Fir Island Farm Final Design and Permitting
Draft Coastal Engineering Report
Skagit County, Washington

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TABLE OF CONTENTS

Page

1.0 INTRODUCTION 1

2.0 SITE AND PROJECT DESCRIPTION 1

3.0 TIDAL AND SURVEY DATUMS 2

4.0 HYDRODYNAMIC, EROSION, AND SEDIMENT PROCESSES 3
- 4.1 Hydrodynamic Modeling Results 3
- 4.2 Sea Level Rise (SLR) 5
- 4.3 Erosion, Sedimentation, and Vegetation Establishment 6
- 4.4 Wood Transport 13

5.0 COASTAL DIKE (LEVEE) DESIGN 14
- 5.1 National Resource Conservation Service (NRCS) Dike Design Practice Standards and U.S. Army Corps of Engineers' (Corps') Design Guidelines 14
- 5.2 U.S. Army Corps of Engineers (Corps) PL84-99 Levee Rehabilitation and Inspection Program 15
- 5.3 Federal Emergency Management Agency (FEMA) Floodplain Regulations 15
- 5.4 Level of Protection – Dike Design Elevation 16
- 5.5 Erosion and Scour Protection 18
  - 5.5.1 Wind Waves 18
  - 5.5.2 Tidal Channel and Marsh Flows 18
  - 5.5.3 Scour Toe-down Depth 19
  - 5.5.4 Wood Debris Impacts 20

6.0 SUMMARY OF COASTAL ENGINEERING DESIGN RECOMMENDATIONS 20

7.0 LIMITATIONS 22

8.0 REFERENCES 24

TABLES

1 Fir Island Farm – Site-specific Tidal Datums
2 Sea Level Rise Estimates
3 Marsh and Tidal Channel Sedimentation, Scour, and Vegetation Tailwater Effects
4 Dike Design Elevation Summary

Draft

FIGURES

1 Project Site Plan
2 Hydrodynamic Modeling Low Tide – Depth/Velocity
3 Hydrodynamic Modeling Flood Tide – Depth/Velocity
4 Hydrodynamic Modeling High Tide – Depth/Velocity
5 Hydrodynamic Modeling Ebb Tide – Depth/ Velocity
6 Hydrodynamic Modeling Low Tide – Shear Stress
7 Hydrodynamic Modeling Flood Tide – Shear Stress
8 Hydrodynamic Modeling High Tide – Shear Stress
9 Hydrodynamic Modeling Ebb Tide – Shear Stress
10 Project Hydrodynamic Effect
11 Hydrodynamic Effect and Existing Conditions
12 Sea Level Rise Projections – 2000 to 2100
13 Hydrodynamic and Sea Level Rise Effects and Existing Conditions
14 Levee Coastal Engineering Design Recommendations

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FIR ISLAND FARM FINAL DESIGN AND PERMITTING
DRAFT COASTAL ENGINEERING REPORT
SKAGIT COUNTY, WASHINGTON

1.0 INTRODUCTION

This coastal engineering report accompanies the Hydrodynamic Modeling Analysis report prepared by Battelle for the Fir Island Estuary Restoration Project (Battelle, 2013). The Battelle report provides information on hydrodynamic modeling of levee (dike) setback alternatives, tidal channels and breach areas, and includes information on the expected maximum water elevation for the project. The purpose of this report is to review hydrodynamic results from the study performed by Battelle (Battelle, 2013) for consistency, and to provide design recommendations for the setback levee, marsh areas, and interior drainage system.

Our services were conducted in accordance with the contract and scope of services stated in the Washington State Department of Fish and Wildlife (WDFW) Contract No. 10-1431, Amendment 7, dated May 2, 2013.

2.0 SITE AND PROJECT DESCRIPTION

The Fir Island Farm restoration project (the project) is located on the WDFW Snow Goose Reserve (the Reserve) at Fir Island. The project site is comprised of 245 acres that are currently farmed, with special farming provisions to meet the reserve's Snow Goose management objectives. The project is located on the historic Skagit River Delta between Dry Slough and Brown Slough, with (Claude O.) Davis Slough located near the center of the project dike removal and marsh restoration area (Figure 1).

Natural tidal exchange and historical distributary flows to the site have been eliminated and blocked by historic construction of coastal dikes along Skagit Bay and around Fir Island. One-way tidegates installed through the existing levee block inflow of tides and allow for drainage of interior farm lands. The combination of tidegates and dikes protects interior farm (and drainage) areas.

The proposed project will include setting back the existing dike on the Reserve and restoring 127 acres of farm land to tidal marsh. The feasibility study defined the general dike setback alignment (Shannon & Wilson [S&W], 2011). A number of engineering considerations are addressed in this coastal engineering recommendations report, including:

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- Interpretation of the Battelle hydrodynamic model with respect to dike and interior drainage design criteria.
- Evaluation of the need for a spur dike to protect the Brown Slough drainage system.
- Analysis of setback dike design alignment, elevations, erosion, and scour protection measures.
- Assessment of tidal hydrodynamic, sediment, and wood transport effects on the interior drainage system and marsh restoration areas.

3.0 TIDAL AND SURVEY DATUMS

The project survey datum is Washington State Plane North, North American Datum 1983, North American Vertical Datum 1988 (NAVD88). Documenting project survey datums and transformations is a necessity, especially in the Skagit River Delta where various stakeholders and projects use a variety of datums.

The tidal Mean Lower Low Water (MLLW) datum published by the National Oceanic and Atmospheric Administration (NOAA) is a common tidal reference. This datum is referred to in NOAA tide prediction and tidal data websites and many tide-prediction handbooks. Conversion from MLLW to NAVD88 datum is often published for each tide gage location on the survey datum reference sheet.

Local tide gages in the area are:

- NOAA 9447592 Crescent Harbor Whidbey Island, Washington
- NOAA 9448576 Sneeoosh Point, Washington
- NOAA 9448558 LaConner – Swinomish Channel, Washington

Review of the Swinomish tide gage indicated that there was North Fork Skagit River surge influence on the tidal observations, which can affect MLLW datum transformation calculations. This study elected to use the Crescent Harbor and Sneeoosh Point tidal gages only for calculating MLLW to NAVD88 tidal datum transformations. In coordination with WDFW's professional land surveyor, Al Hammond, a site-specific MLLW-to-NAVD88 tidal datum transformation was estimated by using proportioned scaling based on tide gage latitudes between the Crescent Harbor and Sneeoosh Point. The calculated tidal datum and transformation from MLLW to NAVD88 are summarized in Table 1. Table 1 tidal datum information supersedes previously reported project datums and transformations. The transformation of MLLW to NAVD88 datum for the project site is calculated as follows:

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NAVD88 (feet [ft]) = MLLW (ft) – 2.13 ft

4.0 HYDRODYNAMIC, EROSION, AND SEDIMENT PROCESSES

The proposed project will affect the local tidal hydrodynamics along the Skagit Bay front area between Brown and Dry Sloughs by setting back the existing dike and allowing for exchange of tidal flows to the restored marsh areas. Potential effects could include changes in hydrodynamic flow patterns, tidal inundation periods, water levels, sedimentation and erosion, tidal channel development, and vegetation patterns. The following section of the report discusses information and findings from the project hydrodynamic modeling study (Battelle, 2013), sea level rise (SLR) projections, and overview of erosion and sediment processes and their potential project effects.

4.1 Hydrodynamic Modeling Results

Hydrodynamic modeling of the project has been performed by Battelle and involves modeling of existing and proposed levee setback conditions (Battelle, 2011a and 2011b). The existing conditions model results and initial setback modeling results and recommendations were presented in the Fir Island Farm Estuary Restoration Feasibility report (S&W, 2011). Since that time, the "spur dike" alternative has been analyzed.

The spur dike alternative involves leaving a portion of the existing dike in place, south of the WDFW parking lot, and extending a 200-ft section of dike south into the Skagit Bay marsh in order to isolate the dike levee setback project from Brown Slough. The hydrodynamic modeling output for the two setback alternatives (without and with spur dike) is evaluated for a typical spring season tidal cycle (Figures 2 through 9). The hydrodynamic modeling output was used to evaluate tidal flow patterns and high velocity and shear stress areas that could lead to increased erosion and deposition. The following general observations were made regarding hydrodynamic modeling results.

The setback with spur dike effectively isolates secondary tidal flows, currents, velocities, and shear stresses in Brown Slough. Without the spur dike, a secondary tidal inflow pathway occurs on the east side of Brown Slough to the marsh restoration area. These tidal flows have high enough velocities and shear stresses such that there is an increased risk for erosion and sedimentation that could impact Brown Slough.

The Claude O. Davis main tidal channel inlet "breach" location at the existing dike has predicted velocities and shear stresses exceeding tidal channel erosion thresholds. This area is likely to

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experience sizeable erosion if the breach is sized similar to the existing Claude O. Davis tidal channel width. A majority of eroded material will likely move northward into the restored marsh areas due to the higher velocities and stronger shear stresses occurring on the flood tide as compared with the ebb tide. However, sedimentation to the south in Skagit Bay could occur on the ebb tide. Excavation of the main tidal inlet breach would limit the potential for adverse erosion and sedimentation in the tidal channels.

Predicted tidal velocities and shear stresses in the marsh area along the dike setback structure are less than the referenced published erosion thresholds (see following section on erosion and sedimentation), with the exception of a few preferential flow paths. This indicates that significant erosion along the toe of the dike is not likely. Erosion and scour of the dike setback will therefore likely be driven by wind waves and large wood debris impacts. Erosion from tidal flows along preferential flow paths is has a low likelihood for which selective fill grading can limit these effects. The two likely preferential flow path areas are existing borrow ditches on the current landward (north) side of the existing levee, and the west side of the levee setback in the far southeast corner of the site that is low in elevation. Future designs should consider these effects and develop plans to minimize and mitigate them.

Shallow ponding will likely exist across much of the marsh restoration area at low tide and the site will not fully drain. The marsh and tidal drainage pilot channels (including No Name Slough) will not drain to the same extent as the existing tidal drainage channels (Claude O. Davis Slough). Existing conditions in Claude O. Davis Slough immediately downstream from the current dike and tidegates are compared with proposed conditions in No Name Slough immediately downstream from the proposed dike and tidegates (Figure 1). These are the common tailwater control locations for existing and proposed conditions. For the purposes of this study, this predicted effect is termed a “hydrodynamic effect” of the project (Figure 10). The modeling predictions indicate an increased low tide water surface elevation from 0.7 to 1.0 ft greater than existing conditions. In Figure 10, the hydrodynamic modeling output shows the low-tide water (tailwater) elevations of 4.8 ft for existing conditions in Claude O. Davis Slough downstream from the existing dike ranging in (tailwater) elevation from 5.5 to 5.7 ft for proposed conditions in No Name Slough downstream from the new tidegates, hence, an approximate increase of 0.7 to 1.0 ft.

Our interpretation of the Battelle report hydrodynamic modeling predictions is that the “relative increase” in tailwater elevations is likely representative of future conditions, and that the model predictions of future tailwater elevations of 5.5 to 5.7 ft is overly high. The rationale for this is that the hydrodynamic model existing conditions output show a low tide elevation oscillating

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around 4.7 ft, which is 1.5 ft higher than observed tailwater conditions in Claude O. Davis Slough and should therefore be ignored (Figure 11). The observed tailwater conditions site data were reviewed for a variety of seasons and Skagit River flow conditions and are relatively consistent in low tide elevation, and approximately 1.5 feet lower than the model predicts. Therefore, we interpret the hydrodynamic modeling "relative increase" in tailwater elevations ranging from 0.7 to 1.0 ft as a more likely prediction of changes in future tailwater elevations. Figure 11 shows how this interpretation is applied for use as tailwater boundary conditions for the proposed project, interior drainage modeling analyses.

4.2 Sea Level Rise (SLR)

SLR design criteria are not specified for the drainage design aspects of the project by the National Resources Conservation Service (NRCS) Dike Practice Standard, nor the U.S. Army Corps of Engineers (the Corps) Levee Design Guidelines, or for the habitat restoration aspects of the project. WDFW, with input and coordination from the project steering committee and regulatory and funding agencies, decided that a reasonable approach to the project would be to consider SLR for a period of time commensurate with the 50-year dike design life cycle (the period 2013 through 2063).

The project SLR predictions use information and guidance available from the *National Academy of Sciences (NAS), 2012, Sea Level Rise for the Coasts of California, Oregon and Washington, Past, Present and Future (NAS, 2012).* Sea level rise estimates (low, average, and high) provided by NAS (2012) for the Seattle area including vertical land mass adjustments associated with the Cascadia subduction tectonics, and glacial isostatic adjustments (isostatic rebound) for the Puget Sound (Table 2). A review of the NAS study land mass adjustments factors were similar to those published by Mote (2008) for the Skagit Bay area. Table 2 and Figure 12 summarize the range of estimated SLR for the project. The average predicted SLR is 0.93 ft in the year 2063, with an uncertainty of ±0.5 ft. Figure 13 shows how the combined SLR and project hydrodynamic effects on marsh water surface elevations and culvert tailwater conditions are applied to the interior drainage models.

One method of adaptation or building resiliency associated with the uncertainty of potentially higher levels of SLR, or other tidal and wave calculations, is to build the levee with additional top width to allow for raising the levee in the future, without needing to build or expand the levee on the landward or waterward slope. For the project, an additional 3-ft top width would allow for raising the levee 0.5 ft, which is similar to the upper confidence boundary of uncertainty for SLR in 50 years (i.e., year 2063). For the project, a minimum design top width of

15 ft has been requested by Consolidated Diking District 22 (CDD22). The project team recommends adding 3 ft for a total top width of 18 ft to accommodate for uncertainty associated with SLR.

SLR and climate change will also affect existing and restored marsh area inundation characteristics, sedimentation and erosion rates. It is likely that the mud and vegetation lines will be increasing in elevation due to SLR. Resiliency measures, considering the potential lack of sediment supply to the system discussed in the following section, could be accounted for by building up marsh surfaces using selective fill grading in areas with low shear stresses to improve vegetation establishment.

4.3 Erosion, Sedimentation, and Vegetation Establishment

Erosion and sedimentation are key considerations for the project. These processes are being considered to understand their potential effects on interior drainage functions, as well as the potential for restoring tidal channels and vegetated marsh areas. The general project approach is to limit the potential for significant erosion that could result in adverse sedimentation affecting the interior drainage performance. An example of this type of sedimentation would be sedimentation in a tidal channel resulting in an increased tailwater elevation such that the interior drainage areas cannot fully drain. To the extent feasible, the project is evaluating and proposing design and construction methods that reduce these risks to the interior drainage system, while maximizing the benefits of erosion and sedimentation to habitat restoration.

There are several erosion and sedimentation processes that will influence the marsh restoration response:

- Erosion and expansion of the main tidal inlet area and main tidal channel into the marsh.
- Erosion of marsh plain surfaces that are more frequently inundated and have higher shear stresses, and will not readily establish marsh vegetation.
- Erosion of tidal drainage channels.
- Sedimentation of eroded materials in the new and existing marsh and tidal channel areas.
- External shoreline transport and supply of sediments into the marsh restoration area.

The hydrodynamic modeling results provide predictions of flow patterns, depths, velocities, and shear stresses. This study uses the hydrodynamic modeling predictions in combination with a

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conceptual framework to evaluate erosion and sedimentation risks, benefits, and to develop strategies for the project. The following (simplified) sedimentation and erosion framework was developed based studies by Fagherazzi (2012), Kirwan (2007) and Hood (2009).

- Sedimentation is the primary long-term process affecting development of the tidal channel network and vegetation marsh surfaces, not erosion (Hood 2009).
- Sedimentation rates are likely to be higher in deeper areas that are more often inundated and in areas proximate to tidal channels that deliver sediment (Fagherazzi, 2012). Areas that are further from tidal channels will have lower sediment supplies and, hence, lower sedimentation rates.
- Bare soil areas exposed to tidal flows exceeding critical shear stress thresholds will erode and become local sediment sources. Vegetated areas have much higher critical shear stress erosion thresholds and are less likely to erode. Vegetation establishment will likely occur above the mudline, which can vary from site to site. The mudline for the existing marsh is between elevation 5.5 and 6.0 ft, and expected to be somewhat similar for the new marsh area.
- Considering long-term SLR, the mudline elevation will likely be increasing over time. If sedimentation rates are not high enough, lower-lying areas may be flooded out and become mudflats. Areas that are inundated for significant amounts of time or exposed to high shear stresses will not likely establish vegetation and will become mudflats, tidal channels, or remain permanently ponded.
- Marsh plant establishment will benefit from quiescent flow conditions (low velocity and shear stress areas) as well as being located in a sedimentary environment. Plant establishment can create a biofeedback that increases sedimentation rates and can promote marsh plain accretion. These areas, however, are typically further away from tidal channels that supply sediments.
- Tidal channel and lower-lying marsh areas exposed to coastal waves (near the main tidal inlet) will likely erode and become local sediment sources.
- If the regional sediment supply to the marsh is not high enough to keep up with SLR, the mudline advance over time may consume (or limit) vegetated marsh areas.
- Establishment of marsh vegetation will focus tidal flows into tidal drainage channels and promote development of these channels, which are considered key habitat for juvenile Chinook.
- Large exposed mud flat and erosion areas are more likely to have erosion and sedimentation that could adversely affect tidal drainage channel functions as it relates to interior drainage.

Using this framework, the first analysis performed was a review of the hydrodynamic modeling shear stresses (Figures 7 and 9) to evaluate erosion potential. The hydrodynamic model

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predictions indicate that the main tidal inlet area, and areas north and south of the inlet, have the highest potential for erosion for both modeling alternatives (with and without spur dike) primarily on the flood and ebb tides. These areas are likely to be exposed to additional wave action, which will also contribute to erosion. Considering the flood tide has elevated shear stress and velocity as compared with the ebb tide, eroded sediments will mostly likely transport into the restored marsh area. It is anticipated that sedimentation would occur along the fringes and circumference of the high-shear-stress zones (Figure 7). This observation is based on evaluation of shear stresses exceeding published critical shear stress erosion thresholds. A literature review of published permissible erosion shear stress values was performed and is summarized below.

- Smeardon and Beasley, 1956, estimate the erosion threshold of bare clayey silts as 0.09 to 0.22 psf.
- Van Rijn (1993) and Amhad (2011) evaluated critical shear stress thresholds for cohesive sediments based on various factors including silt, sand, clay content, cohesion, and density. They report much lower erosion thresholds for bare soils on the order of 0.002 to 0.02 psf.
- Kirwan (2007) and Fagherazzi (2001) use critical shear stress threshold of approximately 0.01 psf for bare mudflat and tidal channel surfaces.
- The U.S. Bureau of Reclamation Erosion and Sediment Manual (2006) Chapter 4 presents critical stress thresholds for bare cohesive soils, such as clayey silts, ranging from 0.004 to 0.125 psf.
- Grass vegetation permissible shear stresses range from 0.4 to 4.0 psf according to the Federal Highway Administration (FHWA) (2011).

Discounting the lowest reported critical shear stress erosion thresholds, a value of 0.1 psf is used to identify likely erosion for bare soil areas. A value of 2.2 psf is used to identify likely erosion areas for vegetated areas. Both alternatives have shear stresses that exceed bare soil and vegetated area critical shear stress erosion thresholds. The with-spur-dike alternative has high shear stresses at the main tidal inlet, extending into the marsh along the pilot channels and adjacent marsh areas. The without-spur-dike alternative has similar pattern at the main tidal inlet, albeit to a lesser degree, and high shear stresses on the western side of the marsh along Brown Slough. Surface shear stresses for these areas exceed 10 psf, which are well above the reviewed permissible shear stress values for both bare soils and vegetated surfaces.

The spur dike alternative is the recommended alternative, so the following discussions will focus on the spur dike alternative. The spur dike alternative will have erosion of the main tidal inlet, tidal channels, and adjacent marsh areas nearer the inlet. These areas have blue, green, and

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yellow colors in Figure 7 flood tide conditions, which represent shear stresses in excess of 5 psf. Sediment derived from these erosion areas will likely deposit in adjacent lower-shear-stress zones near the tidal channels and sediment sources.

Areas located beyond the higher-shear-stress zones will be less likely to erode and will likely support sedimentation and establishment of vegetation, depending upon inundation and sedimentation characteristics. Based on the marsh process framework from above, however, sedimentation rates will be lower in these areas as they are less frequently inundated and further away from the tidal channel sediment sources. These areas have no color or are red color in Figures 6 through 9. Lower sedimentation rates implies that these areas might be at risk for limited vegetated marsh areas due to long term SLR and mudline elevation increases.

There are different methods for mitigating these erosion and sedimentation risks for the project:

- Allow for erosion of the main tidal inlet and Claude O. Davis channel and adjacent marsh areas with expectation that eroded materials will primarily deposit along the margins of the high-shear-stress zones. The risk is that the fairly quick change in tidal hydrodynamics may create erosion and sedimentation conditions that deposit large bars or shoals in tidal channels and thereby affect tidal channel drainage and tailwater conditions for interior drainage. It will be difficult to dredge or maintain the tidal channels out in the marsh in the future. This is the least conservative and least costly approach.
- Allow for erosion of the main tidal inlet and Claude O. Davis channel, and plant areas with a crop cover that will not be consumed by snow geese in marsh restoration areas and along the margins of the high-shear-stress areas. The expectation is that the main tidal inlet area will erode and transport materials into the new marsh. The cover crop will resist erosion and promote deposition and sedimentation processes similar to natural marsh accretion and vegetation processes. The risk for erosion and sedimentation effects in the tidal channel remains, but it is likely less than the first method. The cover crop would promote sedimentation and limit erosion of adjacent marsh surfaces.
- The third option builds on the second method and considers adding excavation and dredging of the main tidal inlet and Claude O. Davis channel, and placing dredge spoils and planting these areas in the new marsh in areas with low shear stresses and low erosion potential. The risk for erosion and sedimentation effects in the tidal channel will be lower than the first two methods because it will promote more rapid establishment of marsh vegetation. This method requires more construction and work in the existing marsh, rather than allowing for natural erosion processes to modify the main tidal inlet. Also, even with excavation of the inlet, additional erosion and

sedimentation adjustments should be anticipated. This is the most conservative, and costly approach.

The recommended method for the project is presented later in the report. Other erosion and sedimentation framework elements are considered such as regional (Skagit Bay) erosion and sedimentation conditions.

Shoreline sediment shoaling and littoral drift processes could supply sediment to the marsh restoration areas. The project hydrodynamic forces will likely draw in some amount of sediments from Skagit Bay, albeit the central Bay front area is likely limited in sediment supply and likely has higher sediment supply similar to the Wiley Slough site near the South Fork Skagit River.

Grossman (2011) presents evidence that sediment delivery to the North and South Fork distributaries has increased dramatically since 1850 due to a combination of land use change (e.g., logging and road building), clearing and dredging in the lower river, and channelization of flow. However, several studies observe different sedimentation characteristics along the central Fir Island Bay front area as compared with adjacent distributaries of the North and South Fork Skagit Rivers resulting from diking and cutting off river distributary channels (i.e., Dry Slough).

The Cowles (2012) study of coastal erosion and sediment transport conditions along the Skagit Bay and Skagit Delta, North and South Fork distributaries indicates that the confined river distributaries have higher erosion potential (with higher supply) versus the central Skagit Bay front, which has lower erosion potential. These higher sediment supply and erosion areas of the distributaries are likely to be more dynamic and have increased sedimentation and erosion characteristics as compared with the lower-supply, calmer areas of the central Fir Island, Bay front area.

Grossman (2013) provided preliminary communications to the study regarding long-term, Skagit Bay front sediment transport conditions may change with climate change and SLR. These changes may include increased supply and transport rates along the Bay front, but studies of this potential have not been performed to date on this topic. In contrast, Hood (2007) and Phil Williams Associates (2004) studies document recent trends indicating reductions in sediment supplies to the central areas of Skagit Bay which have resulted in marsh erosion pedestals along the central Fir Island Skagit Bay front area.

Based on limited hydrodynamic modeling and available sediment studies along the central areas of the Skagit Bay front, our interpretation of existing information on sediment transport

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conditions is that sediment supply and sources along the central Fir Island Bay front area (Fir Island Farm site) are low.

The importance of this discussion is that the project site likely has different sediment supply conditions than the neighboring Wiley Slough project. Wiley is located at the mouth of the South Fork Skagit River and has experienced sediment shoaling conditions affecting interior drainage. This is noted as the project team and its stakeholders often compare the Fir Island Farm and Wiley Slough sites.

Another source of information regarding potential erosion and sedimentation effects of the project is the Nisqually Delta Restoration project (the Nisqually project). The Nisqually project is evaluating geomorphologic and sediment effects of a large-scale, more than 700-acre restoration project. Several observations and data sets are presented on the Nisqually monitoring website (U.S. Fish and Wildlife Service [USFWS], 2012). We note that the Nisqually Delta restoration and measurements likely have higher sediment supply than the central Fir Island Bay front, as the project is located near the Nisqually River, and likely has higher sediment supply (similar to the Wiley site near the South Fork Skagit River).

Marsh sedimentation rates at the Nisqually project were measured using a variety of techniques, for which the website provides sedimentation information from surface elevation tables measurements. These measurements show marsh surface elevations increasing due to varying amounts of sedimentation. For the Nisqually refuge (the refuge) restoration area, an initial higher sedimentation rate was observed (38 millimeters per year [mm/year]) between 2009 and 2010 in the marsh restoration area, and then reduced sedimentation rates from 2010 to 2012, decreasing on average to 9 mm/year in 2010 to 2011 and 2 mm/year in 2011 to 2012.

In contrast, tidal channel monitoring at the refuge documented initial tidal channel sedimentation and elevation increases, likely due to the presence of floating grass and peat mats and sediment waves being transported through the site, and then 40 centimeters per year of channel scour between 2010 and 2011 (U.S. Geological Survey [USGS], 2012).

Early monitoring of the Nisqually project generally shows large tidal channels have eroded and widened, and nearby marsh surfaces have experienced low levels of marsh sedimentation. This is similar to the initial indicators for the hydrodynamic modeling predictions on shear stress thresholds discussed above.

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The data set collected for the Nisqually project has a limited time period and limitations regarding the similarity of site characteristics, but has been used for this study as it is some of the only data readily available in the Puget Sound. Tidal channel erosion and scour, and marsh sedimentation rates were compiled from the Nisqually project to provide a range of anticipated erosion and sedimentation rates that may occur over time at the Fir Island Farm site (Table 3). The values used in Table 3 assume that the erosion and sedimentation changes correspond with similar changes in hydrodynamic and tailwater elevations on the interior drainage system, which are used in interior drainage sensitivity analyses. These erosion and sedimentation rates were considered in recommending the erosion and sediment management method, described below.

Considering the low supply of sediment along the central Fir Island Bay front, it is anticipated that the main tidal inlet, pilot channel, and marsh areas directly adjacent to these features will erode and be the primary sources of sediment to the project. In general, a majority of these eroded materials will transport inward, toward the marsh restoration area, due to the larger flood shear stress conditions.

It is not known, nor is it likely, that the Skagit Bay shoreline sediment supply is large enough to promote actively accreting marsh platforms and establish higher marsh elevations, especially in the near term. Also, this lack of sediment supply could be a risk factor associated with increasing inundation levels as SLR occurs, and the deeper inundation has the potential of flooding out marsh areas and limiting vegetation establishment.

Considering the likelihood of limited sediment supply of the central Fir Island Bay front area and the potential erosion of the main tidal inlet and adjacent marsh surfaces and tidal channels, we recommend the third method presented above. This would involve

- Excavation and dredging of the main tidal inlet channel,
- Seeding of marsh areas and establishing grass on the farm areas prior to breaching to limit erosion potential and accelerate sedimentation,
- Excavation of pilot channels, and
- Fill grading using excavated materials and planting of native salt marsh vegetation in quiescent areas along the margins of the of the new marsh and dike setback in low-shear-stress areas.

These potential fill grade areas are more broad than originally conceived in the feasibility study and are located from the southeast corner of the marsh restoration area near Dry Slough, and follow the entire perimeter of the dike all the way north and west around to the Spur Dike area

near Brown Slough. Fill grading would raise farm fields to establish a range of elevations conducive to establishment of native marsh vegetation and tidal channel network development. Establishment of marsh vegetation will reduce risks from erosion and sedimentation in the tidal channels, as well as increase the benefits to juvenile Chinook through establishment of tidal channel network in the vegetated marsh – food source areas. Fill grading will also reduce the risks associated with SLR and low sediment supply, whereby these areas could be flooded out, making it difficult to establish marsh vegetation. Fill grading will also provide a location for onsite disposal of excavated existing dike, main tidal inlet, and pilot channel materials, and build marsh surfaces in desirable areas rather than allowing natural sedimentation over the long term, which may not be viable at the project site due to low sediment supply. The amount of fill grading that can be achieved is limited to available on-site cut quantities and hauling limitations.

The uncertainties associated with the project restoration design include hydrodynamic, erosion, and sedimentation effects, and their influence on drainage and marsh restoration performance. Sedimentation in the marsh is good for habitat restoration, but may be in conflict with interior drainage functions. These are competing criteria, for which both gravity drainage and pump station drainage features will likely be needed to balance the project objectives and outcomes. The adaptive management and monitoring plan is also being developed for the project to monitor future project conditions and performance for drainage and habitat restoration conditions. It is likely that long-term, ongoing adaptive management resources will be necessary for the project.

4.4 Wood Transport

Transport of large wood debris from the Skagit River and Skagit Bay into the marsh is likely, as observed with existing conditions. Wood transport can damage levees through direct impact; dragging and scouring of levee materials; and clogging, impacting, and damaging drainage infrastructure. Existing conditions along the Skagit Bay front marsh include large wood debris that varies in size ranging from small woody debris (typically debris with diameters less than 1-ft), to larger trees ranging in size from 1-ft-diameter bole and smaller rootballs (less than 3 ft in diameter) to massive pieces of wood debris that are 3 ft in diameter along the bole and have rootballs (greater than 3 ft in diameter). Patterns of existing wood deposits along the Skagit Bay front and marsh areas indicate that wood transport is a function of wind direction, topography, and tidal water depth. Wind rose data from nearby Whidbey Island shows that predominant wind directions are from the southerly and northeasterly directions (Battelle, 2013). The wind direction will push wood debris that travels through the main tidal inlet toward the northernmost (east-west) section of the dike and into the southeast corner of the marsh. Site observations indicate that wood debris travels primarily into and along the slough channels. Wood debris may

travel across the marsh, but is limited by tidal depth and wood member size and vegetation. Larger pieces of wood are limited in traveling across higher marsh elevations, as they can get hung up in the marsh. Elevated topography and grading along the levee toe can limit some wood debris impacts due to shallow water depths that will limit wood transport. Drainage structures (tidegates) in No Name Slough, dike setback, will need to be protected with log booms and wood debris racks to prevent wood debris impacts.

5.0 COASTAL DIKE (LEVEE) DESIGN

The dike design is based on a criteria established by dike and levee design practice standards and design guidelines. The following section provides information regarding these design standards and identifies the selected design criteria for the project.

5.1 National Resource Conservation Service (NRCS) Dike Design Practice Standards and U.S. Army Corps of Engineers' (Corps') Design Guidelines

The project coastal levee (dike) protects WDFW and farm property, roads, infrastructure, and rural residential properties from tidal inundation, flooding, storm surge, wind wave overtopping, erosion, and scour of the levee embankment. Depending up the location, type of protection, and type of flood risks, differing design guidelines, regulations, and standards apply and are summarized herein for the project.

The project primarily uses the NRCS, 2002, Conservation Practice Standard, Code 356 Dikes and NRCS National Engineering Handbook Section 16, Chapter 6, Dike Design (NRCS, 1970) guidelines were used to design the project. The USACE levee design guidelines (USACE, 2000) were used in developing design recommendations, especially when the NRCS guidelines were prescriptive and did not provide engineering methods for evaluating the design.

This report focuses on dike design criteria associated with coastal, hydrodynamic, and hydraulic design issues including dike overtopping, scour, and erosion criteria. The levee will be designed to meet certain seepage, foundation and embankment stability, and interior drainage criteria which will be presented in further detail in forthcoming interior drainage and geotechnical engineering reports. The following guidelines were referenced in developing design recommendations for the project:

- NRCS, 2002, Conservation Practice Standard, Code 356 Dikes
- NRCS, NEH Section 16, "Drainage of Agricultural Land," Chapter 6: Dikes (NRCS, 1970)

- USACE EM 1110-2-1913, "Design and Construction of Levees" (Corps, 2000)
- USACE, 2009, ETL 1110-2-6-571, "Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, and Appurtenant Structures"
- USACE, 2008, "Coastal Engineering Manual," EM 1110-2-1100

The Fir Island, Skagit Bay dikes are under the purview of Skagit County CDD22. This report addresses the following hydraulic/coastal design criteria only.

Hydraulic/Coastal Design Criteria:

- Level of protection design elevation for a coastal dike based on tide heights, storm surge, and wind waves (provided in this report).
- Erosion protection design based on wave heights, tidal and storm surge wave velocities, and wood debris impacts (provided in this report).
- Dike vegetation based on erosion protection, maintenance, and inspection as stated in NRCS and Corps guidelines (provided in this report).
- Dike top width design based on maintenance and repair accessibility, and related to level of protection uncertainty and future levee raises such as sea level rise (provided in this report).

Geotechnical and interior drainage design criteria will be presented in separate reports.

5.2 U.S. Army Corps of Engineers (Corps) PL84-99 Levee Rehabilitation and Inspection Program

The project dikes do not participate in (and are not eligible for) the Corps' PL84-99 Levee Rehabilitation and Inspection Program.

5.3 Federal Emergency Management Agency (FEMA) Floodplain Regulations

The project is located on FEMA FIRM Panel 5301510425C, and shown as a Coastal Zone Flood area V4, with a coastal flood elevation based on waves and velocities of 10 ft National Geodetic Vertical Datum of 1929, which translates to a project elevation of 13.7 ft (NAVD88). The project dikes are not considered FEMA-accredited levees providing flood protection under the FEMA National Flood Insurance Program.

The project team consulted with John Graves, FEMA Region 10 (FEMA, 2013), regarding how the FEMA BiOp for endangered species would apply for the project. FEMA indicated that

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because the project is a restoration project, the FEMA Bi-Op provides a safe-harbor provision for Section 7 consultation. Also, there is a nexus with another federal agency and a separate Section 7 consultation will not be necessary for the project.

5.4 Level of Protection – Dike Design Elevation

Using the *NRCS 2002 Conservation Practice Standard*, the Fir Island Farm dikes are considered Class II dikes, reflecting sites where the standard states:

> *"failure may cause damage to isolated homes, secondary highways, minor railroads, relatively important public utilities, high value land, or high value crops."*

In accordance with the *NRCS 2002 Conservation Practice Standard*, the minimum dike design elevation for a Class II dike should be the sum of:

> *1) The water elevation (tidal elevation) attained by a highest astronomical tide for the 25-year design frequency event,*
>
> *Plus the larger of,*
>
> *2.a) The minimum freeboard from the NRCS practice standard Table 1 (which is 2 ft based on a Class II dike that is generally less than 12ft in height), or*
>
> *2.b) The wave height caused by wind wave (assuming wind wave includes storm surge and wind wave runup for the specified design event) or boat traffic*
>
> *Allowance (addition of material overbuild) for settlement based on geotechnical analysis of fill material, foundation material and condition, and compaction methods.*

The project dike design height uses the highest astronomical tide for the current tidal epoch (1983 to 2001) plus the wave design method (item 1 plus item 2.b, above), as it is larger than the 2-ft-of-freeboard method (item 2.a, above). The project design analysis did not calculate a 25-year tidal event; rather, the highest astronomical tide from the current tidal epoch was used. The project design assumes that the highest astronomical tide (HAT) for the current tidal epoch is roughly equivalent to or greater than the 25-year event and is likely less conservative than the 100-year criteria. This is counterbalanced with other conservative approaches used in calculating wave design heights.

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The starting point for dike design elevation is the water elevation HAT elevation. The HAT was calculated by Al Hammond, PLS for the WDFW, by computing proportions of the mean higher high water (MHHW) to HAT at Sneeoosh Point and then extrapolating this ratio to the Crescent Harbor gage for the most recent tidal epoch 1983 to 2001. The project site HAT was then calculated using proportioned scaling based on latitudes between the Crescent Harbor and Sneeoosh Point tidal gages. The project site calculated HAT is 11.28 ft (NAVD88) (Table 1).

Wave height design was interpreted from the NRCS dike conservation practice standard to include storm surge and wind-wave runup components. The NRCS conservation practice standard does not address SLR. The project approach to address SLR was discussed in Section 4.2, using a 50-year SLR prediction.

Storm surge heights were provided in the Battelle report (Battelle, 2013) and based on the 100-year wind storm probability from NOAA's National Climate Data Center station (72797524255) on Whidbey Island. The 100-year storm wind speed of 96.8 miles per hour (29.5 meters per second reported by Battelle, 2013) was used in the Puget Sound three-dimensional hydrodynamic model for the a complete model simulation period. This approach is considered a conservative estimate of wind-induced storm surge height, as the modeled wind speed was run as a continuous wind speed, allowing full wave setup, and did not model wind as gusts and it was a 100-year wind storm event. The model results showed that the water surface elevation near the project site may rise about 2.20 ft (0.67 meters [m] reported by Battelle, 2013) at high tide, during a 100-year storm surge induced by high winds.

Wind wave runup, with breaking waves, was calculated by Battelle (2013) using the methods outlined in the Corps' Coastal Engineering Manual (USACE, 2003), at 0.54 ft (0.166 m). The calculated combined wave height including storm surge plus wind wave runup is 2.74 ft.

According to Zervas (2007), tidal heights above MHHW in Puget Sound range from 1.48 ft for a storm with a return frequency of once a year to 3.19 ft for a storm with a return frequency of once in 100 years. The calculated combined storm surge and wind wave runup tidal height of 2.74 ft falls within the range of reported elevated tidal heights reported by Zervas.

Using the wave height calculation method plus SLR for a 50-year design life, the following equation applies and results in a dike target design elevation of 15.0 ft, neglecting settlement (Table 4). Settlement design will be included as "overbuild" in addition to the 15.0-ft elevation. The amount of settlement will be evaluated in future geotechnical design phases of the project.

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$$\eta_{Design} = \eta_{HAT} + \eta_{surge} + \eta_{wave} + \eta_{slr\text{-}2063} = 15.0 \text{ ft}$$

5.5 Erosion and Scour Protection

Using the *NRCS 2002 Conservation Practice Standard*, the slope protection section states:

> *"Slopes of earthen dikes shall be protected from sheet, rill, and gully erosion; erosion from flowing floodwaters; and wave action created by wind and/or boat traffic. Erosion protection measures such as non-woody vegetation, berms, rock riprap, sand-gravel, or soil cement shall be utilized as needed."*

Based on observations and history of the existing dike erosion characteristics, and the hydrodynamic modeling results, the dike will be subject to erosion from wind waves, possible tidal channel development along the levee toe, and impacts from floating large wood debris. The following approach was used to evaluate erosion and scour for the setback dike.

5.5.1 Wind Waves

Riprap size was based on wind wave attack using two methods presented in HEC-23 (Lagasse and others, 2009): the Hudson method (Douglass and Krolak, 2008), and the Pilarczyk method (Pilarczyk, 1997). In the Hudson method, rock size is a function of the 10 percent wave height (equal to 1.27 times the significant wave height), placed side slope, and the specific gravity of the rock and water. In the Pilarczyk method, rock size is a function of the significant wave height, wave period, and placed side slope. The following parameters were used to calculate the rock size:

- Side slopes = 3 Horizontal to 1 Vertical (3H:1V)
- Rock (riprap) specific gravity = 2.65
- Saltwater specific gravity = 1.03
- Significant wave height = 2.7 ft (Table 3 – Surge and Wind-Wave)
- Wave period = 4.6 seconds (Battelle, 2013)

For the above parameters, the calculated average median particle size (D_{50}) for the two methods is 1.5 ft.

5.5.2 Tidal Channel and Marsh Flows

Tidal channel and marsh flow velocities along the setback dike are relatively nominal. The model shows higher velocities along the southeastern section of the setback levee between Dry and Davis Sloughs due to preferential flow paths. Tidal channel and marsh flow conditions

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along the setback dike do not require riprap protection greater than those calculated for wind wave and wood impacts.

5.5.3 Scour Toe-down Depth

Over the long term, formation of new tidal channels and elongation of new and existing tidal channels (or existing drainage channels) in the marsh could impact the setback dike. Tidal channel sizes were predicted using methods described by Hood (2007) for the Feasibility Study (S&W, 2011). Consideration of tidal channel development along the setback dike results in an estimated tidal channel top width of 6 ft using Hood's empirical formulas. Assuming tidal channel side slopes of 1.5H:1V, the depth of the tidal channel depth would be 2 ft. Overall, the contributing drainage areas near the dike are relatively small and therefore cannot contribute significant flow or volume of water to erode a tidal channel.

In areas more central to the marsh and distal from the dike setback, tidal channels up to 35 ft wide could occur where there is increased volume of tidal prism and increased flow velocities. These areas are associated with No Name and Davis Sloughs and the areas immediately upstream from the main tidal inlet.

There is a potential for tidal channel formation and shallow (2 ft deep) channels along the dike setback. A general riprap erosion protection, toe-down depth of 3 to 4 ft below the waterward (marsh side) toe of the levee is recommended. The toe-down depth of 3 to 4 ft would be 1 to 2 ft below the tidal channel depth calculated above. This does not consider the potential development of a tidal channel running parallel to the toe along a preferential flow path. The areas where this may occur are limited to the southeastern corner of the marsh, for which we are recommending fill grading to limit development of preferential flow paths.

Larger localized scour conditions may develop due to larger tidal channel development, scour along preferential flow paths, or large wood debris deposits or impacts creating localized scour conditions. The exact location and timing of larger localized scour conditions cannot be predicted. This uncertainty is similar for both the existing dike and the setback dike. Future marsh grading plans at the toe are anticipated to limit this type of erosion and scour. Annual inspections and maintenance repairs on the dike toe will need to continue to document localized scour and erosion areas that need repair by the dike and drainage district. This report considers the effects of preferential flow paths and high-shear-stress areas, and recommends selective fill grading in the southeastern/Dry Slough area. Similarly, filling and grading of borrow ditches along the existing dike may not be successful, as preferential flow paths might develop and erode

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ditch fills in areas where erosion is not of concern to the existing dike, and could cause sedimentation in the tidal drainage channels. Marsh fill grading in low-shear-stress areas along the entire setback dike may reduce localized toe erosion and promote native marsh vegetation establishment, thereby protecting the setback dike from scour and erosion.

5.5.4 Wood Debris Impacts

Large wood transported by the Skagit River and along Skagit Bay will likely impact the dike during storm events. Available information on wood impacts on riprap revetments is limited. FEMA (2011) developed a method for calculating debris impacts to structures in the floodway. Using the FEMA method and the following assumptions, a riprap size to resist wood impacts was calculated:

- Tree length = 30 ft
- Tree trunk diameter = 2 to 3 ft
- Tree rootwad diameter = 4 to 6 ft
- Unit weight of saturated wood = 50 pounds per cubic ft
- Velocity of water = 0.5 ft per second
- Coefficient of drag for riprap particle = 0.4
- Factor of Safety = 1.5

Based on these basic parameters, the minimize size of riprap required to resist wood impacts ranges from 1.8 to 2.6 ft. A separate impact analysis was performed for a smaller piece of wood with a 2-ft bole diameter and a 3-ft rootball diameter that resulted in a required minimum rock diameter of 1.4 ft. Considering the factors involved, the following protection measures for wood debris are recommended:

- Erosion protection rock
  - Minimum size D_{min} > 1.5 ft.
  - Average size D_{50} = 2 ft
- Select fill grading along the margins of the setback dike to promote marsh vegetation establishment and protect from wood debris transport, scour and erosion.
- Installation of log booms in No Name Slough to protect new drainage culverts from large and small wood debris impacts

6.0 SUMMARY OF COASTAL ENGINEERING DESIGN RECOMMENDATIONS

The following is a summary of hydraulic and coastal engineering-related design recommendations contained in this report (Figure 14).

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- Alignment Alternative – Spur dike configuration
- Dike Design Elevation – 15.0 ft plus settlement (pending geotechnical analysis)
- Top Width – 18.0 ft to accommodate 0.5 ft of SLR
- Side Slopes – Assumed 3H:1V (pending geotechnical analysis)
- Levee erosion protection for wind wave and woody debris impacts
  - D_{50} = 2.0 ft
  - Thickness = 2.0 to 3.0 ft
  - Toe-down depth = 3.0 to 4.0 ft
  - Bedding = Quarry spall bedding and filter layer (could limit animal burrows) or geotextile filter (geotechnical analysis to finalize)
  - Topsoil 1ft thick with native salt-tolerant grass seed mulch and tackifier, watering and establishment of grass seed prior to existing levee breach. No woody shrubs or trees allowed.
  - Use cut materials as fill in marsh restoration (farm) areas outside high-shear-stress zones along circumference of dike setback to increase marsh restoration potential and reduce scour and erosion, and wood transport potential along dike setback.
- Seepage cutoff – Information to be presented in interior drainage analysis recommendation
- Drainage protection
  - Limit erosion of tidal channels, inlet areas, and ditch fills.
  - Excavate main tidal inlet to width approximating high-shear-stress areas at tidal flood flow to limit erosion and deposition potential in undesirable areas. Use cut materials as fill in marsh restoration (farm) areas outside high-shear-stress zones.
  - Excavate pilot channels, including new channels along preferential flow paths, to limit adverse erosion and deposition potential. Use cut materials as fill in marsh restoration (farm) areas outside high-shear-stress zones.
  - Seed and establish salt-tolerant grasses along margins of high-shear-stress areas to promote deposition and establishment of native marsh species.
  - Limit existing borrow ditch fills to low-shear-stress areas without preferential flow paths, that are less likely to erode.
  - Plant native salt marsh vegetation in select fill grade areas to preserve native salt marsh establishment.
  - Install floating log boom at No Name Slough tidegate outlet to protect tidegates from wood debris impacts and limit maintenance.

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  - Analyze interior drainage system considering hydrodynamic effects, SLR, erosion/sedimentation/vegetation effects on tailwater conditions presented in this report.
- Miscellaneous recommendations from other discussions with WDFW to carry forward in design.
  - Maintain high ground for a section of the existing dike along the Hit & Miss Gun Club, in accordance with landowner request.
  - Maintain 20-ft minimum width between the toe of levee and adjacent drainage structures such as the new interior drainage pond and Dry Slough.
  - Confirm seepage cutoff, side slope, foundation preparation, soil and aggregate and filter material and pipeline penetration specifications, and seismic design as part of geotechnical design report.
  - Confirm access, turnaround, and passing lanes in geotechnical report.

7.0 LIMITATIONS

This report was prepared for the exclusive use of WDFW and other members of the design team for specific application to the design of the project as it relates to the coastal and hydraulic engineering aspects of dike design and marsh discussed in this report. The conclusions contained in this report are based upon site conditions as they existed at the time this report was prepared, and based upon specialized hydrodynamic modeling prepared by others in support of the project. Our analyses and recommendations are interpretations of the modeling predictions. We assume that the data and modeling output provided by others has been accurately developed and calibrated and that it comprises reliable information to perform the analysis. S&W cannot make claims regarding the correctness or accuracy of these models and data, as they are proprietary models. Within the limitations of the scope, schedule, and budget, the data presented in this report were collected and presented in accordance with generally accepted professional engineering practice in this area at the time this report was prepared. No warranty, express or implied, is made.

The scour and erosion types evaluated in this report were limited to those described in this report. Other long-term coastal process and geomorphic changes at the site could influence scour and erosion patterns, but were not specifically evaluated.

Facts and conditions referenced in this report may change over time. Facts and conditions set forth here are applicable as described only at the time this report was written. We believe that the conclusions stated here are factual, but no guarantee is made or implied.

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This report was prepared for the exclusive use of WDFW and its representatives and in no way guarantees that any agency or its staff will reach the same conclusions as S&W.

SHANNON & WILSON, INC.

David R. Cline, P.E.
Senior Associate

DRC:ADH/drc

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8.0 REFERENCES

Ahmad, M.F., Dong, P., Mamat, M., and others, 2011, The critical shear stresses for sand and mud mixture: Applied Mathematical Sciences, v. 5, no. 1-4, p. 53-71, available: http://www.m-hikari.com/ams/ams-2011/ams-1-4-2011/index.html.

Battelle, 2011a, Hydrodynamic modeling analysis of Fir Island Farm restoration – baseline condition: Report prepared by Battelle, Seattle, Washington, project number 58343, for Shannon & Wilson, Seattle, Washington, April.

Battelle, 2011b, Hydrodynamic modeling analysis for the Fir Island Farm restoration project: Report prepared by Battelle, Seattle, Washington, PNWD-4306, for Shannon & Wilson, Seattle, Washington, October.

Battelle, 2013, Hydrodynamic modeling analysis for the Fir Island Farm restoration project in Skagit Bay, Washington: Report prepared by Battelle, Seattle, Washington, PNWD-4398, for Shannon & Wilson, Seattle, Washington, September.

Bertrand, John, 2013, FEMA Bi-Op requirements for the Fir Island Farm restoration project: Personal communication between J. Bertrand, U.S. Federal Emergency Management Administration, and P. Johnson, Shannon & Wilson, Inc., Seattle, Wash., Sept. 10.

Cowles, G.W., [n.d.], An investigation of the influence of waves on sediment processes in Skagit Bay: New Bedford, Mass., University of Massachusetts, School for Marine Science and Technology, 7 p., available: http://www.onr.navy.mil/reports/FY11/locowles.pdf.

Douglass, S.L., and Krolak, J., 2008, Highways in the coastal environment (2nd ed.): Washington, D.C., U.S. Federal Highway Administration, Office of Bridge Technology, Report no. FHWA NHI-07-096, Hydraulic Engineering Circular No. 25, 230 p., available: http://www.fhwa.dot.gov/engineering/hydraulics/libraryarc.cfm?pub number=192&id=137.

Fagherazzi, Sergio and Furbish, D. J., 2001, On the shape and widening of salt marsh creeks: Journal of Geophysical Research - Oceans, v. 106, no. C1, p. 991-1003.

Fagherazzi, Sergio and others, 2012, Numerical Models of Salt Marsh Evolution: Ecological, Geomorphic and Climate Factors. Article in Proof: American Geophysical Union. Review of Geophysics. Paper Number 2011RG000359.

Federal Emergency Management Agency (FEMA), 2011, Coastal construction manual: principles and practices of planning, siting, design, constructing, and maintaining residential buildings in coastal areas (4th ed.): Washington, D.C., FEMA, publication no. P-55, 2 v., available: http://www.fema.gov/media-library/assets/documents/3293?id=1671.

Draft

Grossman, Eric E., George, D.A., Lam, Angela, 2011, Shallow stratigraphy of the Skagit River Delta, Washington, derived from sediment cores: U. S. Geological Survey Open-File Report 2011-1194, 26 p., available: http://pubs.er.usgs.gov/publication/ofr20111194.

Grossman, Eric E., 2014, Skagit Bay sedimentation characteristics: Personal communication between and E. Grossman, U.S. Geological Services, and D. Cline, Shannon & Wilson Inc., Wash., January 9.

Kilgore Consulting and Management, 2005, Design of roadside channels with flexible linings (3rd ed.): Washington, D. C., U.S. Federal Highway Administration, Office of Bridge Technology, Report no. FHWA NHI-05-114, Hydraulic Engineering Circular No. 15, 153 p., available: http://www.fhwa.dot.gov/engineering/hydraulics/pubs/05114/in dex.cfm.

Kirwan, M.L. and Murray, A.B., 2007, A coupled geomorphic and ecological model of tidal marsh evolution: Proccedings of the National Academy of Sciences of the United States of America, v. 104, no. 5, 5 p., available: http://www.pnas.org/content/by/year.

Hood, W.G., 2007, Scaling tidal channel geometry with marsh island area: a tool for habitat restoration, linked to channel formation process: Water Resources Research, v. 43, no. 3, paper W03409.

Hood, W.G., 2009, Estuarine habitat restoration with global climate change and rising sea levels, PowerPoint presented at Northwest Straits Initiative 11th Annual MRC Conference, Bellingham, Wash., 2007: Available: http://www.nwstraits.org/uploads/pdf/Meeting%20and%20Events/Conference/2009/Hood-Skagit%20Climate%20Impacts%20Workshop.pdf

Lagasse, P.F., Clopper, P.E., Pagan-Ortiz, J.E., and others, 2009, Bridge scour and stream instability countermeasures, experience, selection, and design guidance (3rd ed.): Arlington, Va., U. S. Federal Highway Administration, report nos. FHWA NHI-09-111 and FHWA NHI-09-112, Hydraulic Engineering Circular No. 23, 2 v.

Mote, Philip, Petersen, Alexander, Reeder, Spencer, and others, 2008, Sea level rise in the coastal waters of Washington State: Seattle, Wash., University of Washington Climate Impacts Group and Olympia, Wash., Washington State Department of Ecology, 11 p., available: http://cses.washington.edu/db/pdf/moteetalslr579.pdf?.

National Research Council, 2012, Sea-level rise for the coasts of California, Oregon, and Washington: past, present, and future: Washington, DC: The National Academies Press, 201 p.

Nisqually Delta Restoration, 2012, Science: geomorphology and sedimentation: Available: http://nisquallydeltarestoration.org/science_geomorphology_sedimentation.php, January 2, 2014

Draft

Phil Williams and Associates, 2004, An assessment of potential habitat restoration pathways for Fir Island, Washington; Report prepared by Phil Williams and Associates, San Francisco California, PWA REF #1550, for Skagit River System Cooperative, LaConner Washington, February.

Pilarczyk, K.W., 1998, Dikes and revetments: design, maintenance, and safety assessment: Rotterdam, Netherlands, A.A. Balkema, 562 p.

Rijn, L.C. van, 1993, Principles of sediment transport in rivers, estuaries, and coastal seas: Amsterdam, the Netherlands: Aqua Publications, 1 v.

Shannon & Wilson, Inc., 2011, Fir Island Snow Goose Reserve, restoration feasibility study, Washington Department of Fish and Wildlife, Fir Island Washington: Report prepared by Shannon & Wilson. Inc, Seattle, Wash., 21-1-12318-003, for Washington Department of Fish and Wildlife, Olympia, Wash., December.

Smerdon, E.T. and Beasley, R.P., 1961, Critical tractive forces in cohesive soils: Agricultral Engineering, v. 42, no. 1, p. 26-29.

U.S. Army Corps of Engineers (USACE), Engineering and Design, 2000, Design and Construction of Levees, Engineering Manual 1110-2-1913: Washington, D.C., April.

U.S. Army Corps of Engineers, (USACE), 2009, Expires 10 April 2014. Guidelines for landscape planting and vegetation management at levees, floodwalls, embankment dams, and appurtenant structures. Engineering Technical Letter 1110-2-571: Washington, D.C., 10 April.

U.S. Army Corps of Engineers, 2008, Coastal engineering manual: U. S. Army Corps of Engineers Engineer Manual 1110-2-1100, 5 v., available: http://140.194.76.129/publications/eng-manuals/.

U.S. Bureau of Reclamation, 2006, Erosion and sedimentation manual: Denver, Colo., U.S. Bureau of Reclamation, 1 v.

U.S. Geologic Survey, Western Ecological Research Center; the Nisqually National Wildlife Refuge; and the Nisqually Indian Tribe, [n.d.], Assessing the effectiveness of restoration actions in the Nisqually Delta: Report to National Fish and Wildlife Foundation. Puget Sound Marine Conservation Fund #2006-0180-017, 22 p., available: http://www.tidalmarshmonitoring.org/pdf-project/Woo%20et%20al.%202011_Assessing HabitatDevelopmentResponseNisqually.pdf

Zervas, C.E., 2007, Personal communication with Sascha Peterson, University of Washington Climate Impacts Group. November 9, 2007. Part of King County, 2008. Vulnerability of Major Wastewater Facilities to Flooding from Sea-Level Rise.

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TABLE 1
FIR ISLAND FARM - SITE- SPECIFIC TIDAL DATUMS

Tidal Elevations (feet)	Mean Lower Low Water (MLLW-feet)	North American Vertical Datum of 1988 (NAVD88-feet)
HAT	13.41	11.28
MHHW	11.43	9.30
MHW	10.55	8.42
MSL	6.65	4.52
MTL	6.63	4.50
MLW	2.72	0.59
NAVD88	2.13	0.00
MLLW	0.00	-2.13

Notes:

HAT = highest astronomical tide

MHHW = mean higher high water

MHW = mean high water

MLW = mean low water

MLLW = mean lower low water

MSL = mean sea level

MTL = mean tide level

NAVD88 = North American Vertical Datum of 1988 transformation

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TABLE 2
SEA LEVEL RISE ESTIMATES

Year	SLR - Low[1, 2] (feet)	SLR - Avg[1, 2] (feet)	SLR - High[1, 2] (feet)
2000	0.00	0.00	0.00
2013	0.01	0.09	0.17
2030	0.03	0.22	0.40
2033	0.06	0.27	0.47
2050	0.20	0.54	0.89
2063	0.43	0.93	1.44
2100	1.07	2.03	2.99

Notes:

[1] Sea level rise (SLR) rates were provided by the National Academy of Science (NAS), 2012, Sea Level Rise for the Coasts of California, Oregon and Washington, Past, Present and Future. Estimates include Cascadia subduction zone tectonics and post-glacial isostatic rebound, vertical land rate adjustments.

[2] SLR rates were linear interpolated for years 2013, 2033, and 2063 from published NAS values in years 2000, 2030, 2050, and 2100.

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TABLE 3
MARSH AND TIDAL CHANNEL SEDIMENTATION, SCOUR, AND VEGETATION TAILWATER EFFECTS

Year	Tailwater Effects - Low (feet)	Tailwater Effects - Average (feet)	Tailwater Effects - High (feet)
2013	-0.1	0.0	0.1
2033	-0.3	0.2	0.3
2063	-0.4	0.3	0.5

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TABLE 4
DIKE DESIGN ELEVATION SUMMARY

Design Element	(m)	(ft)[1]
n_{HAT}[2]	3.44	11.28
n_{Surge}[3]	0.67	2.20
$n_{Wind\text{-}wave}$[3]	0.17	0.54
$n_{SLR\text{-}2063}$[4]	0.28	0.93
n_{Design}	4.27	14.02
Settlement	TBD	TBD

Notes:

[1] Final dike design elevation rounded to neareast tenth of foot (15.0 foot).

[2] Highest astronomical tide provided by Al Hammond, P.L.S., Washington Department of Fish and Wildlife.

[3] Surge and wind-wave model and calculations provided by Battelle, 2013.

[4] Sea Level Rise (SLR) estimates provided by National Academy of Sciences (NAS) 2012 and interpolated for year 2063 Sea Level Rise (SLR) estimates referenced in NAS 2012 and interpolated for year 2063 average SLR prediction, including vertical land rate adjustments.

ft = foot

m = meter

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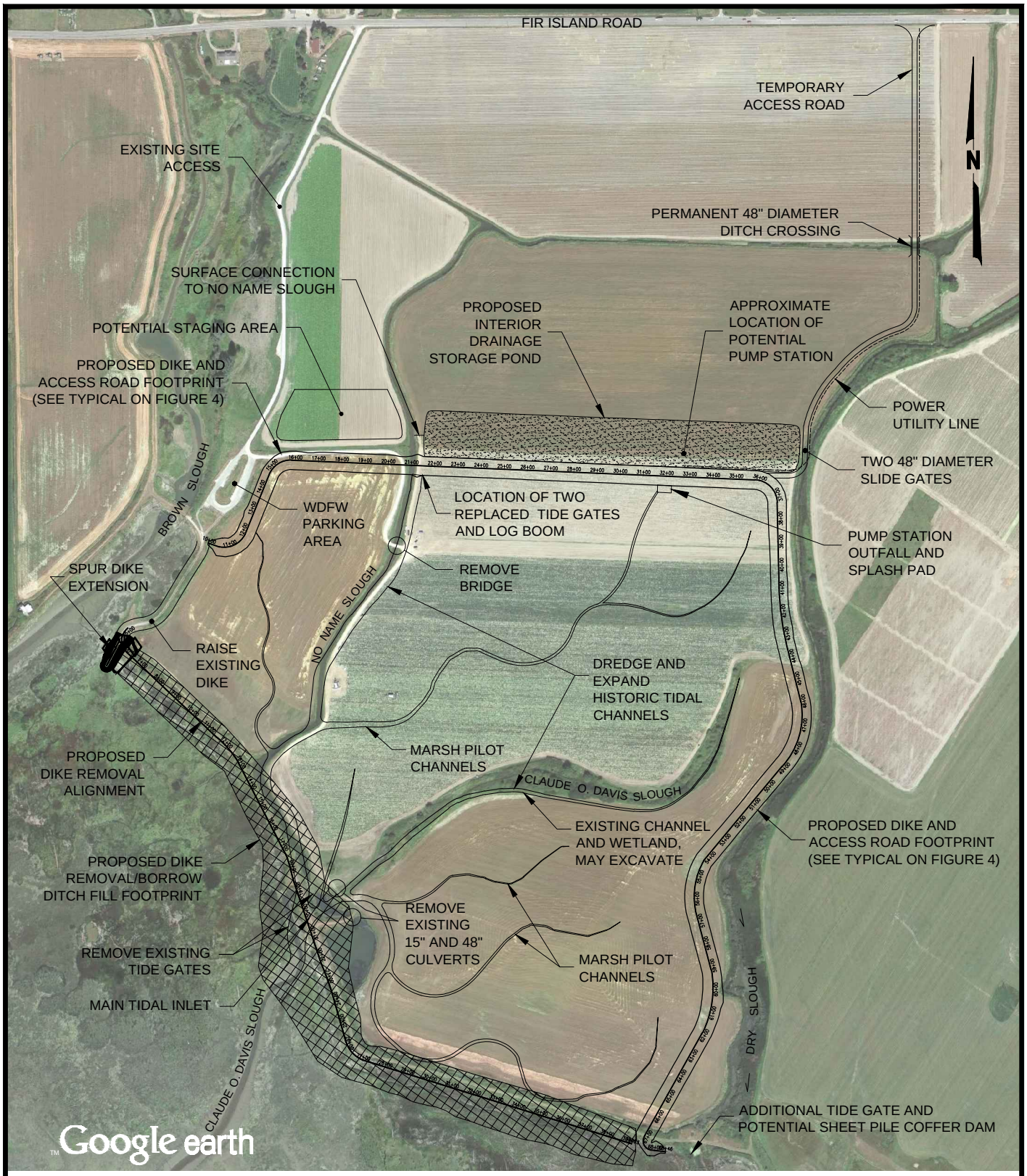

0 600 1200

Scale in Feet

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NOTE

Map adapted from aerial imagery provided by Google Earth Pro, Image U.S. Geological Survey, Image Island County, reproduced by permission granted by Google Earth ™ Mapping Service.

Fir Island Farm
Estuary Restoration Project
Skagit County, Washington

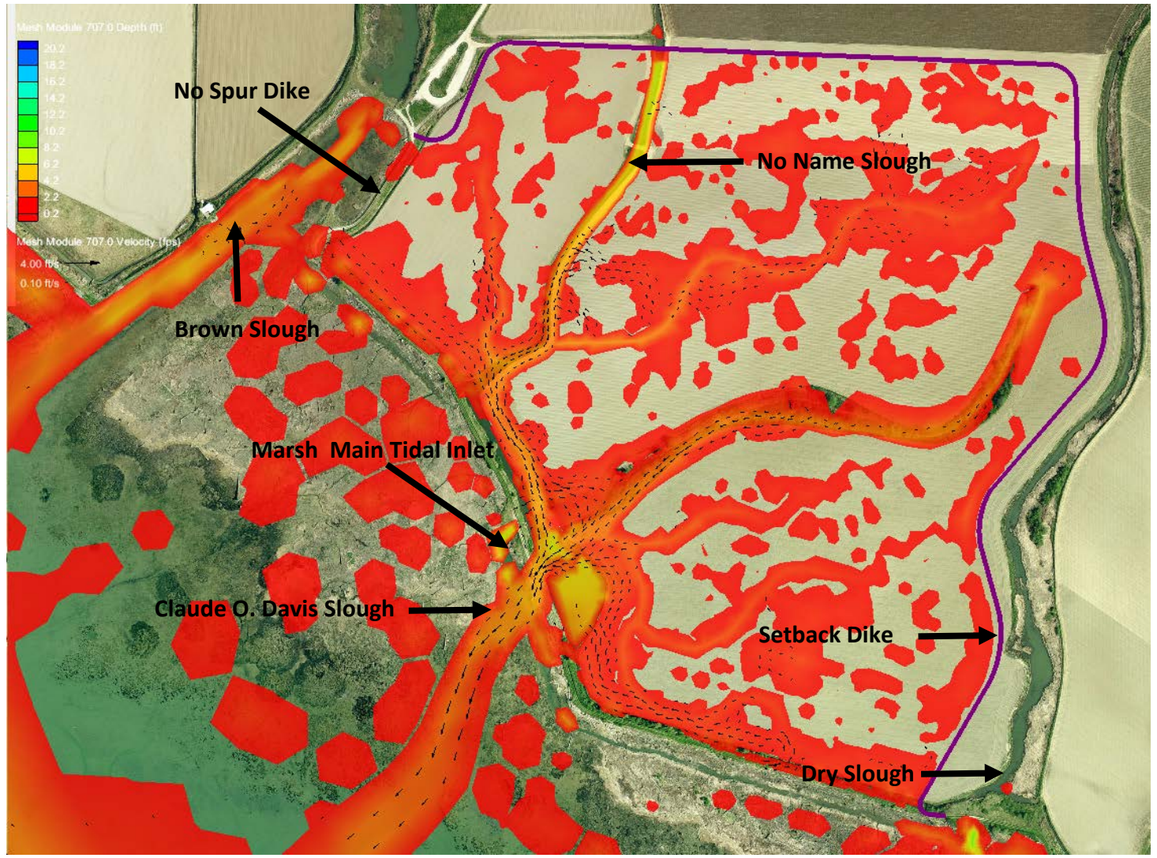
PROJECT SITE PLAN

January 2014 21-1-12318-217

SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

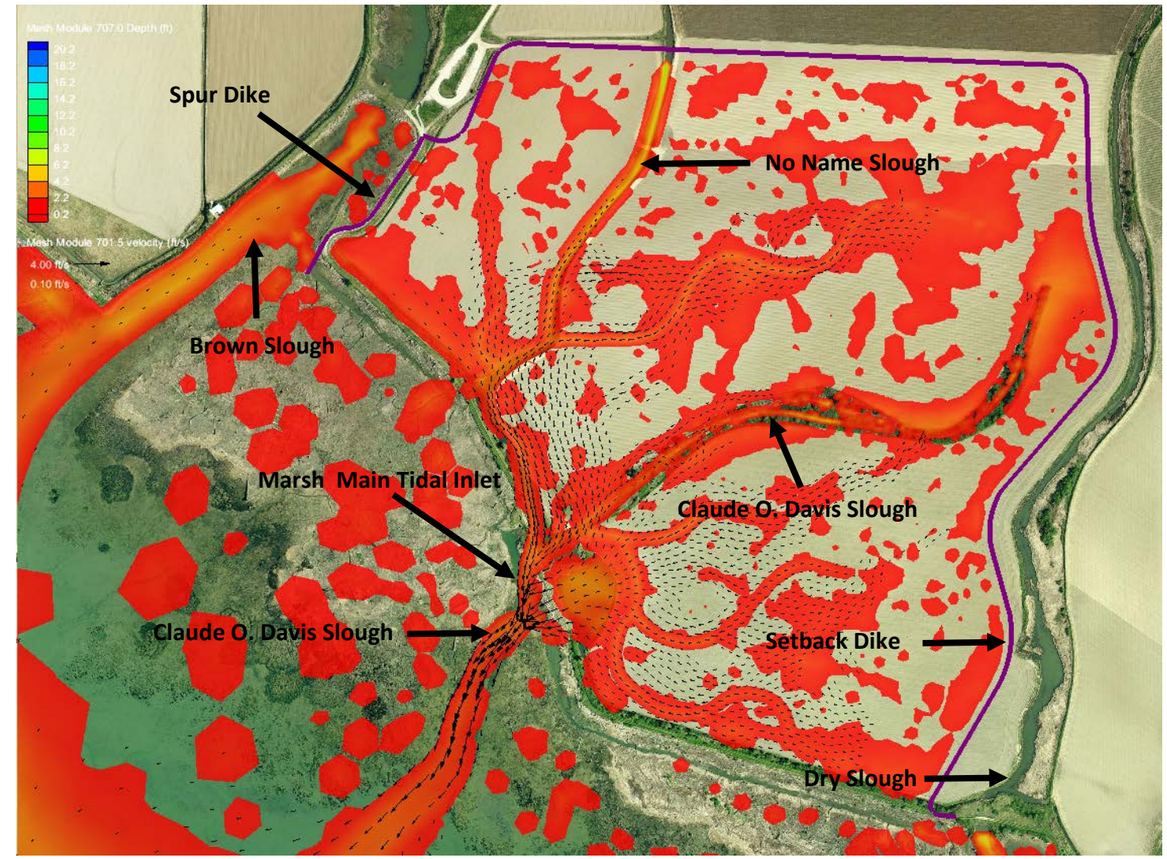
FIG. 1

Filename: J:\211\12318-217\21-1-12318-217 Project Site Plan.dwg Date: 01-10-2014 Login: SAC



PLAN VIEW - NO SPUR DIKE

Not to Scale



PLAN VIEW - WITH SPUR DIKE

Not to Scale

Legend

Depth (ft)

20.2
18.2
16.2
14.2
12.2
10.2
8.2
6.2
4.2
2.2
0.2

Velocity (fps)

4.00 ft/s ⟶

0.10 ft/s -

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Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

HYDRODYNAMIC MODELING
LOW TIDE - DEPTH/VELOCITY

January 2014 | 21-1-12318-217

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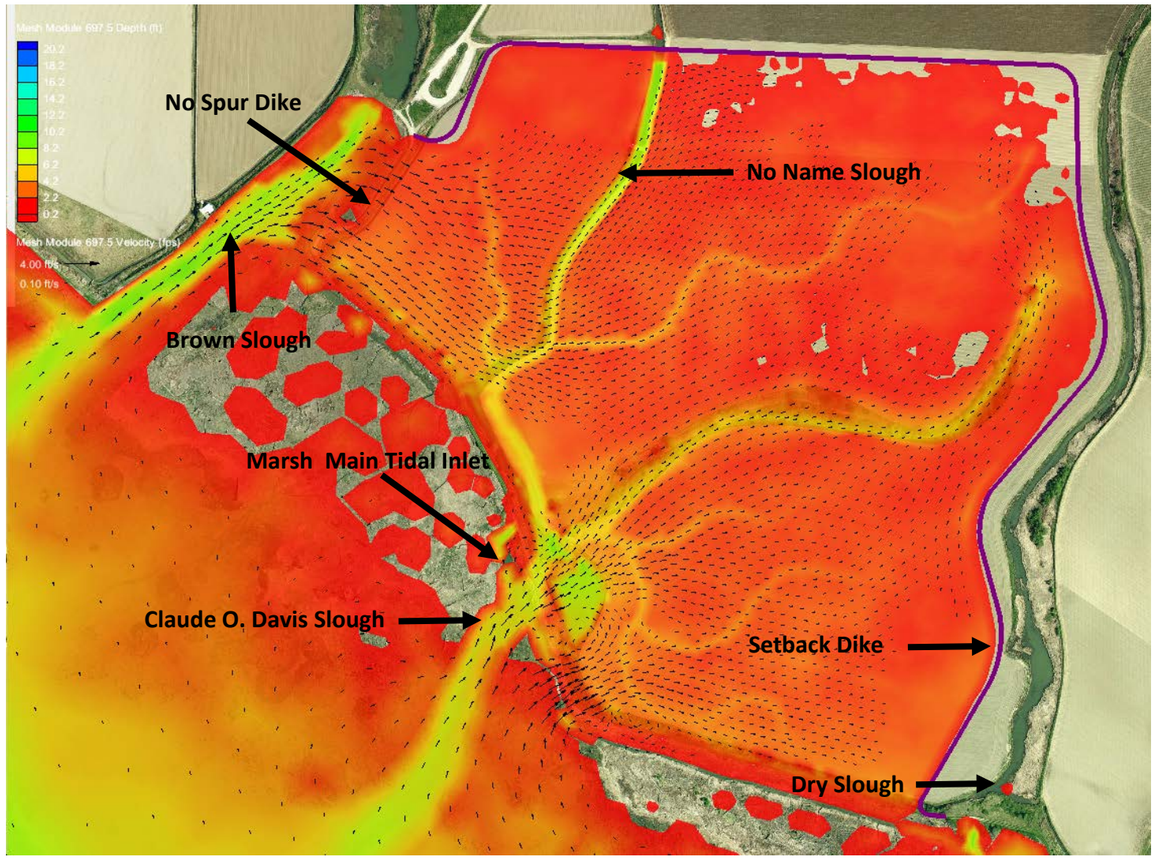
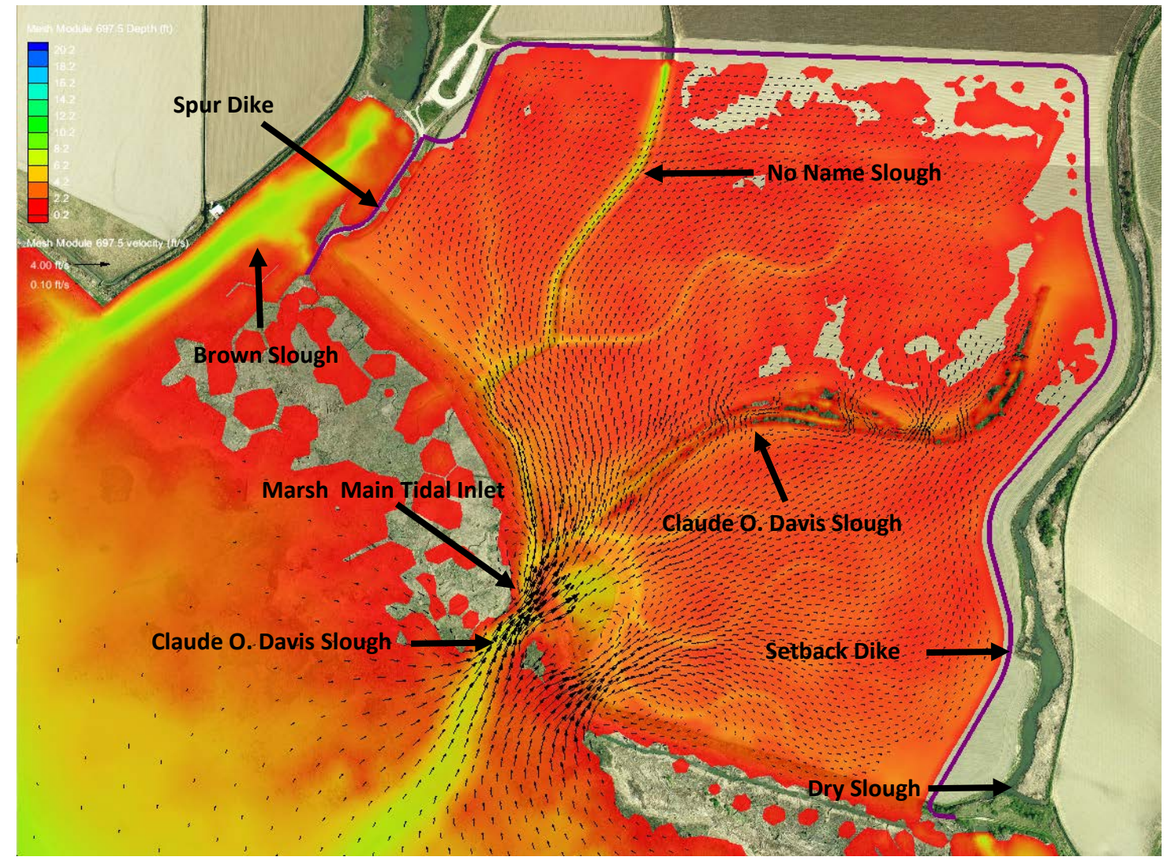
FIG. 2



PLAN VIEW - NO SPUR DIKE

Not to Scale



PLAN VIEW - WITH SPUR DIKE

Not to Scale

Legend

Depth (ft)

20.2
18.2
16.2
14.2
12.2
10.2
8.2
6.2
4.2
2.2
0.2

Velocity (fps)

4.00 ft/s
0.10 ft/s

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Skagit Wildlife Area
Skagit County, Washington

HYDRODYNAMIC MODELING
FLOOD TIDE - DEPTH/VELOCITY

January 2014 | 21-1-12318-217

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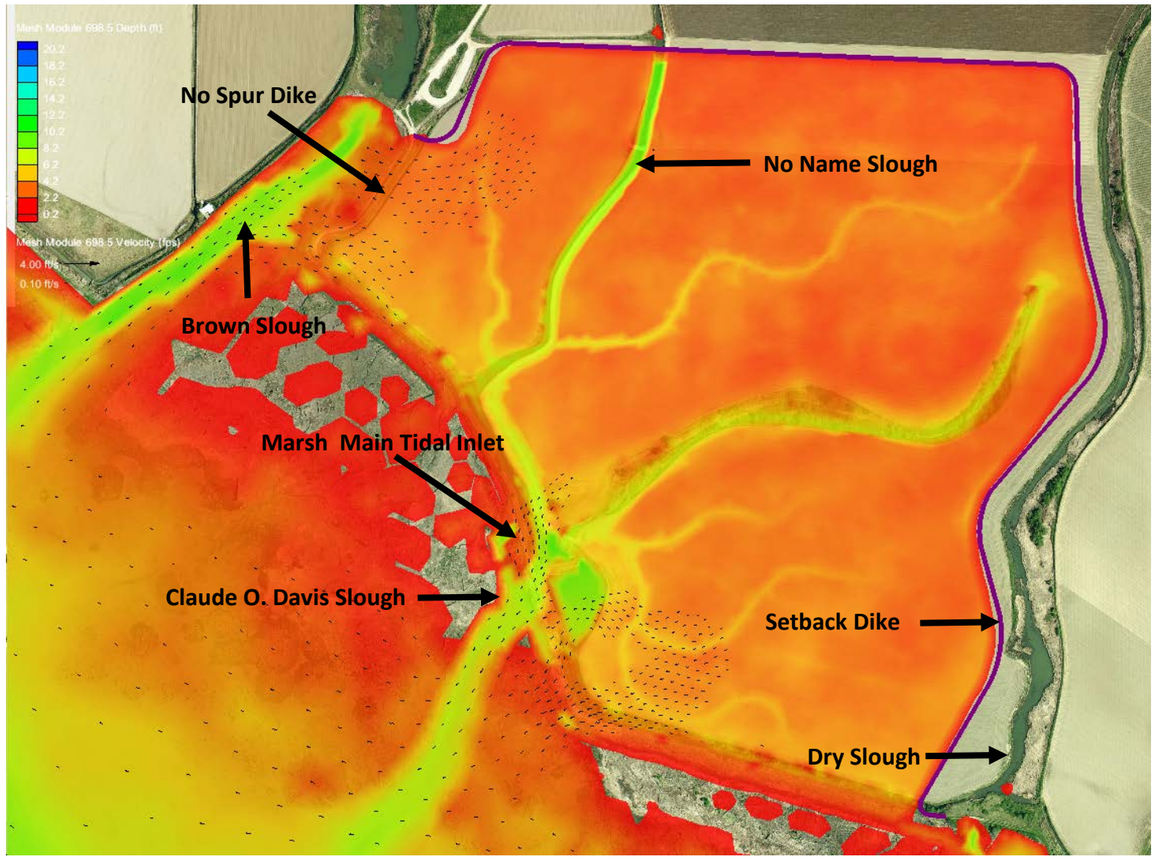
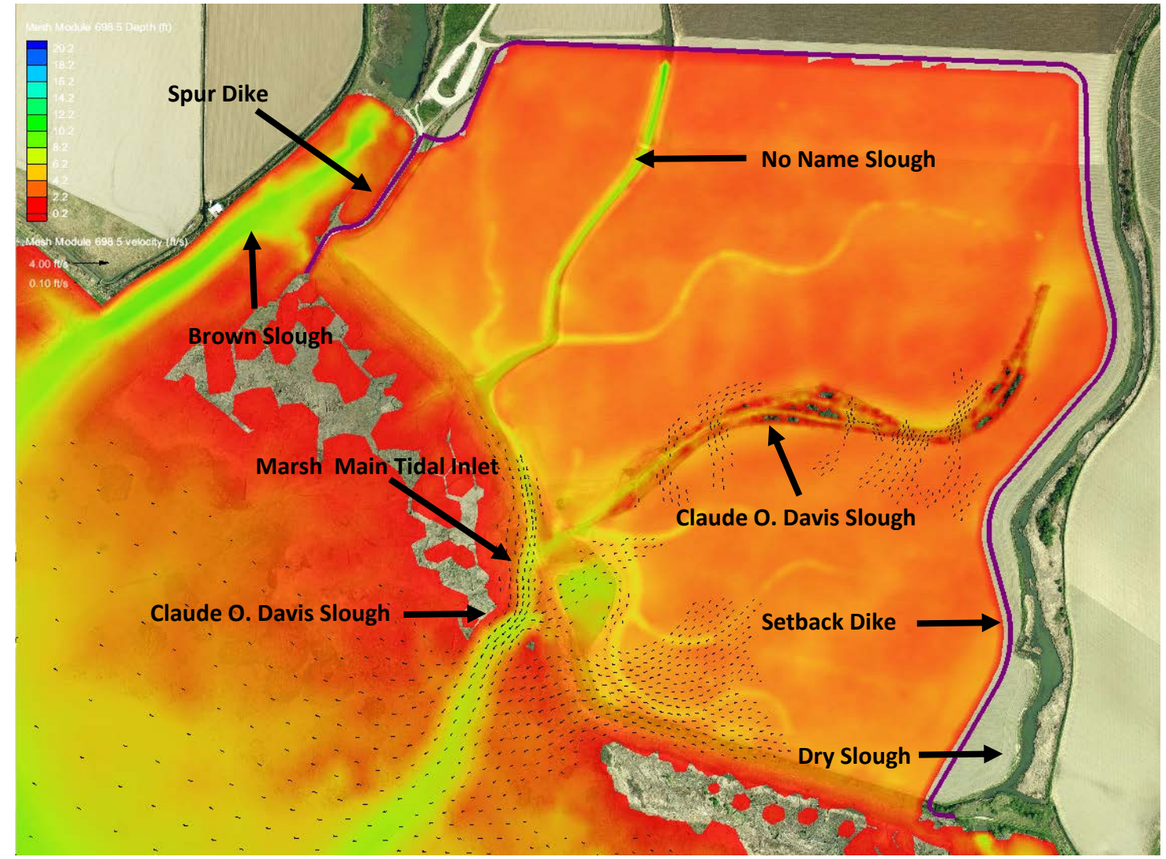
FIG. 3



PLAN VIEW - NO SPUR DIKE

Not to Scale



PLAN VIEW - WITH SPUR DIKE

Not to Scale

Legend

Depth (ft)

20.2
18.2
16.2
14.2
12.2
10.2
8.2
6.2
4.2
2.2
0.2

Velocity (fps)

4.00 ft/s →

0.10 ft/s -

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Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

HYDRODYNAMIC MODELING
HIGH TIDE - DEPTH/VELOCITY

January 2014 | 21-1-12318-217

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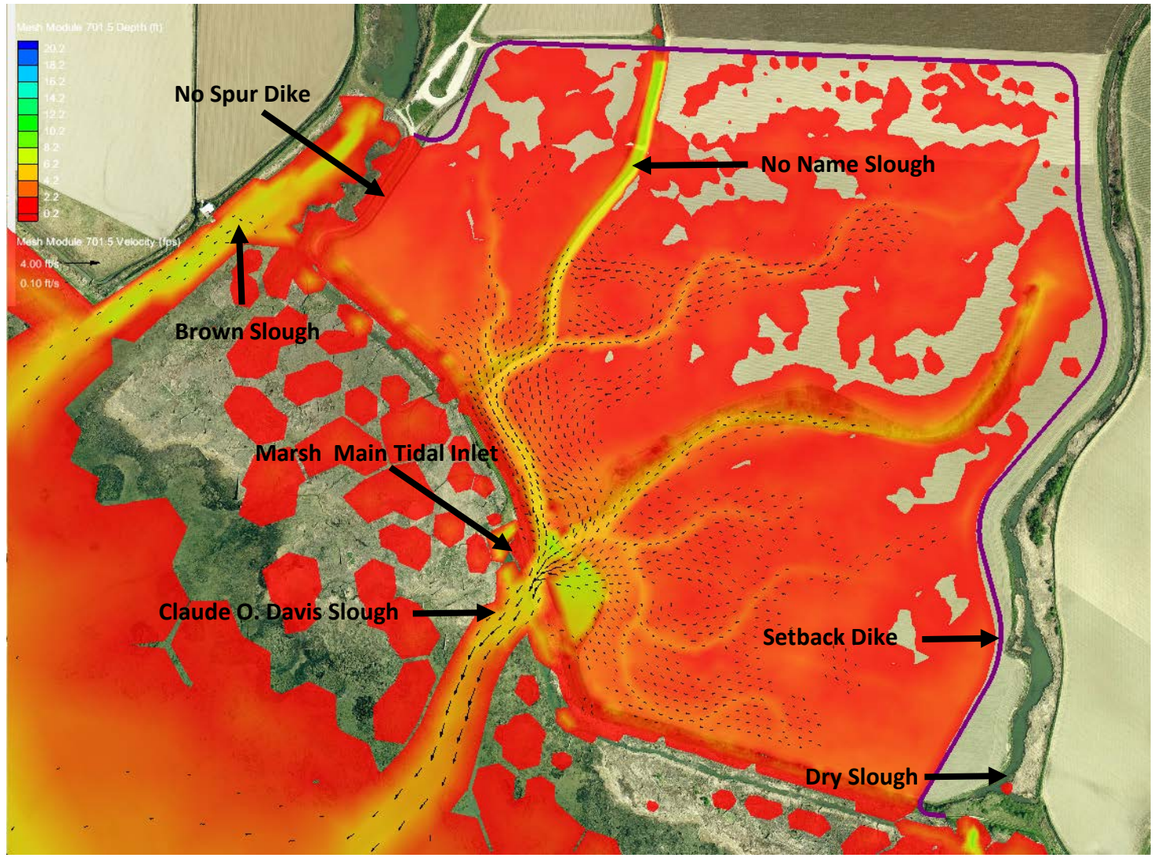
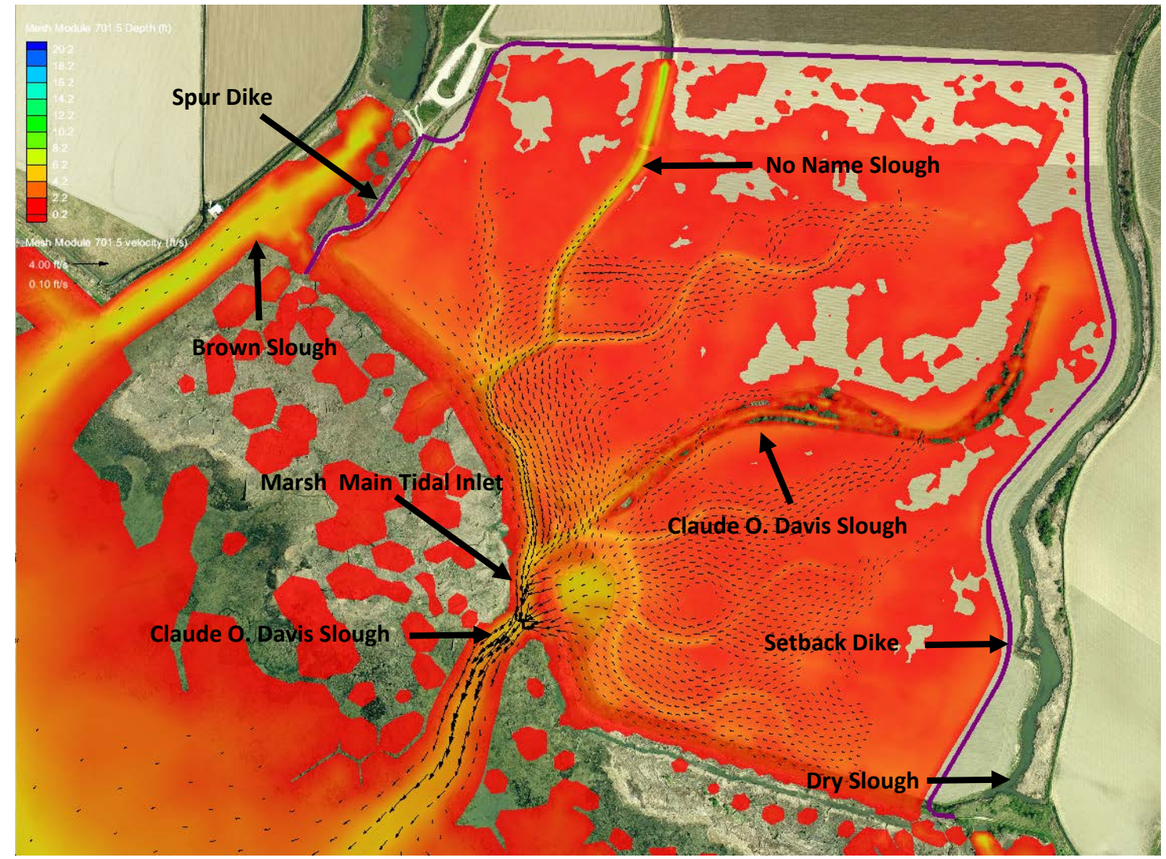
FIG. 4



PLAN VIEW - NO SPUR DIKE

Not to Scale



PLAN VIEW - WITH SPUR DIKE

Not to Scale

Legend

Depth (ft)

20.2
18.2
16.2
14.2
12.2
10.2
8.2
6.2
4.2
2.2
0.2

Velocity (fps)

4.00 ft/s
0.10 ft/s

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Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

HYDRODYNAMIC MODELING
EBB TIDE - DEPTH/VELOCITY

January 2014 | 21-1-12318-217

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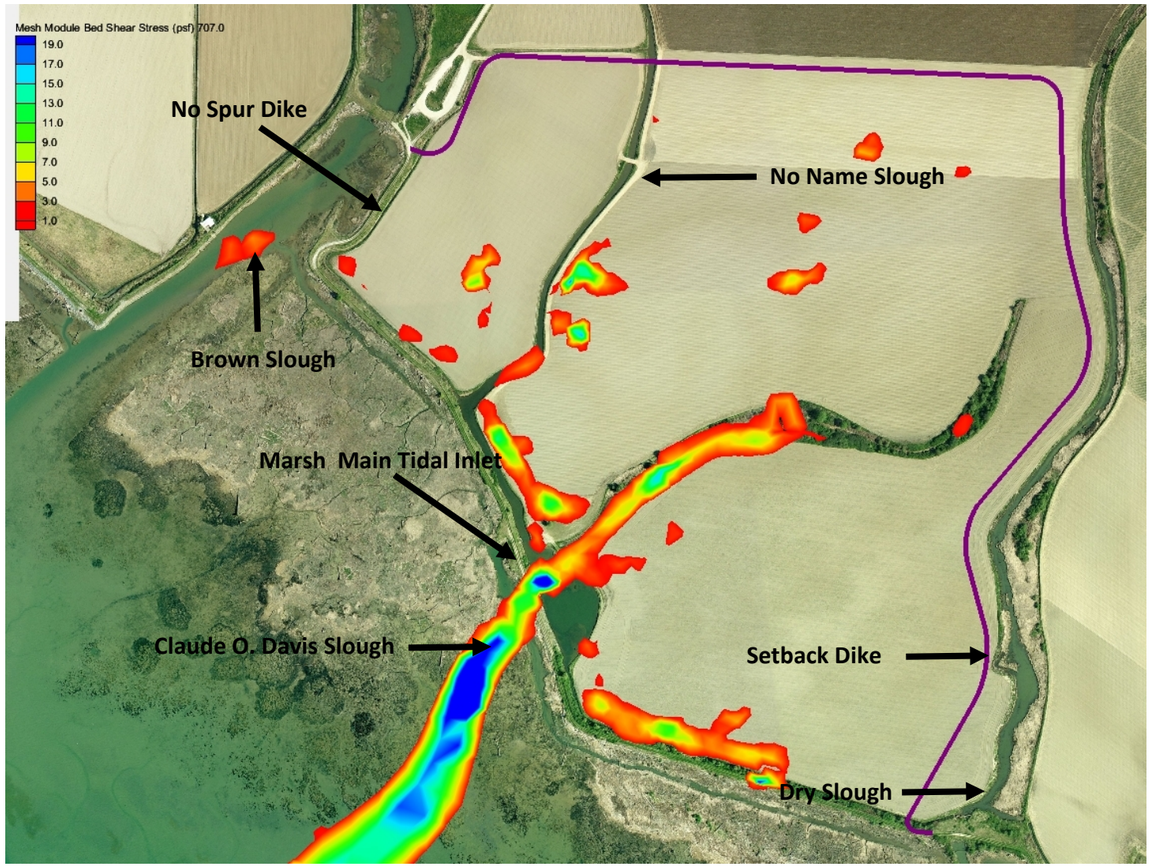
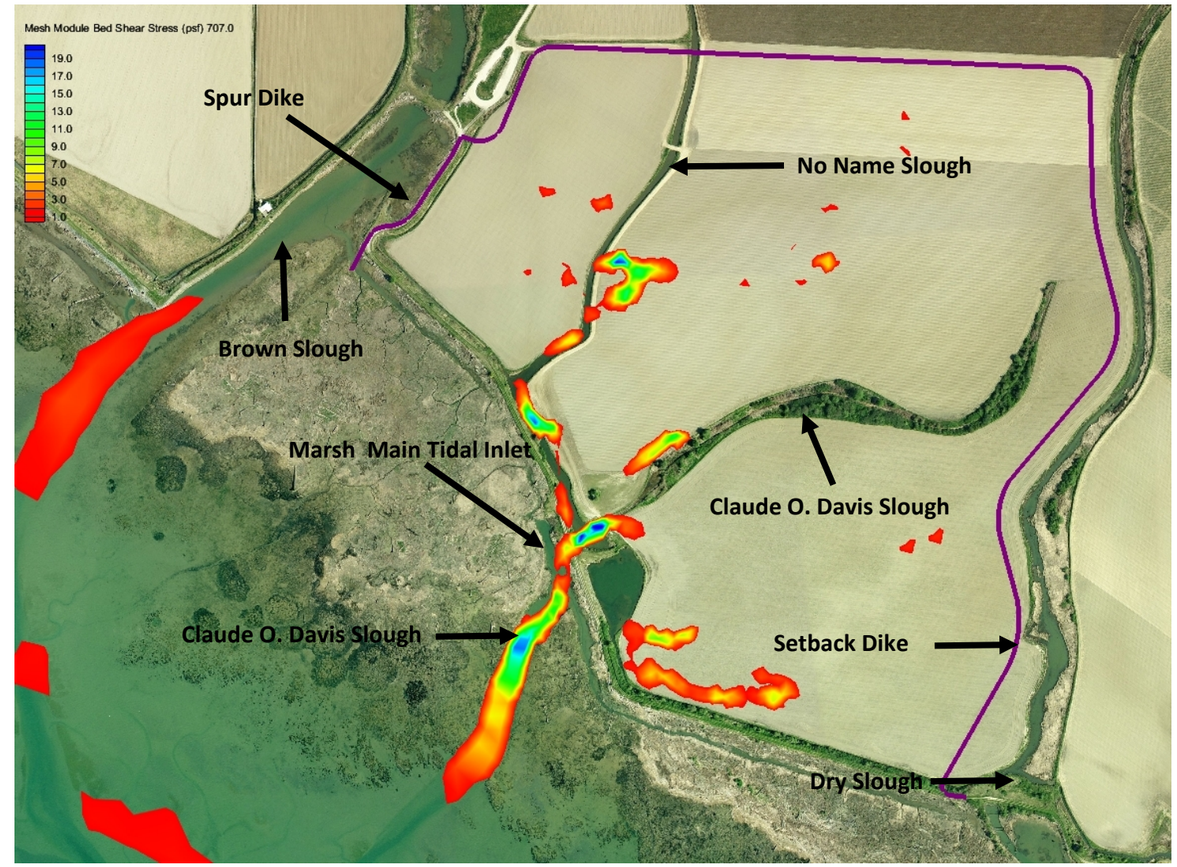
FIG. 5



PLAN VIEW - NO SPUR DIKE

Not to Scale



PLAN VIEW - WITH SPUR DIKE

Not to Scale

Legend

Bed Shear Stress (psf)

19.0
17.0
15.0
13.0
11.0
9.0
7.0
5.0
3.0
1.0

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Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

HYDRODYNAMIC MODELING
LOW TIDE - SHEAR STRESS

January 2014 | 21-1-12318-217

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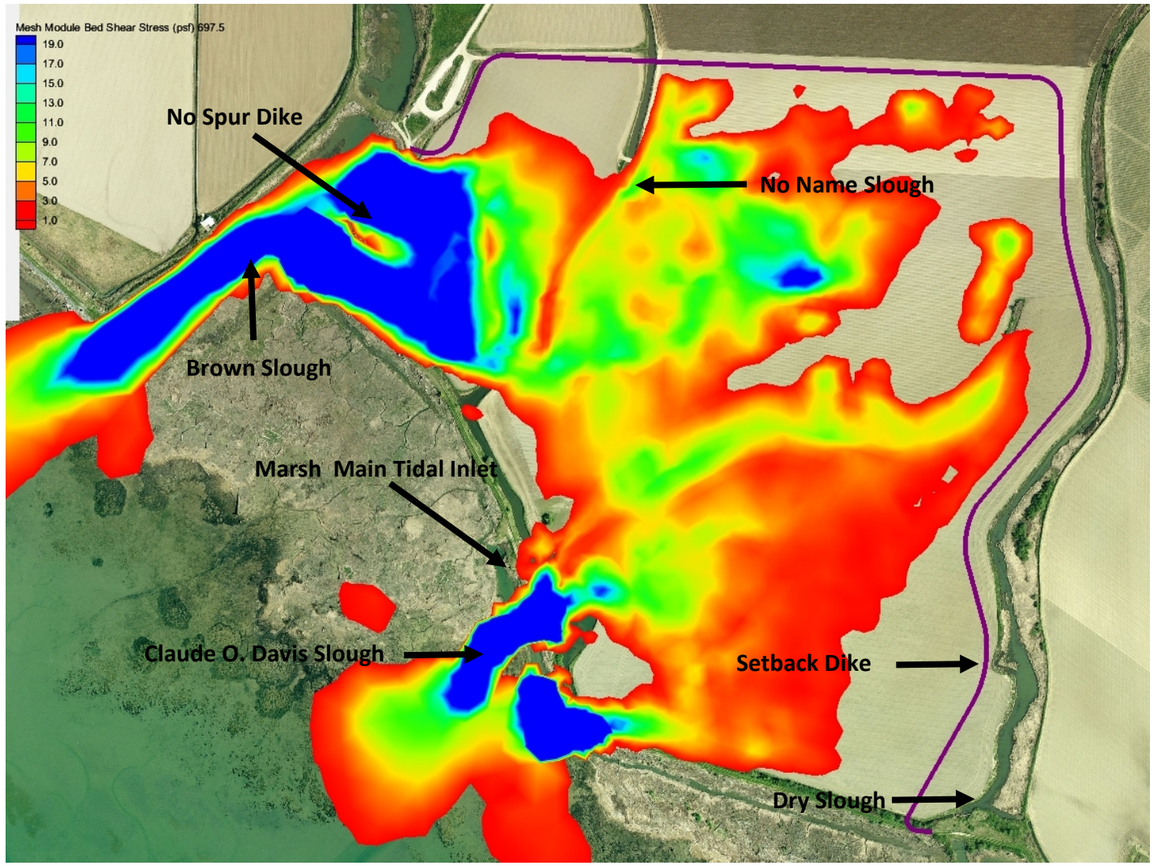
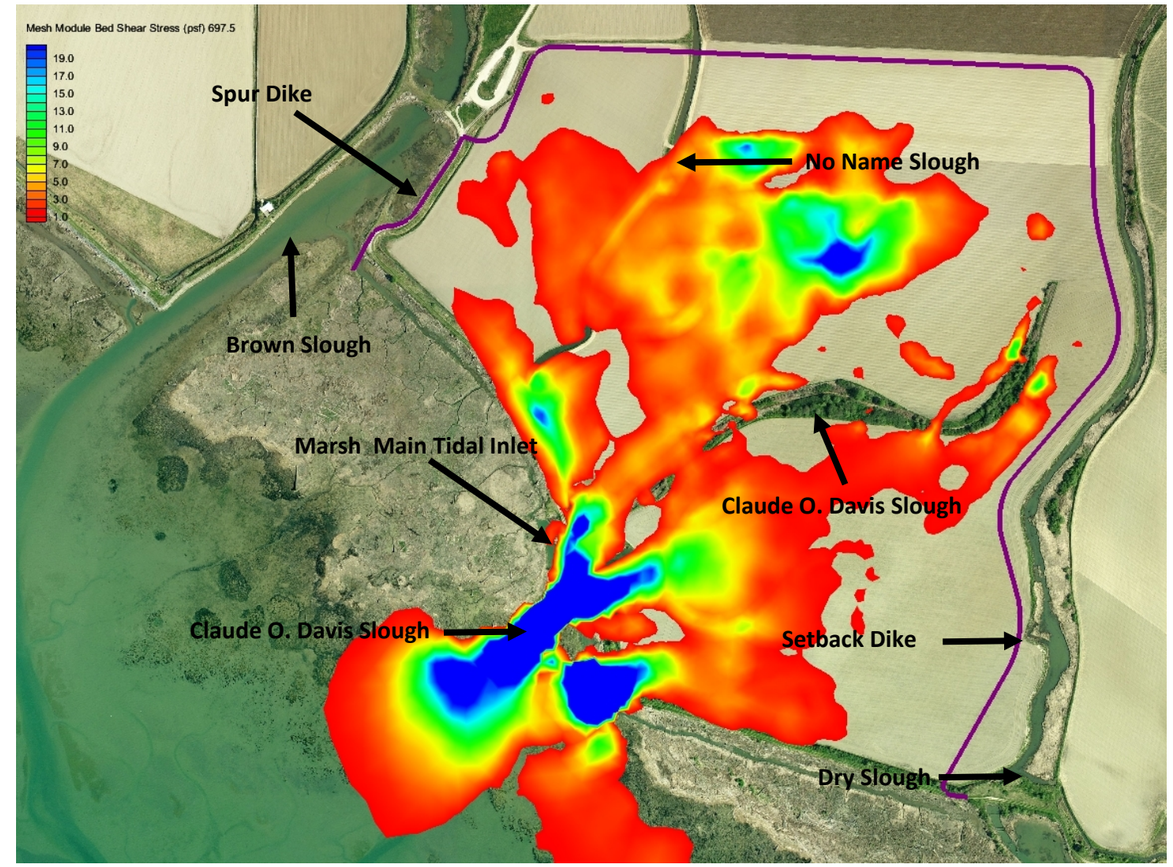
FIG. 6



PLAN VIEW - NO SPUR DIKE

Not to Scale



PLAN VIEW - WITH SPUR DIKE

Not to Scale

Legend

Bed Shear Stress (psf)

- 19.0
- 17.0
- 15.0
- 13.0
- 11.0
- 9.0
- 7.0
- 5.0
- 3.0
- 1.0

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Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

HYDRODYNAMIC MODELING
FLOOD TIDE - SHEAR STRESS

October 2013 | 21-1-12318-217

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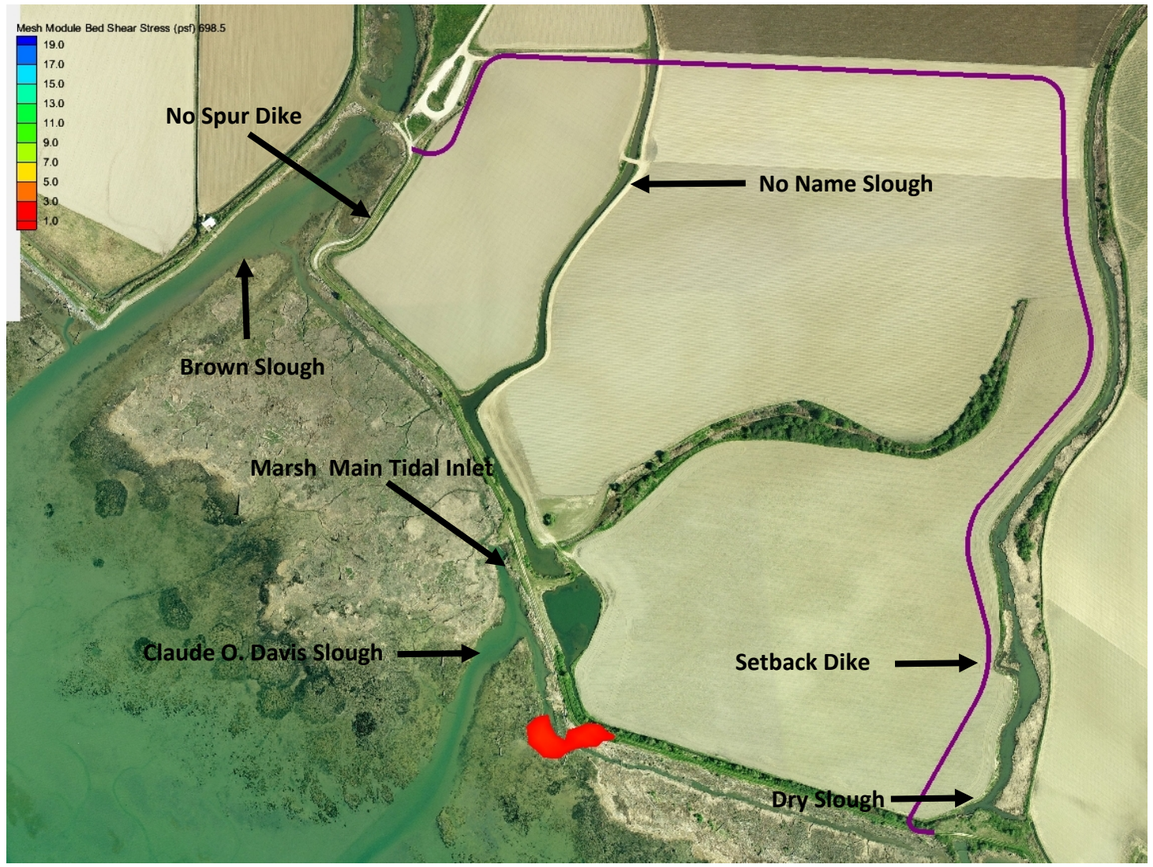
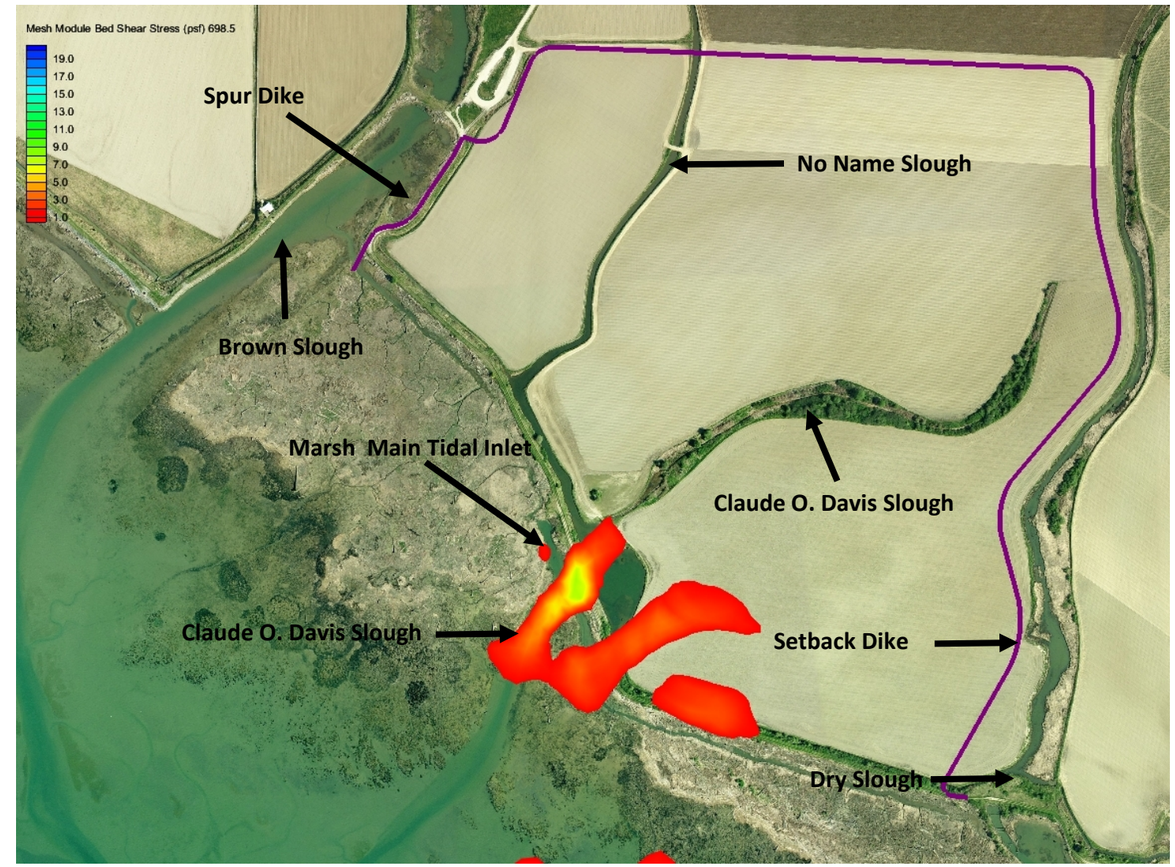
FIG. 7



PLAN VIEW - NO SPUR DIKE

Not to Scale



PLAN VIEW - WITH SPUR DIKE

Not to Scale

Legend

Bed Shear Stress (psf)

19.0
17.0
15.0
13.0
11.0
9.0
7.0
5.0
3.0
1.0

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Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

HYDRODYNAMIC MODELING
HIGH TIDE - SHEAR STRESS

October 2013 | 21-1-12318-217

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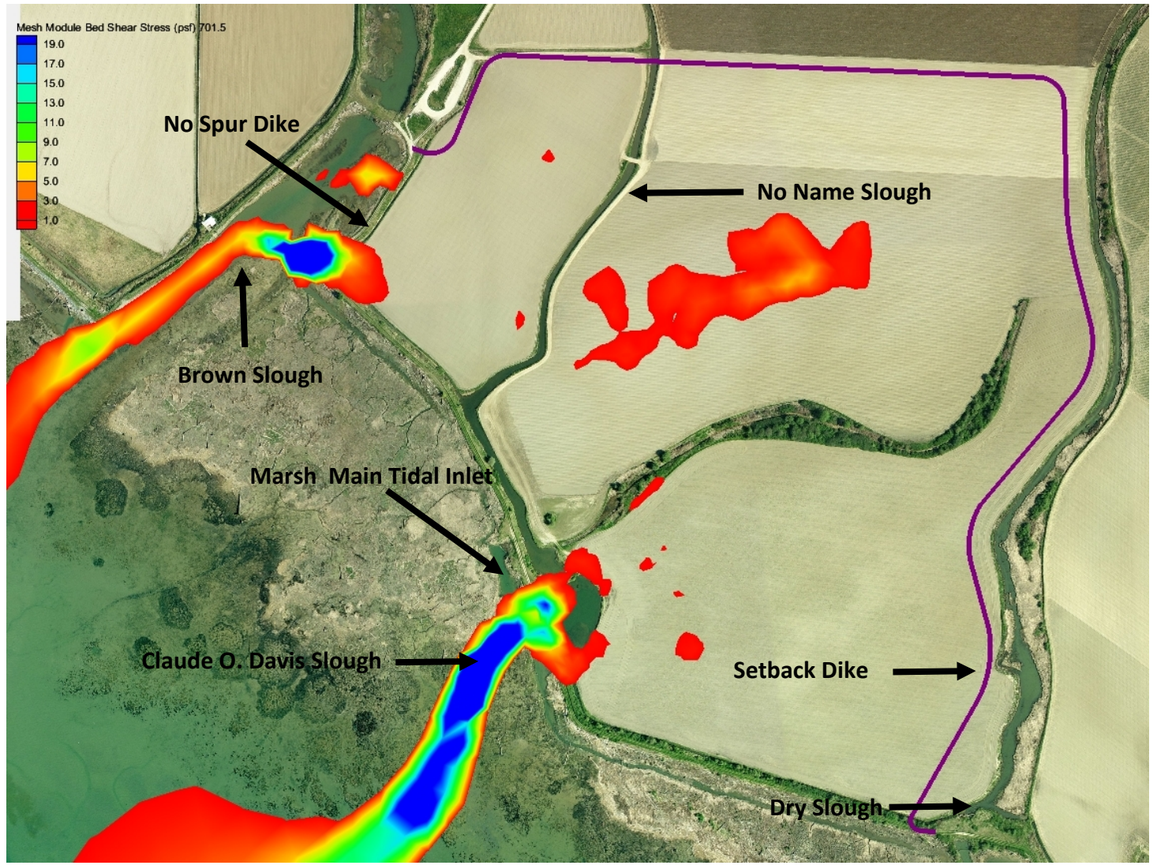
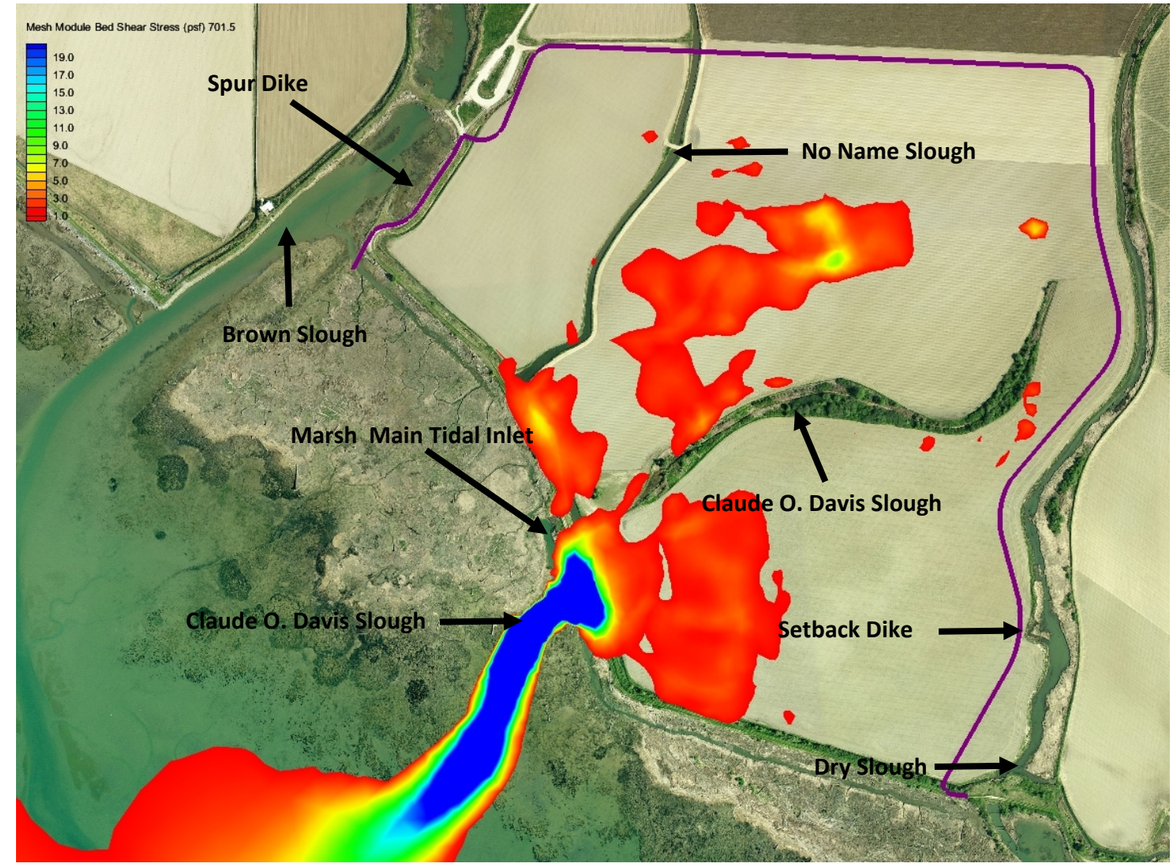
FIG. 8



PLAN VIEW - NO SPUR DIKE

Not to Scale



PLAN VIEW - WITH SPUR DIKE

Not to Scale

Legend

Bed Shear Stress (psf)

19.0
17.0
15.0
13.0
11.0
9.0
7.0
5.0
3.0
1.0

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Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

HYDRODYNAMIC MODELING
EBB TIDE - SHEAR STRESS

October 2013 | 21-1-12318-217

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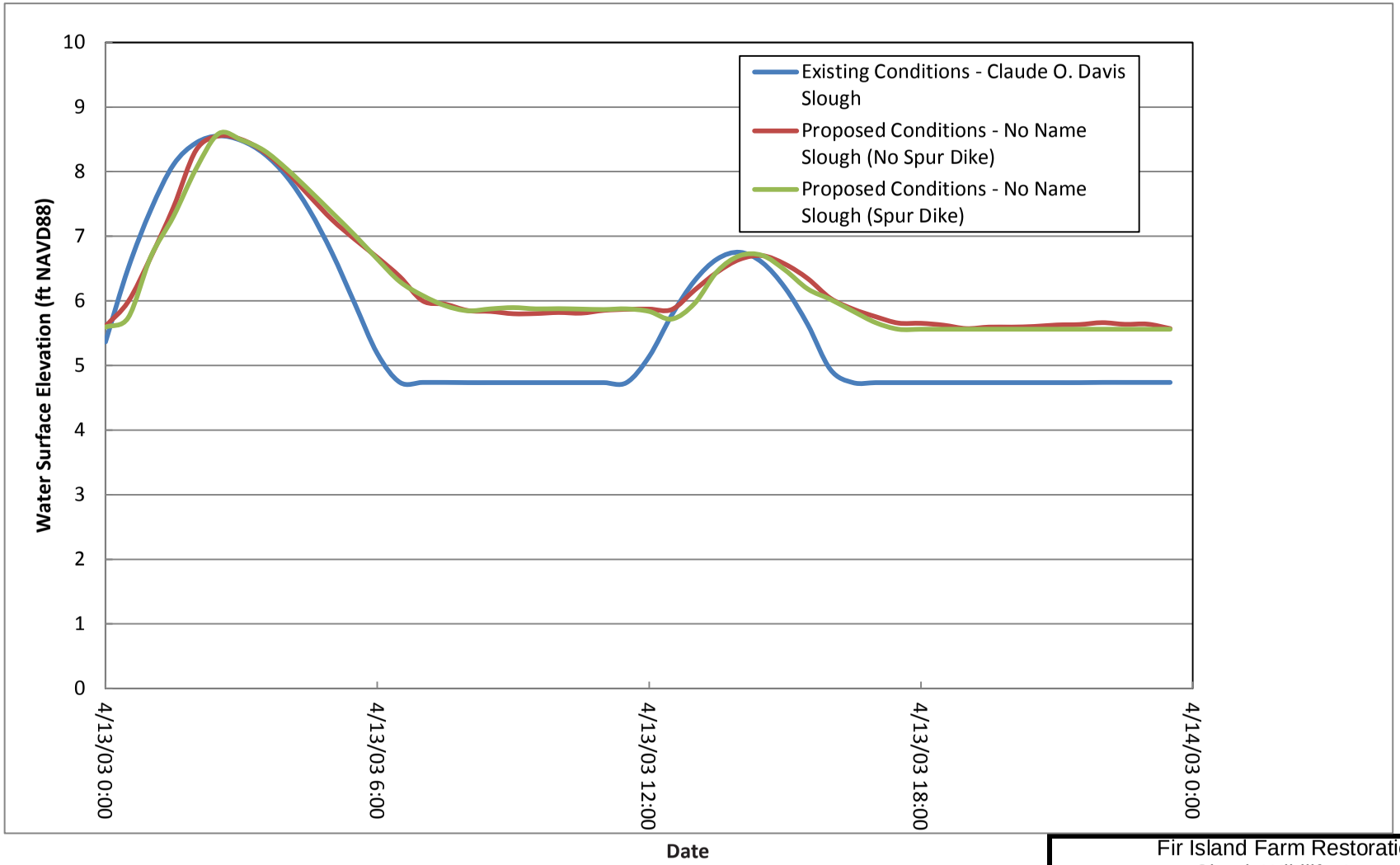
FIG. 9



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Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

PROJECT
HYDRODYNAMIC EFFECT

January 2014 21-1-12318-217

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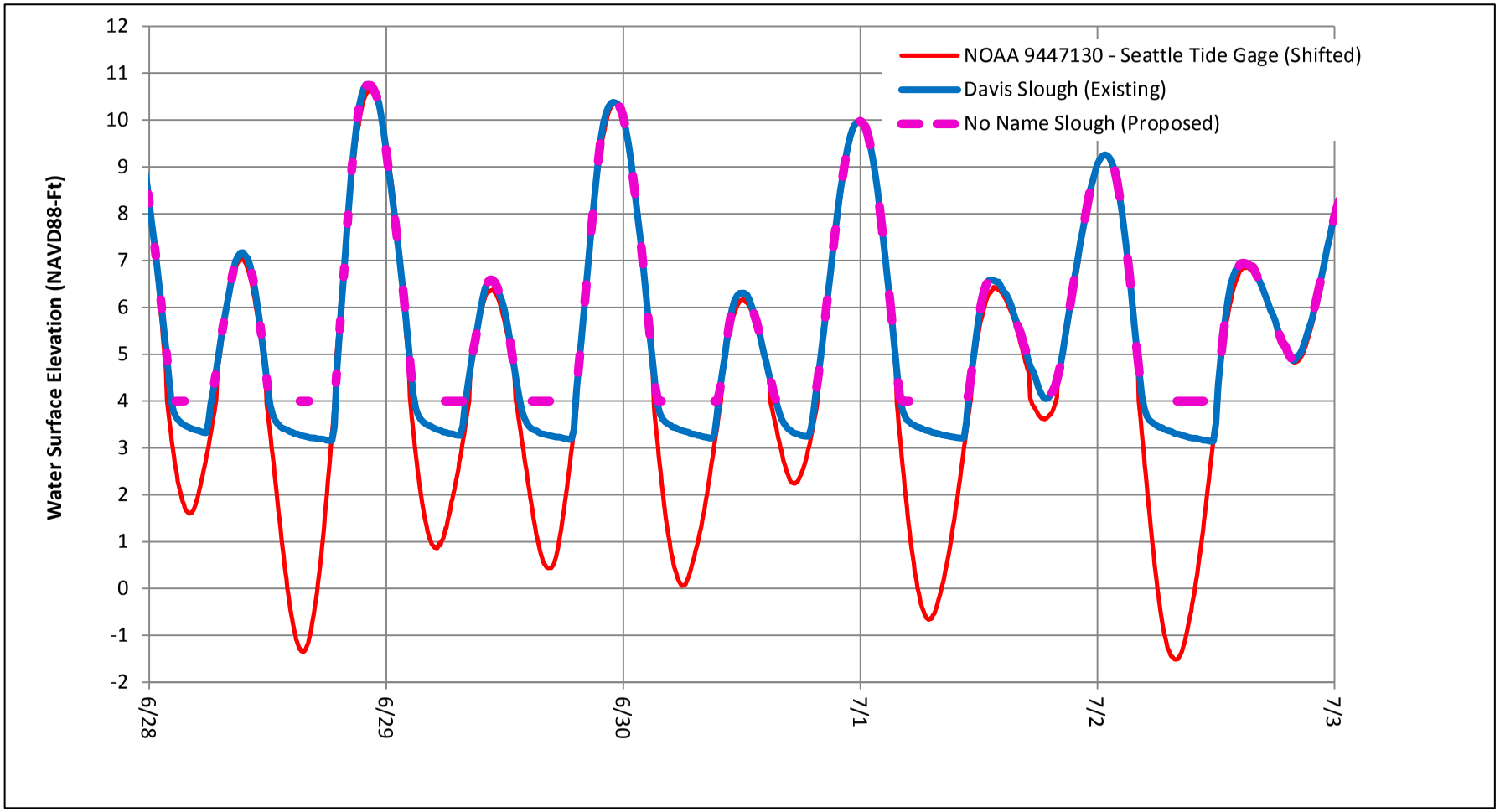
FIG. 10

FIG. 10

I:\WIP\21-1\12318 Fir Island\217_COASTAL_HYD\REPORTS\S&W\21-1-12318-217 Figs 2-13 <FIG10.HYDRO_EFFECT>



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Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

HYDRODYNAMIC EFFECT AND EXISTING CONDITIONS

January 2014 | 21-1-12318-217

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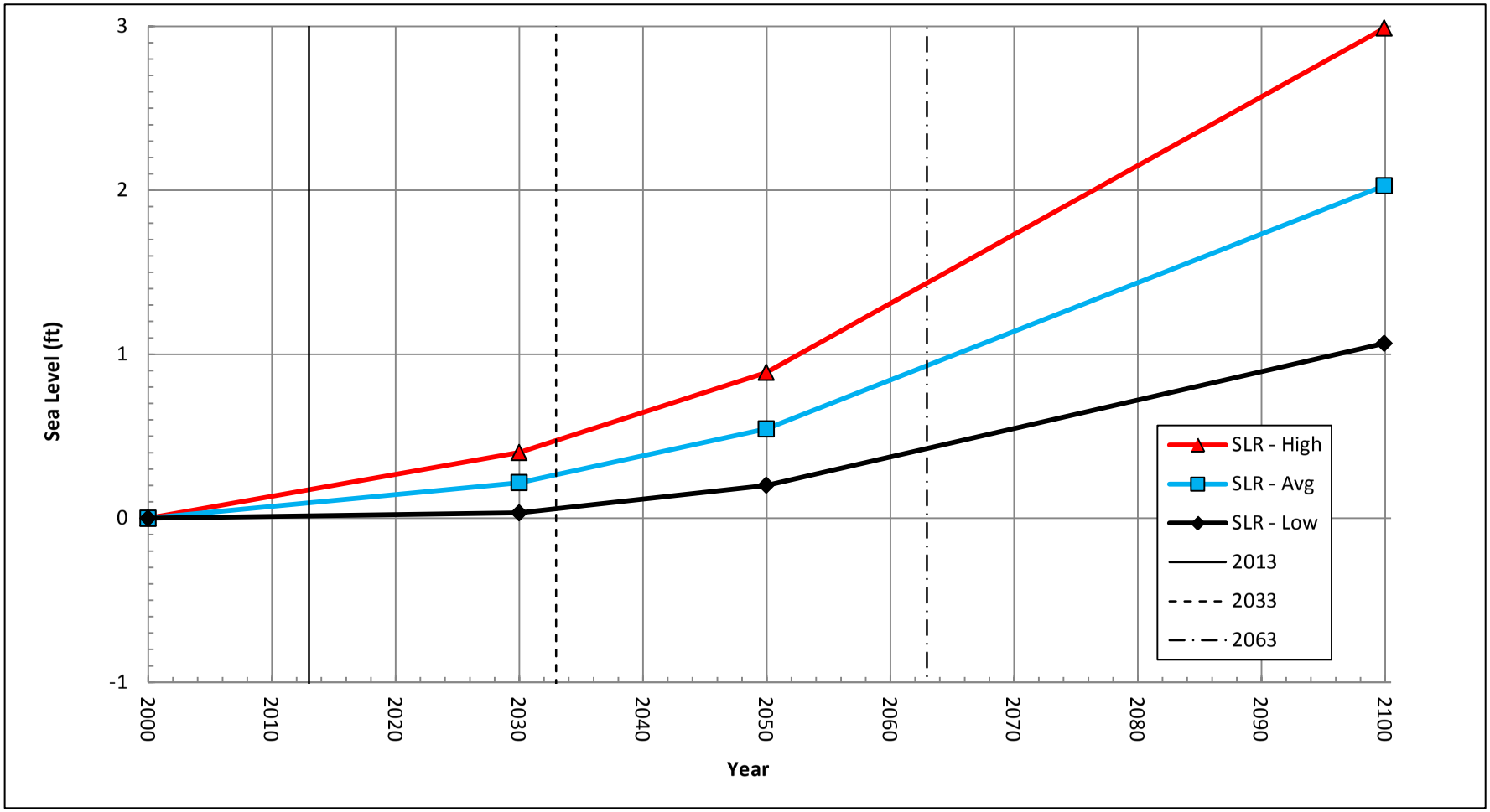
FIG. 11

FIG. 11

I:\WIP\21-1\12318 Fir Island\217_COASTAL_HYD\REPORTS\S&W\21-1-12318-217 Figs 2-13 <FIG11.HYDRO_EFFECT>



Year	SLR - Low (ft)	SLR - Avg (ft)	SLR - High (ft)
2000	0.00	0.00	0.00
2030	0.03	0.22	0.40
2050	0.20	0.54	0.89
2100	1.07	2.03	2.99

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Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

Sea Level Rise Projections
Year 2000 - 2100
Source: NAS, 2013

January 2014 21-1-12318-217

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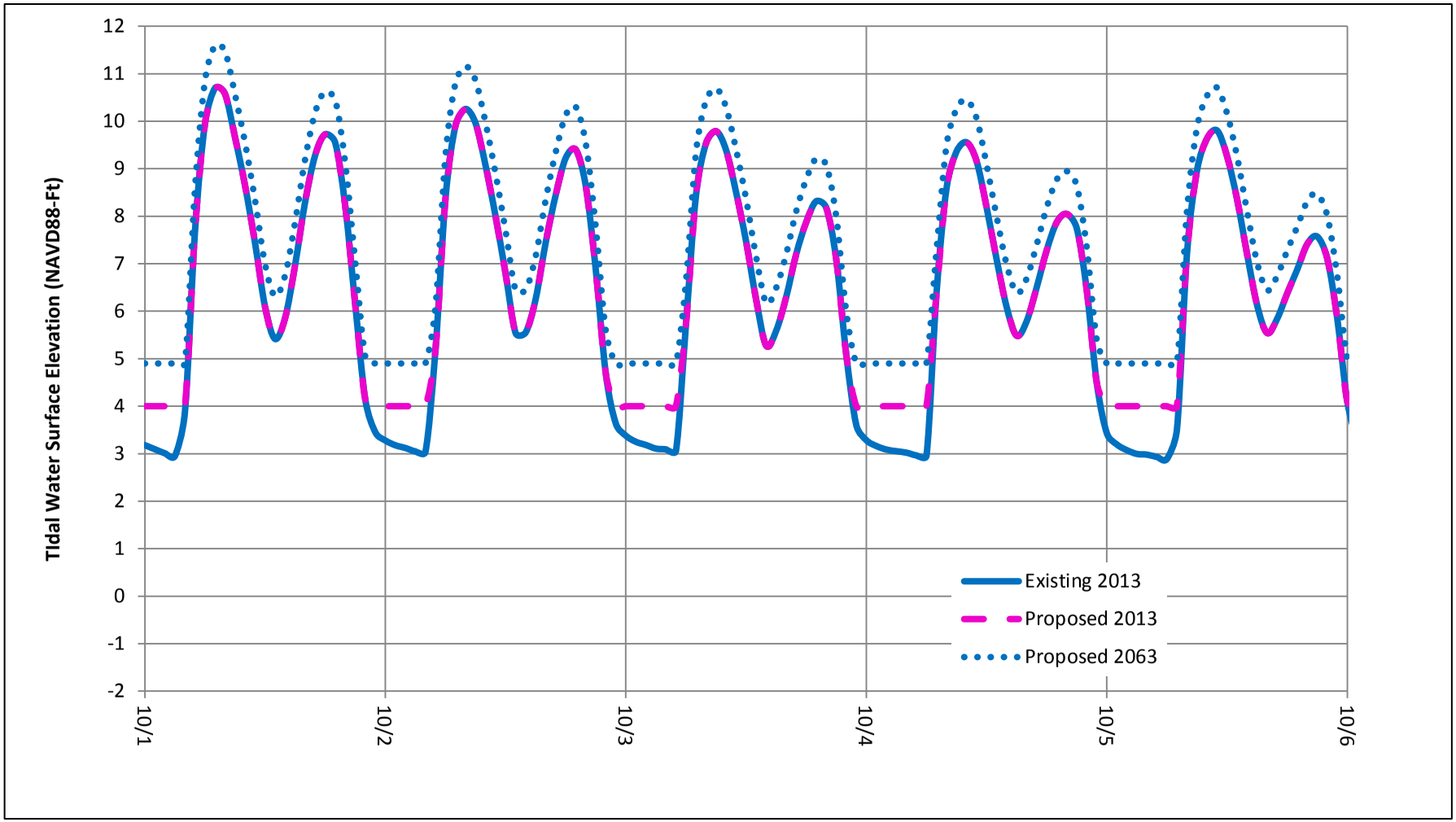
FIG. 12

FIG. 12

I:\WIP\21-1\12318 Fir Island\217_COASTAL_HYD\REPORTS\S&W\21-1-12318-217 Figs 2-13 <FIG12.SLR>



Date

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Fir Island Farms Restoration

Skagit County, WA

HYDRODYNAMIC AND SEA LEVEL RISE EFFECTS AND EXISTING CONDITIONS

January 2014 21-1-12318-217

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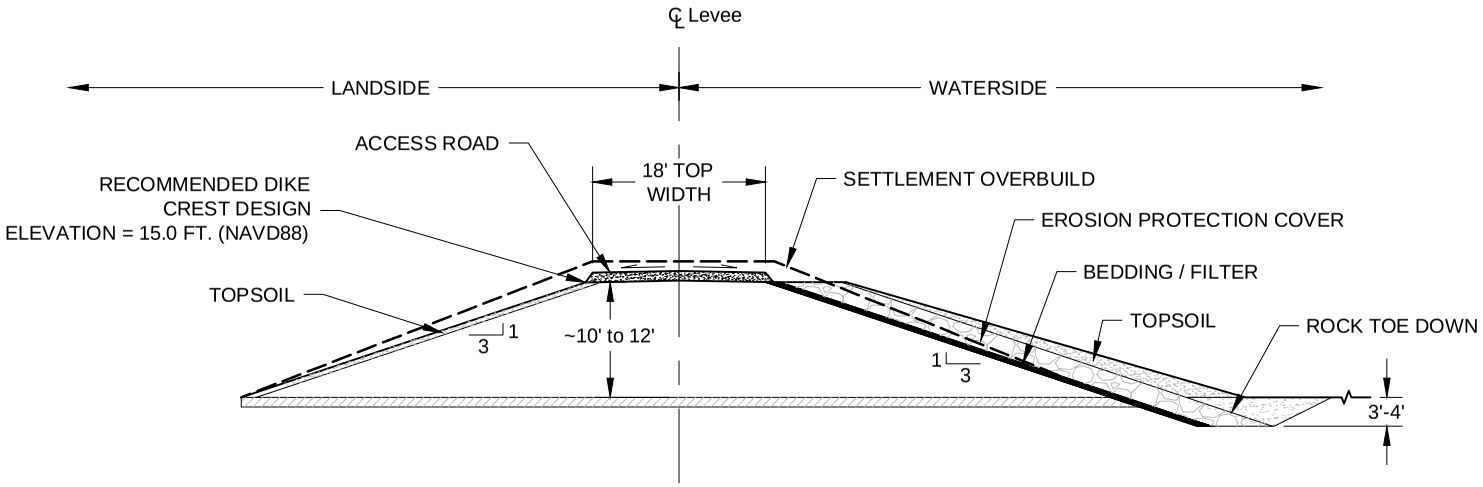
Fig. 13

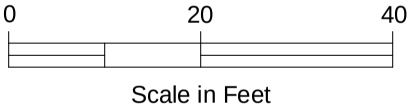
Fig. 13

I:\WIP\21-1\12318 Fir Island\217_COASTAL_HYD\REPORTS\S&W\21-1-12318-217 Figs 2-13 <FIG13.SLR+HYDRO-EFFECT>

Filename: J:\211\12318-217\21-1-12318-217 Fig 14.dwg Date: 01-10-2014 Login: SAC



TYPICAL LEVEE SECTION DETAIL



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Fir Island Farm
Estuary Restoration Project
Skagit County, Washington

LEVEE COASTAL ENGINEERING DESIGN RECOMMENDATIONS

January 2014 21-1-12318-217

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FIG. 14

FIG. 14