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

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FIR ISLAND FARM ESTUARY RESTORATION
FINAL DESIGN AND PERMITTING
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 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 present hydrodynamic results from the study performed by Battelle (2013) for consistency, and to provide design recommendations for the setback dike, 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 estuary 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 dike 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 estuary restoration project will include setting back the existing dike on the Reserve and restoring 127 acres of farm land to tidal marsh. The feasibility study performed in 2011 defined the general dike setback alignment, tidal marsh restoration areas, and pilot tidal

channel configurations (Shannon & Wilson, Inc. [S&W], 2011). This report presents engineering coastal engineering recommendations to be incorporated into the project design, including:

- 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 survey 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. This section of the report describes the methods used for calculating tidal datum transformations.

Local NOAA tide gages in the area with published MLLW datums 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 current transformation of MLLW to NAVD88 datum for the project site is calculated as follows:

$$\text{NAVD88 (feet [ft])} = \text{MLLW (ft)} - 2.13 \text{ ft}$$

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 dike setback conditions (Battelle, 2011a and 2011b). The existing conditions 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 on the west side of the project, and extending a 200-ft section of dike south into the Skagit Bay marsh. This dike configuration isolates the dike setback project and project effects from Brown Slough.

We evaluated the hydrodynamic modeling output for the two setback alternatives (without and with spur dike) for typical spring season tidal cycle (Figures 2 through 9). The hydrodynamic modeling output provided tidal flow pattern, velocity and shear stress information used to evaluate erosion and deposition potential. 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 leading into 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 experience sizeable erosion if the breach is sized similar to the existing Claude O. Davis tidal channel width. Erosion of the main tidal inlet channel is an expected outcome of the project and was documented in the Feasibility Study (S&W, 2011). The primary concern is for significant amounts of erosion and sedimentation impacting interior drainage functions.

A majority of eroded material will likely move northward into the restored marsh areas due to tidal flood dominant velocities and shear stresses. To a lesser degree, ebb flow erosion and sedimentation to the south in Skagit Bay could occur. Excavation of the main tidal inlet breach to a width similar in size to the anticipated equilibrium condition would limit the potential for adverse erosion and sedimentation in the tidal channels, both interior and exterior to the breach area.

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. 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 the existing borrow ditches on the current landward (north) side of the existing dike. They originate from the west side of Dry Slough and the east side of the "spur dike" Brown Slough areas. Future designs should consider these effects and develop plans to minimize and mitigate them. This indicates that significant erosion along the toe of the dike from tidal flows is not likely. The primary factors for dike erosion and scour design are therefore wind waves and large wood debris impacts.

Shallow ponding will likely exist across much of the marsh restoration area at low tide and the site will not fully drain. Moreover, the hydrodynamic modeling indicates that 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 were compared with proposed conditions in No Name Slough immediately downstream from the proposed dike and

tidegates (Figure 10). These are the common tidal tailwater control locations for existing and proposed conditions. The term tailwater refers to the downstream, tidal water surface elevations that "control" the opening, closing and flow rates through the interior drainage tidegates. The hydrodynamic model predicts increases in low tide, tailwater elevations by 0.7 to 1.0 feet. These predicted increases indicate that the marsh will not drain as much as it currently does, and will reduce the amount of time and the elevations to which the interior drainage system can drain (Figure 10).

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. Proposed conditions show a low tide elevation of 5.7 ft for proposed conditions in No Name Slough downstream from the new tidegates; an approximate low tide water elevation 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 proposed conditions. It is our opinion that the hydrodynamic model predictions of future tailwater elevations of 5.5 to 5.7 ft is likely over-predicting low tide water surface elevations. Our justification for this is that observed low tide elevations (Existing Conditions – Claude O. Davis Slough) at similar Skagit River flows and tidal conditions are nearly one foot lower than the low tide water elevations for existing "Without Project" conditions predicted by the hydrodynamic model.

Therefore, we interpret the hydrodynamic modeling results as a "relative increase" in tailwater elevations by 0.7 to 1.0 ft. Figure 11 shows how this interpretation was 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 clearly discussed or specified for applicable dike, drainage and habitat restoration guidelines and standards from the Natural Resources Conservation Service (NRCS) Dike Practice Standard (NRCS, 2001), NRCS National Engineering Handbook Section 16. Dikes (NRCS, 1970), the U.S. Army Corps of Engineers (the Corps) Levee Design Guidelines (Corps, 2000), or habitat restoration guidelines. WDFW, with input and coordination from the project steering committee, regulatory and funding agencies, decided that a reasonable approach for the project would be to consider SLR for a period of time commensurate with the 50-year dike design life cycle (the project design period of 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). SLR 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 and others (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 dike with additional top width to allow for raising the dike in the future, without needing to build or expand the dike on the landward or waterward slope. For the project, an additional 3-ft top width would allow for raising the dike 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), and the 15 ft top width is the current levee design width.

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 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 and others (2012), Kirwan and Murray (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 and others, 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 quiescent areas are, however, typically further away from tidal channels that supply sediments.

- 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.
- Tidal channel and lower-lying marsh areas exposed to coastal waves (near the main tidal inlet) will likely erode and become local sediment sources.
- 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, we reviewed hydrodynamic modeling shear stresses (Figures 7 and 9) to evaluate erosion potential. The hydrodynamic model predictions indicate that the main tidal inlet area, and areas immediately 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 stresses and velocities, 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 pounds per square foot (psf).
- van Rijn (1993) and Amhad and others (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 and Murray (2007) and Fagherazzi and Furbish (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) (2005).

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 following discussions focus on the spur dike alternative, the recommended 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 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 sediment supply 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 could indicate that these areas might be at risk for limited establishment of 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 “adverse” 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 presented. 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 seeding 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 main tidal channel and marsh areas 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 including excavation of the inlet area, 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 as compared with the nearby Wiley Slough site near the South Fork Skagit River.

Grossman and others (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 to the North and South Fork distributaries. However, the central Bay front has had a reduction in sediment supply due to Fir Island diking and channelization of the North and South Forks. Several studies observe different sedimentation, and tidal channel pattern characteristics along the central Fir Island Bay front area as compared with adjacent distributaries of the North and South Fork Skagit Rivers.

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 at the mouth of the South Fork distributary (with higher supply) versus areas along central Skagit Bay front. These higher sediment supply and erosion areas of the Skagit River Delta 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 that may change with climate change and SLR. These changes may include increased supply and transport rates along the Bay front, but in-depth studies of these potential changes have not been performed to date. In contrast, Hood (2007) and Phil Williams and 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 conditions is that sediment supply and sources along the central Fir Island Bay front area (Fir Island Farm site) are limited. The importance of a limited sediment supply that the project site likely has lower sediment supplies than the neighboring Wiley Slough project positioned next to the South Fork Skagit River distributary. Wiley has experienced sediment shoaling conditions affecting interior drainage. Similar conditions could form at the Fir Island site, albeit less likely. This information 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. Geologic Service – Western Ecological Research Center San Fancisco Bay Estuary Field Station [USGS], 2012). We note that the Nisqually Delta restoration and measurements likely have higher sediment supplies than the central Fir Island Bay front, as the Nisqually 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 that larger tidal channels have eroded and widened, and nearby marsh surfaces have experienced low levels of marsh sedimentation. This is similar to the initial indicators using the hydrodynamic modeling predictions and shear stress thresholds discussed above.

The data set collected for the Nisqually project has a limited time period and limitations regarding the similarity of site characteristics. The Nisqually measurements have been used for this study as it is some of the only data readily available in the Puget Sound with large-scale tidal marsh restoration sediment monitoring data.

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 were used in the interior drainage sensitivity analyses.

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 supply 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 new high 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 option for sediment management presented above. This would involve

- Excavation and dredging of the main tidal inlet channel in high shear stress areas,
- Seeding of disturbed marsh restoration areas and establishing grass on the farm areas prior to breaching to limit erosion potential and accelerate sedimentation,
- Excavation of tidal pilot channels, and
- High marsh fill grading using excavated materials from the interior drainage storage pond, 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 up to 3 feet in depth, and would establish a range of tidal marsh elevations. 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 seepage rates underneath and through the dike, and erosion risks to the dike. 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 amount is estimated at slightly less than 80,000cy, which is enough material to raise significant farm areas to elevations competent for establishing high marsh vegetation.

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 dikes through direct impact; dragging and scouring of dike 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 having 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).

For the proposed "Project" the wind will push wood debris that travels through the main tidal inlet toward the northernmost (east-west) section of the dike and also 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 dike toe can limit some wood debris impacts due to shallow water depths that will limit wood transport. Drainage structures (tidegates) in No Name Slough, and the dike setback, will need to be protected with log booms and wood debris racks to prevent wood debris impacts. Significantly large wood deposits could accumulate in the marsh and tidal channels, thereby impacting drainage. This is something that should be monitored and evaluated in the Adaptive Management and Monitoring Plan.

5.0 COASTAL DIKE DESIGN

The dike design is based on a criteria established by dike and dike 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 Natural Resource Conservation Service (NRCS) Dike Design Practice Standards and U.S. Army Corps of Engineers' (Corps') Design Guidelines

The project coastal dike (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 dike 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 Corps dike (levee) design guidelines (Corps, 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 dike will be designed to meet certain seepage, foundation and embankment stability, and interior drainage criteria which will be presented in further detail in separate interior drainage and geotechnical engineering reports. The following guidelines were referenced in developing design recommendations for the project:

- NRCS, 2001, Conservation Practice Standard, Code 356 Dikes
- NRCS, NEH Section 16, "Drainage of Agricultural Land," Chapter 6: Dikes (NRCS, 1970)
- Corps, 2000, EM 1110-2-1913, "Design and Construction of Levees"
- Corps, 2009, ETL 1110-2-6-571, "Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, and Appurtenant Structures"
- Corps, 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, including:

- Level of protection design elevation for a coastal dike based on tide heights, storm surge, wind waves, and SLR (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 dike raises such as sea level rise (provided in this report).

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 dikes providing flood protection under the FEMA National Flood Insurance Program. FEMA coastal zone flood maps will be updated in the near future.

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 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 used 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 event tidal from the entire historical record; 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 slightly greater than the 25-year event.

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 used the methods outlined in Section 4.2, with 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 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 Battelle 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 (Corps, 2003), at 0.54 ft (0.166 m). The calculated combined wave height including storm surge wave setup, 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 wave setup and wind wave runup tidal height of 2.74 ft falls within the range of reported elevated tidal heights reported by Zervas, and therefore representative of the 25 year design event (greater than an annual event and less than 100 year event).

Using the wave height calculation method plus SLR for a 50-year design life, the following equation generates 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 in the geotechnical design phases of the project.

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

For comparison purposes, the existing top of dike elevations range from 13.0 to 14.5 ft, and the dike setback would be raised 0.5 to 1.5 ft for the proposed project.

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 dike toe, and impacts from floating large wood debris. The following approach was used to evaluate erosion and scour of 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, 1998). 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 = 2.5 Horizontal to 1 Vertical (2.5H:1V – based on geotechnical design)
- 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 dike between Dry and Davis Sloughs due to preferential flow paths. Tidal channel and marsh flow conditions 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, near setback dike.

In the central areas of the marsh and further away from the dike setback, tidal channels up to 35 ft wide, and deeper channels on the order of 10 to 20 ft, 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, and not expected along the dike setback.

There is a potential for localized 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 dike is recommended. In the area along the southeast side of the site, the toe-down will occur below native grade. In setback areas along the northeast, north and northwest, the toe-down depth will occur 3 to 4 feet below the high marsh fill grade area, essentially placing rock starting at existing native grade. The toe-down depths 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, which is expected to be limited to the southeast corner of the site. We recommend fill grading in the Southeast 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. These localized scour conditions may exceed the scour design toe-down depth of 3 ft. 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. High marsh fill grading areas will limit this type of erosion and scour. Marsh fill grading in low-shear-stress areas along select areas of the setback dike may reduce localized toe erosion and promote native marsh vegetation establishment, thereby protecting the setback dike from scour and erosion.

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.

Similarly, filling and grading of borrow ditches along the existing dike may not be successful, especially in the areas nearest the main tidal channel entrance near the existing Claude O. Davis Slough tidegates. These area preferential flow paths might develop and erode ditch fills in areas where erosion is not of concern to the existing dike, and could cause sedimentation in the tidal drainage channels. We recommend selective ditch filling along the existing dike removal be limited to areas beyond the predicted high shear stress zones near the main tidal channel entrance.

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 both wind wave and large wood debris factors, 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.
- Monitoring and adaptive management wood removal if marsh wood deposits are excessive and effect interior drainage functions.

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).

- Alignment Alternative – Spur dike configuration
- Dike Design Elevation – 15.0 ft plus settlement (based on geotechnical analysis)
- Top Width – 15.0 ft
- Side Slopes – Assumed 2.5H:1V (based on current geotechnical analysis)
- Dike 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 dike 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 – Not included (information is available in the Drainage Engineering Report)
- Drainage protection
  - Limit erosion of tidal channels, inlet areas, and ditch fills.
  - Excavate main tidal inlet to width to edges of high-shear-stress areas at main tidal entrance, 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 tidal 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.
  - 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 dike 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 INDEPENDENT TECHNICAL REVIEW (ITR)

An ITR of this study and report was performed by Moffatt and Nichol and Golder. A copy of the ITR comments and responses are included in Appendix A.

8.0 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. More information regarding the limitations of this report is included in Appendix B.

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.

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TABLE 1
FIR ISLAND FARM–SITE-SPECIFIC TIDAL DATUMS

Tidal Elevations[1] (ft)	Mean Lower Low Water (MLLW-ft)	North American Vertical Datum 1988 (NAVD88-ft)
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:
[1] Abbreviations
ft = feet
HAT = highest astronomical tide
MHHW = mean higher high water
MHW = mean high water
MLW = mean low water
MSL = mean sea level
MTL = mean tide level
MLLW = mean lower low water
NAVD88 = North American Vertical Datum Transformation

TABLE 2
SEA LEVEL RISE ESTIMATES

Year	SLR - Low[1, 2] (ft)	SLR - Avg[1, 2] (ft)	SLR - High[1, 2] (ft)
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.
ft = feet

TABLE 3
DIKE DESIGN ELEVATION SUMMARY

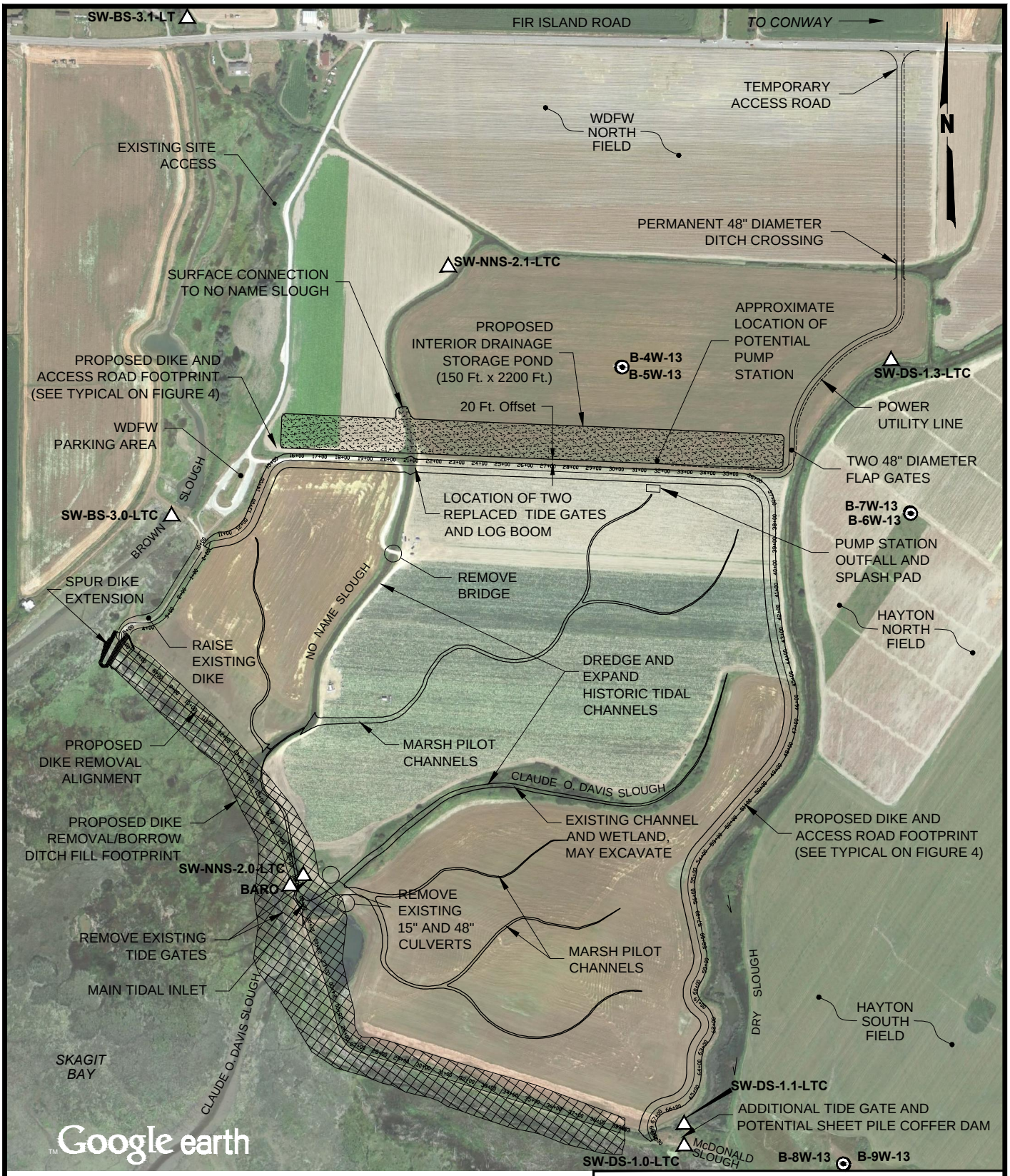
Design Element	(m)	(ft)[1]
n_{HAT}[2]	3.44	11.28
n_{Surge}[3]	0.67	2.20
$n_{Wind\text{-}wave}$[3]	0.17	0.54
$n_{SLR\text{-}2063}$[4]	0.28	0.93
n_{Design}	4.56	14.95
Settlement	TBD	TBD

Notes:
[1] Final dike design elevation rounded to nearest tenth of foot (15.0 feet [ft]).
[2] Highest astronomical tide (HAT) 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 2012 and interpolated for year 2063 SLR estimates referenced in National Academy of Sciences 2012 and interpolated for year 2063 average SLR prediction, including vertical land rate adjustments.
TBD = to be determined

TABLE 4
MARSH AND TIDAL CHANNEL
SEDIMENTATION, SCOUR, AND VEGETATION TAILWATER EFFECTS

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

Note:
ft = feet



0 600 1200

Scale in Feet

LEGEND

B-4W-13 Monitoring Well Designation and Location

SW-DS-1.1-LTC Data Logger Designation and Location

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

April 2014 21-1-12318-217

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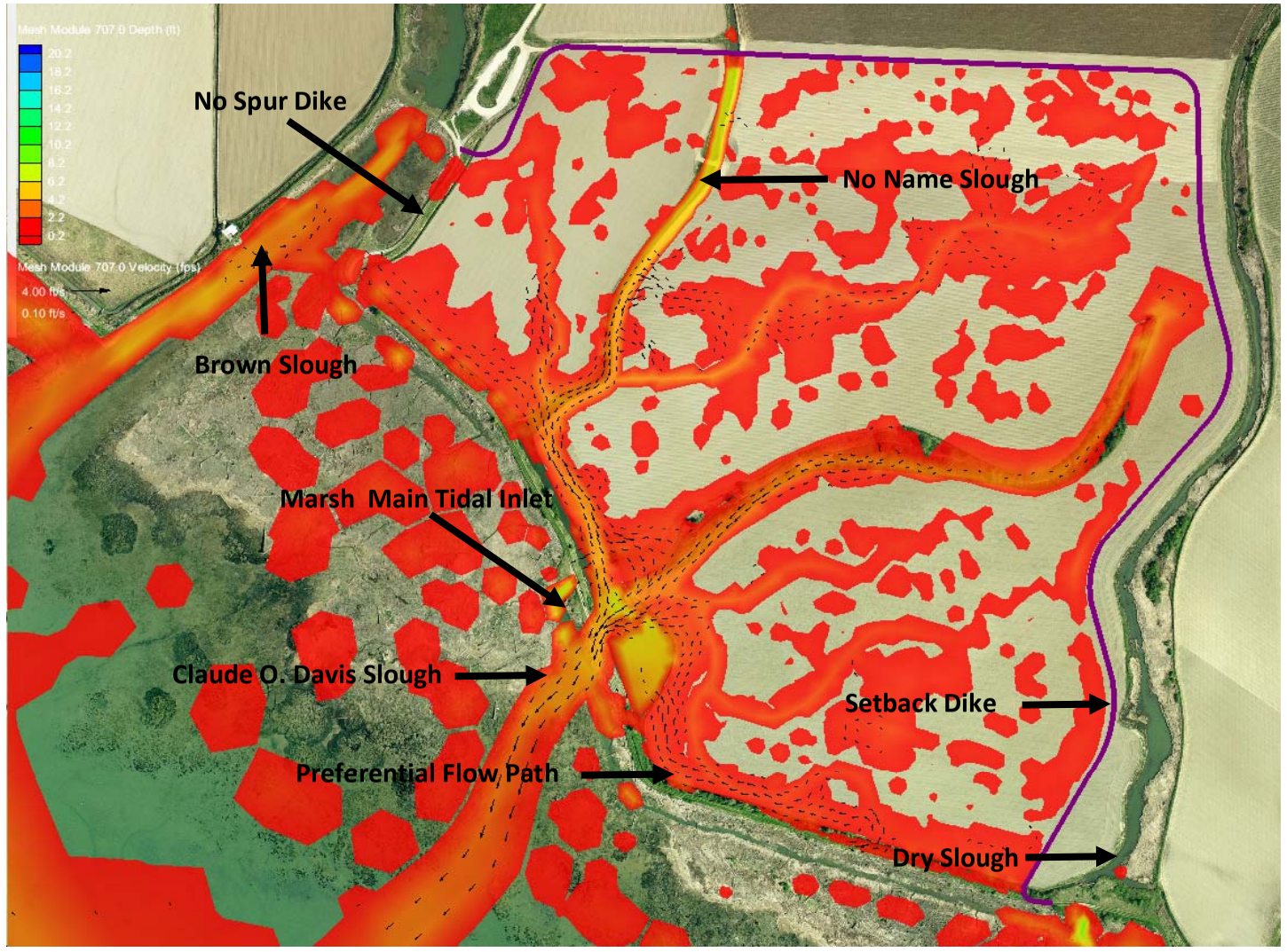
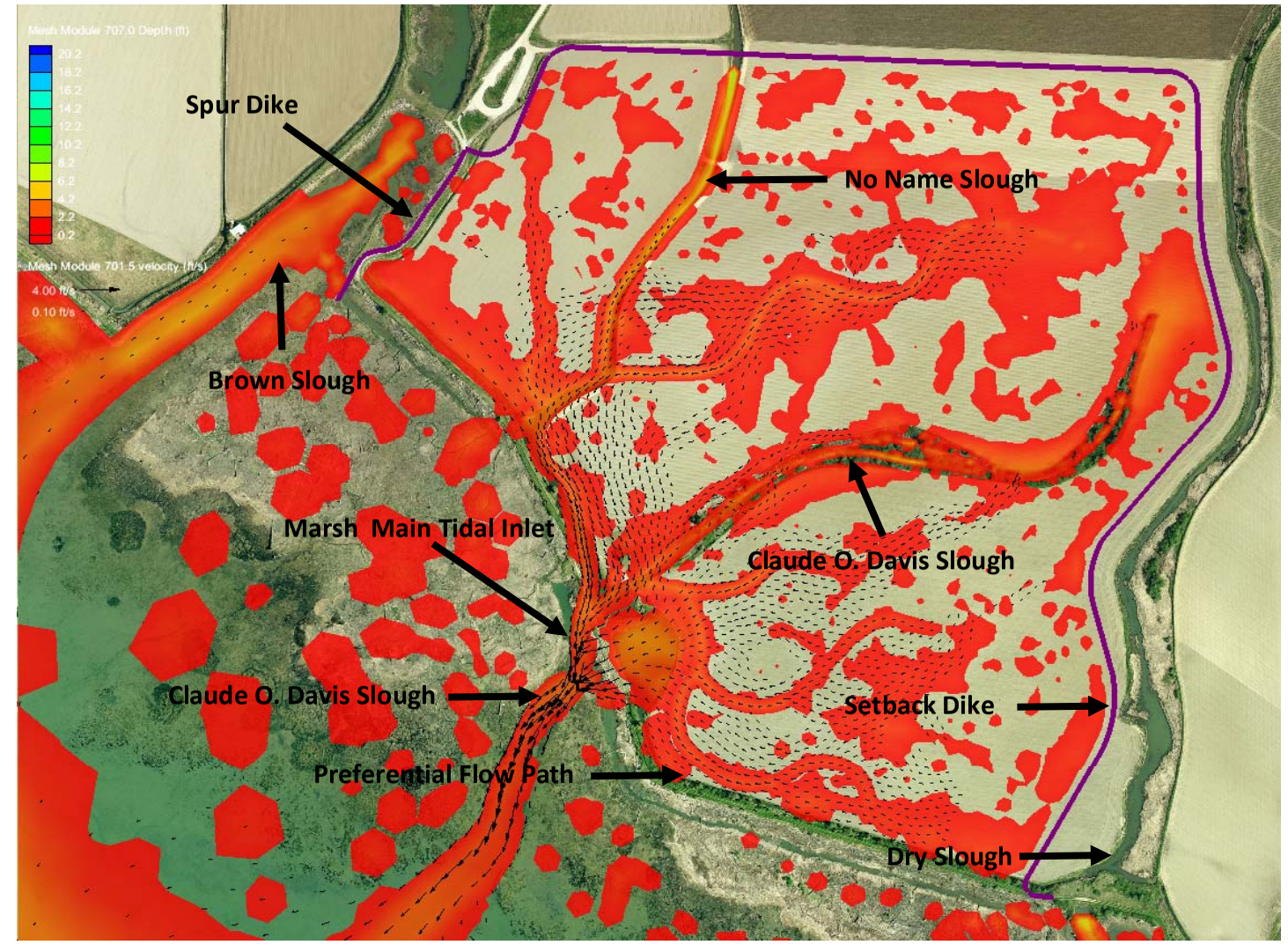
FIG. 1

Filename: I:\WIP\21-1\12318 Fir Island\CAD\FIGURES\-216\21-1-12318-216 Project Site Plan.dwg Date: 05-06-2014 Login: cmh



PLAN VIEW - NO SPUR DIKE

Not to Scale



PLAN VIEW - WITH SPUR DIKE

Not to Scale

Legend

Depth (ft)

20.2
18.2
16.
14.
12.2
10.2
8.2
6.2
4.2
2.2
0.2

Velocity (fps)

4.00 ft/s
0.10 ft/s

N
W E
S

Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

HYDRODYNAMIC MODELING
LOW TIDE - DEPTH/VELOCITY

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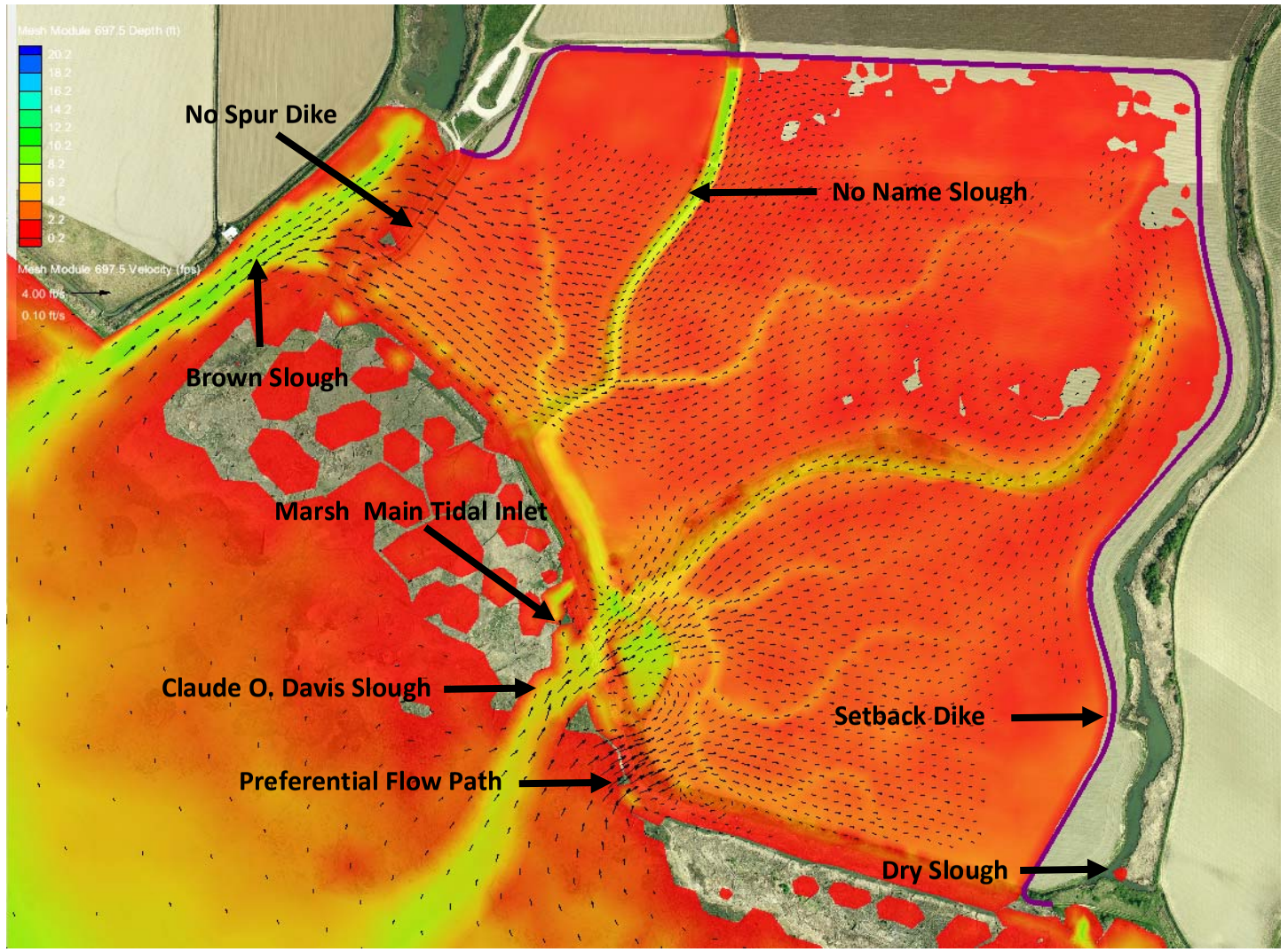
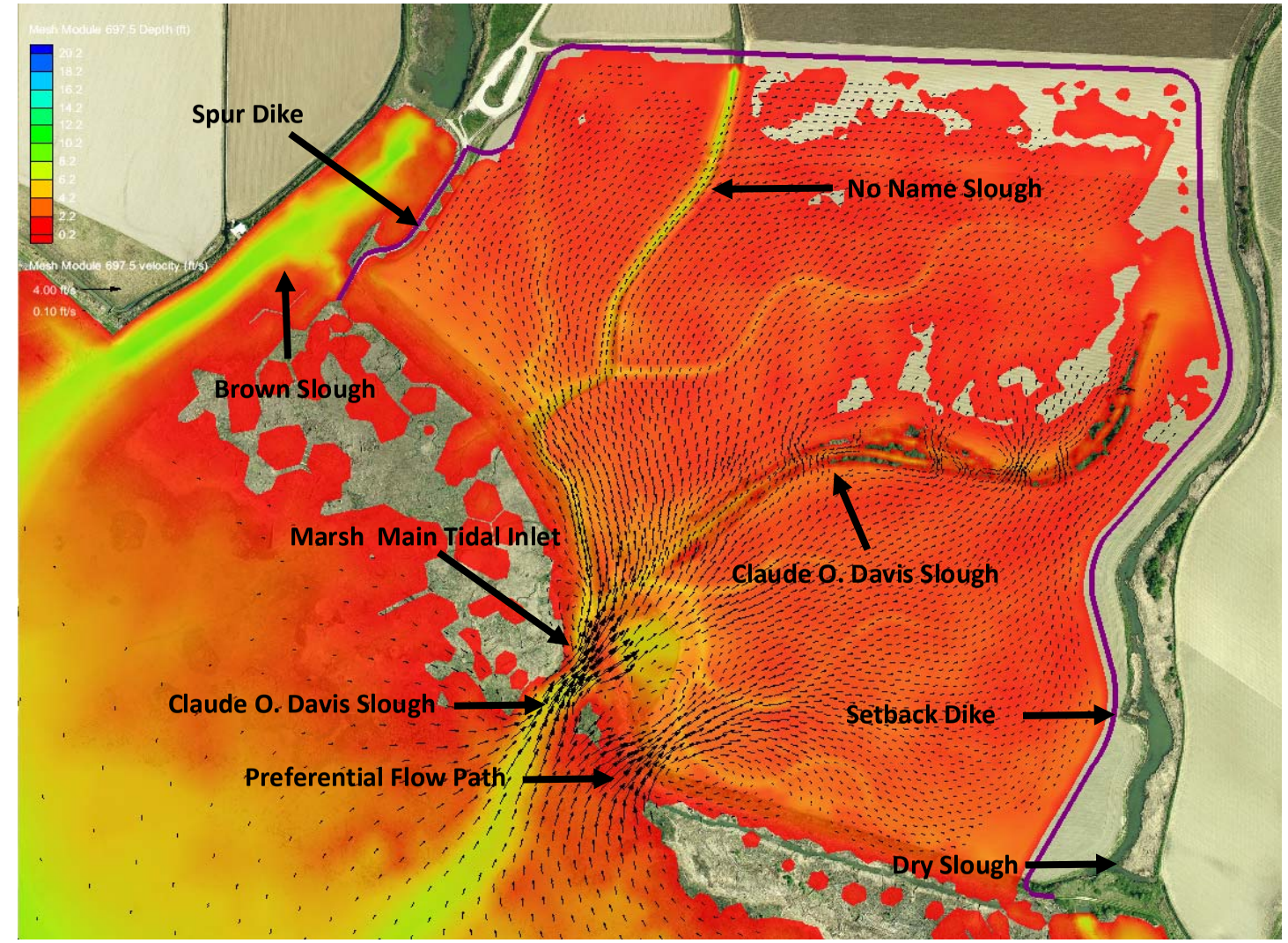
FIG. 2



PLAN VIEW - NO SPUR DIKE

Not to Scale



PLAN VIEW - WITH SPUR DIKE

Not to Scale

Legen

Depth (ft)

20.2
18.2
16.
14.
12.2
10.2
8.2
6.2
4.2
2.2
0.2

Velocity (fps)

4.00 ft/s
0.10 ft/s

N
W E
S

Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

HYDRODYNAMIC MODELING
FLOOD TIDE - DEPTH/VELOCITY

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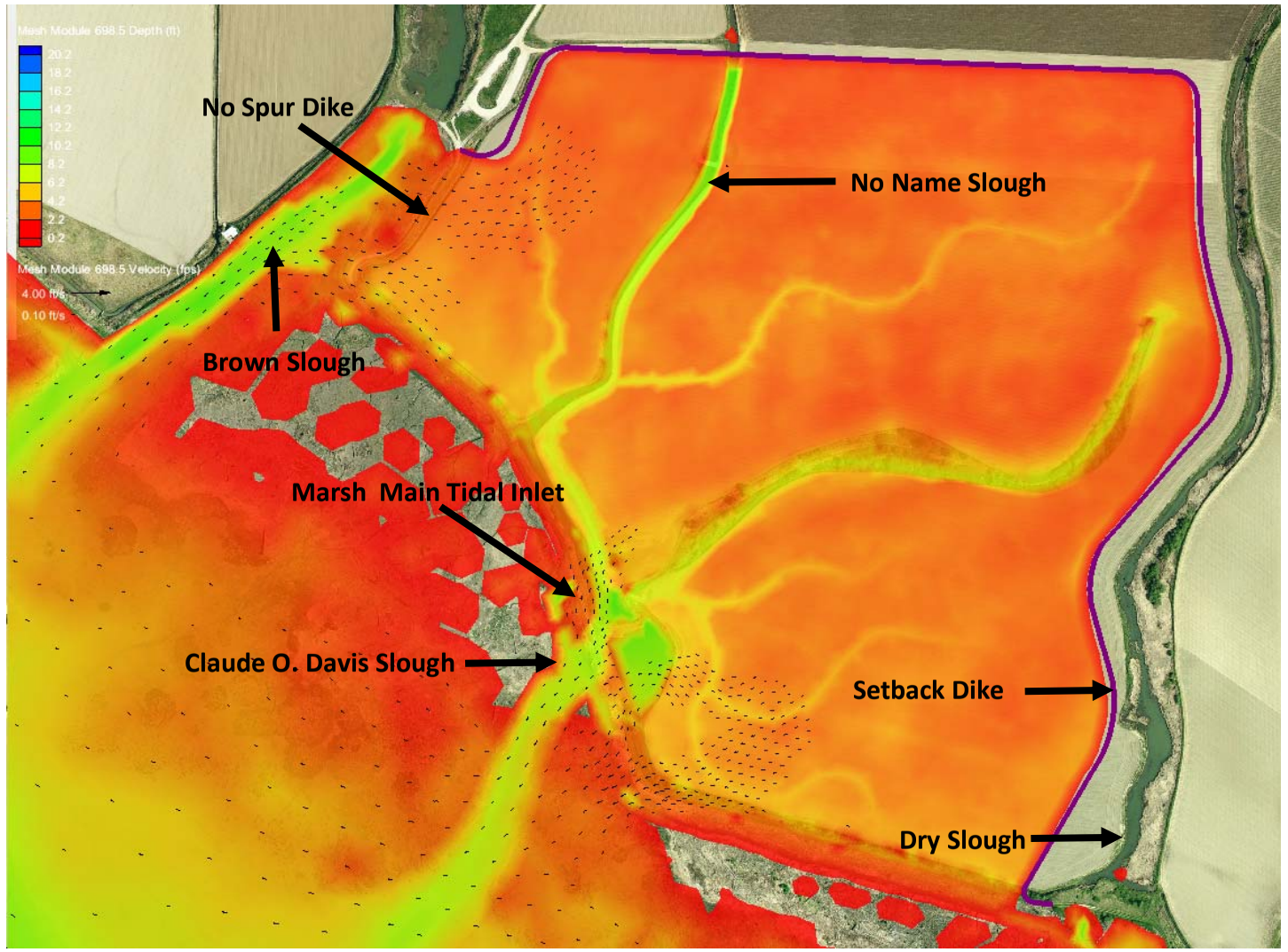
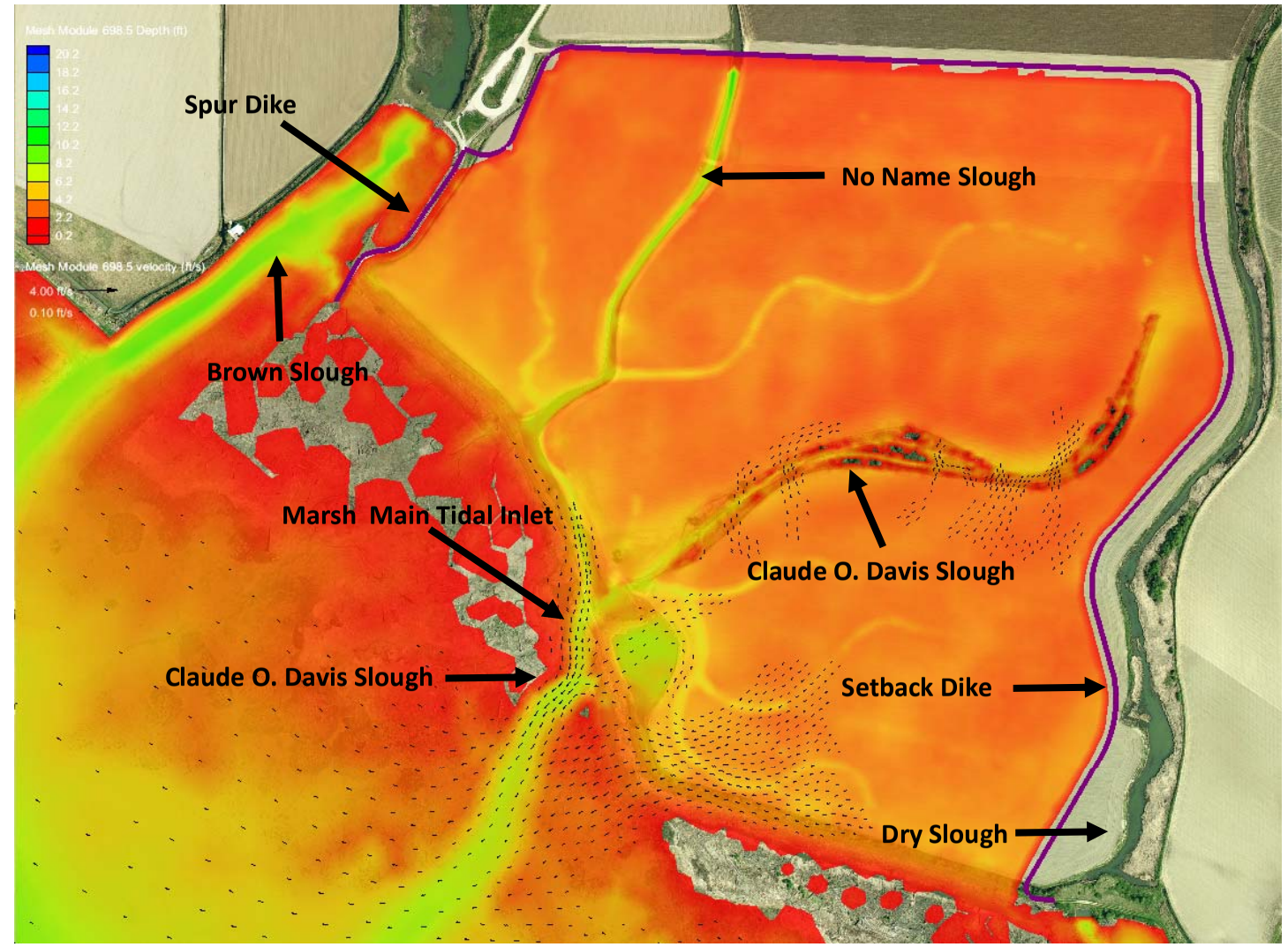
FIG. 3



PLAN VIEW - NO SPUR DIKE

Not to Scale



PLAN VIEW - WITH SPUR DIKE

Not to Scale

Legend

Depth (ft)

20.2
18.2
16.
14.
12.2
10.2
8.2
6.2
4.2
2.2
0.2

Velocity (fps)

4.00 ft/s
0.10 ft/s

N
W
E
S

Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

HYDRODYNAMIC MODELING
HIGH TIDE - DEPTH/VELOCITY

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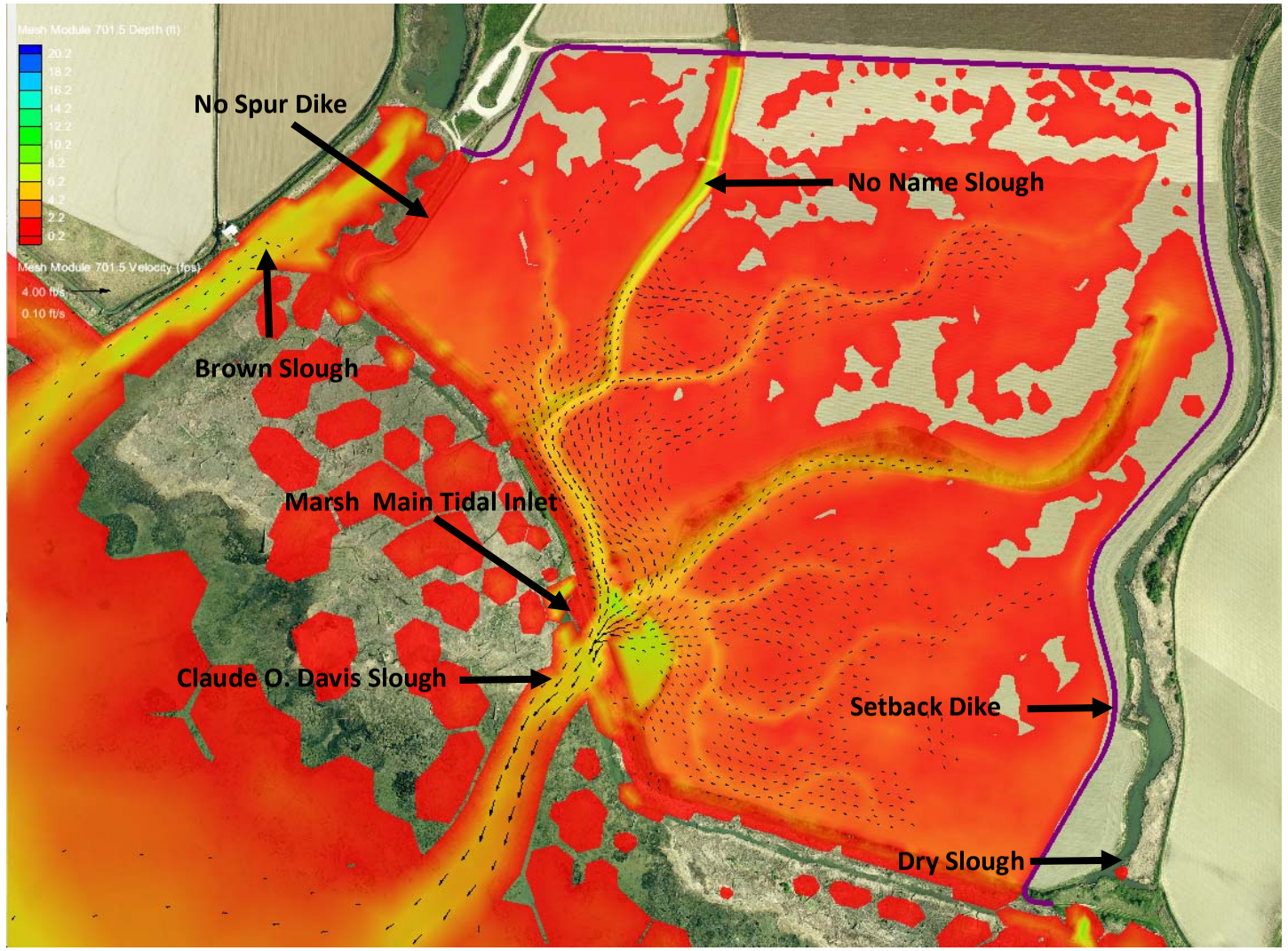
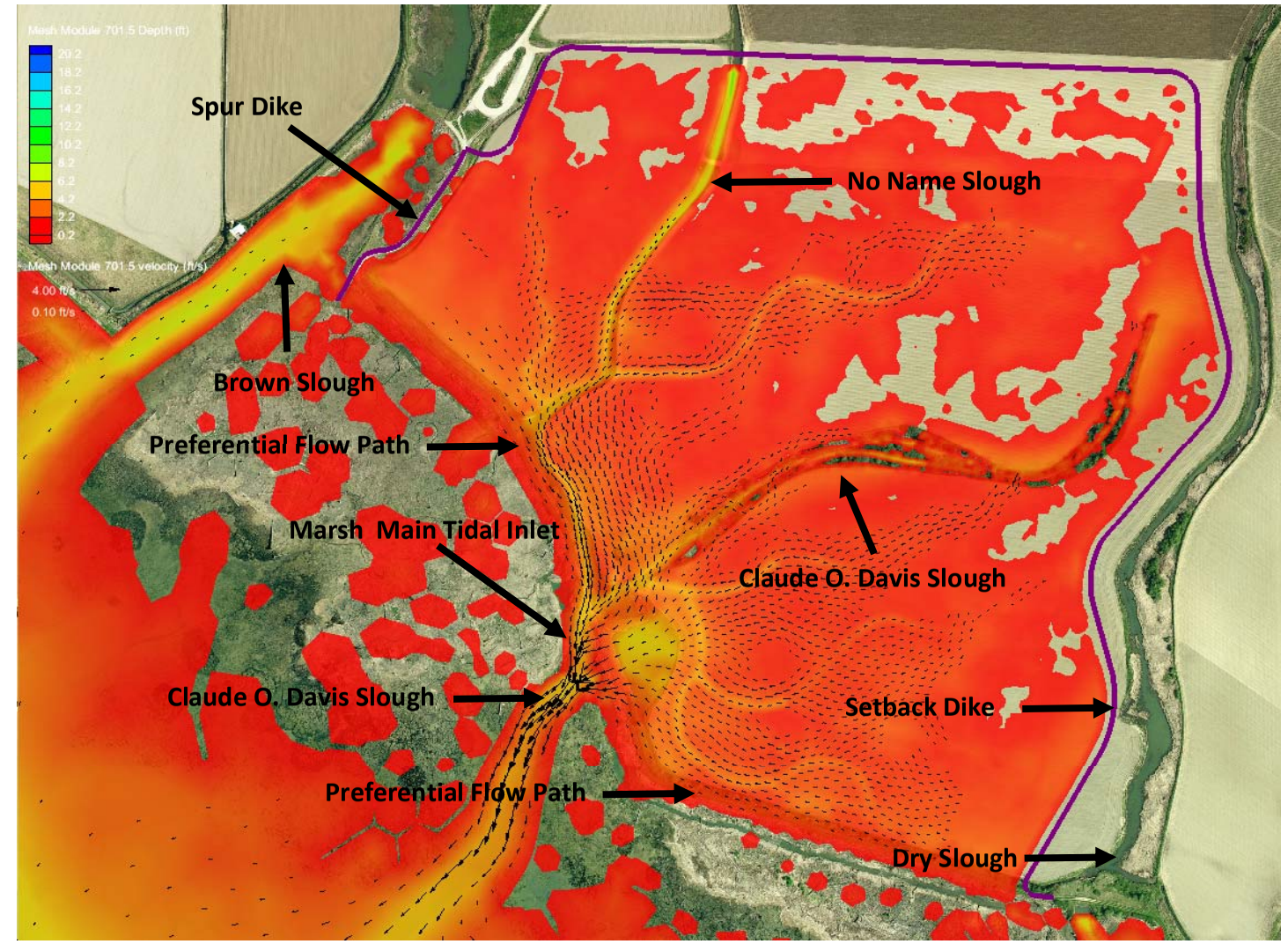
FIG. 4



PLAN VIEW - NO SPUR DIKE

Not to Scale



PLAN VIEW - WITH SPUR DIKE

Not to Scale

Legend

Depth (ft)

20.2
18.2
16.
14.
12.2
10.2
8.2
6.2
4.2
2.2
0.2

Velocity (fps)

4.00 ft/s
0.10 ft/s

N
W E
S

Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

HYDRODYNAMIC MODELING
EBB TIDE - DEPTH/VELOCITY

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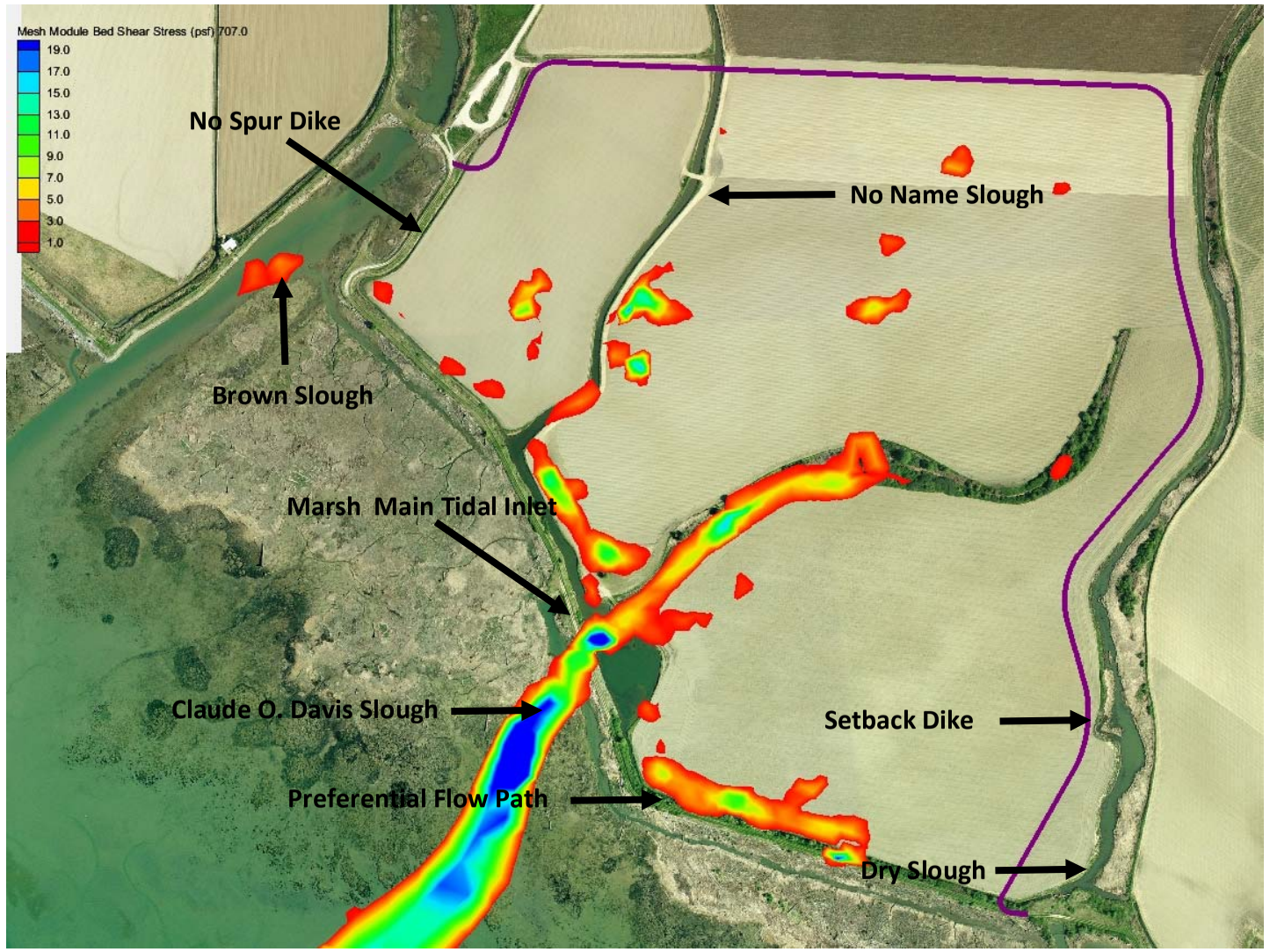
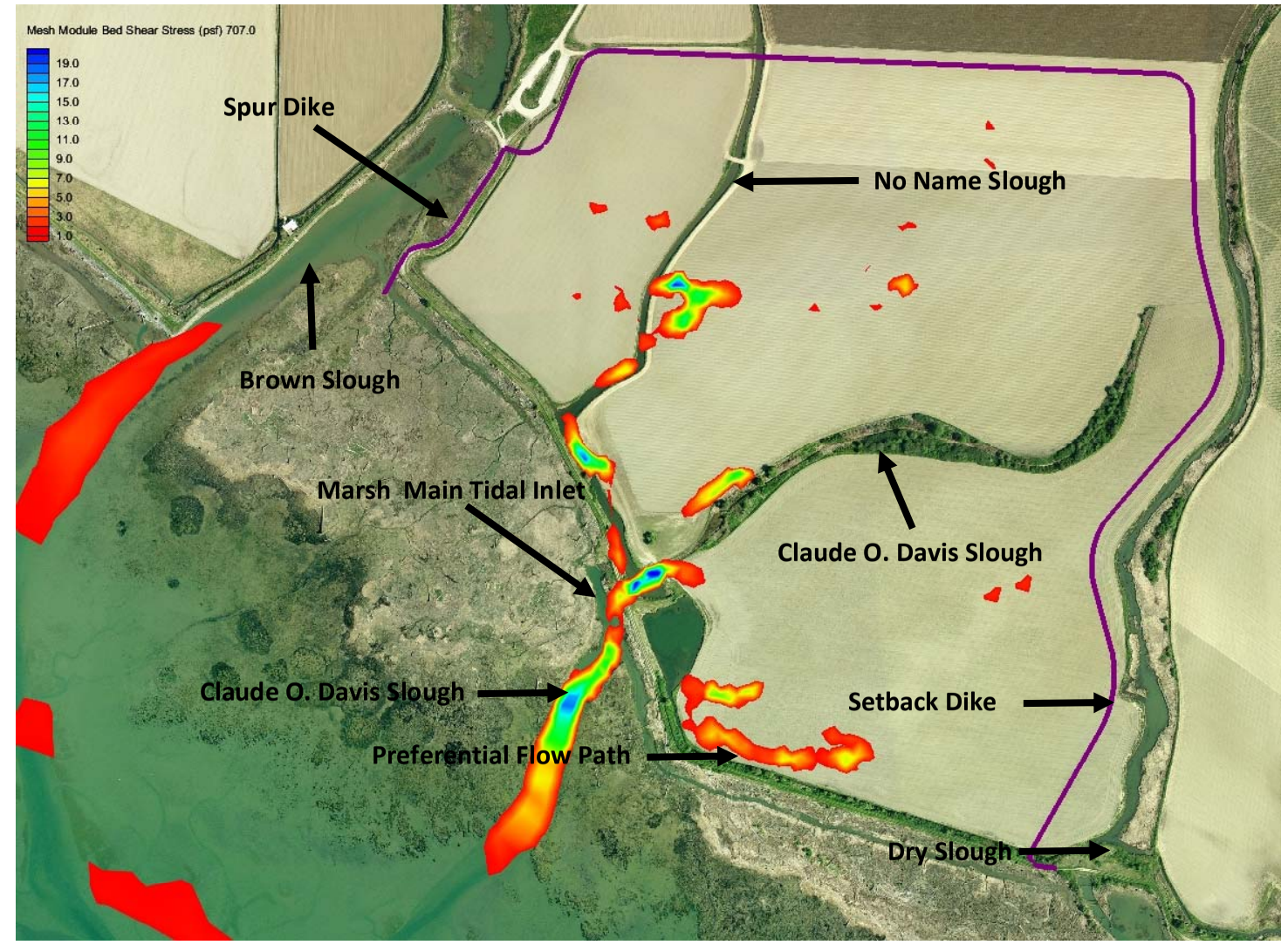
FIG. 5



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

N
W E
S

Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

HYDRODYNAMIC MODELING
LOW TIDE - SHEAR STRESS

May 2014 | 21-1-12318-217

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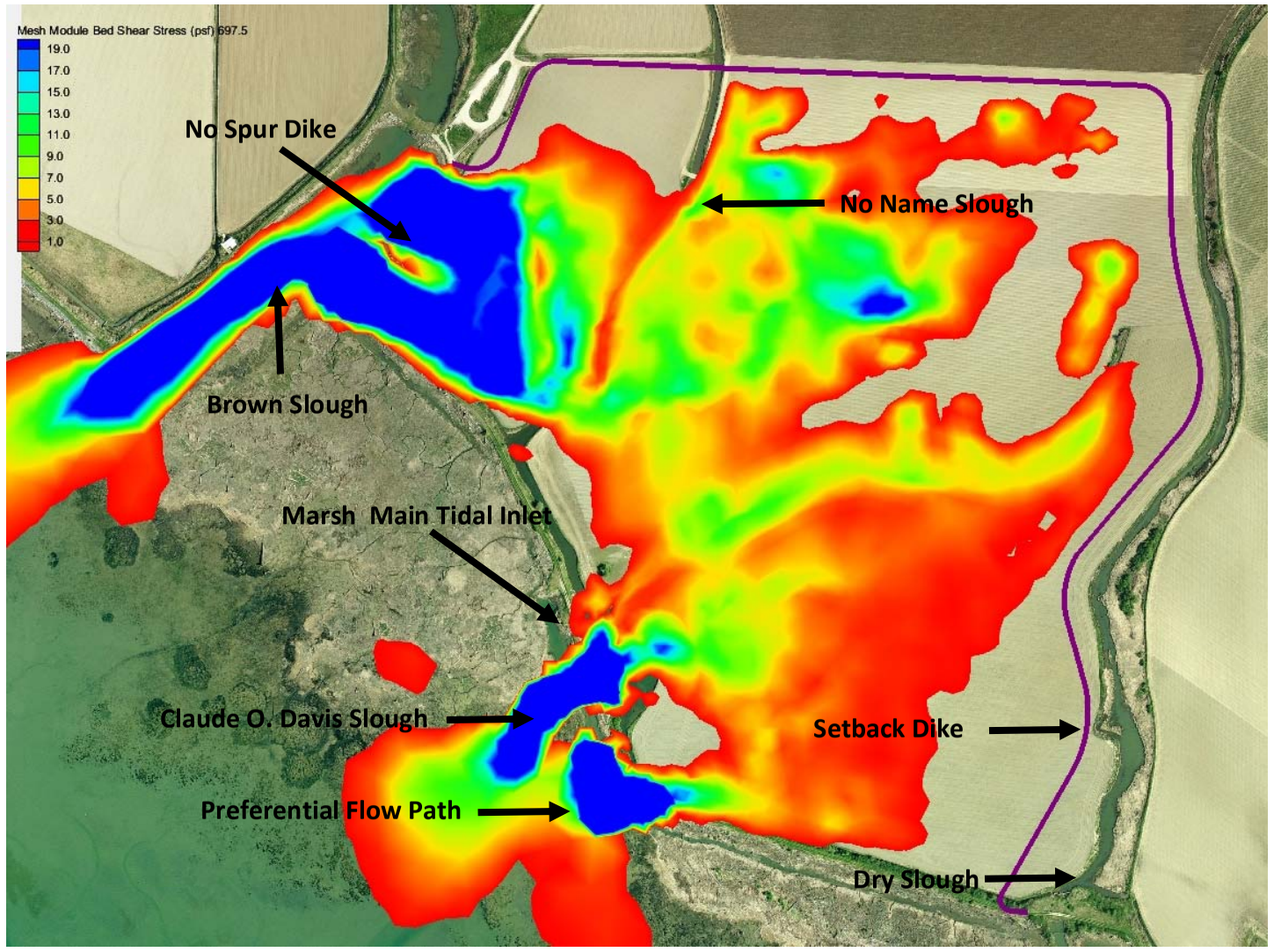
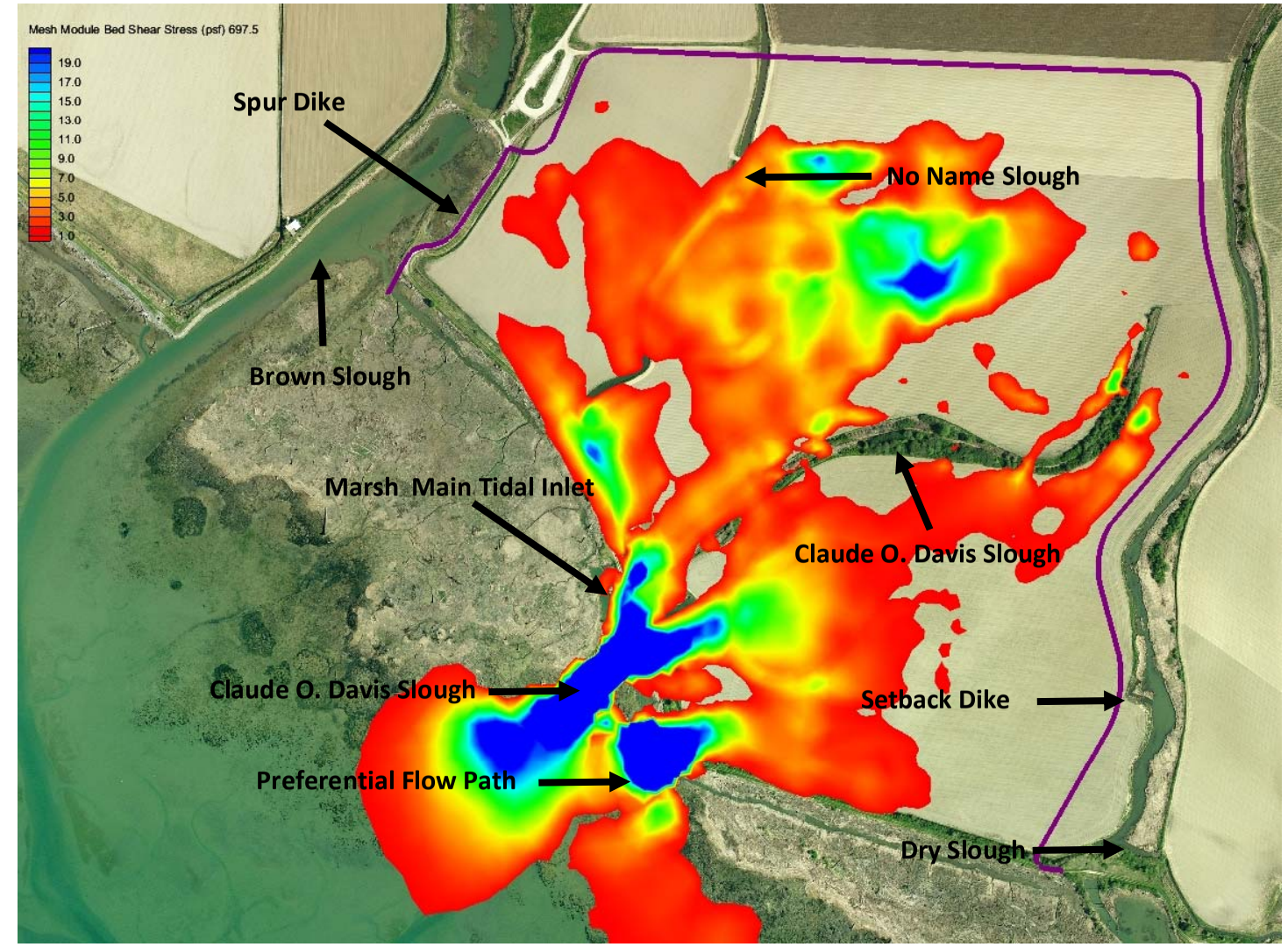
FIG. 6



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

N
W E
S

Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

HYDRODYNAMIC MODELING
FLOOD TIDE - SHEAR STRESS

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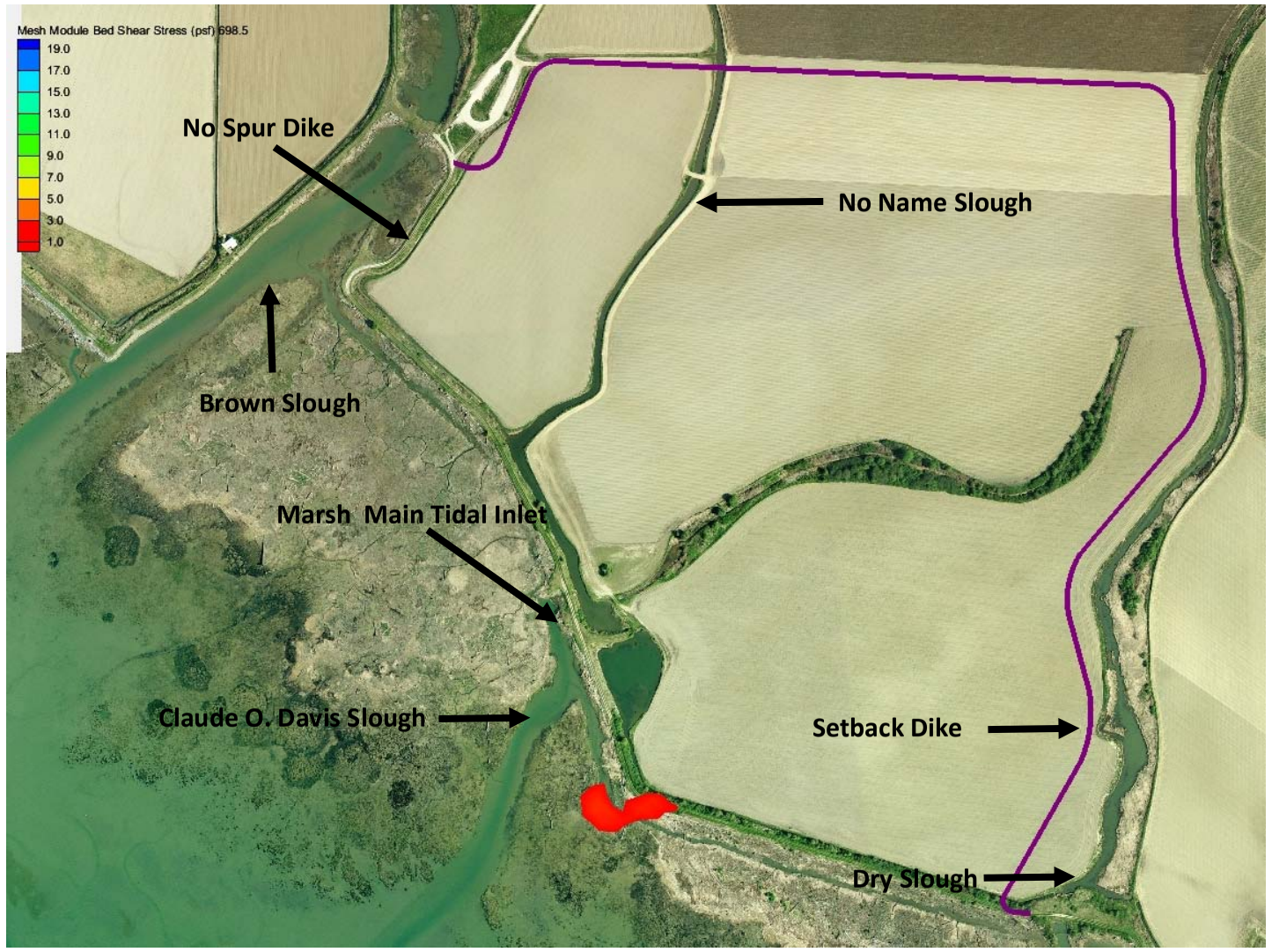
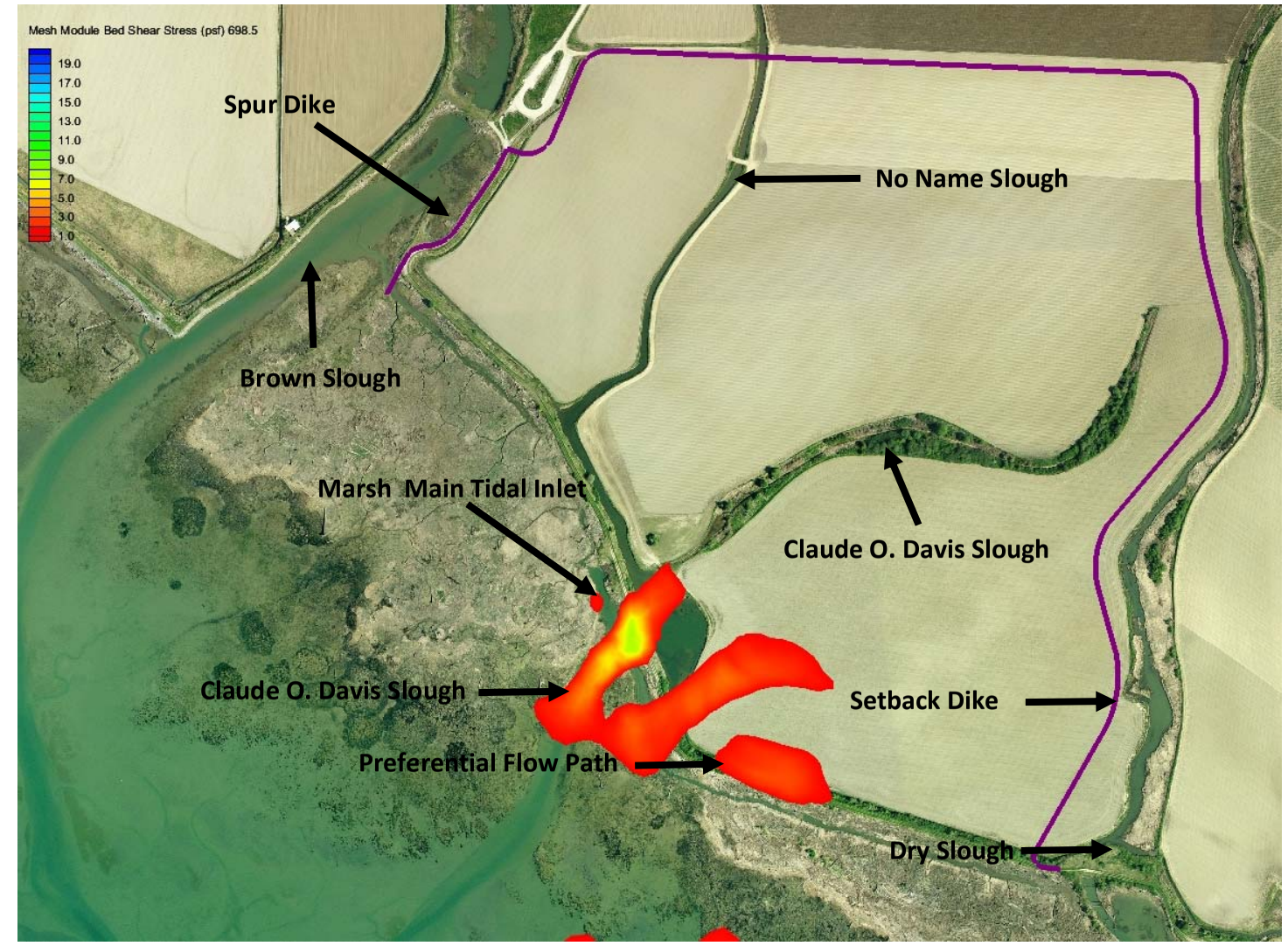
FIG. 7



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

N
W E
S

Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

HYDRODYNAMIC MODELING
HIGH TIDE - SHEAR STRESS

May 2014 | 21-1-12318-217

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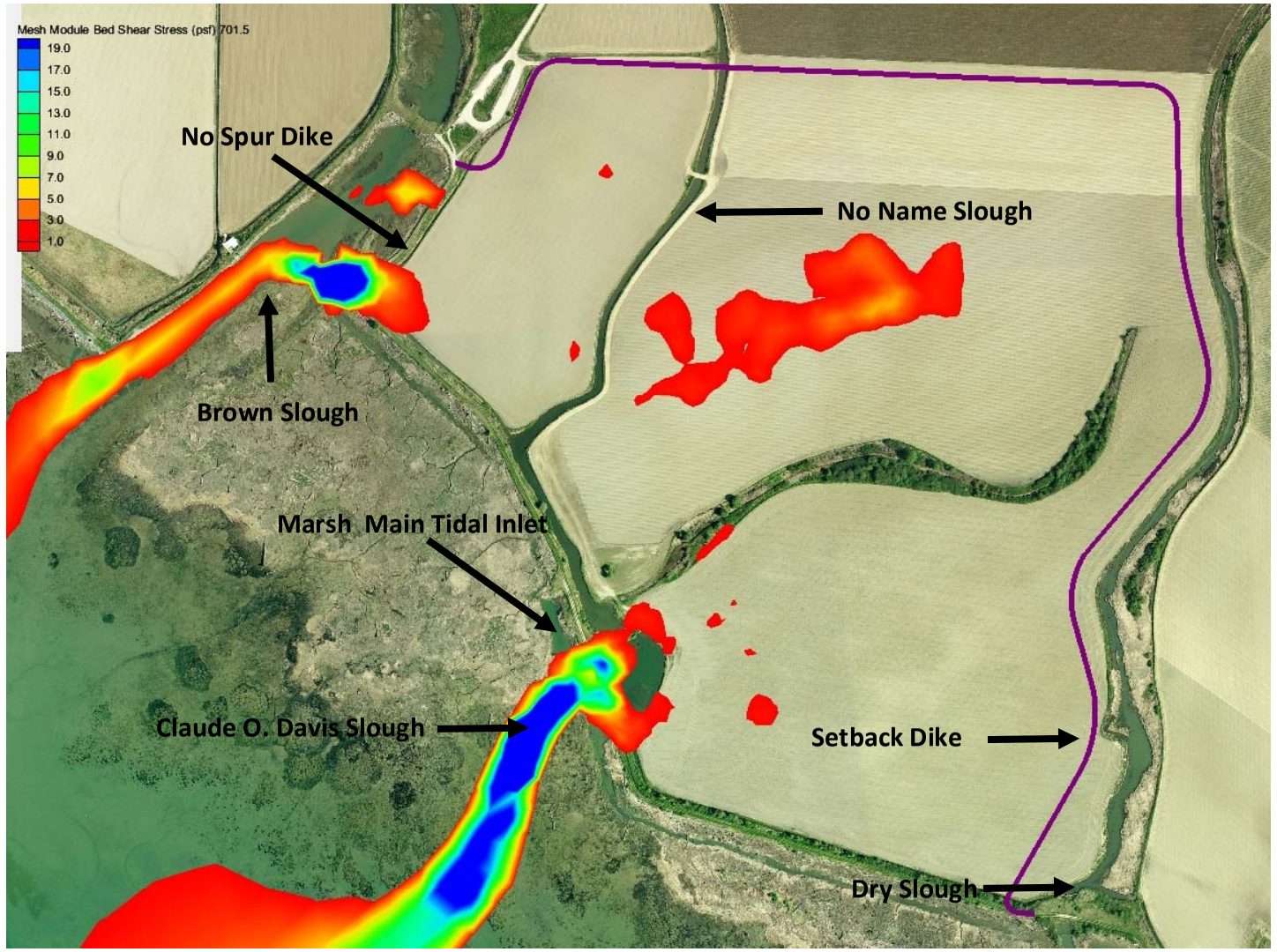
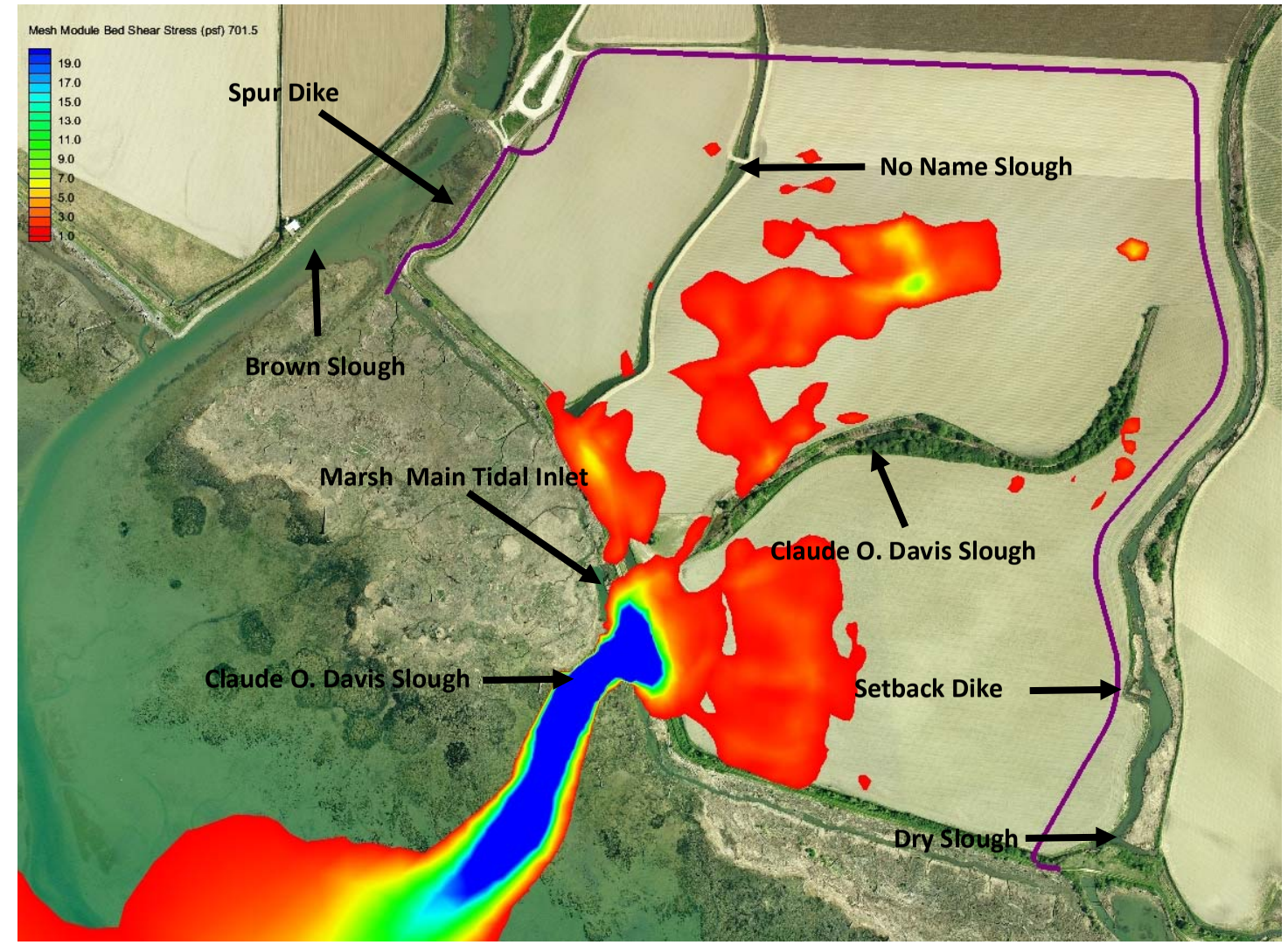
FIG. 8



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

N
W E
S

Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

HYDRODYNAMIC MODELING
EBB TIDE - SHEAR STRESS

May 2014 | 21-1-12318-217

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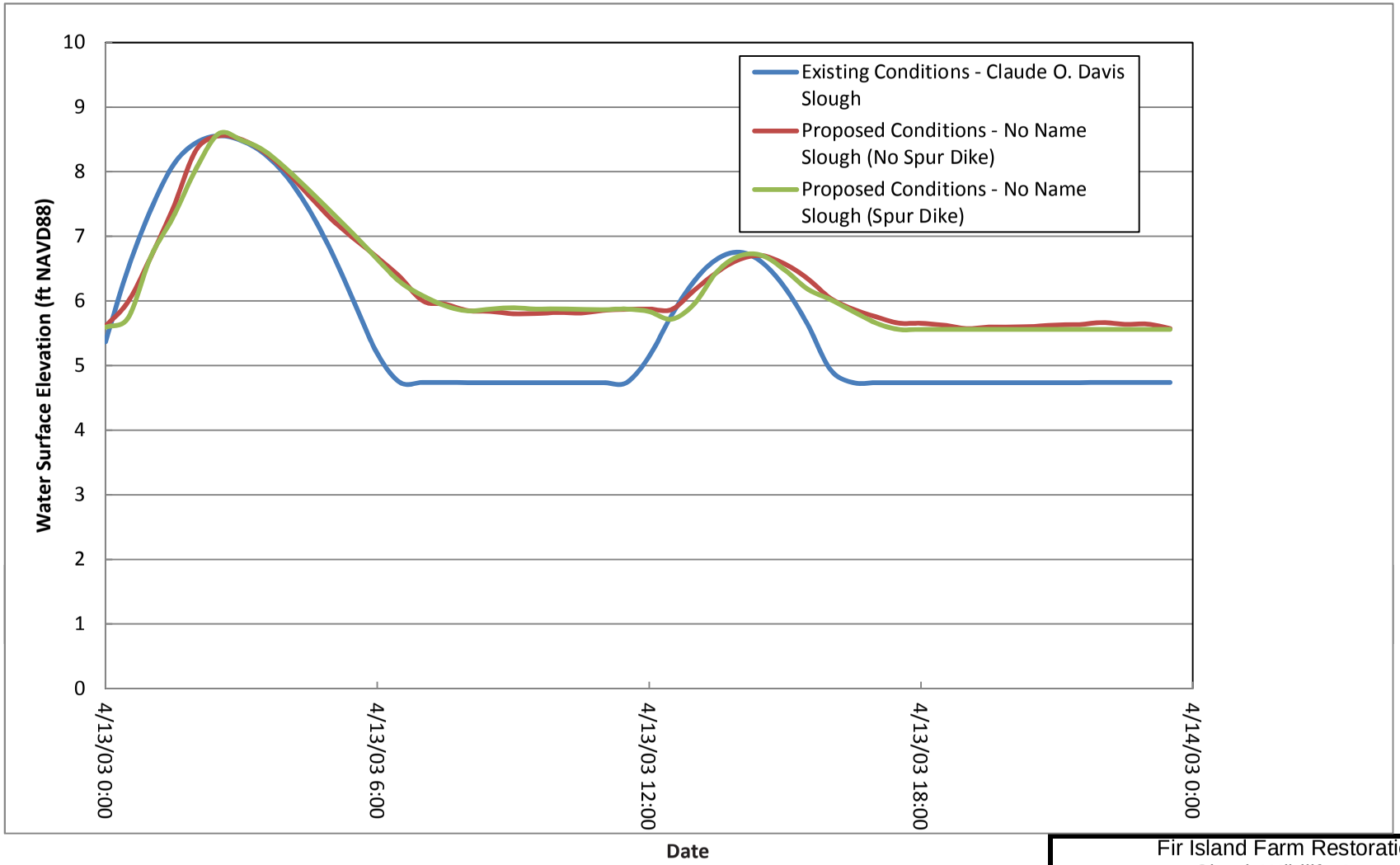
FIG. 9



Note: This figure shows the anticipated increase in low tide tailwater elevations, resulting from the project hydrodynamic effect.

Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

PROJECT HYDRODYNAMIC EFFECT

May 2014 | 21-1-12318-217

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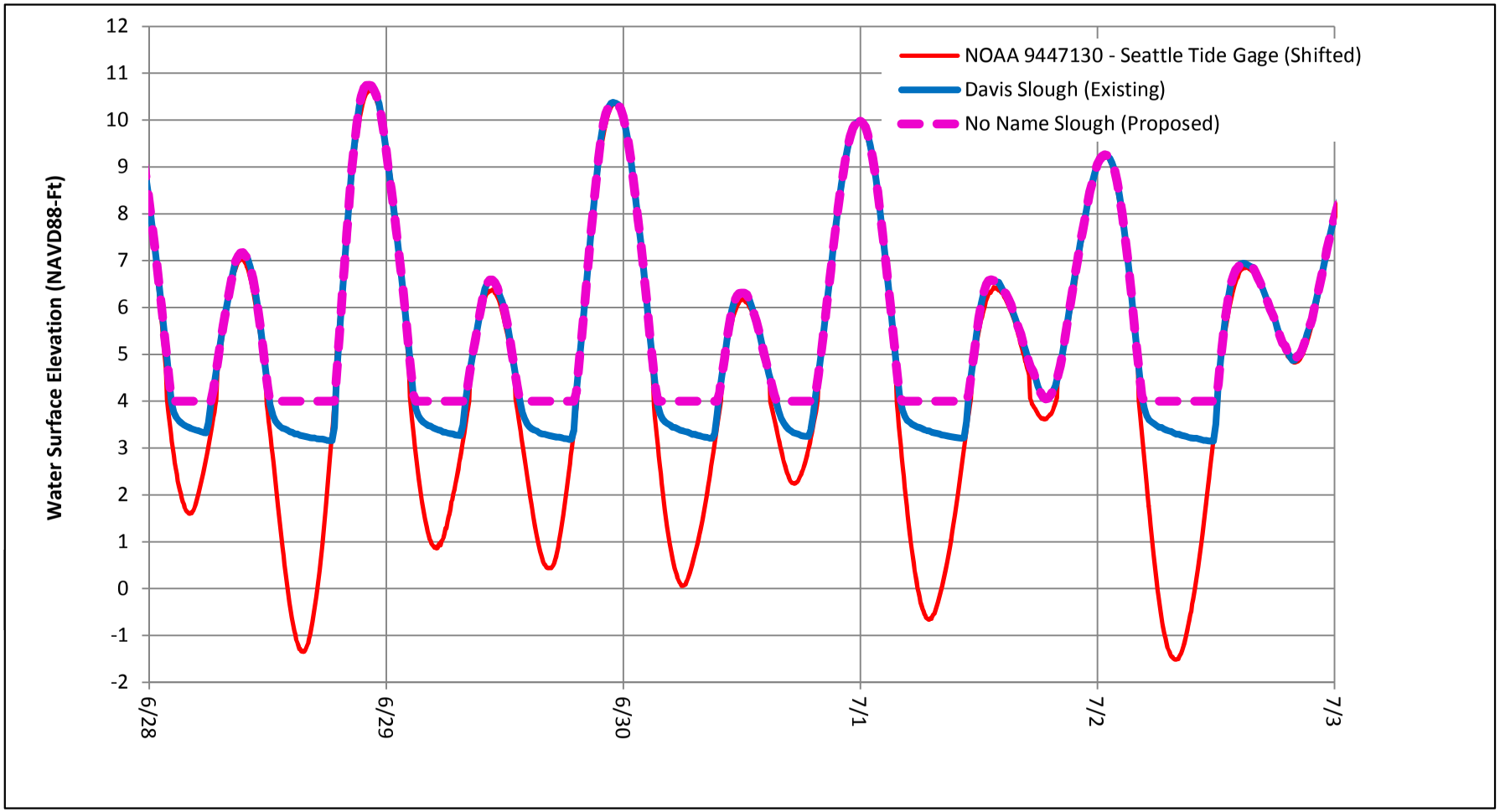
FIG. 10

FIG. 10

I:\WIP\21-1\12318 FIR ISLAND\217_COASTAL_HYD\REPORTS\S&W\1. Native\21-1-12318-217 Figs 2-13.xlsx <FIG10.HYDRO_EFFECT>



Note: Seattle Elliott Bay Gage shifted and scaled to fit Fir Island Farm site data.

Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

HYDRODYNAMIC EFFECT AND EXISTING CONDITIONS

May 2014 | 21-1-12318-217

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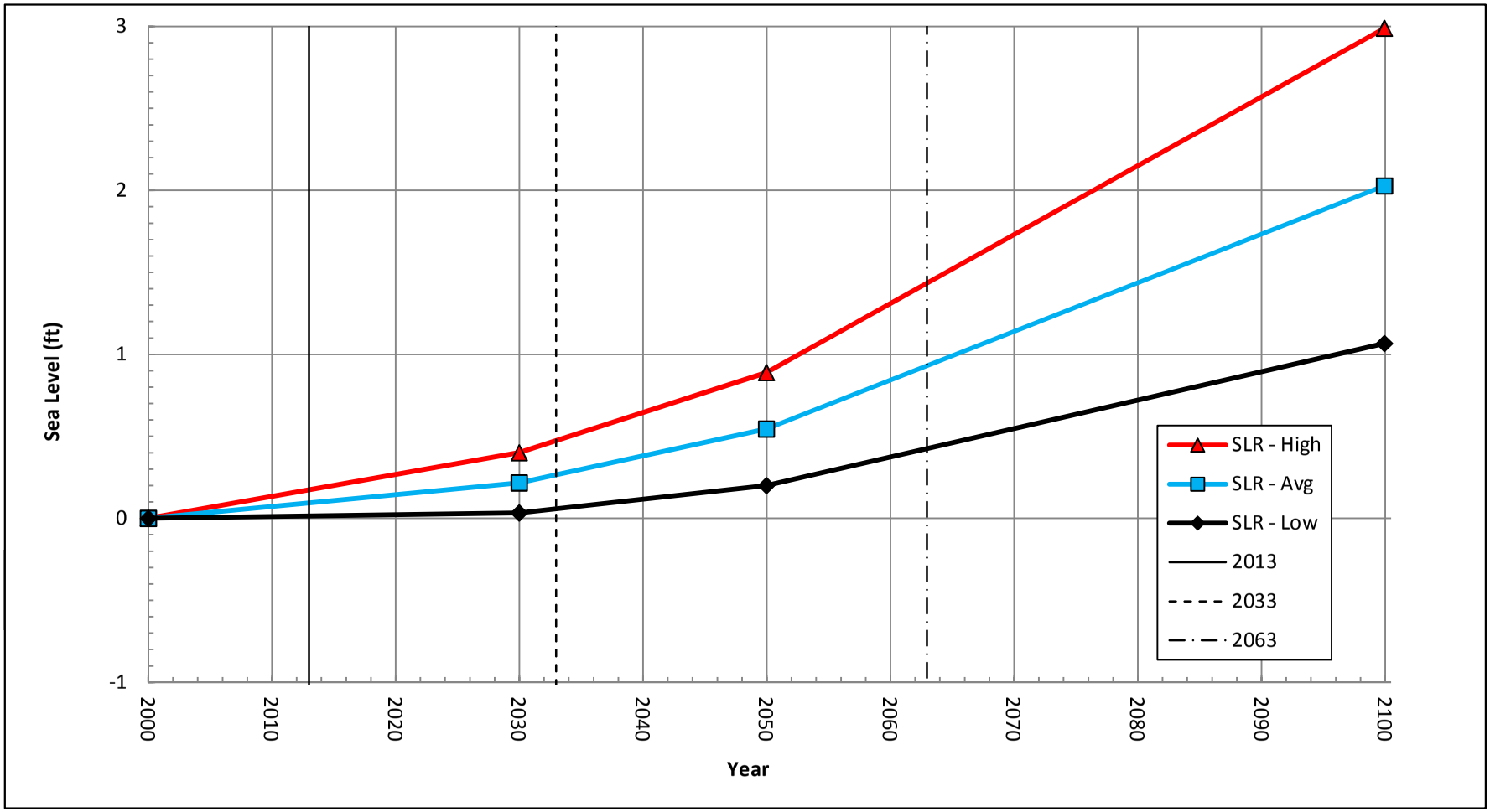
FIG. 11

FIG. 11

I:\WIP\21-1\12318 FIR ISLAND\217_COASTAL_HYD\REPORTS\S&W\1. Native\21-1-12318-217 Figs 2-13.xlsx <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

Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

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

May 2014 21-1-12318-217

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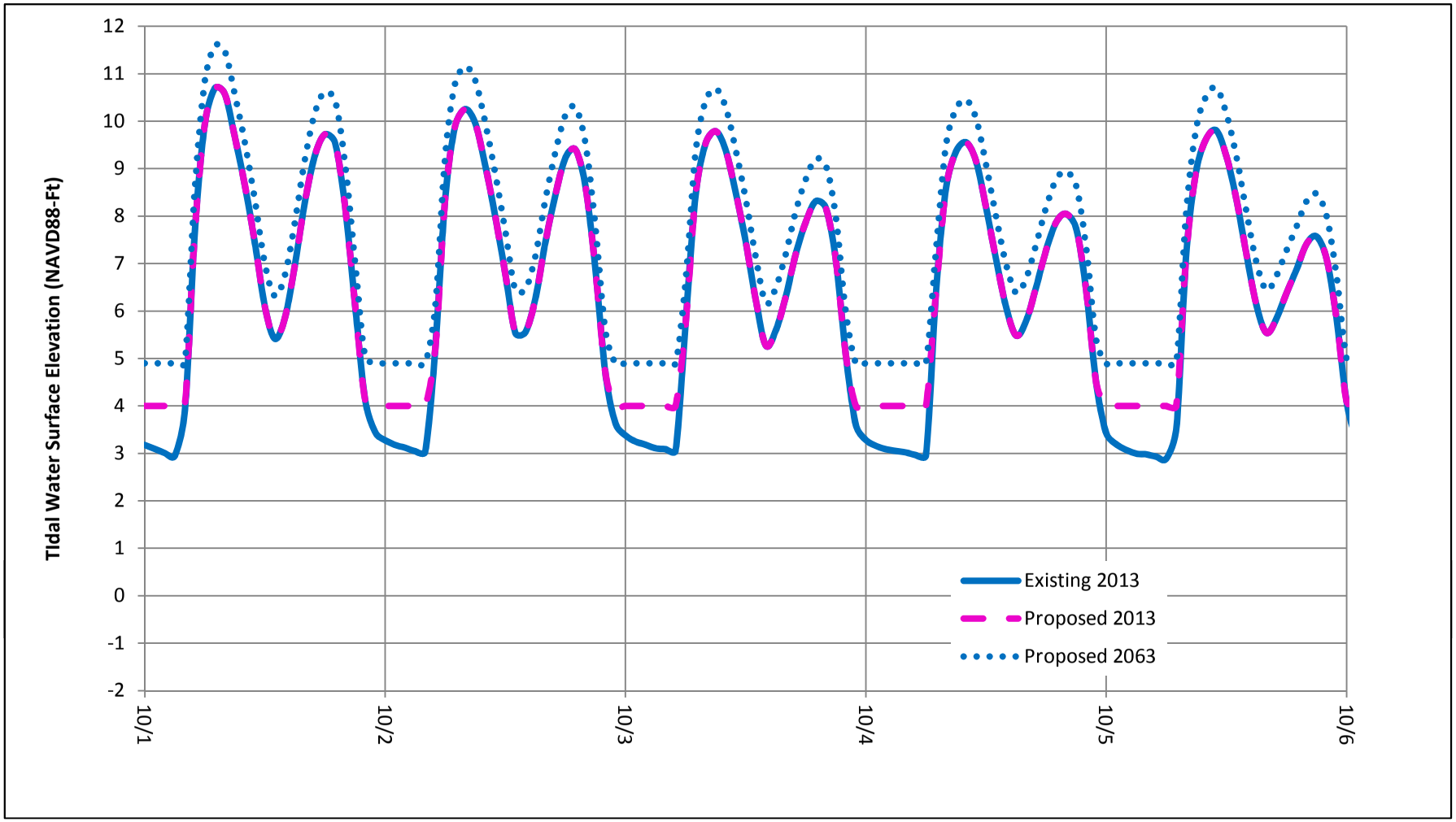
FIG. 12

FIG. 12

I:\WIP\21-1\12318 FIR ISLAND\217_COASTAL_HYD\REPORTS\S&W\1. Native\21-1-12318-217 Figs 2-13.xlsx <FIG12.SLR>



Date

Fir Island Farms Restoration

Skagit County, WA

HYDRODYNAMIC AND SEA LEVEL RISE EFFECTS AND EXISTING CONDITIONS

May 2014 21-1-12318-217

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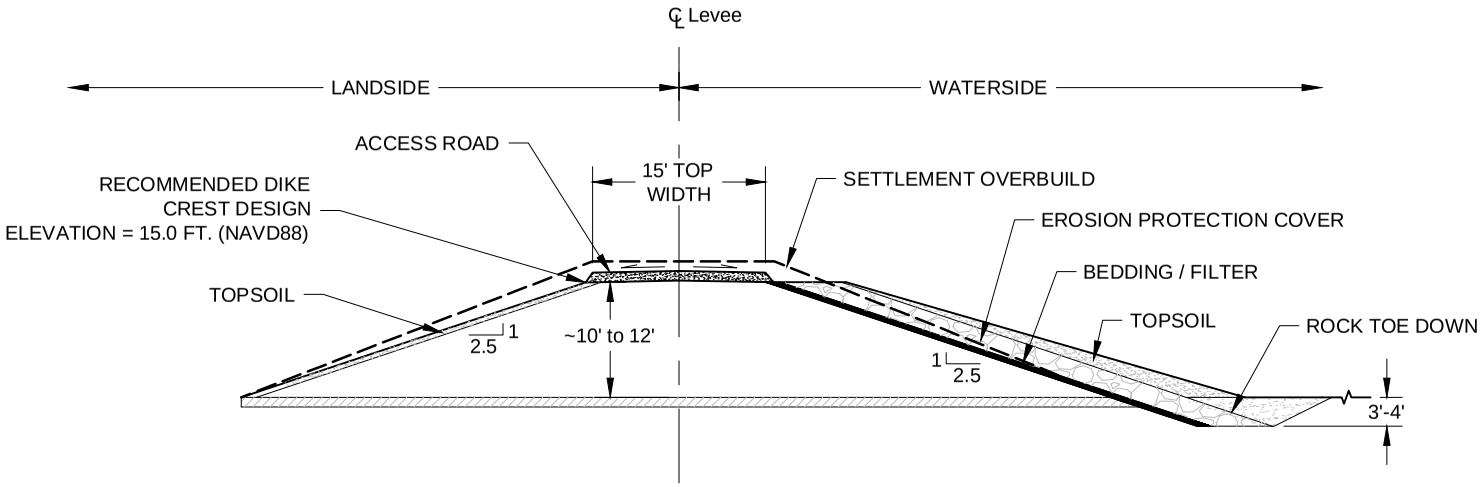
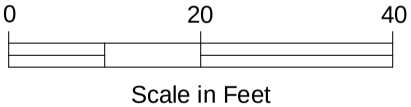
Fig. 13

Fig. 13

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



TYPICAL LEVEE SECTION DETAIL



Fir Island Farm
Estuary Restoration Project
Skagit County, Washington

LEVEE COASTAL ENGINEERING DESIGN RECOMMENDATIONS

April 2014 21-1-12318-217

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FIG. 14

FIG. 14

APPENDIX A

INDEPENDENT REVIEW TECHNICAL COMMENT FORM

Independent Review Technical Comment Form

Owner	**Washington Department of Fish & Wildlife**
Project	**Fir Island Farm - Estuary Restoration Project, Final Design and Permitting**
Reviewer Name	**Susan Tonkin, PhD, PE**
Reviewer Firm	**Moffatt & Nichol**
Reviewer Email	stonkin@moffattnichol.com
Reviewer Phone	206.622.0222
Date of Review:	10-Feb-14

No.	Report Name	Report Section, Page, Paragraph	Reviewer	Reviewer Comment	Responder	Responder Response	ITR Backcheck Complete
1	Draft Coastal Engineering Report, January 10, 2014	Section 4.1, page 4, last paragraph	Susan Tonkin	Regarding the overprediction of muting immediately offshore of the tidegates: is there any input from the modelers about this?	DRC	I have put the question to Battelle and am waiting on a resopnse. I think the higher water elevations on the low tide has to do with model tidal channel resolution. The finite element grids are larger than the channels, resulting in higher than actual ground/surface elevations, that could artificially increase the predicted water surface elevations. I also think there may be some variability in the roughness coefficient for tidal channels in marsh areas. My understanding is that the Battelle model uses a uniform roughness coefficient in marsh areas, without differentiating between tidal channels and vegetated marsh areas.	
2	same	Section 4.1, page 4, last paragraph	Susan Tonkin	I would like to drill down on this. One question would be to look at the model bathymetry and water surface elevations (including profile) across the existing Davis Slough and the proposed Dry Slough. Another consideration is that if the water surface is generally lower, would the wse gradient along No Name Slough actually be greater than predicted here, because of increased friction in the shallower water?	DRC	If the water surface is generally lower than the model predicts, the gradient could be higher. This would result in a lower tailwater elevation, which would reduce the potential for interior drainage impacts. Therefore, I believe we were conservative in our interpretation and application of the hydrodynamic modeling outputs.	
3	same	Section 4.3, general	Susan Tonkin	How much does it matter if the site pulls in sediment from offshore, eroding the central Bay front area? Albeit a very different physical situation, this happened at Crissy Field in San Francisco when a tidal channel was opened out and the adjacent beaches immediately eroded away. If it's not too much of a problem, you could overdredge the main tidal channel to provide more material with which to build up the marsh interior, and expect the shoreline will retreat as the main channel fills back to its equilibrium condition. If it is a big problem, you need to put some significant thought into a monitoring effort and (ideally) have some contingency plans in place.	DRC	Sediment transport from further off-shore into the site would be ideal from a restoration perspective. It is my understanding that WDFW understands that the exterior marshes will erode, and it is expected to some degree. I recommend this infomration be included in the monitoring and adaptive management plans, and a statement that no additional measures will be taken if exterior marshes experience erosion.	

Independent Review Technical Comment Form

Owner	**Washington Department of Fish & Wildlife**
Project	**Fir Island Farm - Estuary Restoration Project, Final Design and Permitting**
Reviewer Name	**Susan Tonkin, PhD, PE**
Reviewer Firm	**Moffatt & Nichol**
Reviewer Email	stonkin@moffattnichol.com
Reviewer Phone	206.622.0222
Date of Review:	10-Feb-14

No.	Report Name	Report Section, Page, Paragraph	Reviewer	Reviewer Comment	Responder	Responder Response	ITR Backcheck Complete
4	same	Section 4.3, page 10, third paragraph	Susan Tonkin	Editorial: I think you want to replace "likely has higher sediment supply similar to the Wiley Slough site" with "less than the sediment supply at the Wiley Slough site". (If not, I'm not sure what this is saying).	DRC	Sentence revised.	
5	same	Section 5.4, page 16, general	Susan Tonkin	As a general statement, I could quibble with the details of the calculation (selection of wind speed, neglect of wide area storm surge, and how the waves are calculated and used) but the final result seems about right. You may get splashover from high waves at this elevation.	DRC	It is acknowledged that splashover may occur.	
6	same	Section 5.5.1, page 18, general	Susan Tonkin	Would you armor the crest? It could be helpful given the possibility of wave splashover, although the rock size might not need to be so large.	DRC	We have not yet considered or included armoring the shoulders of the levee. I think this should be discussed further in 60% design.	
7	same	Figures 10, 11	Susan Tonkin	Can you state the source of these curves? Which are from the hydrodynamic report and which are from measurements (or elsewhere)?	DRC	All three curves are from the hydrodynamic model.	

APPENDIX B

IMPORTANT INFORMATION ABOUT YOUR GEOTECHNICAL / ENVIRONMENTAL REPORT

IMPORTANT INFORMATION ABOUT YOUR GEOTECHNICAL/ENVIRONMENTAL REPORT

CONSULTING SERVICES ARE PERFORMED FOR SPECIFIC PURPOSES AND FOR SPECIFIC CLIENTS.

Consultants prepare reports to meet the specific needs of specific individuals. A report prepared for a civil engineer may not be adequate for a construction contractor or even another civil engineer. Unless indicated otherwise, your consultant prepared your report expressly for you and expressly for the purposes you indicated. No one other than you should apply this report for its intended purpose without first conferring with the consultant. No party should apply this report for any purpose other than that originally contemplated without first conferring with the consultant.

THE CONSULTANT'S REPORT IS BASED ON PROJECT-SPECIFIC FACTORS.

A geotechnical/environmental report is based on a subsurface exploration plan designed to consider a unique set of project-specific factors. Depending on the project, these may include: the general nature of the structure and property involved; its size and configuration; its historical use and practice; the location of the structure on the site and its orientation; other improvements such as access roads, parking lots, and underground utilities; and the additional risk created by scope-of-service limitations imposed by the client. To help avoid costly problems, ask the consultant to evaluate how any factors that change subsequent to the date of the report may affect the recommendations. Unless your consultant indicates otherwise, your report should not be used: (1) when the nature of the proposed project is changed (for example, if an office building will be erected instead of a parking garage, or if a refrigerated warehouse will be built instead of an unrefrigerated one, or chemicals are discovered on or near the site); (2) when the size, elevation, or configuration of the proposed project is altered; (3) when the location or orientation of the proposed project is modified; (4) when there is a change of ownership; or (5) for application to an adjacent site. Consultants cannot accept responsibility for problems that may occur if they are not consulted after factors which were considered in the development of the report have changed.

SUBSURFACE CONDITIONS CAN CHANGE.

Subsurface conditions may be affected as a result of natural processes or human activity. Because a geotechnical/environmental report is based on conditions that existed at the time of subsurface exploration, construction decisions should not be based on a report whose adequacy may have been affected by time. Ask the consultant to advise if additional tests are desirable before construction starts; for example, groundwater conditions commonly vary seasonally.

Construction operations at or adjacent to the site and natural events such as floods, earthquakes, or groundwater fluctuations may also affect subsurface conditions and, thus, the continuing adequacy of a geotechnical/environmental report. The consultant should be kept apprised of any such events, and should be consulted to determine if additional tests are necessary.

MOST RECOMMENDATIONS ARE PROFESSIONAL JUDGMENTS.

Site exploration and testing identifies actual surface and subsurface conditions only at those points where samples are taken. The data were extrapolated by your consultant, who then applied judgment to render an opinion about overall subsurface conditions. The actual interface between materials may be far more gradual or abrupt than your report indicates. Actual conditions in areas not sampled may differ from those predicted in your report. While nothing can be done to prevent such situations, you and your consultant can work together to help reduce their impacts. Retaining your consultant to observe subsurface construction operations can be particularly beneficial in this respect.

A REPORT'S CONCLUSIONS ARE PRELIMINARY.

The conclusions contained in your consultant's report are preliminary because they must be based on the assumption that conditions revealed through selective exploratory sampling are indicative of actual conditions throughout a site. Actual subsurface conditions can be discerned only during earthwork; therefore, you should retain your consultant to observe actual conditions and to provide conclusions. Only the consultant who prepared the report is fully familiar with the background information needed to determine whether or not the report's recommendations based on those conclusions are valid and whether or not the contractor is abiding by applicable recommendations. The consultant who developed your report cannot assume responsibility or liability for the adequacy of the report's recommendations if another party is retained to observe construction.

THE CONSULTANT'S REPORT IS SUBJECT TO MISINTERPRETATION.

Costly problems can occur when other design professionals develop their plans based on misinterpretation of a geotechnical/environmental report. To help avoid these problems, the consultant should be retained to work with other project design professionals to explain relevant geotechnical, geological, hydrogeological, and environmental findings, and to review the adequacy of their plans and specifications relative to these issues.

BORING LOGS AND/OR MONITORING WELL DATA SHOULD NOT BE SEPARATED FROM THE REPORT.

Final boring logs developed by the consultant are based upon interpretation of field logs (assembled by site personnel), field test results, and laboratory and/or office evaluation of field samples and data. Only final boring logs and data are customarily included in geotechnical/environmental reports. These final logs should not, under any circumstances, be redrawn for inclusion in architectural or other design drawings, because drafters may commit errors or omissions in the transfer process.

To reduce the likelihood of boring log or monitoring well misinterpretation, contractors should be given ready access to the complete geotechnical engineering/environmental report prepared or authorized for their use. If access is provided only to the report prepared for you, you should advise contractors of the report's limitations, assuming that a contractor was not one of the specific persons for whom the report was prepared, and that developing construction cost estimates was not one of the specific purposes for which it was prepared. While a contractor may gain important knowledge from a report prepared for another party, the contractor should discuss the report with your consultant and perform the additional or alternative work believed necessary to obtain the data specifically appropriate for construction cost estimating purposes. Some clients hold the mistaken impression that simply disclaiming responsibility for the accuracy of subsurface information always insulates them from attendant liability. Providing the best available information to contractors helps prevent costly construction problems and the adversarial attitudes that aggravate them to a disproportionate scale.

READ RESPONSIBILITY CLAUSES CLOSELY.

Because geotechnical/environmental engineering is based extensively on judgment and opinion, it is far less exact than other design disciplines. This situation has resulted in wholly unwarranted claims being lodged against consultants. To help prevent this problem, consultants have developed a number of clauses for use in their contracts, reports and other documents. These responsibility clauses are not exculpatory clauses designed to transfer the consultant's liabilities to other parties; rather, they are definitive clauses that identify where the consultant's responsibilities begin and end. Their use helps all parties involved recognize their individual responsibilities and take appropriate action. Some of these definitive clauses are likely to appear in your report, and you are encouraged to read them closely. Your consultant will be pleased to give full and frank answers to your questions.

The preceding paragraphs are based on information provided by the
ASFE/Association of Engineering Firms Practicing in the Geosciences, Silver Spring, Maryland