and food types will change. Full tidal areas that create intertidal mudflat may lead to an increased proportion of shorebirds. Muted tidal areas that are frequently flooded to shallow depths will provide an extensive amount habitat for waterfowl. Similarly, the managed drained area will continue to provide benefits for waterfowl and geese. Raptors and cavity dwelling birds may lose habitat and the small mammals, reptiles and amphibians that serve as their food base if the existing forest is lost due to tidal inundation; however, some snags near the marsh will provide valuable perches for bald eagles, osprey and hawks.

Inundation and Depth Frequency

In this early, feasibility stage of design, the hydraulic dynamics across the marsh plane have not been modeled in great detail. Therefore, predicting the ecological response of these sites is difficult. Furthermore, the current modeling effort is based on the existing hypsometry of these sites, but most parties agree that earthwork will be an integral part of any restoration process, either excavating “starter” channels and/or piling up material to encourage emergent vegetation and expand edge

habitat. Subsequent levels of design detail will undoubtedly rely on an iterative process between the engineers, hydrodynamic modelers, and biologists to optimize ecological benefits of the site.

Site Evolution

The two natural processes that will be expected to drive site evolution toward equilibrium conditions are tidal (daily) and fluvial (annually and episodically). The tidal prism, or the volume of water that flushes the site during a given tide cycle, is significantly reduced in the proposed muted areas, which means that rates of sediment deposition on the marsh plane, scouring in the channels and the supply of nutrients to the estuarine food web will also be reduced. The connectivity to fluvial processes, represented as the proportion of river edge to marsh area, is also significantly reduced in the muted tidal areas. The perimeter dikes that are left in place will prevent large wood and flood-borne sediments from accumulating across the muted marshes. Because of the limited connection of the muted tidal sites to these two essential processes, the expectations for site evolution should be significantly revised from those developed for the other, fully restored areas.

6.0 CONCLUSIONS AND RECOMMENDED NEXT STEPS

The Ebey Island Habitat Restoration Feasibility Study will conclude with the release of a final version of this report before May 1, 2011. A final (for this phase of the project) 2.5 hour-long meeting will be held with the Advisory Committee in the evening of March 15, 2011. The meeting will be held at the Mill Creek, WA office of the Washington Department of Fish and Wildlife, and will be open to the general public. More details can be found here:
http://wdfw.wa.gov/lands/wildlife_areas/snoqualmie/restoration_study.php

This draft report is intended to convey the preliminary findings of the consulting team to WDFW and Advisory Committee members, so that a greater portion of the March 15 meeting can be devoted to a discussion of the study's findings and the best path forward. Because this report is a draft, and has not been thoroughly vetted or subjected to final editing, it is not meant to be distributed widely or serve as an authoritative source of information. The report will be revised as additional information comes to light over the next several weeks. In particular, we hope to use feedback received from the Advisory Committee to inform the conclusions and recommendations presented in the final report.

The Advisory Committee comprises individuals from diverse backgrounds who share an interest and have been willing to devote significant time to exploring restoration alternatives for the 1,237 acres of Ebey Island land owned by the WDFW. The agency has endeavored to engage stakeholders in the process and, to the extent practicable, address their concerns in the development of a habitat restoration strategy for the Ebey Island property. Members of the Advisory Committee have responded positively by participating in meetings and fieldtrips to the project site, keeping themselves

and others informed on project matters, engaging in debate with their fellow Advisory Committee members, and providing meaningful feedback to the project team.

Bearing in mind that the feasibility study is as yet incomplete, and taking into consideration the facts and analysis presented in this report, several conclusions can be made.

From a technical standpoint, it is feasible to restore high quality estuarine habitat on the WDFW-owned land on Ebey Island. Referring to the degree to which tidally influenced components and processes can be reestablished on the property, restoration can be either partial or complete. Partial restoration refers to restoration that is limited in time or space, resulting in improved, but not ideal, ecological conditions.

Of the 14 conceptual alternatives developed in this study, two were identified as being more desirable than the others and subjected to further analysis. These two “preferred” restoration alternatives would enable water to flow in and out of land located on the inboard side of the existing dike, resulting in tidally influenced habitat and making it possible for salmonids to access the new habitat. The long-term alternative would result in habitat restoration that allowed for full tidal exchange and restoration of many natural processes; the near-term alternative would result in habitat restoration that allowed for a muted tidal exchange and restoration of fewer natural processes. Nevertheless, both alternatives would yield tangible ecological benefits.

The long-term alternative would entail setting back existing dikes so that the entire WDFW site would be under water for at least a portion of each day, the depth of water depending on prevailing river flows and tidal action. This alternative will have direct and adverse impacts on existing agricultural values, and therefore is considered less socially feasible at present. However, implementation of this restoration alternative in the future would be expected to yield significant benefits. Those benefits would be directly proportional to the ecological health of the surrounding estuary; the more degraded the estuary, the greater the relative benefit of restoring Ebey Island. Because existing conditions within the estuary are suboptimal, and the abundance of species such as Chinook salmon that depend on estuarine habitat is depressed, the net benefit of implementing the long-term restoration alternative in the not-too-distant future is considerable.

Regardless of the timing of its implementation, the long-term alternative would yield even greater benefits if it were implemented in conjunction with other large-scale restoration actions in the Snohomish River estuary. Acquiring and restoring nearby properties would amplify the ecological benefits and achieve greater cost efficiencies. One such project – the acquisition and restoration of the north tip of Ebey Island – was examined in this study. We concluded that removing approximately 14,000 lineal feet of existing dike and building a shorter length of new dike across the north tip of

Ebey Island would be relatively inexpensive, cause minimal impact to existing agricultural and recreational values, and result in over 300 acres of new, high quality estuarine habitat in a key juvenile salmon rearing zone of the Snohomish River estuary. This option could be pursued either independently or in tandem with the restoration of the WDFW-owned property on Ebey Island.

The near-term habitat restoration alternative represents an attempt to blend the ideal with the practical; in this case a majority of the existing agricultural land and infrastructure is protected, while the relatively unutilized section of land to the east of the Olympic pipeline, totaling over 400 acres, would be fully restored by constructing a new dike adjacent and parallel to the pipeline. New water control structures and small dikes inside of the island (surrounding approximately 200 acres) would be constructed to facilitate muted tidal exchange under the near-term restoration alternative.

Based on the amount of new habitat that would be created, our first order estimate of the number of juvenile Chinook salmon that would be produced annually as a result of implementation of the near-term restoration alternative is roughly 53 to 264 thousand smolts per year. For the long-term restoration alternative, we estimate that between 263 thousand and 1.32 million Chinook salmon smolts would be produced annually. The option to restore the north tip of Ebey Island would provide habitat for 17 to 87 thousand smolts.

Although both preferred alternatives were deemed feasible from ecological standpoint, they would nevertheless require significant financial capital to implement. Also, from the societal standpoint, several important questions remain unanswered. However, good progress has been made in this area, and there is general support for progressing to the next phase of the project.

For the project to move forward into the permitting and implementation phase, additional information will be required on its potential effects. The Project Team will develop a proposal that identifies the desired information and the best means of obtaining it. To aid us in our planning efforts, we have compiled a list of questions addressed to the Advisory Committee. The responses to these questions will be discussed at the March 15 Advisory Committee meeting. The questions are restated below:

1. Did the Project Team provide sufficient information and opportunities for the Advisory Committee to thoughtfully evaluate and discuss the habitat restoration alternatives and potential paths forward? Specifically, did the Feasibility Study:
    a. Include key stakeholders and provide opportunities for them to express their interests and concerns?
    b. Incorporate Advisory Committee input into the development and evaluation of the alternatives?

c. Provide information that could be used to evaluate the different habitat restoration alternatives, including their effects on ecological and societal values (e.g., fisheries, agriculture, recreation, and wildlife)?

2. Generally, what is your view of the near- and long-term habitat restoration alternatives?

    a. Does the near-term alternative provide a viable outline for a restoration project in the next ten years?

    b. Does the long-term alternative provide a viable outline for a future restoration project?

    c. Do you have specific recommendations that would improve the near- or long-term alternatives for Ebey Island?

    d. Is the North Tip Ebey Island option worth pursuing?

3. What should be the next steps?

    a. Does the Feasibility Study provide a clear path to a restoration project that balances competing values?

    b. If not, what additional information, processes, or steps would be helpful in developing such a path forward?

This report will be updated to reflect the conclusions and recommendations of the Advisory Committee.

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APPENDIX A:
PRELIMINARY GEOTECHNICAL REPORT

Ebey Island Habitat Restoration Feasibility Study

Snohomish County, Washington

Prepared for:

Washington Department of Fish and Wildlife
600 Capitol Way N.
Olympia, WA 98501-1091

Prepared by:

AMEC Earth & Environmental, Inc.
11810 North Creek Parkway North
Bothell, Washington 98011

February 14, 2011

Project No. 0-915-16971-0

February 14, 2011
0-915-16971-0

Washington Department of Fish and Wildlife
600 Capitol Way N.
Olympia, WA 98501-1091

Attention: Mr. Richard Tveten

Subject: Preliminary Geotechnical Report
Ebey Island Habitat Restoration Feasibility Study
Snohomish County, Washington

Dear Mr. Tveten:

AMEC Earth & Environmental, Inc. (AMEC), is pleased to submit this report describing our geotechnical engineering evaluation for the above-referenced project. The purpose of our geotechnical evaluation was to derive preliminary design conclusions and recommendations concerning the feasibility of dike geometry and construction.

As outlined in our proposal dated January 18, 2001, our scope of work comprised geotechnical research, supplemental field exploration, geotechnical analyses, and report preparation.

SITE AND PROJECT DESCRIPTION

The project site is located on Ebey Island, approximately 1 mile east of Everett, Washington. Washington Department of Fish and Wildlife properties are irregularly shaped parcels concentrated in the northern half of Ebey Island and are generally bounded by SR 2 on the north, Ebey Slough on the east, private properties on the south and west, and by City of Everett and WSDOT properties in the northwest. Ground surface elevations are near or at sea level. Levees border Ebey Slough in the site vicinity and rise approximately 12 feet above existing ground surface.

Most of Ebey Island is used for agricultural purposes with isolated residences and barns scattered across the island. An above-grade water pipeline is located to both the north and south of the subject properties traversing east-west, and a below-grade petroleum pipeline crosses the east side of the subject properties traversing northeast-southwest.

Vegetation across the sites consists of tall grasses with isolated trees throughout the grass-covered areas. A relatively large forested area is located on the east side of the subject properties with vegetation consisting of trees, vines, and brush at elevations above the high-tide elevations. Nearby fields are utilized as crop lands.

Ebey Slough is the largest water feature in the vicinity and runs north south across the eastern edge of the subject properties. Smaller sloughs, such as Deadman Slough, are located across the site. These sloughs are influenced by tidal fluctuations and are generally low-gradient waterways and are prone to periodic flooding activity.

The enclosed *Site & Exploration Plan* (Figure 2) illustrates these site boundaries and adjacent existing features. Preliminary plans include construction of partial or full height protection dikes across the mid sections of Ebey Island, where no significant filling has occurred in the past, and very soft and deep peat soils have been reported. During the first stage of the project, several diking alternatives are being evaluated.

EXPLORATORY METHODS

We explored surface and subsurface conditions at the project site during June, 2010. Our exploration and testing program comprised the following elements:

- A visual surface reconnaissance of the site;
- Five Cone Penetration Test (CPT) soundings (designated CPT-1 through CPT-5) advanced at strategic locations across the site;
- A review of the logs and CPT soundings advanced along the SR 2 trestle for the City of Everett Public Works Departments “Everett Waterline Replacement Project-Phase 6” project by ZZA dated October 11, 2004;
- A review of four geotechnical reports from Olympic Pipe Line Company for the petroleum pipe line that crosses the east side of Ebey Island traversing northeast-southwest, by GeoEngineers, dated October 15, 1996, January 22, 2002, and March 10 and November 19, 2004 August, 1991; and
- A review of published geologic maps.

Table 1 summarizes the approximate functional locations, and termination depths of our CPT soundings, and Figure 2 depicts their approximate relative locations. The following text sections describe our procedures used for soil borings and observation well installations.

Table 1 Approximate Locations, and Depths of CPT Soundings

Exploration	Functional Location	Termination Depth (feet)
CPT-1	NW corner of Ebey Island	50.2
CPT-2	NW corner of Ebey Island, approx. 950 ft west of Homeacres Road	50.2
CPT-3	Central portion of Ebey Island, approx. 2,700 ft north of Alexander Property (Barn)	50.2
CPT-4	Central portion of Ebey Island, approx. 1,200 ft north of Alexander Property (Barn)	50.2
CPT-5	East side of Ebey Island, approx. 2,100 ft east of Alexander Property (Barn)	49.9

The specific number, locations, and depths of our explorations were selected in relation to the existing and proposed site features, under the constraints of surface access, underground utility conflicts, and budget considerations. We estimated the relative location of each exploration by measuring from existing features and scaling these measurements onto a layout plan supplied to us by Washington Department of Fish and Wildlife. Consequently, the data listed in Table 1 and the locations depicted on Figure 2 should be considered accurate only to the degree permitted by our data sources and implied by our measuring methods.

It should be realized that the explorations performed for this evaluation reveal subsurface conditions only at discrete locations across the project site and that actual conditions in other areas could vary. Furthermore, the nature and extent of any such variations would not become evident until additional explorations are performed or until construction activities have begun. If significant variations are observed at that time, we may need to modify our conclusions and recommendations contained in this report to reflect the actual site conditions.

CPT PROBING PROCEDURES

Our exploratory CPT probings consisted of advancing an electric cone penetrometer piezocone, using a track-mounted probe rig operated by an independent firm working under subcontract to AMEC. CPT probes were advanced while electronic monitoring equipment in the probe rig automatically logged the subsurface conditions. After each probing was completed, the probehole was backfilled with a mixture of sand and bentonite chips.

Throughout the probing operation, soil and groundwater properties were measured by means of the CPT per ASTM:D-3441. This testing procedure involves pushing an electric piezocone mounted on 1.5-inch diameter cylindrical steel rod into the soil with hydraulic rams. The cone consists of a standard design having a 60-degree tip apex, a 10-cm^2 projected area at the tip, a 150-cm^2 sleeve, and a porous element at the tip. The cone was advanced at a rate of approximately 2 cm per second, and the cone tip resistance (q_T), sleeve friction (f_s), and penetration porewater pressure (u_2) were

recorded continuously during the tests. As the penetrometer is pushed downward, the tip resistance, sleeve friction, and porewater pressure are measured electronically and plotted as a function of depth. Through interpretation, the resulting graphs can reveal soil types and groundwater levels, as well as the relative density of granular soils and the relative consistency of cohesive soils.

The enclosed CPT graphs present the vertical plots of several soil properties and groundwater pressures measured by the cone penetrometer in each probing. These graphs also depict the Standard Penetration Resistance (N_{60}) corresponding to each test interval, based on published conversion charts. The enclosed *Probing Logs* describe the vertical sequence of soils encountered in each probing, based primarily on interpretation of the CPT graphs and supported by correlation with our logs of nearby borings.

SITE CONDITIONS

The following sections of text present our observations, measurements, findings, and interpretations regarding development, utility, surface, soil, groundwater and seismic conditions at the project site.

DEVELOPMENT CONDITIONS

Most of Ebey Island is used for agricultural purposes with isolated residences and barns scattered across the island. An above grade water pipeline is located to both the north and south of the subject properties traversing east-west, and a below grade petroleum pipeline crosses the east side of the subject properties traversing northeast-southwest. Although not observed, the presence of utilities corridors along the existing roadway alignments should be assumed.

SURFACE CONDITIONS

The Washington Department of Fish and Wildlife properties are irregularly shaped parcels concentrated in the northern half of Ebey Island and are generally bounded by SR 2 on the north, Ebey Slough on the east, private properties along the Snohomish River on the south and west, and by City of Everett and WSDOT properties in the northwest. Ground surface elevations are near or at sea level. Levees border Ebey Slough and the Snohomish River in the site vicinity and rise approximately 12 feet above existing ground surface.

SOIL CONDITIONS

According to the published geologic map of the Ebey Island area, *Geologic Map of the Everett 7.5 minute Quadrangle, Snohomish County, Washington* (Minard, 1985), soil conditions in the site vicinity are characterized by Peat deposits (Qp) and Alluvium (Qal). The Peat deposits are composed predominantly of organic matter consisting of plant material and woody debris and occasionally contain small amounts of sand, silt, clay, and volcanic ash deposited in swamps and bogs. The

Alluvium deposits are composed of clay, silt, very fine to fine sand, and abundant organic material deposited by streams and running water. Glacial soils including till, recessional outwash, and advance outwash are mapped within upland areas to the south, east, and west. No glacial units are mapped within the subject property.

Our on-site explorations revealed similar near-surface soil conditions as the mapped stratigraphy. In general, the results of our CPT soundings showed that compressible soils consisting of peat and silty clay underlie the site(s). The silty clay was predominantly very soft to soft with occasional zones that would be described as medium stiff. These compressible soils were encountered to a depth of about 17.5 feet below existing grade in the NW corner of the Ebey Island (CPT-1) and were underlain by predominantly medium dense to dense sand and silty sand with occasional interbedded layers of medium stiff to stiff clays and silts. The compressible peat and clay was encountered in the other four CPT soundings to the full depth explored (50 feet below existing grade) with the peat generally encountered within the upper 15 feet.

AMEC obtained the subsurface information in the form of borings logs and a cross section for the City of Everett Public Works Departments “Everett Waterline Replacement Project—Phase 6” project. These explorations traverse E-W along the north side of Ebey Island parallel to the HWY 2 trestle. The soils underlying the waterline alignment west of Homeacres Road generally consist of about 20 to 25 feet of compressible soils consisting of peat and very soft to soft clayey silt, sandy silt, organic silt, and silty clay. East of Homeacres Road, these same compressible soils were generally encountered up to 80 to 120 feet below existing grade. Along the entire alignment, the peat was generally encountered within the upper 20 to 30 feet. The compressible soils were underlain by medium dense to dense sand, gravelly sand, and sandy gravel. A cross-section illustrating these subsurface conditions is presented in Figures 3A through 3C.

AMEC obtained four geotechnical reports from Olympic Pipe Line Company for the petroleum pipe line that crosses the east side of Ebey Island traversing northeast-southwest. Compressible soils consisting of very soft to soft peat, silt and organic silt were encountered to depths of about 50 to 90 feet below existing grade. The compressible soils were underlain by medium dense sand and silty sand and medium stiff to stiff silt.

We interpret these soils to be above their optimum moisture contents, and to be highly sensitive to moisture content variations. These soils are moisture sensitive and would be impossible to use as structural fill due to the presence of abundant organic material

GROUNDWATER CONDITIONS

Groundwater measurements were not taken during our CPT soundings. However, based on the geotechnical information provided in the City of Everett Public Works Departments "Everett Waterline Replacement Project—Phase 6" project and the four geotechnical reports from Olympic Pipe Line Company for the petroleum pipeline that crosses the east side of Ebey Island traversing southwest and northeast, groundwater was encountered at various depths ranging from within 1 to 2 feet of the ground surface to as deep as 88 feet below ground surface. Shallow groundwater depths were observed in the north end of Ebey Island, whereas groundwater was generally encountered much deeper toward the south.

SEISMIC CONDITIONS

The soils beneath the site consist of peat deposits and alluvium overlying mostly medium dense to dense and silty sand (older alluvium). In accordance with 2006 *International Building* Code Table 1613.5.2, we recommend using Site Class D, due to the relatively soft condition of the upper 100 feet of soil (based on geologic maps and our explorations).

The following maximum considered spectral accelerations should be used to determine the design response spectrum, per Figure 1613:

Spectral Acceleration for short periods (Ss):	114 percent of gravity (1.143g)
Spectral Acceleration for a 1-second period (S1):	40 percent of gravity (0.397g)

A value of 0.90 should be used for site coefficient Fa and 2.412 for site coefficient Fv.

The peak ground acceleration for the site was determined using the U.S. Geological Survey Website (http://earthquake.usgs.gov/research/hazmaps/design/) and the project area latitude and longitude. According to current USGS mapping, the peak ground acceleration for a 10 percent probability of exceedance in 50 years (475 year return period) is 0.28g.

LIQUEFACTION ANALYSIS

Liquefaction is a sudden increase in porewater pressure and a sudden loss of soil shear strength caused by shear strains, as could result from an earthquake. Research has shown that saturated, loose sands with a fines (silt and clay) content less than about 25 percent are most susceptible to liquefaction. The soils are not likely to liquefy during an earthquake due to the relatively high silt and clay content of the upper alluvial soils and the density of the deeper, older alluvial soils.

CONCLUSIONS AND RECOMMENDATIONS

Preliminary plans include construction of partial or full height protection dikes across the mid sections of Ebey Island, where no significant filling has occurred in the past, and very soft and deep peat soils have been reported. During the first stage of the project, several diking alternatives are being evaluated. We offer the following preliminary geotechnical conclusions and recommendations concerning this improvement project.

We understand that a full height cross dike will be about 13 to 15 feet high and smaller muted tidal exchange dikes will be about 6 to 8 feet high. The crown for both dikes will be a minimum of 10 feet wide for access and have side slopes of 2H:1V. Based on our review, the construction of new dikes is feasible, with the following considerations:

SITE PREPARATION AND GRADING

Preparation of the project site should involve temporary drainage, clearing, subgrade compaction, and construction of access roads. The paragraphs below discuss our preliminary geotechnical comments and recommendations concerning site preparation.

Prior to site development, the contractor should install a temporary erosion control system to divert runoff away from the areas to be exposed during grading, and to prevent sediments from being transported off the site. Also, the contractor should make provisions for the interception and diversion of any groundwater seepage entering the work areas. After surface and near-surface water sources have been controlled, the construction areas should be cleared of all trees and bushes and, where possible, the grass mat should be closely mowed. Grubbing should be performed to remove any localized larger stumps or root wads. We do not recommend stripping the grass sod or topsoils since the underlying disturbed, soft organic silts will be difficult for heavy equipment to operate upon.

Due to the soft nature of near surface soils across the site, it may be necessary to use special, low-impact, track-mounted vehicles to perform most of the earthwork. Additionally, it will likely be necessary to temporary construction roads using reinforcement geogrid, or lightweight fills, such as hog-fuel, shells, or lightweight rock (pumice or scoria). Typical construction traffic across the existing ground would likely destroy the surface, resulting in severe rutting or even the possible loss of equipment.

DIKE CONSTRUCTION

Following clearing and grubbing, we recommend that a layer of soil stabilization geotextile per WSDOT 9-33.2, Table 3, Soil Stabilization, Non Woven be installed on the native ground prior to the placement of new fill. Fill placed atop the separation fabric should be constructed by advancing a

single initial soil lift with a dozer. In no case should dump trucks or other heavy equipment operate directly upon the native subgrade or separation fabric. We would recommend an initial, loose lift thickness of 2 feet be placed by this method. Subsequent filling should be accomplished by spreading level lifts not exceeding 1 foot in loose thickness, with each lift compacted to at least 90 percent density, using ASTM:D1557 as the standard.

Since the foundation soils are very soft and nearly saturated, rapid fill placement during levee construction would likely cause bearing capacity failures of foundation soils. Therefore, we recommend that both the new and expanded levees be constructed in two or three stages to avoid potential bearing capacity failure of foundation soils. We estimate that 6 to 7 feet of fill can be constructed and left in place following the site preparation. The first stage fill should remain in place for approximately 1 year prior to the placement of the remaining fill. During the 1-year period, the foundation soil will consolidate and regain most of its drained strength. Settlement plates should be installed along the levees to monitor the progress of consolidation of the foundation soils.

We anticipate that approximately 2.5 to 5 feet of overfill would need to be added during initial construction to account for the primary consolidation of the foundation soils within the first 2 years. The estimate for future settlement, i.e. the actual amount of overfill, can be more accurately refined following the settlement observation of the first stage levee construction.

STRUCTURAL FILL

On-Site Soil Considerations: The on-site soils that would be excavated from the channels have elevated moisture contents, are high in organic matter, and would require significant drying in order to re-use as structural fill. While these soils would not be suitable for use as structural fill within the new levees, they could be used in the berms that would be constructed within the habitat area, or as organic topsoil material on the side slopes of the levees.

Borrow Sources: According to the US Army Corps of Engineers Engineering and Design Manual for the Design and Construction of Levees (EM-1110-2-1913), there is no specific requirement for levee borrow material. Section 4-2a of the manual states that “almost any soil is suitable for constructing levees, except very wet, fine-grained soils or highly organic soils.” Most of the near-surface on-site soils meet the description of very wet, fine-grained, or highly organic soils and would therefore not be a suitable borrow source. At this time, we are not aware that a possible borrow source of “low-permeability” soils has yet been identified.

As the sources of imported material are identified, we recommend conducting at least two grain size distribution tests and two Proctor compaction tests for soils obtained from each borrow source. In addition, we recommend conducting a direct shear test on soil samples prepared by using standard

Proctor compaction (ASTM D-698) for each borrow source to verify the design shear strength of the levee soils. If desired, the hydraulic conductivity of the compacted soils can be determined by a series of laboratory permeability tests for seepage analysis purposes.

EROSION CONTROL

We anticipate that 2H:1V slopes would be feasible on embankments not exposed to water, assuming the embankment is fully compacted and is protected from erosion with continuous grass vegetation cover. On the other hand, embankment slopes that are inundated by water could experience surficial erosion or sloughing under sudden drawdown conditions. For several of the alternatives considered on this project, both sides of the embankment would be inundated by water with fluctuating water surfaces. We anticipate that these water-side embankments will need to be on the order of 2.5H:1V or flatter. We would recommend that slopes exposed to water be blanketed with a 1-foot layer of quarry spalls per WSDOT 9-13.6, or shoulder ballast, per WSDOT 9-03.9(2). A geotextile fabric (per WSDOT 9-33.2, Table 1, Moderate Survivability, Non Woven and Table 2, Class A) should be placed beneath the crushed rock armoring, to provide separation and to limit fines migration out of the embankment. It may be feasible to protect the slopes with permanent erosion control fabric and a thick grass vegetative cover. However, in our experience, there may be a need for periodic maintenance using additional planting, or by placing shoulder ballast or quarry spalls in failed areas. If quarry spall facing is not permitted, vegetated slopes of 3H:1V or flatter would be required.

If portions of the dike are also to be protected from periodic overtopping, more extensive armoring and flatter slope inclinations may need to be considered. NCRS has recommended slopes as flat as 5H:1V with thick grass vegetation to protect against uniform overtopping of a dike. If concentrated flow is directed to a portion of the dike as an emergency spillway, heavy rock armoring or concrete facing would need to be considered.

FUTURE MAINTENANCE

Due to the anticipated long-term settlement, additional fill may be required to maintain the design heights of the dikes. Surficial erosion and sloughing may occur on the slope, especially following a rapid drawdown event. As a result, periodic repair of the slope and restoration of vegetation may be necessary. We would recommend the slope conditions be examined after each major rainstorm (or at least monthly) for the first year after construction. Less frequent visits (semi-annual or quarterly) would be anticipated in the future.

RECOMMENDATIONS FOR GEOTECHNICAL DESIGN PHASE

After the preferred alternatives have been established, we should be retained to perform a design-phase geotechnical evaluation. Such an evaluation should include advancing additional borings along

the new dike alignments, conducting laboratory tests, performing geotechnical engineering analyses including slope stability, seepage, and settlement analyses of the dikes, and preparing a *Geotechnical Engineering Report*.

CLOSURE

The preliminary conclusions and recommendations presented in this report are based, in part, on the explorations that we performed for this study. If our design-phase geotechnical explorations reveal significant variations in subgrade conditions, we may need to revise these conclusions and recommendations. AMEC would be pleased to submit a proposal for a design-phase evaluation after building locations and details have been established.

We appreciate the opportunity to be of service on this project. If you have any questions regarding this report or any aspects of the project, please feel free to contact our office.

Sincerely,
AMEC Earth & Environmental, Inc.

CARLO EVANGELISTI
STATE OF WASHINGTON
43063
REGISTERED
PROFESSIONAL ENGINEER

14 Feb 11

Carlo Evangelisti, P.E.
Senior Engineer

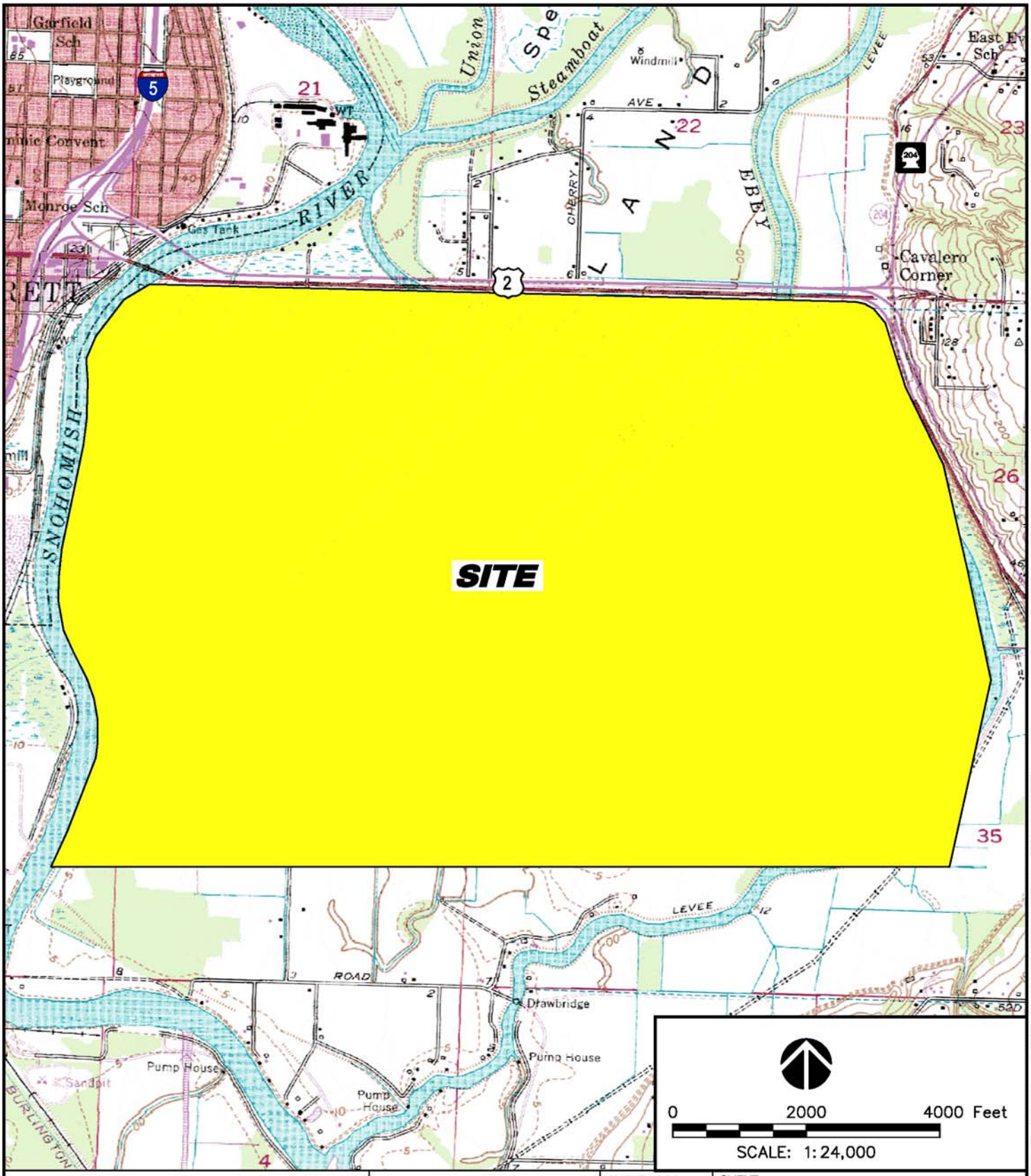
Reviewed by: James S. Dransfield, P.E., Principal

CE/JSD/VM/LS

Enclosures:

Figure 1	Location Map
Figure 2	Site & Exploration Plan
Figure 3A – 3D	Plan and Generalized Subsurface Profile—WSDOT Eastbound SR-2 LE Centerline (From Everett Waterline Replacement Project—Phase 6)

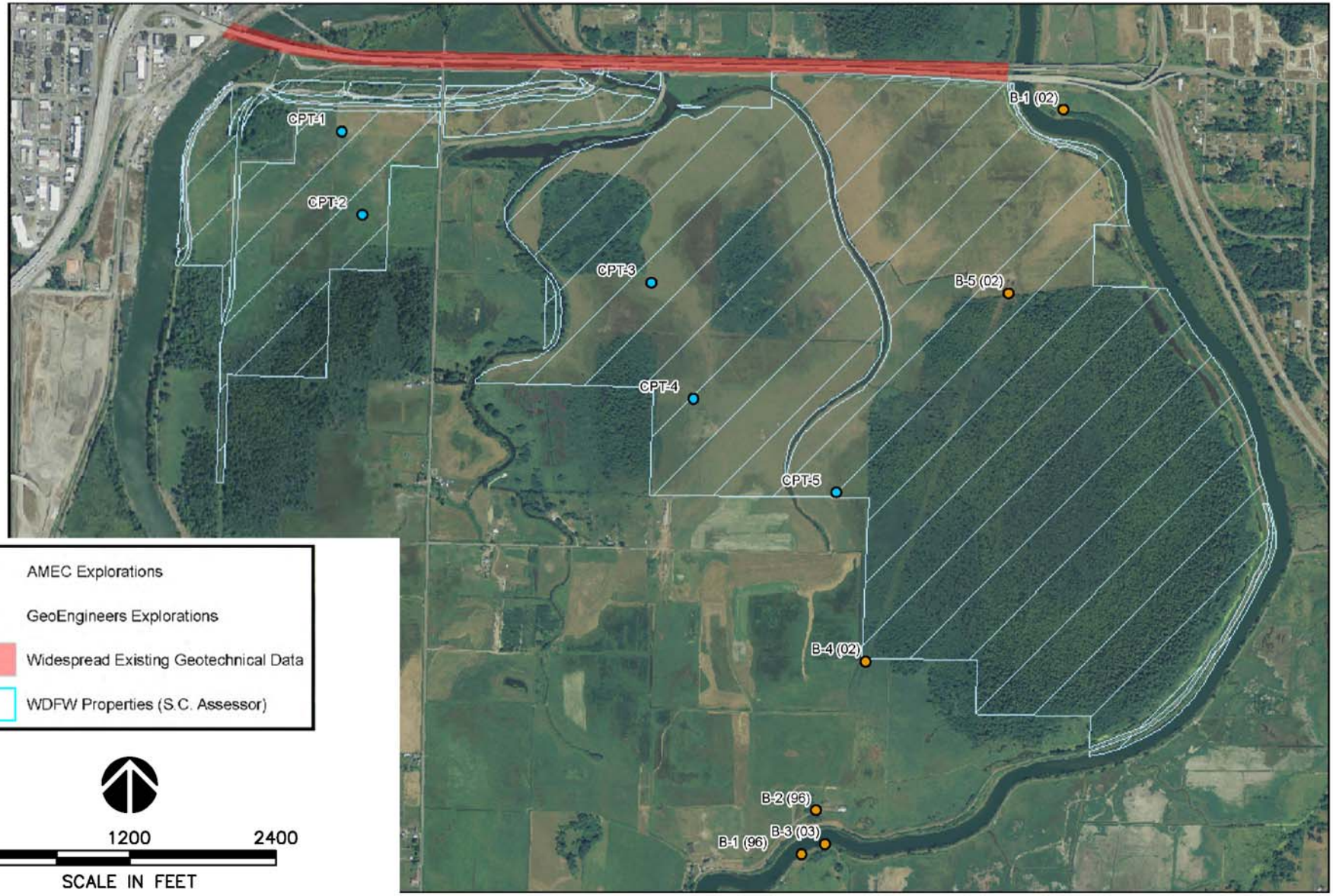
CPT Logs CPT-1 Through CPT-5



AMEC Earth & Environmental 11810 North Creek Parkway North Bothell, WA, U.S.A. 98011-8201	amec	CLIENT LOGO	CLIENT WASHINGTON DEPARTMENT OF FISH AND WILDLIFE

PROJECT EBEY ISLAND HABITAT RESTORATION FEASIBILTY STUDY	DWN BY: JRS	DATUM: NAD83	DATE: JULY 2010
TITLE SITE LOCATION MAP	CHK'D BY: CE	REV. NO.:	PROJECT NO: 0-915-16971-0
	PROJECTION: WA STATE PLANE	SCALE: AS SHOWN	FIGURE No. 1

G:\91\16000\16971 – Ebey Island\16971-01.dwg – Layout1 – Jul. 12, 2010 1:21pm – jeffrey.sanders



AMEC Explorations

GeoEngineers Explorations

Widespread Existing Geotechnical Data

WDFW Properties (S.C. Assessor)

0 1200 2400

SCALE IN FEET

CLIENT LOGO	CLIENT WASHINGTON DEPARTMENT OF FISH AND WILDLIFE	DWN BY: JRS CHK'D BY: CE	PROJECT EBEY ISLAND HABITAT RESTORATION FEASIBILITY STUDY	REV. NO.: DATE: JULY 2010
AMEC Earth & Environmental 11810 North Creek Parkway North Bothell, WA, U.S.A. 98011-8201	amec	DATUM: NONE PROJECTION: NONE SCALE: AS SHOWN	TITLE SITE AND EXPLORATION PLAN	PROJECT NO: 0-915-16971-0 FIGURE No. 2

G:\91\16000\16971 – Ebey Island\16971–02.dwg – Layout1 – Jul. 12, 2010 1:28pm – jeffrey.sanders

SOIL UNIT DESCRIPTION

UNIT 1	FILL - GRAVELLY SAND, SILTY SAND AND SAND
UNIT 2	VERY SOFT TO SOFT CLAYEY SILT, SANDY SILT, ORGANIC SILT AND SILTY CLAY WITH THIN TO THICK LAYERS OF PEAT. FIBROUS ORGANIC MATERIAL IS PRESENT THROUGHOUT THE DEPOSIT. INCREASING TO MEDIUM STIFF TO STIFF WITH DEPTH AND WHERE UNIT 2 UNDERLIES UNTI 4.
UNIT 3	VERY LOOSE TO MEDIUM DENSE SAND AND SILTY SAND
UNIT 4	MEDIUM DENSE TO VERY DENSE SAND, GRAVELY SAND, AND SANDY GRAVEL WITH VARIABLE AMOUNTS OF SILT AND INTERBEDS OF SANDY SILT. COBBLES WERE ENCOUNTERED IN THIS UNIT IN SOME AREAS.
UNIT 4B	SAME AS UNIT 4 BUT LOOSE TO DENSE.
UNIT 5	INITERBEDDED MEDIUM STIFF TO STIFF CLAYEY SILT AND SANDY SILT, AND MEDIUM DENSE TO VERY DENSE SILTY SAND.
UNIT 6	THIS SOIL UNIT, WHICH IS DESCRIBED IN THE GEOTECHNICAL REPORT FOR STAGE 1 OF THE WSDOT EASTBOUND SR-2 PROJECT, WAS NOT ENCOUNTERED IN THE EXPLORATIONS WITHIN PHASES 6 AND 7 OF THE CITY OF EVERETT WATERLINE REPLACEMENT PROJECT.
UNIT 7	VERY DENSE SILTY SAND, SAND, GRAVELLY SAND AND SANDY GRAVEL.
UNIT 8	THIS SOIL UNIT, WHICH IS DESCRIBED IN THE GEOTECHNICAL REPORT FOR STAGE 1 OF THE WSDOT EASTBOUND SR-2 PROJECT, WAS NOT ENCOUNTERED IN THE EXPLORATIONS WITHIN PHASES 6 AND 7 OF THE CITY OF EVERETT WATERLINE REPLACEMENT PROJECT.
UNIT 9	MEDIUM STIFF TO STIFF, MASSIVE, NON-PLASTIC SILT AND LOW PLASTICITY CLAY.
UNIT 10	VERY SOFT TO SOFT, GRAY TO VERY DARK BROWN, SATURATED, FINE SANDY, SILTY PEAT AND PEAT WITH OCCASIONAL GRAVEL CLASTS AND INTERBEDS OF UNIT 2 SOILS.

SOURCE: PLAN & PROFILE LEGEND, FROM EVERETT WATERLINE REPLACEMENT PROJECT - PHASE 6 PROJECT BY ZIPPER ZEMAN ASSOCIATES, INC., DATED FEBRUARY 20, 2004.

AMEC Earth & Environmental
11810 North Creek Parkway North
Bothell, WA, U.S.A. 98011-8201

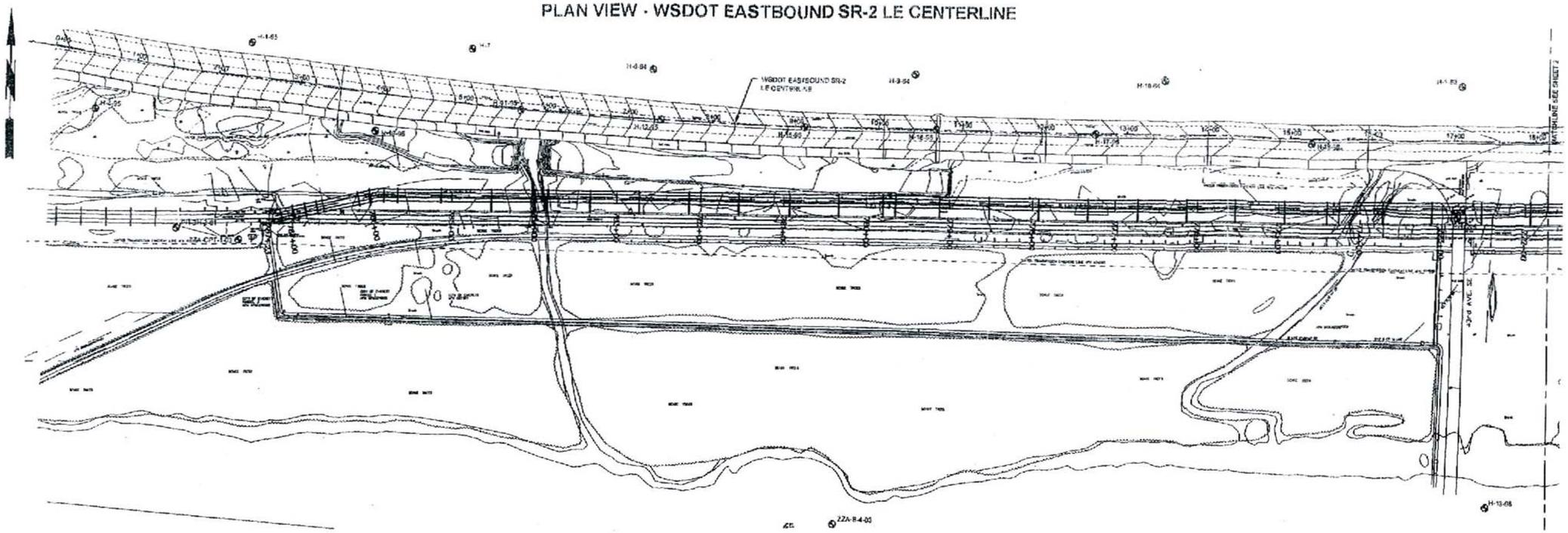
CLIENT LOGO

CLIENT: WASHINGTON DEPARTMENT OF FISH AND WILDLIFE

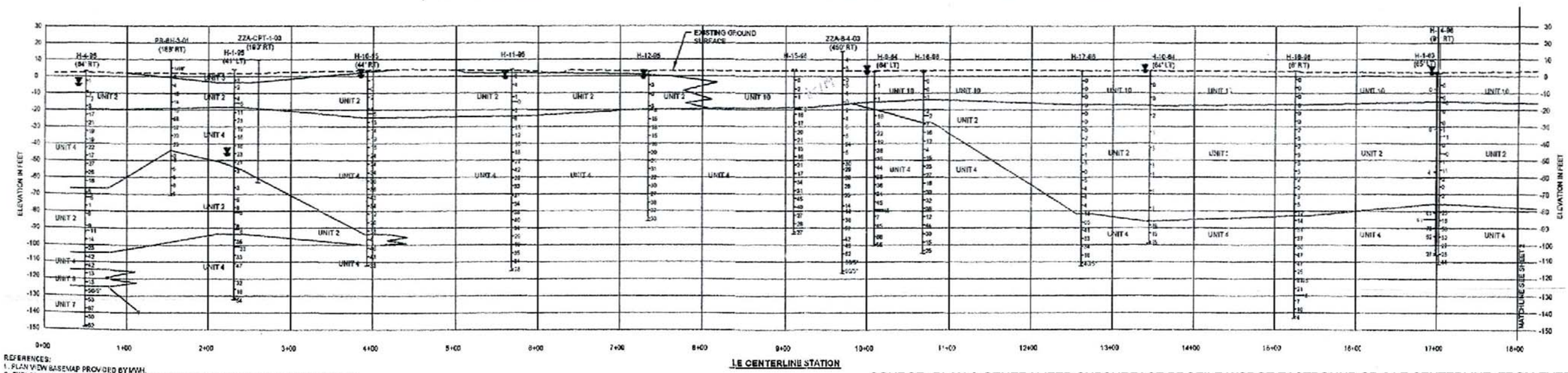
PROJECT: EBEY ISLAND HABITAT RESTORATION FEASIBILITY STUDY	DWN BY: JRS	DATUM: NONE	DATE: JULY 2010
TITLE: SOIL UNIT DESCRIPTION FOR PROFILES	CHK'D BY: CE	REV. NO.:	PROJECT NO: 0-915-16971-0
	PROJECTION: NONE	SCALE: NONE	FIGURE No. 3A

G:\91\16000\16971 – Ebey Island\16971-04.dwg – Layout1 – Jul. 12, 2010 1:31pm – jeffrey.sanders

PLAN VIEW - WSDOT EASTBOUND SR-2 LE CENTERLINE



GENERALIZED SUBSURFACE PROFILE - WSDOT EASTBOUND SR-2 LE CENTERLINE



REFERENCES:
1. PLAN VIEW BASEMAP PROVIDED BY MWH.
2. EXPLORATION LOCATIONS AND LOGS PROVIDED BY WSDOT, CONVERSE CONSULTANTS N.W. AND PACRIM.

SOURCE: PLAN & GENERALIZED SUBSURFACE PROFILE WSDOT EASTBOUND SR-2 LE CENTERLINE, FROM EVERETT WATERLINE REPLACEMENT PROJECT - PHASE 6 PROJECT BY ZIPPER ZEMAN ASSOCIATES, INC., DATED FEBRUARY 20, 2004.

0 70 140 280
SCALE IN FEET

CLIENT LOGO

CLIENT:
WASHINGTON DEPARTMENT OF FISH AND WILDLIFE

AMEC Earth & Environmental
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Bothell, WA, U.S.A. 98011-8201

DWN BY:	JRS
CHK'D BY:	CE
DATUM:	NONE
PROJECTION:	NONE
SCALE:	AS SHOWN

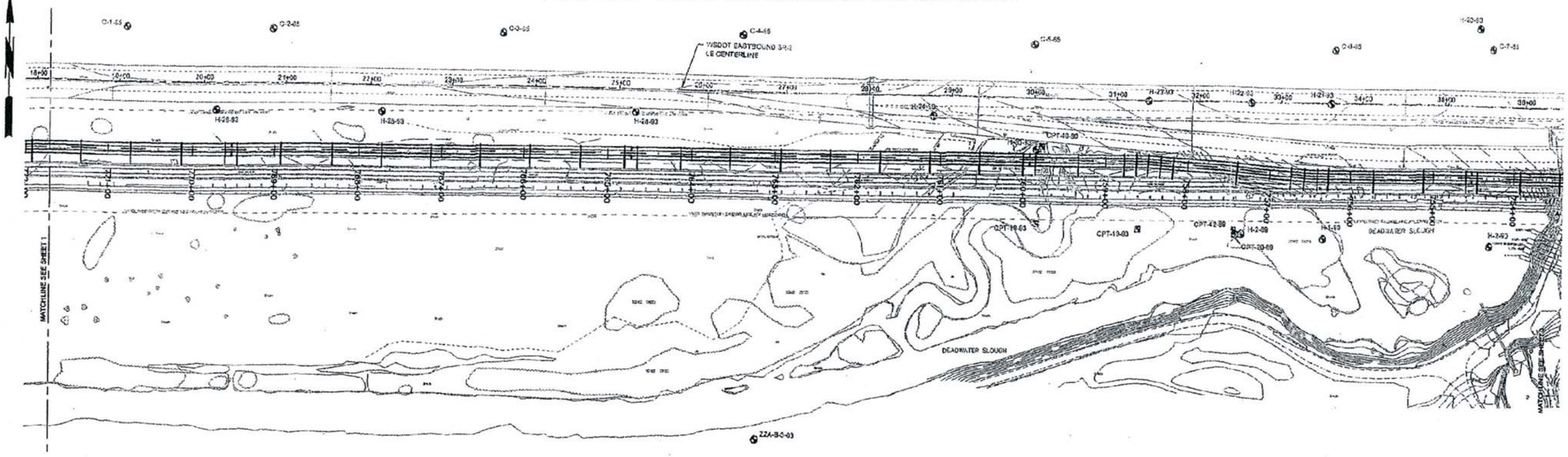
PROJECT
EBEY ISLAND HABITAT RESTORATION FEASIBILITY STUDY

TITLE
PLAN AND GENERALIZED SUBSURFACE PROFILE WSDOT EASTBOUND SR-2 LE CENTERLINE

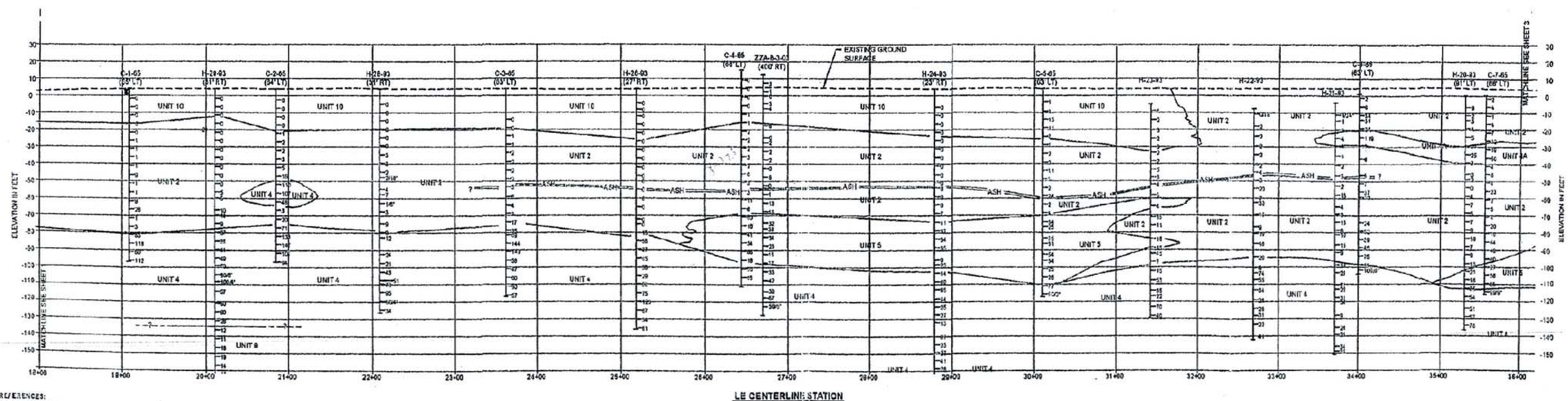
DATE: JULY 2010
PROJECT NO: 0-915-16971-0
REV. NO.:
FIGURE No. 3B

G:\91\16000\16971 – Ebey Island\16971–03.dwg – Profile–1 – Jul. 12, 2010 1:43pm – jeffrey.sanders

PLAN VIEW - WSDOT EASTBOUND SR-2 LE CENTERLINE



GENERALIZED SUBSURFACE PROFILE - WSDOT EASTBOUND SR-2 LE CENTERLINE



REFERENCES:
1. PLAN VIEW BASEMAP PROVIDED BY NWH.
2. EXPLORATION LOCATIONS AND LOGS PROVIDED BY WSDOT, CONVERSE CONSULTANTS N.W. AND PACRIM.

SOURCE: PLAN & GENERALIZED SUBSURFACE PROFILE WSDOT EASTBOUND SR-2 LE CENTERLINE, FROM EVERETT WATERLINE REPLACEMENT PROJECT - PHASE 6 PROJECT BY ZIPPER ZEMAN ASSOCIATES, INC., DATED FEBRUARY 20, 2004.

0 70 140 280
SCALE IN FEET

CLIENT LOGO

CLIENT:
WASHINGTON DEPARTMENT OF FISH AND WILDLIFE

AMEC Earth & Environmental
11810 North Creek Parkway North
Bothell, WA, U.S.A. 98011-8201

DWN BY:	JRS
CHK'D BY:	CE
DATUM:	NONE
PROJECTION:	NONE
SCALE:	AS SHOWN

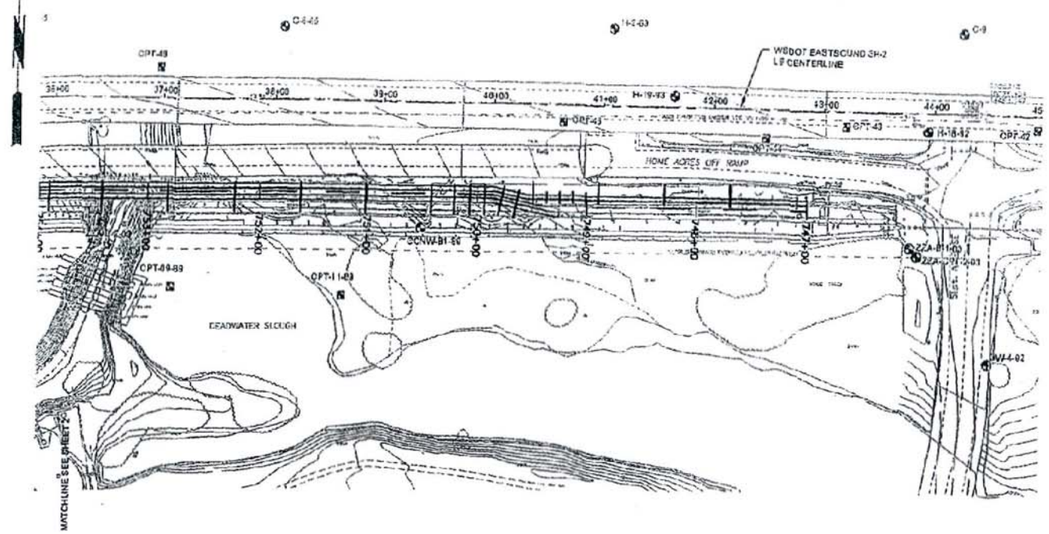
PROJECT
EBEY ISLAND HABITAT RESTORATION FEASIBILITY STUDY

TITLE
PLAN AND GENERALIZED SUBSURFACE PROFILE WSDOT EASTBOUND SR-2 LE CENTERLINE

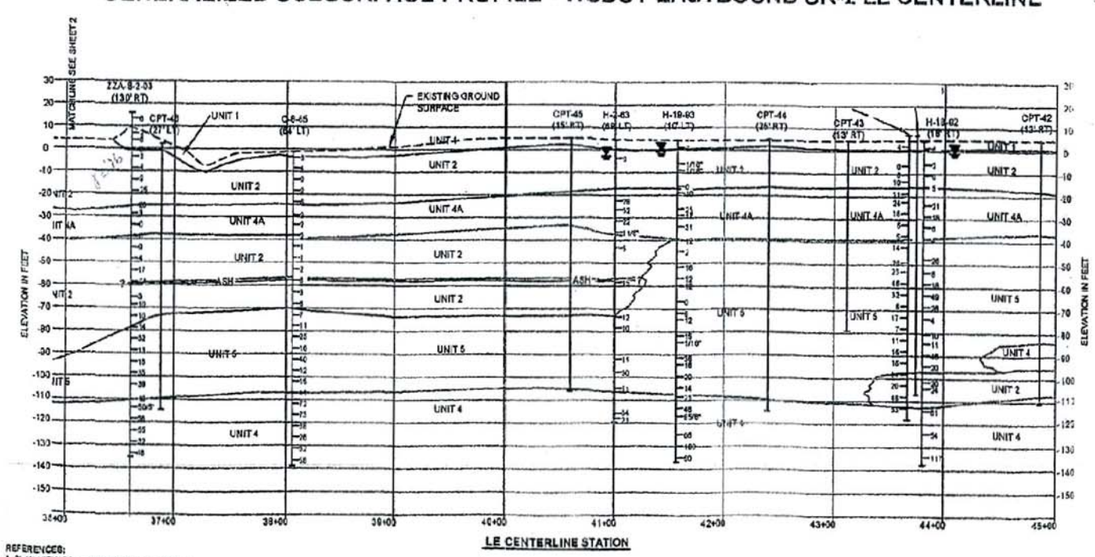
DATE: JULY 2010
PROJECT NO: 0-915-16971-0
REV. NO.:
FIGURE No. 3C

G:\91\16000\16971 – Ebey Island\16971–03.dwg – Profile–2 – Jul. 12, 2010 1:36pm – jeffrey.sanders

PLAN VIEW - WSDOT EASTBOUND SR-2 LE CENTERLINE



GENERALIZED SUBSURFACE PROFILE - WSDOT EASTBOUND SR-2 LE CENTERLINE



REFERENCES:
1. PLAN VIEW BASEMAP PROVIDED BY MWH.
2. EXPLORATION LOCATIONS AND LOGS PROVIDED BY WSDOT, CONVERSE CONSULTANTS N.W. AND PACRIM.

SOURCE: PLAN & GENERALIZED SUBSURFACE PROFILE WSDOT EASTBOUND SR-2 LE CENTERLINE, FROM EVERETT WATERLINE REPLACEMENT PROJECT - PHASE 6 PROJECT BY ZIPPER ZEMAN ASSOCIATES, INC., DATED FEBRUARY 20, 2004.

0 70 140 280
SCALE IN FEET

CLIENT LOGO

CLIENT:
WASHINGTON DEPARTMENT OF FISH AND WILDLIFE

AMEC Earth & Environmental
11810 North Creek Parkway North
Bothell, WA, U.S.A. 98011-8201

DWN BY:	JRS
CHK'D BY:	CE
DATUM:	NONE
PROJECTION:	NONE
SCALE:	AS SHOWN

PROJECT
EBEY ISLAND HABITAT RESTORATION FEASIBILITY STUDY

TITLE
PLAN AND GENERALIZED SUBSURFACE PROFILE WSDOT EASTBOUND SR-2 LE CENTERLINE

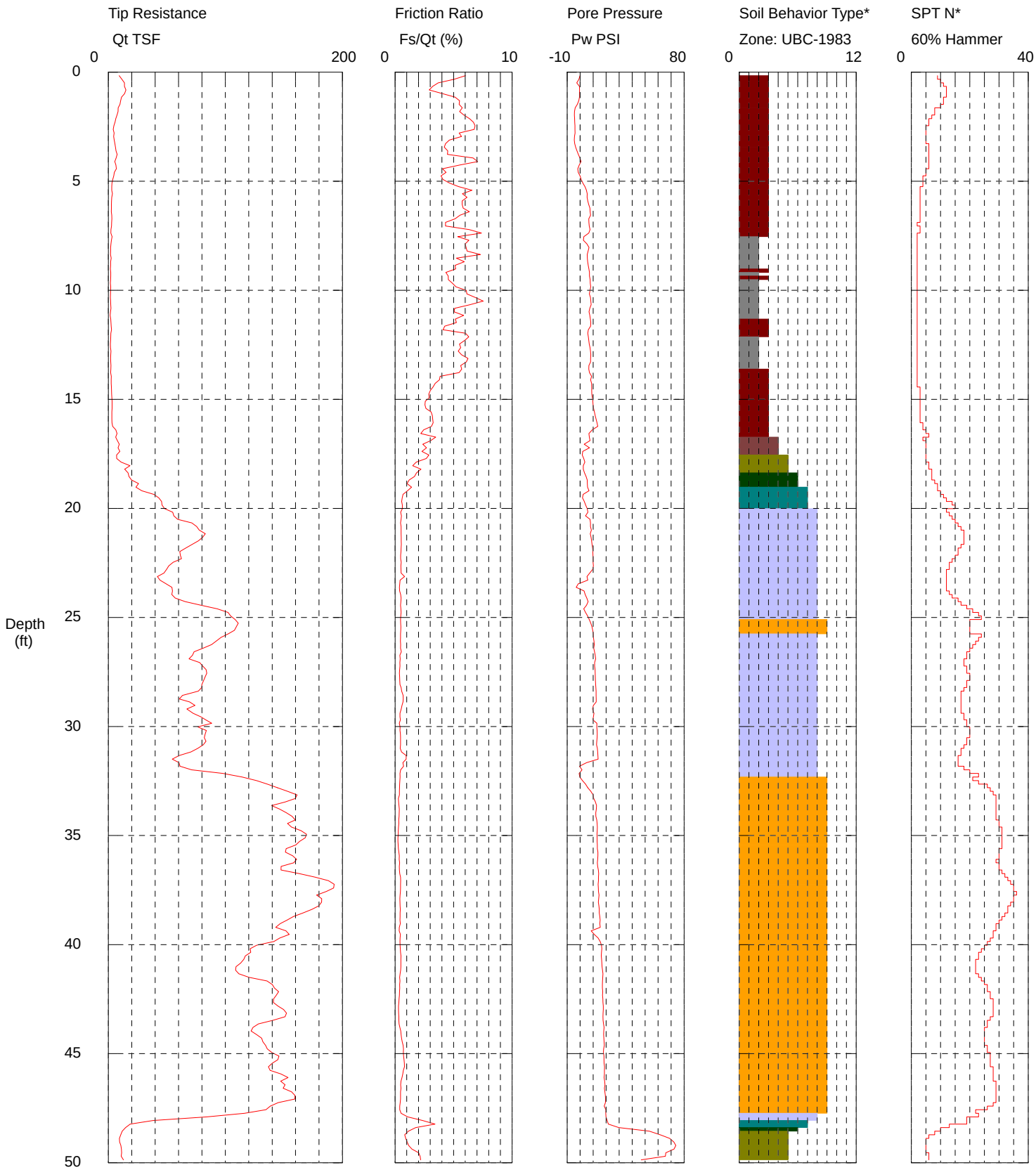
DATE:	JULY 2010
PROJECT NO:	0-915-16971-0
REV. NO.:	
FIGURE No.	3D

G:\91\16000\16971 – Ebey Island\16971–03.dwg – Profile–3 – Jul. 12, 2010 1:38pm – jeffrey.sanders

AMEC

Operator: Witthus
Sounding: CPT-1
Cone Used: DSG1079

CPT Date/Time: 6/15/2010 9:08:35 AM
Location: Ebey Island Restoration Feasibility Study
Job Number: 0-917-16971-0



Maximum Depth = 50.20 feet

Depth Increment = 0.164 feet

1 sensitive fine grained
2 organic material
3 clay
4 silty clay to clay
5 clayey silt to silty clay
6 sandy silt to clayey silt
7 silty sand to sandy silt
8 sand to silty sand
9 sand
10 gravelly sand to sand
11 very stiff fine grained (*)
12 sand to clayey sand (*)

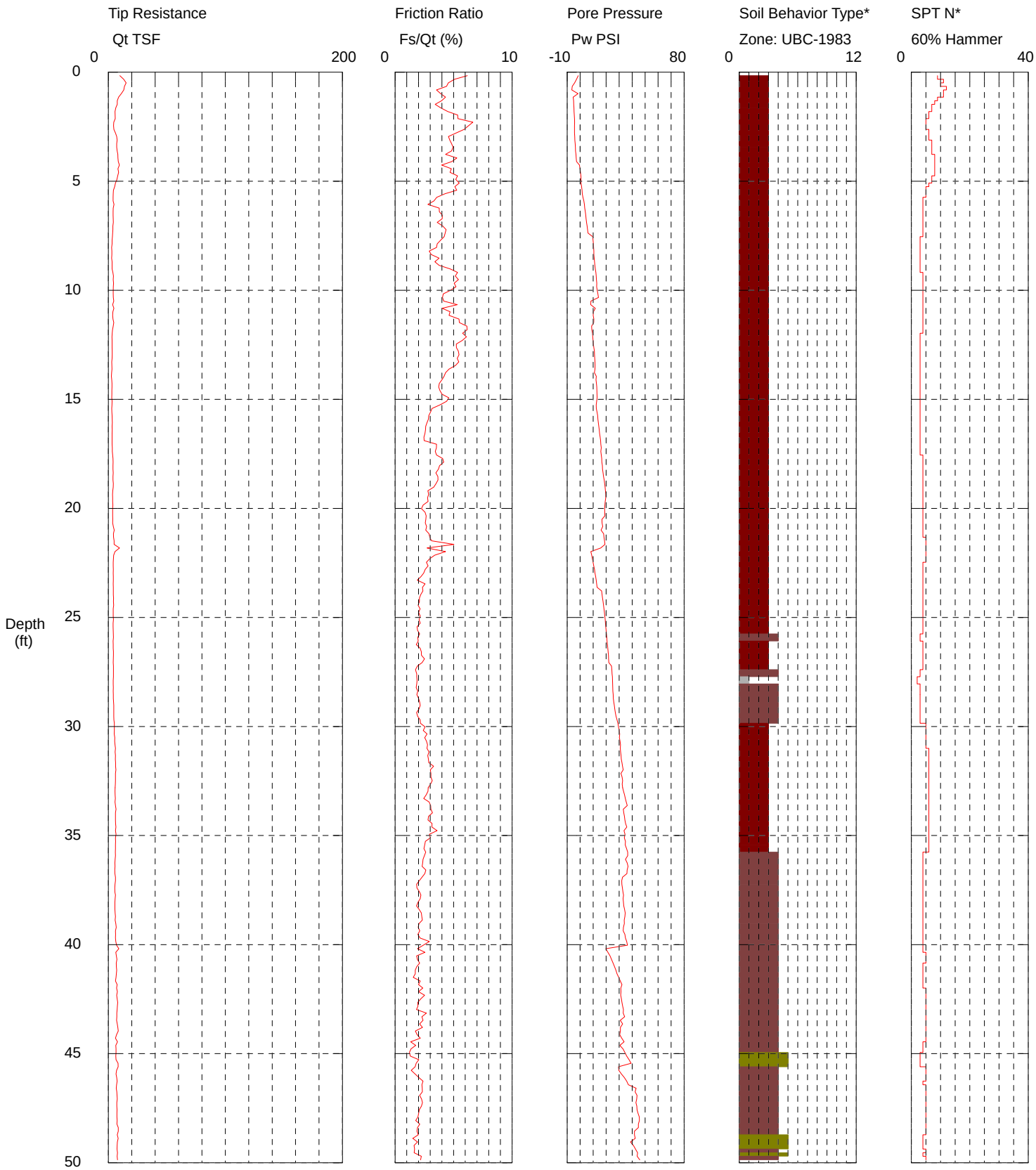
In Situ Engineering

*Soil behavior type and SPT based on data from UBC-1983

AMEC

Operator: Witthus
Sounding: CPT-2
Cone Used: DSG1079

CPT Date/Time: 6/15/2010 10:14:49 AM
Location: Ebey Island Restoration Feasibility Study
Job Number: 0-917-16971-0



Maximum Depth = 50.20 feet

Depth Increment = 0.164 feet

1 sensitive fine grained
2 organic material
3 clay
4 silty clay to clay
5 clayey silt to silty clay
6 sandy silt to clayey silt
7 silty sand to sandy silt
8 sand to silty sand
9 sand
10 gravelly sand to sand
11 very stiff fine grained (*)
12 sand to clayey sand (*)

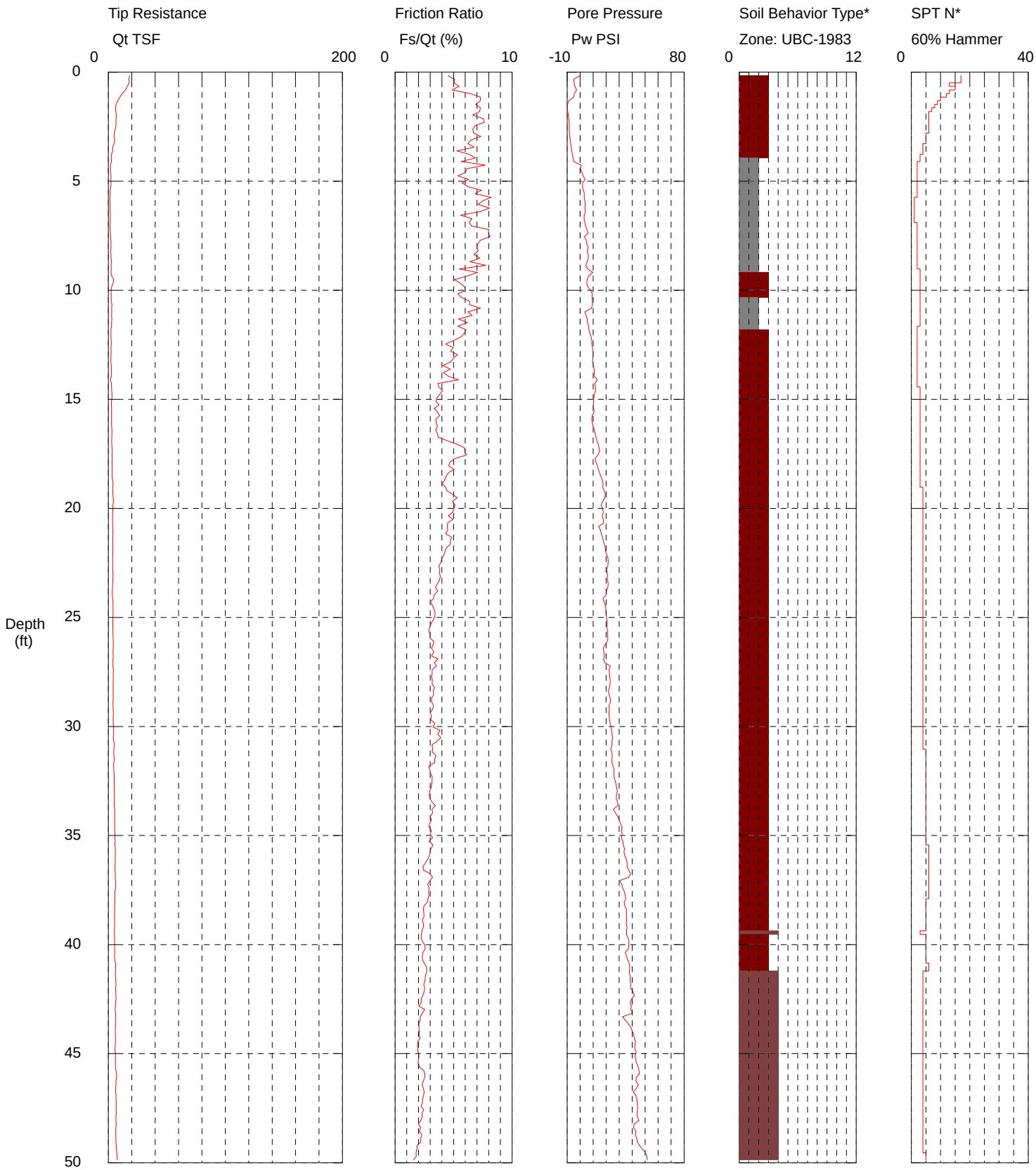
In Situ Engineering

*Soil behavior type and SPT based on data from UBC-1983

AMEC

Operator: Witthus
Sounding: CPT-3
Cone Used: DSG1079

CPT Date/Time: 6/15/2010 12:40:49 PM
Location: Ebey Island Restoration Feasibility Study
Job Number: 0-917-16971-0



Maximum Depth = 50.20 feet

Depth Increment = 0.164 feet

1 sensitive fine grained
2 organic material
3 clay
4 silty clay to clay
5 clayey silt to silty clay
6 sandy silt to clayey silt
7 silty sand to sandy silt
8 sand to silty sand
9 sand
10 gravelly sand to sand
11 very stiff fine grained (*)
12 sand to clayey sand (*)

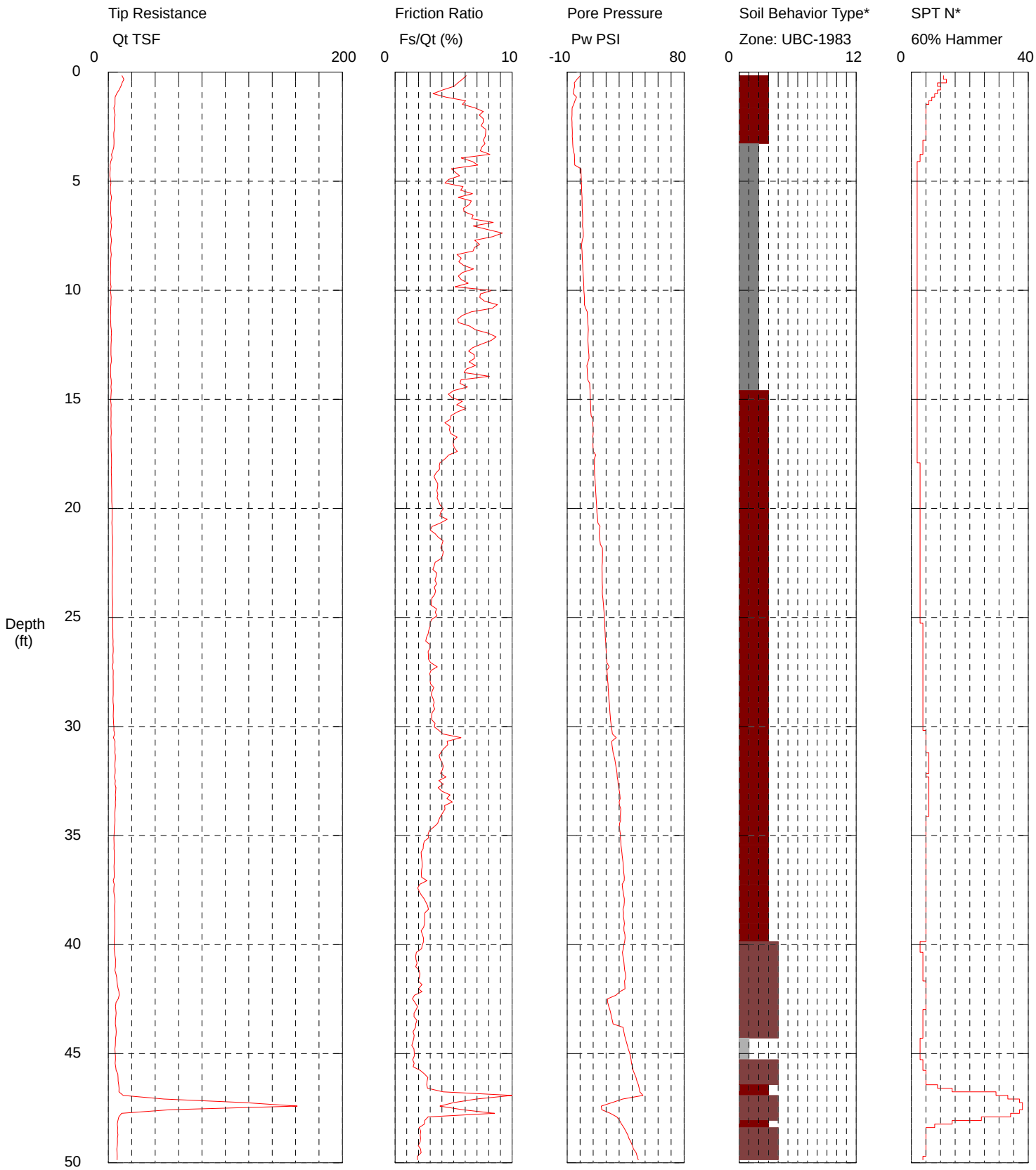
In Situ Engineering

*Soil behavior type and SPT based on data from UBC-1983

AMEC

Operator: Witthus
Sounding: CPT-4
Cone Used: DSG1079

CPT Date/Time: 6/15/2010 1:58:07 PM
Location: Ebey Island Restoration Feasibility Study
Job Number: 0-917-16971-0



Maximum Depth = 50.20 feet

Depth Increment = 0.164 feet

1 sensitive fine grained
2 organic material
3 clay
4 silty clay to clay
5 clayey silt to silty clay
6 sandy silt to clayey silt
7 silty sand to sandy silt
8 sand to silty sand
9 sand
10 gravelly sand to sand
11 very stiff fine grained (*)
12 sand to clayey sand (*)

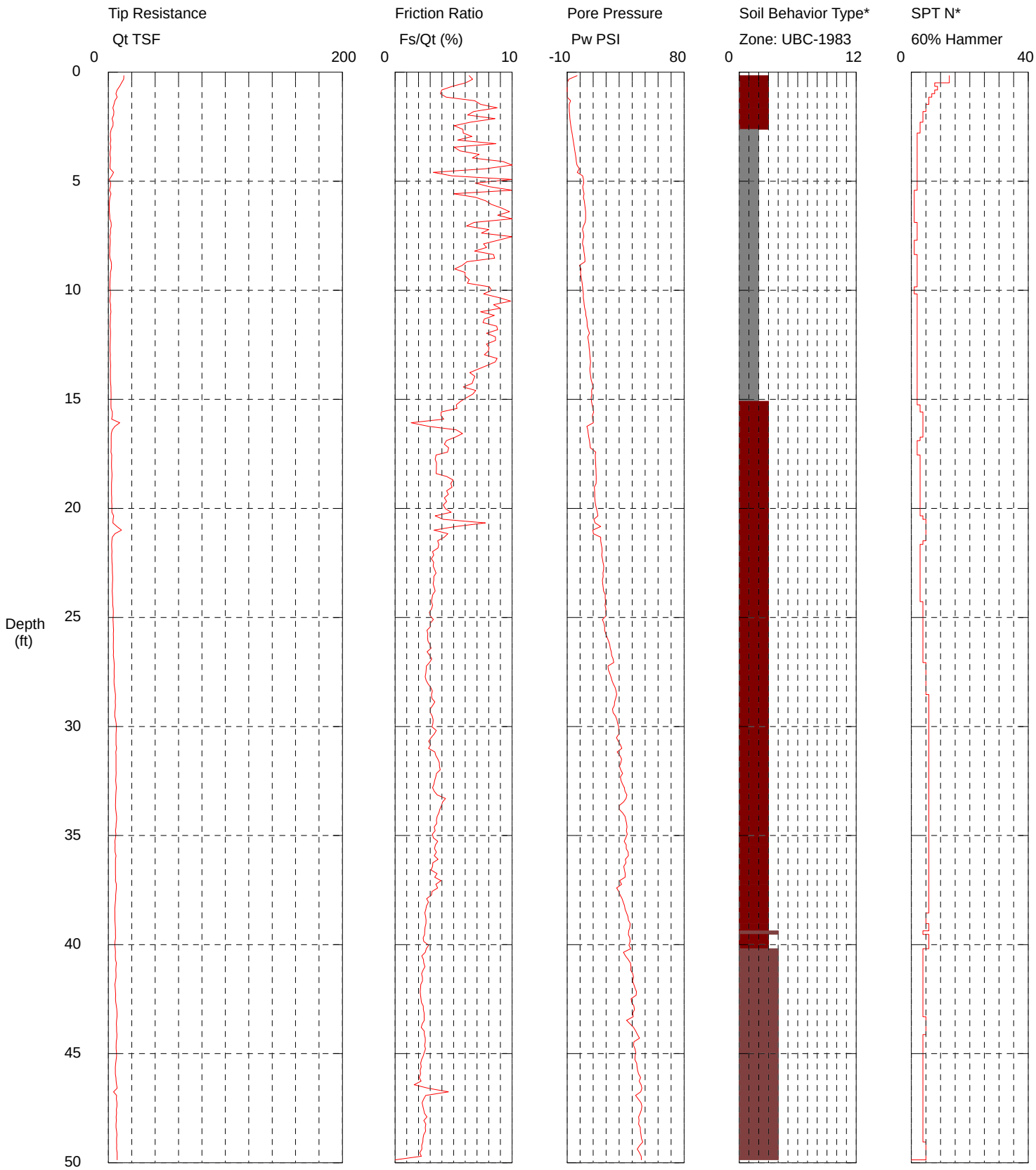
In Situ Engineering

*Soil behavior type and SPT based on data from UBC-1983

AMEC

Operator: Witthus
Sounding: CPT-5
Cone Used: DSG1079

CPT Date/Time: 6/15/2010 3:56:21 PM
Location: Ebey Island Restoration Feasibility Study
Job Number: 0-917-16971-0



Maximum Depth = 49.87 feet

Depth Increment = 0.164 feet

1 sensitive fine grained
2 organic material
3 clay
4 silty clay to clay
5 clayey silt to silty clay
6 sandy silt to clayey silt
7 silty sand to sandy silt
8 sand to silty sand
9 sand
10 gravelly sand to sand
11 very stiff fine grained (*)
12 sand to clayey sand (*)

In Situ Engineering

*Soil behavior type and SPT based on data from UBC-1983

APPENDIX B: CRITERIA CONSIDERED BUT NOT USED IN THE EVALUATION

Criterion	Concept	Potential Metrics	Reason Not Used
Ability to improve soil fertility	If prime agricultural conditions do not exist for a particular parcel, can they be made available or the land improved, and what is the estimate cost of improving soil conditions?		This criterion was dropped since most of the soils in the area are essentially the same (prime agricultural), thus there was no real differentiating factor.
Impacts on local community	Might there be a nearby community (e.g., town or neighborhood) that would be affected by the restoration of the property? If so, how? Would it cause physical, social, or economic impacts?		There are no larger communities that would be substantially affected by the Ebey Island project. While there is a small community of individual property owners (farmers), most of their concerns had more to do with continued agriculture, which is already accounted for in the final criteria.
Compatibility with Adjacent Uses	Would the restoration of parcels affect adjacent uses (either negatively or positively)? For instance, would restored land preclude or make farming more difficult on an adjacent property? Would it make it easier?		It was determined that this would not be determinatively measurable on such a small, homogenous subset of properties. It would be more of a judgment as to whether the restored property "works well" with adjacent lands in terms of access, effects, lack of impacts on farming, etc., and that most of these issues could be avoided or minimized through proper design. Restoration in and of itself would not preclude farming on adjacent properties.
Permitability	A restoration project would require federal, state, and/or local permitting. Does it meet current regulations? Furthermore, a project may support one agency's goals, but contravening another's (e.g., restoration supports salmon recovery, but removing or breaching dikes runs contrary to the Diking	• Obtain opinions from various permitting agencies as to their level of support for said project • Obtain estimates of timeframes for obtaining permits	It was determined that going into such detail at this stage (feasibility) was not within the scope or budget of this project. Once final alternatives are chosen, this step would need to be done as part of the due diligence process.

Criterion	Concept	Potential Metrics	Reason Not Used
	District's mission). It could be helpful to determine if a particular project is acceptable to all agencies that have a regulatory role in its permitting, and if not, explore what could be done to make the project acceptable.		
Assessed Value	Would the value, and thus cost, of particular parcels have any bearing on which alternative(s) to choose?	• Assessed Value • Assessed Value per acre	It was determined that since the project was focusing primarily on restoring parcels already owned by WDFW, property value would not have any bearing on choosing between alternatives. Additionally, an analysis was run and most properties had relatively the same value per acre (differences being in whether there were any buildings on the parcel, but even this was not a huge difference).
Comprehensive Plan Land Use Designation & Zoning	Is restoration (or some of the ancillary uses such as recreation) even allowed under the local jurisdictions Comprehensive Plan and zoning code? If not, would WDFW need to work with that jurisdiction to try to amend the codes, and how long would that take?	• Determine the zoning of the property, and whether habitat restoration and recreation are permissible uses in the property's zone.	In Snohomish County (agency with jurisdiction), habitat restoration is not specifically listed as an allowed use, but neither is it a non-permissible use. Other such projects have been allowed, including some done by Snohomish County. Recreational uses are allowed under the current zoning. Thus, this was found to be non-determinative.
Project Costs	Each project alternative will have an estimated cost of designing, constructing, maintaining, and policing it. In determining the best alternatives, a cost-benefit analysis could be performed.	• Estimated costs of designing, building, and maintaining/policing the habitat restoration projects	WDFW decided that cost should not play a role in determining what the best alternative should be (explained more fully in Section 5.1.2.1.
Visibility from Public Spaces & Rights-of-Way	Would the completed projects be more or less aesthetically pleasing to the public than what is there now? Which properties can best be seen from public	• Conduct a viewshed analysis, analyzing changes in the public's view of restored properties.	It was determined that this would not be very useful on this project given that all potentially restored properties are equally visible to the public, and that the public

Criterion	Concept	Potential Metrics	Reason Not Used
	vantage points?		probably wouldn't readily distinguish (or have a strong opinion about) the difference between restored habitat or agricultural uses (both being rural in nature).
Agricultural Impacts on Surrounding Properties	Dust, odors, farm equipment on public roads, etc., often bring complaints from adjacent non-agricultural (residential) neighbors, which cause political pressures against agriculture. Conceivably, some properties would be more or less prone to causing impacts to neighbors if used for agriculture. Those properties that would likely cause more such impacts might better be used for restoration. In Snohomish County, this may not be as big of a political problem since the County has a Right-to-Farm ordinance.	• Proximity to residential neighborhoods • Number of such complaints received by local Code Enforcement Division	There are not many residential uses in close proximity (other than the farmers on the island. The County had no reportable complaints from this area.
Recent/Previous Land Uses	What were the past uses were on the properties? Was there ever anything that might have caused hazardous conditions (e.g., contaminated soil)? Remediation of contaminated site might be prohibitively costly.	• Review historical records (County records, aerial photographs) to determine whether there were any uses that might have contaminated the soil. • Check the Department of Ecology Brownfield database.	No such sites were found on the WDFW properties.
Opportunities to Restore Agricultural Land Values	Could restoration of some properties provide an opportunity to improving farming on adjacent properties through acquisition and improvements in infrastructure or exchanging low quality agricultural land for habitat?	• Estimate cost of providing agricultural infrastructure to properties that do not have it now.	Not a measurable criteria, but through the other criteria one can judge whether it would be possible to trade lands better suited to agricultural for those better suited for habitat restoration. Furthermore, WDFW intends to "cause no harm" to adjacent agricultural properties, and will build into any restoration project components to improve their continued use.

Criterion	Concept	Potential Metrics	Reason Not Used
Value That Land Has for Other Purposes	What is the opportunity cost of using land for salmon recovery rather than for industrial, commercial, or residential uses?	• Appraised $/ac value based on highest and best alternative uses. • See if there are any recent appraisals done for any of the major utility or roadwork done on the island. •	It is highly unlikely that Snohomish County would rezone any of these properties to something other than agriculture. Additionally, there is no budget to have appraisals done for all these properties, let alone one that looks at all the alternative restoration scenarios.
Size of Restored Area	How much surface area will be opened to tidal processes?	• Wetted Area at Mean High High Water	This metric was incorporated into the formula used in determining *Value to Fish*
Amount of Fish Habitat	How much channel area or ponded water will remain available to fish at low tide?	• Wetted Area at Mean Low Low Water	This metric was incorporated into the formula used in determining *Value to Fish*
Energetics/Exchange	How much water will flush the site during a tide cycle? How much exchange of sediment, nutrients, and productivity will occur between the site and existing river network? This is a number that can be calculated, but is only relevant comparatively between scenarios.	• Tidal Prism (Volume)	This metric was incorporated into the formula used in determining *Value to Fish*
Connectivity to Total Fish Population	What is the percent of the total fish population that can access the restored habitat? How readily can fish get to the restored areas, especially if a muted design? Do any fish passage barriers prevent access? How easily will fish find the habitat? What proportion of the fish will take advantage of it? Is it connected to a main channel, or a side channel? Each channel has differing % of total fish population	• If known, use percent of total fish population each channel has; otherwise, use: • Channel order • List of barriers	This metric was incorporated into the formula used in determining *Value to Fish*

Criterion	Concept	Potential Metrics	Reason Not Used
	(main stem of river is presumed to have the most).		
Influence by Adjacent Land Uses	What are the surrounding land uses, and how might those uses affect the restoration site? Adjacent land uses could affect success of salmon recovery by introducing pollutants, noise, etc. For example, channels that extend beyond the WDFW properties (e.g., Deadwater Slough) could transmit agricultural contaminants (e.g., fertilizer, pesticides). Noise from heavy machinery could affect wildlife.	• Relative scoring system for adjacent land use types (e.g., spruce forest = 5, scrub/shrub = 4, mowed wetland = 3, grazing = 2, crops = 1)	Was determined that this criterion, though potentially useful in a higher density land use setting, it is not very differentiating in this rather homogeneous, low-intensity agricultural/residential area.
Completeness of Restored Tidal Action	Will the full tidal signal be restored, or will it only be a muted signal (e.g. through tide gate)?	• Percent of full tidal signal at relevant location	This metric was incorporated into the formula used in determining *Value to Fish*
Impacts of Restoration Project on Agricultural Uses	Does the restoration project have negative, or positive, impacts on agriculture? Does it preclude certain uses? Or, does it help create new agricultural opportunities?	•	This metric was incorporated into the formula used in determining *Agricultural Productivity*.
Soil Suitability for Agriculture	Different lands have different types of soil, some being more valuable to different types of agriculture (e.g., crops, animal husbandry), and some being more suitable for the restoration projects. From agricultural point of view, it is better to maintain prime agricultural land in agricultural production and use those that are not quite as good for restoration.	• Soil Conservation District's soil rating • Value as agricultural land, where 0 = no value, 1 = low value, 2 = medium value, 3 = high value	All lands within the study area are homogenous and similarly categorized; all are considered prime agricultural soils, with minor differences in how well it is drained, which can be remedied through infrastructure and management.
Acres of WDFW Land Removed from Agricultural Production	How much of WDFW's land currently leased for agricultural uses will be removed from production?	• Number of WDFW acres leased to farmers	Agricultural leasing decisions are based on a variety of fish and wildlife management and recreation objectives. It would be inappropriate to consider leases would continue

Criterion	Concept	Potential Metrics	Reason Not Used
			even if salmon restoration projects were not to occur.
Contiguity of Agricultural Land	As with other types of uses, agricultural activities are more efficient when clustered. Often the closer agricultural parcels are to one another makes them more valuable; isolated farms are more expensive to operate. This is true whether they are large or small farms.	• Percentage of an agricultural parcel's (or group of parcels') boundary the restoration project shares	This metric was incorporated into the formula used in determining *Agricultural Productivity*.
Effects on Recreational Uses - Hunting/Shooting	Are any of the properties currently used for hunting or shooting? Would any existing hunting/shooting opportunities be lost due to project implementation? Are any added? Which properties have the most potential for hunting/shooting uses?	• 1 – 5 rating of recreational potential; or 1 point for each activity that could be done? • -1 – -5 rating of recreational potential; or, -1 point for each activity that could be lost?	It was decided to combine all potential recreational impacts (positive or negative) into one criterion, *Effects on Recreational Opportunities*.
Effects on Recreational Uses - Boating	Are any of the properties currently used for boating? Would any existing boating opportunities be lost due to project implementation? Are any added? Which properties have the most potential for boating uses?	• 1 – 5 rating of recreational potential; or 1 point for each activity that could be done? • -1 – -5 rating of recreational potential; or, -1 point for each activity that could be lost?	It was decided to combine all potential recreational impacts (positive or negative) into one criterion, *Effects on Recreational Opportunities*.
Effects on Recreational Uses - Hiking/Walking	Are any of the properties currently used for hiking or walking? Would any existing hiking/walking opportunities be lost due to project implementation? Are any added? Which properties have the most potential for hiking/walking uses?	• 1 – 5 rating of recreational potential; or 1 point for each activity that could be done? • -1 – -5 rating of recreational potential; or, -1 point for each activity that could be lost?	It was decided to combine all potential recreational impacts (positive or negative) into one criterion, *Effects on Recreational Opportunities*.
Effects on Recreational Uses - Bird Watching	Are any of the properties currently used for bird watching? Would any existing bird watching opportunities be lost due to project implementation? Are any added? Which properties have the most	• 1 – 5 rating of recreational potential; or 1 point for each activity that could be done? • -1 – -5 rating of recreational potential; or, -1 point for	It was decided to combine all potential recreational impacts (positive or negative) into one criterion, *Effects on Recreational Opportunities*.

Criterion	Concept	Potential Metrics	Reason Not Used
	potential for bird watching uses?	each activity that could be lost?	

APPENDIX C: POTENTIALLY USEFUL CRITERIA

Criterion	Concept	Potential Metrics
Topography	Knowing the existing topography will help determine the ability of a property to be tidally influenced. Lands below Ordinary High Water Mark (OHWM) will be best for habitat restoration projects. Could help determine how much a property will need to be altered (i.e., soil removal or augmentation) and thus potentially a large part of the cost of the project. Elevation can also help determine what type of habitat it provides (ponds, tidally influenced mudflats, or other); whether there would be variable topography in the finished project helping to create more areas of land/water interface, and thus shorelines where protective cover can grow, and the overall predicted hydraulics of the island and river. Would also need to know elevations of ditches to assist with hydrological modeling.	• Existing elevation throughout the WDFW properties
Predicted long-term elevation distribution	What is the expected breakdown of land area within different elevation ranges? Does this distribution reflect natural conditions observed in reference sites? What are the general habitat types expected based on these elevations?	• Histogram of area per elevation, compared with associations between communities' elevation ranges
Complexity and Diversity of Habitats	Will the restoration design lead to the formation of dendritic channels, different habitat types, natural vegetation communities, natural bank structure Large Woody Debris (LWD), riparian shade/cover?	• Histogram of area per elevation; compared with associations between communities elevation ranges • Planting plans • Channel creation plans • Hydrodynamic model results
Other Species: Birds	How will the predicted changes in habitat types affect use of the site by different waterfowl guilds (e.g. dabblers, divers, waders, geese, etc.)?	• General change in predicted species composition based on bird guild associations with habitat types and predicted habitat types based on elevation
Effects On or Due To Other Restoration Projects and Salmon Recovery Actions	One restoration project may affect another (or others) hydrologically. If vast areas of Ebey Island are flooded, will it affect others' (e.g., DD6's) projects by lowering the overall water level?	• Determine through modeling how proposed project will affect OHWM • Determine via other projects' design specifications whether there would be an affect

Criterion	Concept	Potential Metrics
Water quality	Clarity, oxygen content, & temperature. How long will water sit without being exchanged for fresh?	• Residence time
Current Land Use	In considering whether to restore a parcel, look at whether the property is currently or recently used for agriculture. If not, it might not be as important in terms of removing it from the agricultural inventory. If it is, there may be more opposition to removing it from the inventory.	• Score based on whether agricultural or not, and • Whether high production or not
Drainage System Required for Continued Agricultural Use	The height of the water table, especially during the growing season, can play an important role in determining the usability and thus value of land for agriculture. Land that is too wet is not as valuable as well drained soil. Ditches and other methods of managing the land can modify the height of water table. Maintenance of those facilities plays a huge role. If ditches are maintained improperly, the water table can rise; proper maintenance can lower the water table. Different properties under same circumstances, or even the same property, might have different water tables based on how well the drainage system is maintained. In terms of choosing between project alternatives, it is less costly if the land remaining in agriculture can be drained by gravity rather than equipment. Height of water table will also have an impact on the ability and cost of moving/replacing infrastructure.	• Water table elevation
Effects on Archaeological, Historical, and Cultural Resources	Are there any protected archaeological, historic, or cultural resources on the property? Would the project destroy, protect, or have no effect on them? Would they be better protected if the property were restored, or remain in agricultural use? What would the mitigation measures be?	• Presence of important archaeological, historic, or cultural resources. 0 = none; 1 = minor resources that can be impacted w/o mitigation; 2 = resources that can be impacted but mitigation required; 3 = important resources that cannot be impacted
Effects on Existing Flood Protection Infrastructure	Will the project(s) cause erosion, sedimentation or slope stability issues for the existing dikes (i.e., will breaching one area cause stability issues for dikes in other areas?)	• Soil erodability and slope stability based on geotech analysis/opinion, where 0 = no issues; 1 = project will cause minor issues that can be easily mitigated; 2 = project will cause medium issues that can be mitigated, but it is relatively expensive to do so; 3 = project will cause major issues that cannot be mitigated.

Criterion	Concept	Potential Metrics
Feasibility of New Flood Protection Infrastructure	If dikes are breached to allow tidal influence, can new dikes/ditches be feasibly built to protect remaining farmland? Will the soils support them? Can we minimize diking while maximizing area to be flooded because of geography?	• Ratio of area (ac) to be flooded to length (mi) of dike • Will the soils support them?
Other Stakeholder Concerns	This was originally a placeholder for any issues raised by the Advisory Committee or other stakeholders that were not in the preliminary list develop by the project team. However, though these groups had great interest and influence on refining and narrowing the final criteria, no new concerns were raised.	

APPENDIX D: Hydrodynamic Modeling and Geomorphic Analysis

A.1. UNET MODEL

The Ebey Island restoration feasibility study adapted the UNET model used to conduct FEMA flood insurance studies on the lower Snohomish River. The model was used to assess potential changes to hydraulic conditions as a result of the proposed restoration alternatives. UNET, developed by the U.S. Army Corps of Engineers (USACE, 2001), is an unsteady, one-dimensional model that can represent a network of channels and storage areas. The application of the UNET model to the lower Snohomish River is documented in FEMA (2001).

A.1.1. Geometry

Snohomish River, its distributary channels, and adjacent flood plains were schematized as a networks of channels as shown in Figure 1a. In addition to these channels, significant areas of overbank storage were represented in the model as stage-storage nodes (Figure 1b). Geometry in the existing UNET model was derived from a prior FEQ model of the Snohomish River. Bathymetric data from the older FEQ model was supplemented and updated with survey data from the US Army Corps, WSDOT bridge plans, and other assorted surveys. Within the model, all data was reference to the 1929 NGVD vertical datum. Conversion between the model datum and the NAVD vertical datum were accomplished by adding 3.68 ft, as provisional tidal datums developed by the Corps for Everett.

A.1.1.1. Existing conditions

The FEMA version of the UNET model became unstable when modeling tidally-dominated flow conditions such as the low discharge conditions in late summer, 2002. The unstable conditions were traced to the geometry of the SR-529 Bridge where it crosses the downstream end of Union Slough. Therefore, these bridge cross sections were removed from the model. A sensitivity analysis indicated that the changes to water level and velocity as a result of this modification were local and did not affect the project site, which is more than four river miles the removed cross sections.

A.1.1.2. Near Term

The existing conditions geometry described above was modified to represent the full tidal area and the muted tidal areas of the Near Term Alternative. Details of the modification which restored tidal exchange to portions of Ebey Island are described below. In addition to adding these tidally connected areas, the stage-storage node for the portion of the Island which would remain inside the perimeter dike was altered to reflect its decreased extent.

A.1.1.2.1. Full tidal area

The Near Term Alternative proposes that the tree-covered eastern portion of the project site be converted to fully tidal by building a setback dike which mostly follows the existing pipeline right-of-way, and then removing the existing dike along Ebey Slough. This restoration area was incorporated into the model by adding cross sections along the Ebey Slough reach and also extending the western side of the new and existing cross sections to describe the full tidal area. The additional cross sections were added at the upstream end, downstream end, and width transitions of the restored area to capture its planform dimensions. Bed elevations in the restored area were estimated from limited ground survey data collected primarily along the pipeline right-of-way in October 2010. The restored area was assigned a Mannings n value

equal to 0.15. This value was selected based on Acrement and Schneider (1989) to capture the roughness associated with the trees that are expected to cover a substantial portion of the restored area.

A.1.1.2.2. Muted tidal areas

Each of the muted tidal areas was represented in the Near Term Alternative as a state-storage node connected by a hydraulic structure to the adjacent outboard channel. UNET does not have the capability to specify gate operations that prevent flow through the structure as a function of water level. Therefore, UNET predictions of water levels for the muted tidal areas are considerably higher than target water levels for creating intertidal habitat and reducing flood hazard. To provide a better understanding of habitat conditions and hydraulic structure design specifications, separate models of the muted tidal areas were developed using HEC-RAS, a model which can specify water-level-controlled gate operations. These models are described in more detail in Section X below. After the hydraulic structure configuration in HEC-RAS was completed to achieve target water levels in the muted tidal areas, the hydraulic structures' flow rates predicted by the HEC-RAS model were compared to the flow rates predicted by the UNET model. The peak flow rates were of similar magnitudes (100-200 ft3/s), as expected since the structures' cross-sectional area, which was identical between the models, is the limiting factor. Since the peak flow rate predicted by the UNET model is similar to the more refined HEC-RAS model and also considerably less than the flow rates in the outboard channel (approximately 9,000 ft3/s in Ebey Slough and 16,000 ft3/s in the Snohomish main stem), the flow rate predictions from the UNET model can be used to assess restoration impacts on off-site scour.

A.1.1.3. Long Term

To represent the Long Term Alternative, Ebey Island was divided into a series of linked stage-storage areas: one for the southern diked area, one for the northern diked area, and a pair of stage-storage areas for the full tidal area. This treatment of the Long Term conditions follows the level of detail used in the FEMA flood study. The full tidal area was split into two stage-storage areas to associate the western two thirds to the Snohomish main stem via Deadwater Slough and the eastern third draining to Ebey Slough. Besides echoing natural watersheds, this configuration establishes flood pathways that are consistent with existing conditions. Specifically, the partitioning of flow between Ebey Slough and the Snohomish main stem is roughly preserved during the 100-year discharge event. The crest elevation of the new cross dikes which separate the restored tidal area from the developed areas were set to constant values similar to the crest elevation of the adjacent existing levee. For the south cross dike, the crest elevation is 17.7 ft NAVD; for the north cross dike, the crest elevation is 14.7 ft NAVD.

A.1.1.3.1. North Tip Option

The option of restoring the north tip of Ebey Island to full tidal conditions was modeled by dividing the stage-storage node representing Ebey Island north of Highway 2. The first node, adjacent to Highway 2, maintains its existing dike configuration to protect developed areas. The second node, at the northern tip, is connected to full tidal exchange by lowering the dike elevation to existing bed grade and adding a breach at the location of the historic channel entering Ebey Island from Steamboat Slough. The crest elevation of the new cross dike between these two regions is 13.7 ft NAVD, an elevation consistent with the existing dikes to which it connects.

A.1.2. Boundary conditions

Three sets of boundary conditions were used to assess the potential hydraulic response to the restoration alternatives. To evaluate typical conditions, water year (WY) 2002 was simulated, spanning the period from October 1, 2001, to September 30, 2002. To evaluate both mild and extreme dike overtopping during flood conditions, both the 5-year and the 100-year riverine flood were simulated. Each of these scenarios requires two boundary conditions:

- discharge specified at the upstream end of the model domain
- water levels specified at the downstream end of the model domain

The details of the boundary conditions representing these two scenarios are provided below.

A.1.2.1. WY2002

Verified discharge observations from the USGS gage on the Snohomish River near Monroe (Station ID 12150800) were downloaded from the USGS website (http://waterdata.usgs.gov) for the period from October 1, 2001 to September 30, 2002. This discharge time series is plotted in Figure 2. This data was applied to Snohomish River at the upstream end of the model domain, near the city of Monroe. The peak flow rate during this year was 56,000 ft3/s. This flow rate is slightly less than the estimated 2-year flow of 64,000 ft3/s (FEMA, 2001).

Verified water level observations from the NOAA gage on Puget Sound near Seattle (Station ID 9447130) were downloaded from the NOAA website (http://tidesandcurrents.noaa.gov) for the period from October 1, 2001 to September 30, 2002. This water level time series is plotted in Figure 3. This data was applied to the three downstream ends of the model domain, where the Snohomish River, Union Slough and Ebey Slough connect with Puget Sound.

A.1.2.2. 5-year flood

The 5-year peak river discharge, estimated in the hydrology section of the FEMA FIS for the Snohomish River (FEMA, 2001), was used to the upstream end of the model domain. The hydrograph describing the rate of rise and fall to and from this peak was derived from a modeling study of the DD6 restoration project (Snohomish County, 2001) and is shown in Figure 4.

Following Snohomish County (2001), the water level at the downstream end of the model domain was a synthetic tide with three successive higher high waters of 10.7 ft NAVD (Figure 5). This water level falls between the average annual high water level and the 2-year return interval for Puget Sound (USACE, 2002).

A.1.2.3. 100-year flood

The 100-year river discharge hydrograph, estimated in the hydrology section of the FEMA FIS for the Snohomish River (FEMA, 2001), was applied to the upstream end of the model domain. This synthetic flood event occurs over a period of seven days and has a peak flow of 204, 000 ft3/s. This discharge time series is plotted in Figure 6. In addition, the estimated 100-year discharge from the Pilchuck River into the Snohomish was also applied to the model. Peak flow in the Pilchuck River is only 5% of the peak discharge in the main stem.

The water level at the downstream end of the model domain was held fixed at 6.2 NGVD, which is one foot above MHHW for Puget Sound. This downstream water level, which follows FEMA

guidance, was carried over from the FEMA flood study so that results from the proposed restoration alternatives would be comparable to the flood study.

A.2. HEC-RAS MODEL

Balancing water levels within the muted tidal areas for habitat and flood mitigation calls for connecting these areas to the adjacent outboard channels with hydraulic control structures that can be operated to open and close at specific water levels. The UNET model that has been developed for flood mapping in the lower Snohomish does not have the capability to specific operating rules for hydraulic structures. Therefore, HEC-RAS, a U.S. Army Corps of Engineers model which can apply operating rules for hydraulic structures (USACE, 2010), was used to model the muted tidal areas. Besides this difference in operating rules, the two models are similar since the unsteady solver in HEC-RAS is based on UNET. HEC-RAS is a publicly available model widely used for hydraulic analysis. It represents open channel flows as one-dimensional networks of channel reaches and stage-storage area nodes.

A.2.1. Geometry

Two HEC-RAS models, one for each of the muted tidal areas, were created to assess the Near Term restoration alternative for Ebey Island. Each model consisted of a short reach of the adjacent outboard channel and the muted tidal area, as depicted in Figure 7 for the eastern muted tidal area. The dimensions of the outboard channel were derived from the existing UNET model of the entire estuary. The muted tidal area was represented as a stage-storage node. The Puget Sound LiDAR Consortium data collected in 2009 provided the basis for estimating the stage-storage relationships. Because the muted tidal areas are anticipated to include tidal channels that do not exist in the current topography, the stage-storage relationships were modified to add additional volume below the exiting bed to account for these channels. The volume and depth of the tidal channels that may form were predicted from hydraulic geometry relationships between marsh area, tidal prism, and channel depth (Williams et al, 2002).

A.2.2. Hydraulic Structures

The outboard channel and stage-storage node representing the muted tidal area were connected with a gated spillway with closed top, which only permits flow when water levels in the outboard met specific elevation criteria. The model representation is similar to the performance characteristics of a culvert with a self-regulating tide gate (SRT) on its outboard end. A SRT includes a mechanism whereby the gate is closed, blocking flow through the culvert, when the water level exceeds a specified value. For the proposed muted tidal areas, the hydraulic structures' dimensions were set as follows:

Width: 12 ft

Height: 6 ft

Sluice discharge coefficient: 0.5

Orifice coefficient: 0.8

Broad-crested weir coefficient: 3

Invert: -3.5 ft NAVD

Outboard water level closure criteria: 2.5 ft NAVD (east), 4.0 ft NAVD (west)

The outboard water level closure criteria were set to obtain target water levels within the restored muted tidal areas. The target water levels were selected to sustain vegetated intertidal habitat and to promote bed accretion while also limiting water levels that pose a flood risk to adjacent Ebey Island properties. The invert is approximately 2 feet below the lowest water levels in the outboard channel to ensure adequate flow depths and drainage capacity even at the lowest tides.

A.2.3. Boundary conditions

Water levels in the outboard channels from WY2002 were predicted by the UNET model and used as boundary conditions for the muted tidal area models. This time period represents conditions in the estuary during a typical year.

A.3. REFERENCES

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Williams, P, M. Orr, and N. Garrity. 2002. Hydraulic Geometry: A Geomorphic Design Tool for Tidal Marsh Channel Evolution in Wetland Restoration Projects. Restoration Ecology 10(3), 577-590.

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USACE. 2002. Qwuloolt/Poortinga Technical Report, Prepared for the Tulalip Tribes of Washington by the USACE Seattle District, January 17, 2002.

USACE. 2010. HEC-RAS River Analysis System User's Manual. Institute for Water Resources, Hydrologic Engineering Center.

A.4. FIGURES

Figure 1. Snohomish River UNET Model

Figure 2. Snohomish River Discharge at Monroe, WY2002

Figure 3. Water level at Seattle, WY2002

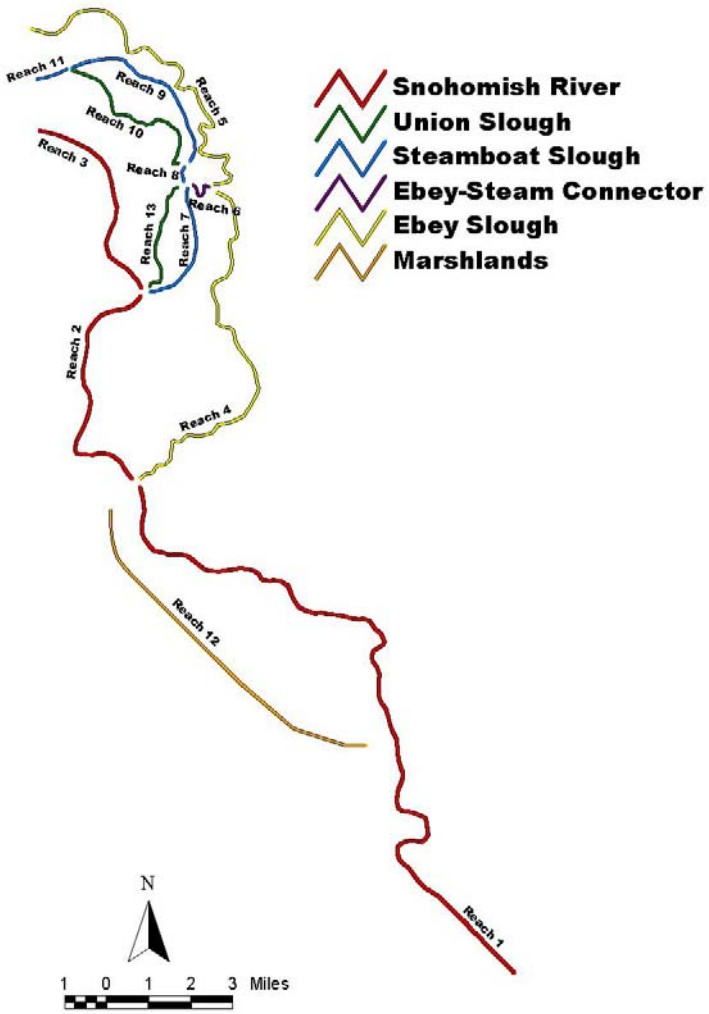
Figure 4. Snohomish River Discharge at Monroe, 5-Year Event

Figure 5. Water Level at Mouth of Snohomish Estuary, 5-Year Event

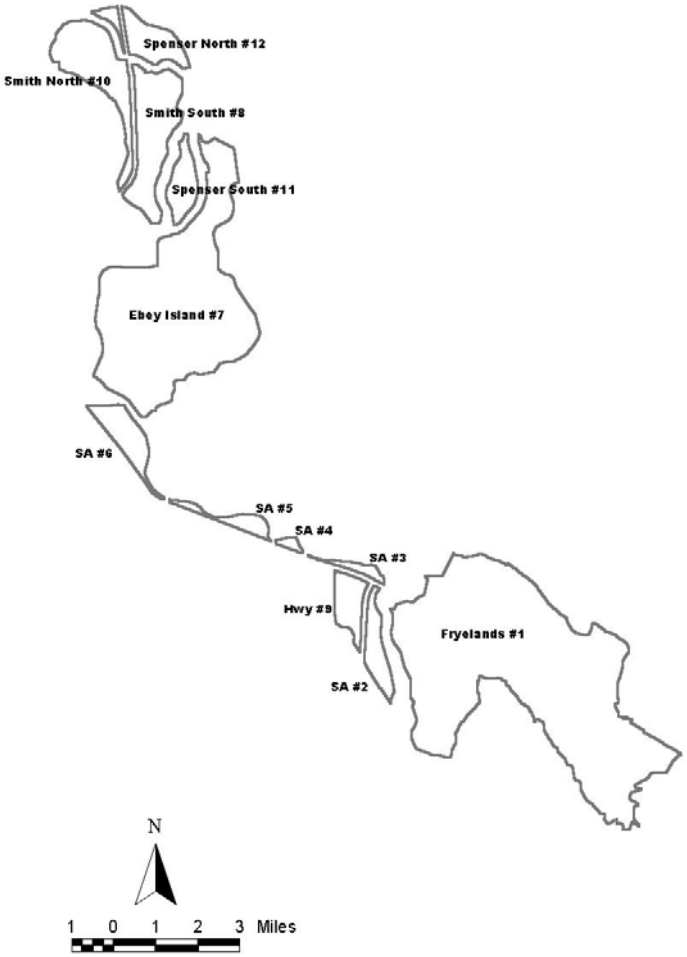
Figure 6. Snohomish River Discharge at Monroe, 100-Year Event

Figure 7. HEC-RAS Model Extent, East Muted Tidal Area

a)



b)



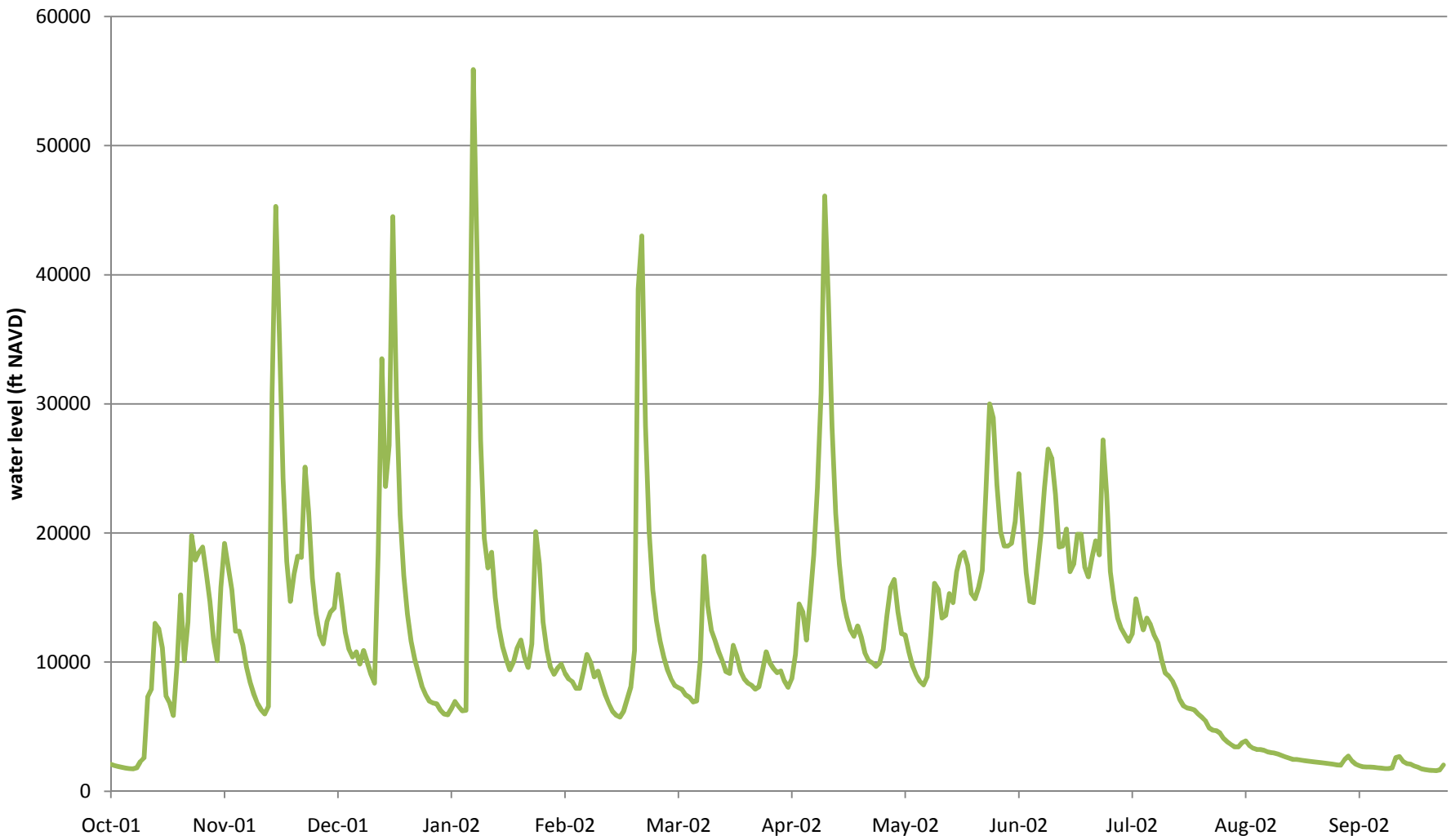
Source: FEMA (2001)

figure 1
Ebey Island Restoration Project

Snohomish River UNET Model

PWA Ref# 2022

ESA PWA



Sources: USGS, Snohomish River near Monroe (Station ID 12150800)

figure **2**

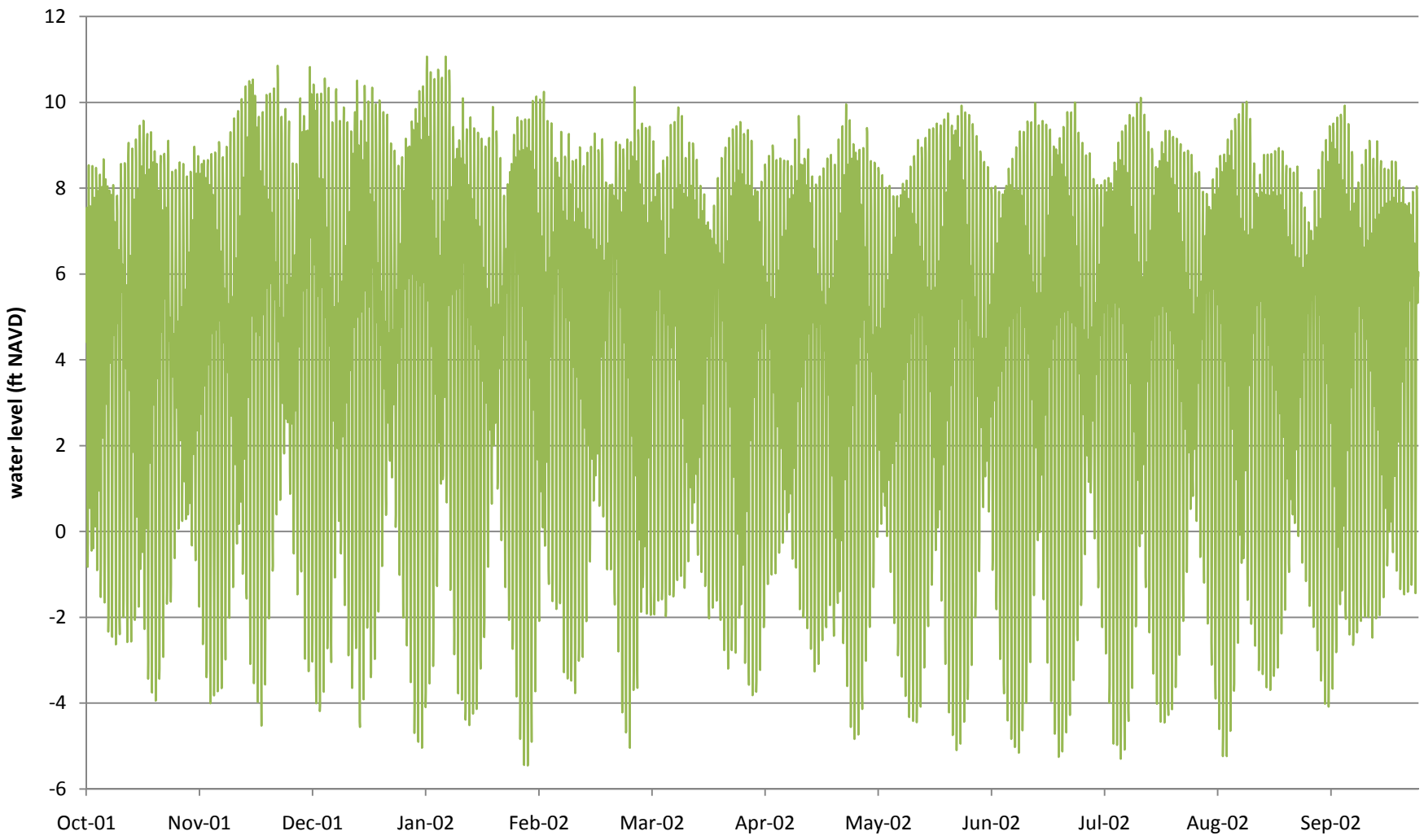
Ebey Island Restortation Project

Snohomish River Discharge at Monroe, WY2002

ESA PWA Ref #: 2022

ESA PWA

A02 WY2002 q BC.xls / PlotWLaug2002



Sources: NOAA , Seattle (Station ID 9447130)

figure ***3***

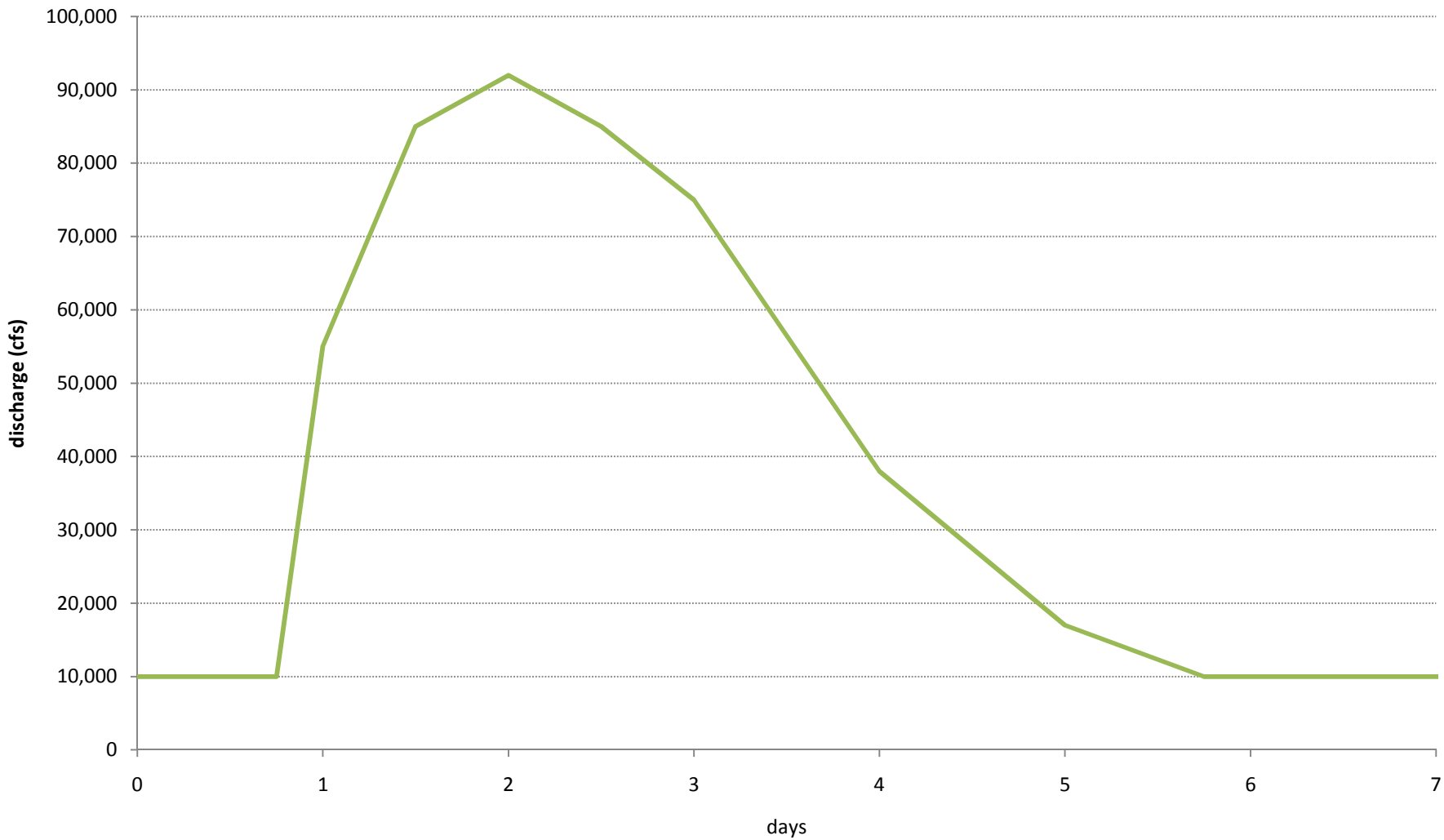
Ebey Island Restortation Project

Water level at Seattle, WY2002

ESA PWA Ref #: 2022

ESA PWA

A03 WY2002 wse BC.xls / PlotWLaug2002



Sources: FEMA (2001), Sonohomish County (2001)

figure ***4***

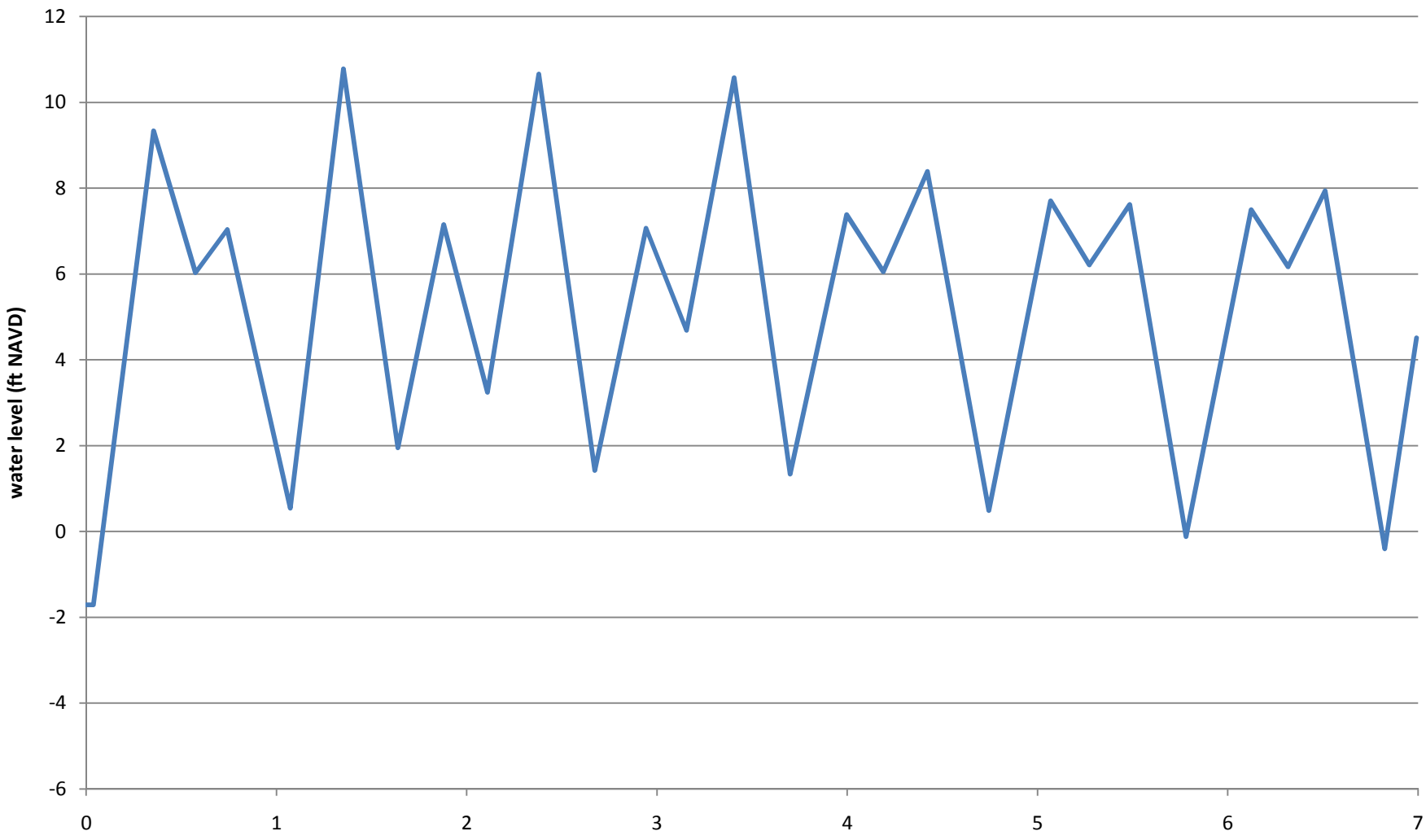
Ebey Island Restortation Project

Snohomish River Discharge at Monroe, 5-Year Event

ESA PWA Ref #: 2022

ESA PWA

A04 Q5 q BC.xls / Plot



Sources: Snohomish County (2001)

figure **5**

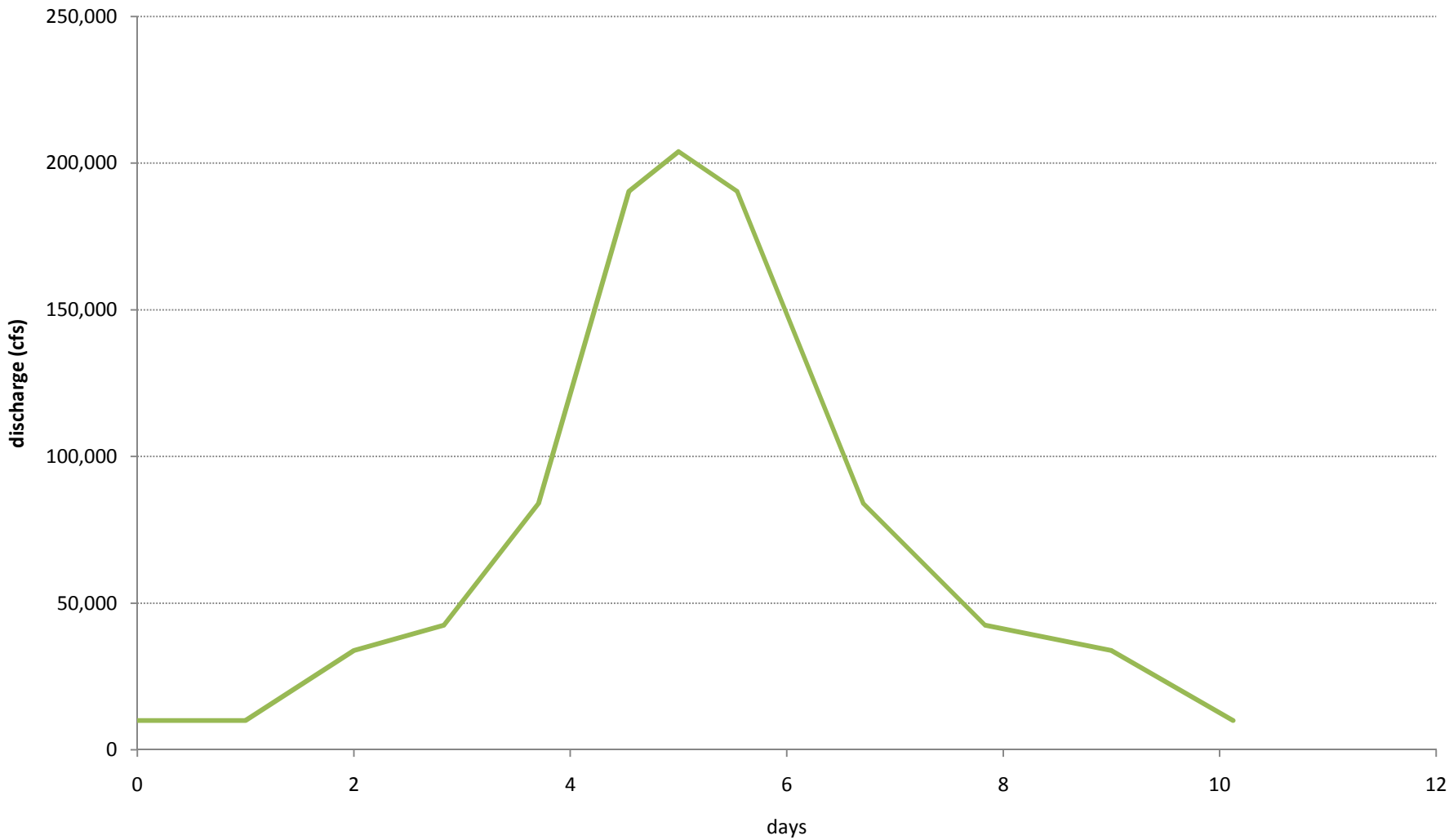
Ebey Island Restortation Project

Water Level at Mouth of Snohomish Estuary, 5-Year Event

ESA PWA Ref #: 2022

ESA PWA

A05 Q5 wse BC.xls / Plot



Sources: FEMA (2001)

figure **6**

Ebey Island Restortation Project

Snohomish River Discharge at Monroe, 100-Year Event

ESA PWA Ref #: 2022

ESA PWA

A06 Q100 q BC.xls / Plot

figure 7
Ebey Island Restoration Project

HEC-RAS Model Extent, East Muted Tidal Area

PWA Ref# 2022

ESA PWA