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

February 26, 2014

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

1.0 INTRODUCTION

This report presents the results of the interior drainage engineering analyses and design recommendations for the proposed Fir Island Farm restoration project in Skagit County, Washington. The purpose of this report is to summarize the site hydrology and hydrogeology, present results of groundwater seepage and interior drainage surface water modeling, and provide design recommendations for mitigation of effects of the Fir Island Farm marsh restoration project on the 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 1, 2013. The scope of services are summarized as follows:

- Install, reinstall, and collect and analyze ground and surface water data for the project to measure and collect data to document the existing conditions baseline and establish a monitoring network for long-term observations, including:
  - Install three pairs of dual-depth groundwater monitoring wells and associated pressure transducer equipment.
  - Perform slug tests in each of the groundwater observation wells.
  - Reinstall up to six surface water data loggers.
- Use data and observations to calibrate for baseline conditions and models, and evaluate proposed project effects on groundwater seepage, mounding, saltwater intrusion, and surface water drainage, specifically:
  - Potential changes of interior drainage surface water elevations and groundwater elevations in the spring and early summer growing season.
  - Likely changes of salinity conditions in the spring and early summer growing seasons, and fall/winter flood seasons.
  - Seepage into the interior drainage stormwater ponds and channels in the spring and early summer growing seasons and the fall/winter flood seasons.
- Perform a sensitivity analyses on select aspects of surface and groundwater conditions including:

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- Tailwater conditions such as hydrodynamic effects of the proposed project, erosion, sedimentation and vegetation (ESV).
- Upstream headwater factors such as storage pond vegetation growth and effects on limiting storage and conveyance for the proposed project (SPC).
- Sea level rise on "Without Project" and proposed "Project" (SLR).

2.0 PREVIOUS REPORTS AND STUDIES

Shannon & Wilson, Inc. (S&W) prepared the following reports related to interior drainage as part of the 2011 project feasibility study:

- Technical Memorandum 1.2.1, Hydrologic Monitoring and Modeling of Interior Drainage Baseline Conditions, May 27, 2011.
- Technical Memorandum 1.2.1b, Datalogger Redeployment, October 19, 2011.
- Technical Memorandum 3.3, Interior Drainage Hydrologic and Hydraulic Assessment of Alt. 2A, November 4, 2011.
- Fir Island Snow Goose Reserve, Restoration Feasibility Study, 2011.

The hydrologic monitoring and modeling technical feasibility study reports developed in 2011 provide an overview of the baseline conditions and analysis of the preferred restoration alternative for the project. These reports provide information on site and basin characteristics, modeling, calibration, and alternatives analyses, and include. In summary, these reports include:

- The proposed setback levee has the potential to impact interior drainage areas with elevated flood storage peak water surface elevations. The feasibility study demonstrated this effect could be mitigated by constructing a larger storage pond immediately north of the levee setback project.
- Seepage through the levee into the interior drainage system would likely be low and not directly impact the drainage system.
- Localized groundwater effects could occur including minor increases in ditch surface water elevations and groundwater elevations along the levee setback. These effects could be mitigated using gravity drainage (tidegates). If needed, a pump station may be necessary to mitigate these effects.

This report presents analyses of the potential effects as identified in the feasibility study, and uses new data and boundary condition information now available from recent coastal hydrodynamic modeling, coastal engineering studies and seepage analyses.

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3.0 DRAINAGE BASIN AND SITE CHARACTERIZATION SUMMARY

The Fir Island Farm restoration project is located on the WDFW Snow Goose Reserve at Fir Island, as shown in Figure 1. The project site is located south of Fir Island Road, approximately 3.1 miles west of Conway, Washington. The WDFW Snow Goose Reserve property is comprised of 245 acres that are currently farmed, with special farming provisions and lease agreements with the neighboring property, to meet the reserve's Snow Goose management objectives. Natural tidal exchange to the site has been eliminated from the historic construction of levees along Skagit Bay. One-way tidegates in the existing levee provide interior farm drainage and block inflow of tidal flow to the farm areas. The proposed restoration involves a 5,700-foot-long setback levee and approximately 127 acres of tidal marsh restoration.

The Fir Island Farm Snow Goose Reserve site has three major interior drainage areas, namely Brown and Rawlins Road Slough (Brown), Claude O. Davis/No Name (No Name) Slough, and Dry/MacDonald (Dry) Slough (Figure 2). Nearly all land within the 3,456-acre (5.4-square mile) drainage basin is rural farm land and rural residential properties supporting farming. Roads and associated infrastructure make up but a small fraction of the drainage basin.

Brown Slough and Rawlins Road Sloughs (Brown) have a combined drainage area of 629 acres draining through a set of two 48-inch, top-hinge flapgates and one 48-inch screwgate at the Brown Slough tidegate complex just west of the Fir Island Farm parking area.

No Name and Claude O. Davis Sloughs (No Name) have a combined drainage area of 1,007 acres draining through a set of two 48-inch, top-hinge flapgates near the center of the existing levee to be removed at the project site. One of the pipes is plugged due to pipe damage and leakage.

Dry Slough and MacDonald Slough (Dry) have a combined drainage area of 1,720 acres. MacDonald Slough drains areas east of Dry Slough and meets with Dry Slough just upstream from the levee drainage outlet. Dry Slough drains through the levee through two 48 inch, top-hinge flapgates.

Surficial soils in the basin are generally dominated by Skagit Silt Loam with varying degrees of Sumas silt loam, Sedro Woolley silt loam, Mount Vernon very fine sandy loam, and Briscot fine sandy loam (Natural Resources Conservation Service [NRCS], 2012). Nearly all surficial soils in the basin are characterized as hydrologic group D, with high potential for runoff when soils are saturated (NRCS, 2012).

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We note that the NRCS soil data and classification of hydrologic group D indicates high clay contents (NRCS, 2012). However, soil testing of surficial soils at the project site indicates soils are classified as slightly clayey SILT or sandy SILT that overlie a layer of slightly silty SAND. It is likely that the hydrologic group D classification exists due to shallow depth to groundwater (i.e., small volumes of soil storage) in the area (NRCS, 2007). This would imply that the soils have some higher level of storage if well drained, but will have a higher runoff potential due to high groundwater table.

4.0 HYDROLOGIC MONITORING

S&W, in collaboration with WDFW, installed the groundwater and surface water, hydrologic monitoring network (Figure 1). The purposes of these installations are to: 1) document existing baseline conditions for use in engineering design and modeling calibrations, and 2) monitor and track post-project effects and for use with future adaptive management decision making.

For this project phase, S&W installed seven surface water data loggers, three pairs of groundwater data loggers (six data loggers total), and one barometric data logger at the site in June and July 2013. Locations and identification are shown in Figure 1. Installation of data loggers provides information regarding the existing (or "baseline") conditions for surface and groundwater elevations, temperature, and salinity. Data currently being collected will be used to document the baseline conditions and monitor future project conditions and effects.

A detailed discussion of data logger installations and monitoring results is provided in Appendix A (Hydrologic Monitoring). A few key observations were made during the June 2013 through October 2013 monitoring period:

- Groundwater observation wells B-4w-13 and B-5W-13 are located in the WDFW North Field, north of the proposed levee setback and new interior drainage storage pond. The average groundwater elevation (measured in the deeper well B-4w-13) was 2.9 feet. Groundwater was on average 4.0 feet lower than the ground elevation (6.9 feet) at the well location.
- Groundwater observation wells B-6w-13 and B-7W-13 are located in the Hayton North berry field on the east side of Dry Slough. The groundwater elevations ranged from 2.6 to 4.1 feet with an average observed groundwater elevation of 3.5 feet (measured in the deeper well B-6W-13). Groundwater was on average 3.6 feet lower than the ground elevation (7.1 feet) at the well location.
- Groundwater observation wells B-8w-13 and B-9W-13 are located in the Hayton South "Bay" Field, on the east side of Dry Slough. The observed groundwater elevations ranged from 2.9 to 4.6 feet, and the average groundwater elevation was

3.6 feet (measured in the deeper well B-8W-13). During the summer groundwater measurement period, the groundwater was an average of 2.5 feet lower than the adjacent ground elevation. This is nearly one foot less than the observed ground elevation to groundwater elevation than the WDFW North and Hayton North Fields.

- Salinity ranged from 0.6 to 1.5 practical salinity units (psu) and averaged 1.1 psu, which is considered mildly brackish for the WDFW North and Hayton North Fields. Salinity ranged from 0.9 to 3.4 psu in the Hayton South "Bay" field, which is also considered mildly brackish.
- Surface water data loggers installed in the Bay area collected tidal water elevations measurements. The tidal data collected exhibited mixed tides with a truncated low tide, similar to conditions reported in previous studies.
- Surface water data loggers installed in Dry Slough captured the irrigation operations, which exhibit semi-steady water elevations, as compared with typical groundwater drainage and tidegate cycling conditions.
- Surface water data loggers installed in the Bay area collected tidal water temperature measurements. Temperatures ranged from 10 to 30 degrees Celsius. Water temperature spikes were observed in late June 2013.
- Surface water data loggers installed in the Bay area collected tidal water conductivity measurements that were used to calculate salinity. Salinity ranged from 0.1 to 29 psu.
- Surface water data loggers installed in interior drainages (No Name and Brown Sloughs) exhibited typical groundwater baseflow and tidegate drainage cycling of water surface elevations. Dry Slough did not follow this pattern due to the irrigation operations.
- Salinity in No Name Slough (SW-NNS-1.0-LTC) ranges from 2.5 to 10.2 psu. Salinity in Dry Slough, near the existing levee, ranged from 5 to 8 psu. Both of these ditches had elevated salinity levels, with farm operations nearby and along the top of channel banks.
- Data loggers had various calibration and equipment issues during the data collection period. Frequent maintenance and management is needed to continue the data collection program during the baseline period, and into the future for longer-term, post-project implementation monitoring.

Overall, the groundwater elevations appear to be several feet below the adjacent farm grade during the observation period. Dry and No Name Sloughs had elevated salinity levels exceeding agricultural crop irrigation water quality criteria for salinity. Considering the farmers' ability to grow crops along ditches with higher salinity concentrations, the key criteria for assessing drainage effects and farm functions appears to be groundwater elevations with respect to farm

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field elevations and root zone depths. Salinity is a secondary issue and only comes into play if groundwater exceeds the critical root zone elevations.

5.0 SEEPAGE ANALYSIS

We performed a seepage analysis to evaluate the potential for seepage-related impacts to the interior drainage storage pond, upstream drainage channels, and adjacent farm areas. The seepage analysis involved the following tasks:

- Analyzing in situ field slug test data to estimate a range of hydraulic conductivities for the deeper sandy soil unit.
- Estimating seepage rates to the interior drainage storage pond using hydrologic monitoring data.
- Using a numerical model to predict seepage rates to the interior drainage storage pond.
- Presenting seepage results and using the seepage flow rates as inflow boundary conditions to the hydraulic surface water (interior drainage pond) model.

A detailed discussion of the seepage analyses is provided in Appendix B. The following is a summary of the field testing, seepage analysis and modeling methods, and recommendations for seepage inflows to the interior drainage surface water system.

S&W performed single-well slug tests to support analysis and calculation. We analyzed the test data to derive hydraulic conductivities for the project site using the Bouwer and Rice method. These soil properties were used in discrete cross sectional SEEP/W models to estimate seepage inflows through and underneath the levee to the interior drainage system.

The seepage model uses a two-dimensional, finite-element seepage analysis program SEEP/W, which simulates fluid flow and pressure distribution in saturated and unsaturated porous media. Land surface, soil layering and properties, and surface and groundwater boundary conditions are described in detail in Appendix B. Steady-state seepage analyses were performed for three representative sections along the existing levee, the northern section of the levee setback, and the eastern section of the levee setback. The SEEP/W model calculates existing condition seepage flux across the levee ranging from 91 to 232 gallons per minute (gpm) along the length of the existing levee system using the Bower and Rice-derived soil hydraulic conductivity properties from the soils tested at the site. The SEEP/W model calculates proposed condition seepage flux across the “Project” levee ranging from 62 to 120 gpm using the Bower and Rice-derived soil

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hydraulic conductivity properties from the soils tested at the site, and the new setback levee materials.

Hydrologic monitoring data were also used to estimate existing condition seepage inflow to the No Name Slough drainage system. The estimate was performed by calculating the change in interior drainage channel storage volume while the tidegates are shut on each cycle. Seepage inflows include both existing levee seepage and upstream groundwater drainage inflows. Using the hydrologic monitoring data for the site, total seepage inflows are estimated at 1 cubic foot per second (cfs) (449 gpm).

For the purposes of modeling seepage inflows to the proposed interior drainage system for the surface water hydraulic analysis, the recommended seepage rate to the No Name Slough interior drainage pond is based on the calculated existing seepage and groundwater inflow condition of 1 cfs (449 gpm). An additional 100 gpm seepage was included in the Dry Slough using the SEEP/W modeling outputs to account for the increase in seepage along the setback. These values are conservative as the SEEP/W model indicates that expected seepage rates to the interior storage pond and Dry Slough will likely be less for proposed conditions than the existing conditions. Also, the proposed condition project has reduced interior drainage channel lengths and drainage areas, as compared to existing conditions, and therefore would likely have less upstream groundwater inflow to the system.

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6.0 SURFACE WATER MODELING

Surface water modeling for the project involves hydrologic runoff modeling combined with hydraulic open channel flow modeling. These models are used to calculate interior drainage and pond water surface elevations that occur upstream from the system drainage tidegates. Existing “Without Project” and proposed “Project” conditions modeling was performed to compare average pond elevations and salinity conditions during key farm planting and growing seasons. The modeling analyses evaluated a 50-year levee and drainage lifecycle period of 2013 through 2063.

The key concern of the adjacent property owners and farmers is that the project will raise water surface elevations in the drainage ditches, thereby impacting farming on adjacent property. This study evaluated interior storage pond elevations during early spring (April) planting periods when groundwater tables are highest and most likely to impact planting operations and root zones. Maximum flood water surface elevations were also evaluated.

Critical root zone depths depend upon crop types, soil type, drainage, and groundwater conditions. Crops grown on the adjacent Hayton Farm include strawberries, raspberries, blackberries, blueberries, and other berry crops such as marionberries and loganberries. Crops grown on the WDFW Snow Goose Reserve property are subject to snow goose foraging winter crop rotations. Crops typically include spring-planted vegetable seed crops such as spinach, red beets, and radish, or annual summer crops such as potatoes and broccoli. Root zone depths for the crops listed above range from 6 to 18 inches (NRCS, 2005). The study selected a critical root zone depth of 24 inches (2 feet) to conservatively estimate potential groundwater effects on adjacent farm properties and crops.

The second aspect of the root zone criteria is the duration of root zone inundation. The study assumes that crops can withstand minor increases in root zone inundation. The inundation criteria selected for the project is when a 10 percent increase (three to four days) of critical root zone elevation inundation (i.e., the storage pond water surface elevations) occur in the month of April when comparing "Without Project" to "Project" conditions. The potential areas of impact extend beyond the project site and area shown in Figure 2.

Increases in pond and ditch salinity are the second project metric being evaluated for potential farm and property effects. The study considers salinity criteria a secondary (or dependent) criterion because salinity levels in the existing ditches and current farm areas are fairly high (see Appendix A). For impacts, high-salinity groundwater needs to occur and inundate the critical root zone elevations. Typically, farm drainage operations focus on keeping the groundwater table low rather than preventing salt water intrusion. Also, salinity concentrations in the drainage ditches and groundwater are typically low during periods when groundwater tables are highest (i.e., winter and spring).

Hydrologic runoff modeling of the drainage basins was performed using the Western Washington Hydrology Model (WWHM) 2012. Seepage inflows and groundwater base flows were added as inflow to the surface water runoff calculated from the WWHM modeling inflows to the interior drainage system. Hydrologic modeling inflow was coupled with downstream tidal boundary conditions and sensitivity factors over a 50-year modeling scenario as input to the hydraulic surface water model of the interior drainage storage pond. Details of the hydrologic runoff modeling and boundary conditions are provided in Appendix C.

An unsteady-state HEC-RAS (U.S. Army Corps of Engineers [USACE], 2010) model was created for the No Name Slough and Dry Slough interior drainage systems. The hydraulic model was used to evaluate the effects of the levee setback on potential increases in spring season and

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flood water surface elevations of the interior drainage storage pond. The original model setup and calibration was developed as part of the S&W Fir Island Farm Feasibility Study (S&W, 2011). For this phase of study, "Without Project" and "Project" conditions were modeled over a 50-year time period to evaluate current and long-term effects on the interior drainage system and adjacent farm properties. Details of the hydraulic modeling and boundary conditions are provided in Appendix C.

A variety of sensitivity factors were also analyzed as part of a sensitivity analysis. These factors include sea level rise (SLR), marsh erosion, sedimentation and vegetation (ESV) effects on drainage tailwater conditions, and possible changes to interior drainage pond vegetation and roughness conditions that may affect storage pond capacity (SPC) over time with varying degrees of drainage maintenance. More detailed information for the sensitivity analysis is included in Appendix D.

The hydraulic modeling results for SLR scenarios and effects in No Name Slough are summarized in Appendix C, Tables C-4 and C-5. The project effects are limited primarily to No Name Slough, as this is the location subject to the tidal hydrodynamic effect and the sensitivity parameters discussed in Appendix D. Seepage effects are not great enough alone to result in effects on adjacent and upstream farm areas in No Name Slough. Dry Slough will not likely have the same tidal hydrodynamic or sensitivity factor effects, as it is mostly isolated. The anticipated minor increases in seepage can be accommodated by an additional 48-inch tidegate to the existing drainage system.

The hydraulic modeling results indicate that the proposed project will likely increase storage pond water surface elevations during early season (April) periods in No Name Slough and may have an effect on farm properties in the No Name Slough Basin, for "Project" conditions. The results show that farm properties will be affected by SLR for both "Without Project" and "Project" conditions. However, the "Project" SLR and hydrodynamic tailwater conditions could have effects on an additional 106 acres in 2013 and 319 acres in 2063. This is 11 to 32 percent of the No Name Slough drainage basin farm properties. These effects do not consider the uncertainty associated with the SLR estimates or the key sensitivity factors such as marsh erosion and sedimentation, and storage pond capacity conditions discussed further in Appendix D.

A mass balance model was used to estimate salinity effects on the interior drainage storage pond. The mixing parameters included seepage inflow rates along the length of the "Without Project" and "Project" levee sections, base flow groundwater inflows to the storage pond, and average

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Skagit Bay and No Name Slough salinity concentrations recorded during the 2013 data collection period. The calculations indicate that salinities in the pond will be slightly lower for the "Project" condition (Appendix C, Table C-6).

7.0 SENSITIVITY ANALYSIS

A sensitivity analysis was performed on the interior drainage system performance, to evaluate the effects of coastal hydrodynamics, marsh erosion, sedimentation and vegetation, and interior storage pond vegetation and maintenance conditions on the performance of the interior drainage system. The sensitivity analysis considers how changes in these conditions may occur over a design life period of 50 years. The study uses a Monte Carlo analysis to perform the sensitivity analysis. Details of the sensitivity analysis are provided in Appendix D.

The Monte Carlo method is a statistical technique used to model the range of expected sensitivity factors (inputs) to characterize the uncertainty of the pond water surface elevation (output). For the Fir Island project, there are three assumed key sensitivity factors of concern, including:

- Sea Level Rise (SLR)
- Erosion, sedimentation and vegetation (ESV) conditions in the restored marsh that can affect interior drainage system tailwater conditions
- Vegetation and maintenance conditions in the interior storage pond that can affect storage pond capacity (SPC)

The input parameters that are considered the key factors of concern for the study have been identified as SLR, ESV effects, and SPC volume effects. The uncertainties associated with each of the factors of concern were generated based on data, monitoring, studies, and other anecdotal site information. The recommendations for SLR and ESV sensitivity factors and input parameters were presented in S&W Coastal Engineering Recommendations Report (S&W, 2014). These factors and the SPC sensitivity factors, the input/output relationships and probability distributions applied in the Monte Carlo analysis are described in Appendix D.

The "Without Project" SLR Only and "Project" SLR+Hydrodynamic, ESV, and SPC combined effects probability distributions were randomly sampled and analyzed using a Monte Carlo simulation. The resulting range of probable storage pond water surface elevation outputs and statistics are shown as a cumulative distribution functions (Appendix D, Tables D-6 and D-7, Figures D-12 – D-14). The sensitivity analysis results are summarized as follows:

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- For 2013, the expected range (10 to 90 percent cumulative probability) of average April pond water surface elevations is:
  - 3.3 to 3.6 feet for the "Without Project," 100 percent of the effect is SLR
  - 4.1 to 4.4 feet for the "Project," 98 percent of the effect is related to SLR plus the "Project" hydrodynamic effect
- For 2033, the expected range (10 to 90 percent cumulative probability) of average April pond water surface elevations is:
  - 3.4 to 3.8 feet for the "Without Project," 100 percent of the effect is SLR
  - 4.1 to 4.9 feet for the "Project," 88 percent of the effect is related to SLR plus the "Project" hydrodynamic effect
- For 2063, the expected range (10 to 90 percent cumulative probability) of average April pond water surface elevations is:
  - 3.7 to 5.1 feet for the "Without Project," 100 percent of the effect is SLR
  - 4.4 to 6.2 feet for the "Project," 88 percent of the effect is related to SLR plus the "Project" hydrodynamic effect

For reference, the farm elevations in the basin are typically between 6.0 feet and 8.0 feet in elevation. The farm areas less than 7 feet in elevation are those most exposed to risks from groundwater effects.

The results of the sensitivity analysis are interpreted that the "Project", in its current form, is expected to have an effect on the interior drainage system and adjacent farm properties, in its current configuration. The effects could include hundreds of acres of farm property upstream from the proposed project. The predominant factor driving these effects is the hydrodynamic tailwater effect resulting from the levee setback. SLR effects are equal for the "Without Project" and "Project" alternatives, and the ESV and SPC factors for the "Project" alternative are of lesser concern.

Additional sensitivity analysis could be performed on the hydrodynamic tailwater effect by rerunning the coastal hydrodynamic model, calibrating to more recent hydrologic low-tide data in the vicinity, and by varying the model loss (vegetation and channel roughness) coefficients over a range of conditions. That said, the hydrodynamic tailwater effect seems logical, as it will take longer for a larger volume of tidal water to drain the restored marsh area, and the low tide period is fixed not allowing full drainage. Additional modeling may add certainty and reduce predictions of the size of the hydrodynamic tailwater effect (i.e., 0.5 foot instead of 0.75 foot),

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but impacts to upstream farm areas are likely to occur regardless of the certainty of the tailwater effects. Instead, we recommend evaluating alternatives to mitigate these effects.

8.0 RECOMMENDATIONS

The results of the study indicate that the proposed project is expected to have an effect on adjacent farm fields, using the proposed design configuration. The primary contributing factor affecting the farm fields appears to be SLR in combination with the predicted hydrodynamic tailwater effects resulting from the levee setback. The hydrodynamic effects occur because a larger marsh area will be open to tidal inflow, and the tidal prism will flow (drain) through longer tidal channels and take more time to drain on the low tide. This results in increased tailwater elevations at the storage pond tidegate outlets. Other contributing factors such as seepage, marsh erosion, sedimentation and vegetation, and storage pond capacity are expected to have lesser effects on the storage pond water surface elevations, and increase over time.

The information contained in this report has been presented to Consolidated Diking District 22 (CDD22) as preliminary findings at a series of CDD22 meetings in late 2013. S&W and WDFW made a preliminary recommendation to evaluate a pump station as part of the project design. CDD22 indicated that their preference is to evaluate gravity drainage options by connecting the storage pond to Dry Slough through a set of vertical slide gates on the east side of the pond for gravity drainage as a first option. Then a pump station would provide backup in the interior drainage storage pond. This study has, to date, attempted to isolate No Name Slough from Dry Slough. This is due to the concern that shunting drainage flows from No Name Slough to the east into Dry Slough could have additional effects on the Hayton Farm property. The Hayton South Fields have low field elevations that could be affected by these types of operations. More information regarding the potential effect of the gravity drainage, flow control option will be known at the completion of the proposed response studies listed below.

CDD22 also questioned the seepage rates estimates provided in the study. This is based on certain members' experience with dewatering pumping operations being overwhelmed by seepage in other areas along Fir Island. The seepage rates used in our estimates are based on hydrologic monitoring data of the current interior drainage system. They also expressed concern that a seepage cutoff structure may still be needed. In order to address these questions, additional seepage analysis and cutoff studies are included in the recommended response studies below.

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To mitigate for the project effects and address CDD22 concerns, we recommend studying the following alternatives and including the outcomes from the study in the final design.

- Assess vertical slide gates connecting the No Name Slough storage pond to Dry Slough.
- Assess a pump station in the No Name Slough storage pond.
- Assess a third tidegate connecting Dry Slough to the Skagit Bay to accommodate additional inflows from the storage pond and minor increases in seepage, and shunting of flows from No Name to Dry Slough.
- Assess the combined operations of these features.
- Further evaluate and reduce uncertainty of seepage estimates and evaluate the need and costs of a seepage cutoff system.

It is anticipated that one (or a combination) of the above alternatives will mitigate for the expected interior drainage effects. Performing the additional response study identified in the project grant application and budget is recommended. This can be performed in parallel with other design activities and the findings and designs incorporated into the project 60 percent designs.

9.0 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 Fir Island Farm Restoration Project. The data contained in this report are based upon site conditions as they existed at the time this report was prepared, and based in part upon specialized hydrodynamic modeling prepared by others in support of the project. 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 related analyses. S&W cannot make claims regarding the correctness or accuracy of these models and data provided by others, as it is a proprietary model. 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.

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.

2/26/14

David R. Cline, P.E., CFM
Senior Associate

DRC: ADH: SDT:CAR/adh

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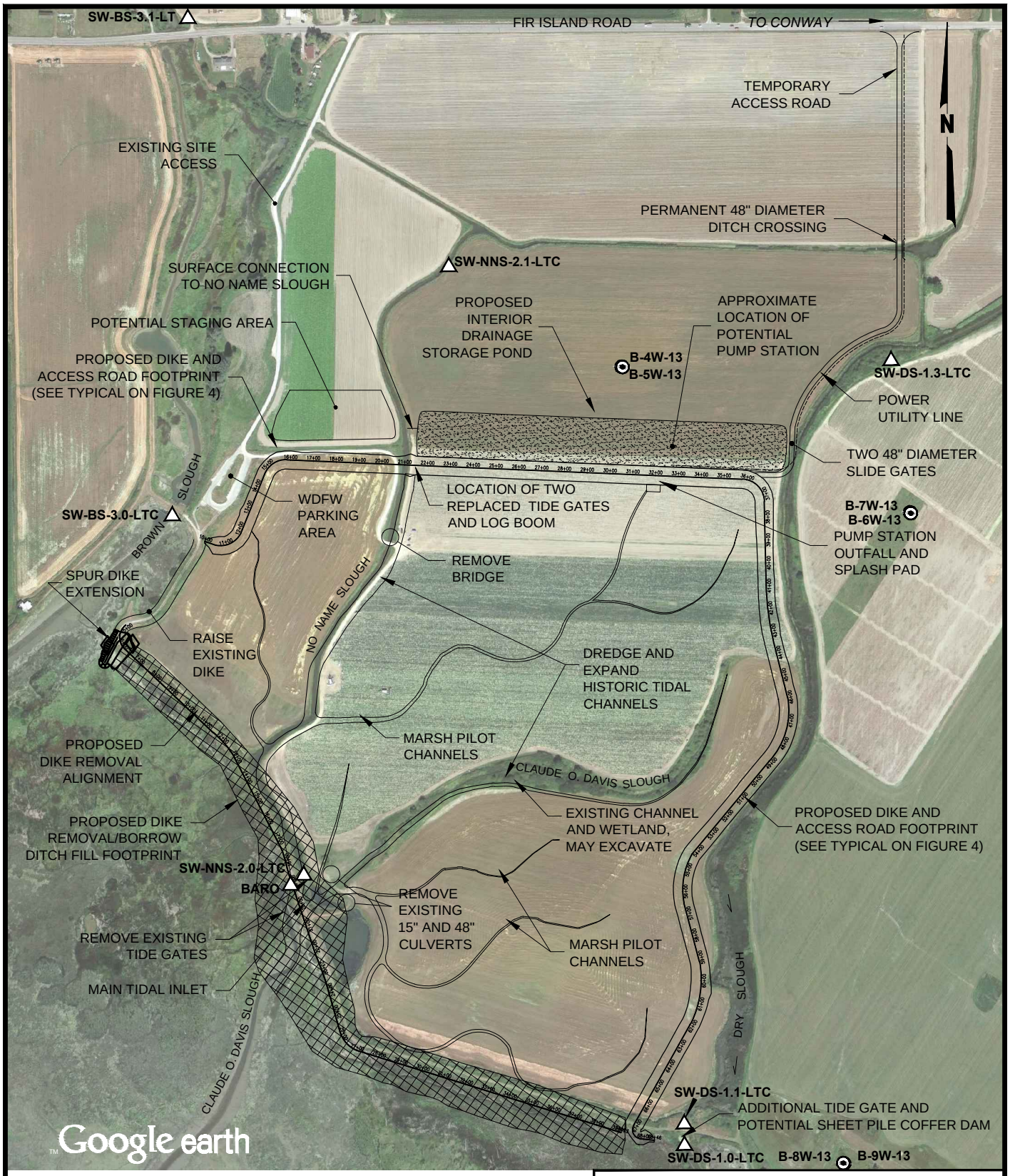

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Scale in Feet

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.

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Fir Island Farm
Estuary Restoration Project
Skagit County, Washington

PROJECT SITE PLAN

February 2014 21-1-12318-216

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FIG. 1

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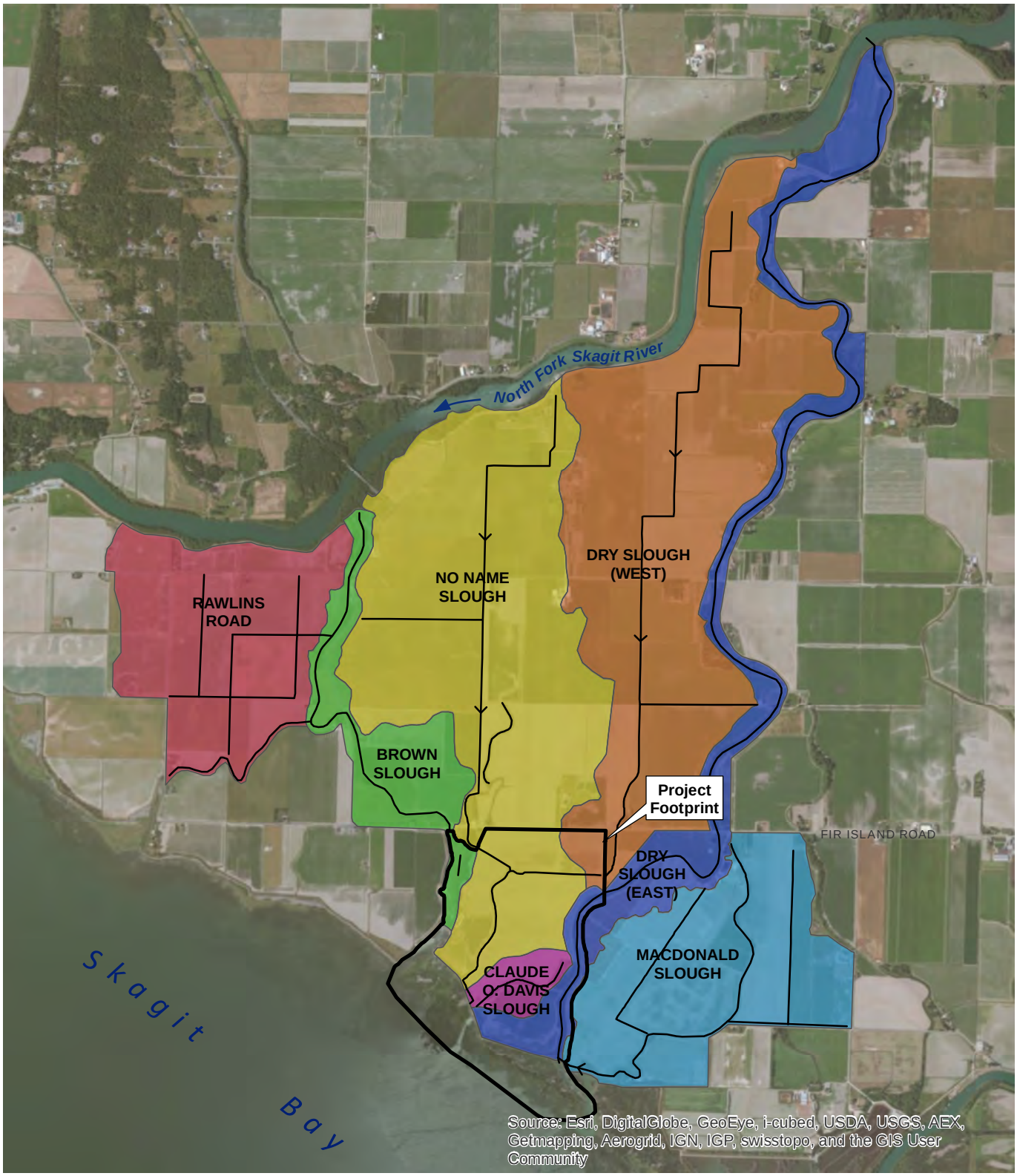

Interior Drainage Channel

N
W E
S

0 3,000 6,000 Feet

Fir Island Farm Restoration Project
Mount Vernon, Washington

INTERIOR DRAINAGE BASINS

February 2014 21-1-12318-216

SHANNON & WILSON, INC.
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FIG. 2

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APPENDIX A

HYDROLOGIC MONITORING

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APPENDIX A

HYDROLOGIC MONITORING

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APPENDIX A

HYDROLOGIC MONITORING

A-1 INTRODUCTION

Shannon & Wilson, Inc. (S&W), in collaboration with the Washington Department of Fish and Wildlife (WDFW), installed the new, and reinstalled and reconfigured the existing, groundwater and surface water hydrologic monitoring network (Figure A-1). The purpose of these instrument installations is to: 1) document baseline conditions for use in engineering design and modeling calibrations, and 2) monitor and track post-project effects for use with future adaptive management decision making.

For this project phase, S&W installed seven surface water data loggers, three pairs of groundwater data loggers (six data loggers total), and one barometric data logger. Locations and identification are shown in Figure 1. The data loggers record water pressures (elevation), temperature, and conductivity (salinity).

A.1.1 Data Logger Installations

A total of 14 Solinst brand data loggers were used for the project (groundwater and surface water data loggers). They include 12 Solinst Model 3001 LTC surface water data loggers, which measure pressure (used to calculate water surface elevation), temperature, and conductivity (used with temperature to calculate the salinity of the water), and one Model 3001 LT surface water data logger, which measures pressure and temperature only. One barometric data logger, which measures air pressure and temperature only, was also deployed to collect data used to compensate for air pressure readings of the water pressure data loggers. Prior to deployment, each of the data loggers with conductivity sensors was calibrated using the manufacturer's recommended procedure and calibration solutions. Pressure and temperature sensors are factory calibrated and checked during data downloads and compared with measured water depths. All data loggers were set to record data at a 15-minute interval, on the hour.

S&W deployed the surface water and groundwater data loggers in June and July 2013. All of the loggers were installed within locked 2-inch polyvinyl chloride (PVC) pipes. The cap is locked to the pipe with a commercial padlock. WDFW surveyed a vertical reference point for each data logger unit. The three data loggers deployed on the bay side of the levee each have a staff gage to measure the water elevation, at each data logger download. The remaining surface

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water loggers utilize the top of the black plastic cap for the reference elevation. The groundwater loggers utilize the top of the lid of the well monument as the reference elevation. The water surface elevation for these installations at download is measured from the top-of-cap elevation. The staff gages and reference points were surveyed by WDFW and were tied to local survey control. Table A-1 summarizes the pertinent information related to the data loggers. Photographs A-1 through A-13 show installations and descriptions of each of the groundwater and surface water data logger.

A.1.2 Groundwater Monitoring

Previous groundwater monitoring for the project was performed along the east side of Dry Slough from the existing levee northward for about 2,000 feet, and is described in the feasibility study documents (S&W, 2011). These wells were removed by the landowner in 2011.

Current groundwater observation well installations and monitoring include three pairs of (dual-depth) observation wells on the Hayton and WDFW properties (Figure 1, main report). Each well paring is installed with one well in the shallow, estuarine, slightly clayey SILT/upper farm soil layer, and the second well located in the underlying, slightly silty SAND, alluvial layer.

A.1.2.1 Observation Well Installation

S&W subcontracted with Boart Longyear, Inc. (Boart) of Fife, Washington, to install three pairs of observation wells (six total) at the site (Figure 1). Boart used a CME 850 track-mounted drill rig to drill and install the wells between June 17 and 20, 2013. Each pair of wells consisted of one well drilled to 21.5 feet below ground surface (bgs) and one well drilled 3 to 4.5 feet bgs. Generally, the upper farm soil layer ends between 4 and 6 feet bgs. Generally, farm field elevations range between 5 feet and 7 feet (North American Vertical Datum of 1988 [NAVD88]).

Each of the observation wells consists of a 2-inch-diameter PVC well casing with a portion that is slotted to allow groundwater inflow. Slots are 0.01 inch wide (No. 10 slot). Slotted sections are about 10 feet long in the deeper wells B-4w-13, B-6w-13, and B-8w-13. Slotted sections are 1.3 feet long in the shallower well B-5w-13, 2.3 feet long in B-7w-13, and 0.8 foot long in B-9w-13. A sand pack (size 10–20) was placed around the slotted portion of the pipe to act as a filter against the adjacent soil. The depth of the slotted section for each well was selected based on soil units encountered in the boring and anticipated groundwater levels. A sump is attached to the bottom of the slotted section. A steel monument was placed aboveground to protect the top of the pipe. Four concrete ecology blocks were placed around

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each pair of monuments to protect the wells from farming activities. For reference, deeper wells are even numbered and shallow wells are odd numbered. Information regarding groundwater observation well locations is summarized in Table A-1.

A.1.2.1.1 Observation Well Development

S&W developed the observation wells on June 21, 2013. Well development increases the hydraulic connection between the well and the aquifer by reducing skin effects from drilling and removing fines from the filter pack and formation adjacent to the well screen. We purged approximately 35 gallons at deeper well locations (B-4w-13, B-6w-13, and B-8w-13). At the time of development, the shallow wells (B-5w-13, B-7w-13, and B-9w-13) did not have enough groundwater present to develop them. Therefore, approximately 5 gallons of tap water was added to each of the shallow wells to flush the fines out of the filter pack. The added water was then surged and pumped by the same method as the groundwater well development at the deep wells. Between 5 and 10 gallons were removed from each of the shallow wells. Development continued until our field representative did not observe sediment in the discharge water.

A.1.2.2 Groundwater Level, Temperature, and Salinity Measurements

Groundwater observation wells B-4w-13 and B-5W-13 are located in the WDFW field, north of the proposed levee setback and new interior drainage storage pond. The shallow and deep groundwater observation well data loggers recorded water pressures that are nearly equal (Figure A-1). The shallow well (B-5W-13) likely went dry between early July and late August. The average groundwater elevation (measured in the deeper well B-4W-13) was 2.9 feet during the late June through early October 2013 data collection period. The ground surface elevation at the observation well is 7.1 feet and was on average 4.2 feet higher than the measured groundwater elevations. Observed groundwater temperatures ranged from 9.5 to 11.2 degrees Celsius (˚C) with an average of 10.3˚C (Figure A-2). Salinity ranged from 0.6 to 1.5 practical salinity units (psu) with an average of 1.1 psu, which is considered mildly brackish (Figure A-3).

Groundwater observation wells B-6w-13 and B-7W-13 are located in the Hayton North berry field on the east side of Dry Slough. The shallow and deep groundwater observation well data loggers recorded water pressures that did not track closely, which indicated either a local groundwater anomaly, or a problem with a pressure transducer. Our opinion was that the B-6w-13 sensor had failed and it has since been replaced. Comparisons of water level measurements are not reasonable, considering the data logger replacement due to pressure

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transducer issues. The groundwater elevations ranged from 2.6 to 4.1 feet with an average observed groundwater elevation (measured in the deeper well B-6W-13) of 3.5 feet during the late June through early October 2013 data collection period (Figure A-4). Observed groundwater temperatures ranged from 9.9 to 11.2˚C with an average of 10.3˚C (Figure A-5). Salinity ranged from 0.6 to 1.5 psu with an average of 1.1 psu, which is considered mildly brackish (Figure A-6). Measured groundwater elevations in the Hayton North berry field were 0.6 foot higher than those measured in the WDFW North Field. This is likely due to irrigation operations occurring in Dry Slough during the period of measurements. Observed temperature and salinities have nearly identical average values, comparing the Hayton North berry field with the WDFW North Field.

Groundwater observation wells B-8w-13 and B-9W-13 are located in the Hayton South "Bay" Field, on the east side of Dry Slough. In this area, the shallow and deep groundwater observation well data loggers recorded water pressures tracked closely, except toward the end of the data collection period, when the shallow well B-9W-13 began to drift. Our opinion was that the B-9w-13 sensor had failed and it has since been replaced. The observed groundwater elevations ranged from 2.9 to 4.6 feet during the late June through early October 2013 data collection period with an average groundwater elevation (measured in the deeper well B-8W-13) of 3.6 feet (Figure A-7). During the summer groundwater measurement period, the ground water was 2.5 feet lower than the adjacent ground elevation, on average.

Two things stand out about the Hayton South Field groundwater elevation data. First is that the groundwater data have a tidal signal and show daily, muted, tidal fluctuations. Second, the difference between average ground and groundwater elevation is nearly 1.0 foot lower than the previous two pairs of gages in the WDFW North Field and Hayton North Field, respectively. The groundwater gradient is towards Skagit Bay. Also, the Hayton South Field has been identified as a marginal farm field due to drainage conditions which are a function of ground elevation compared to groundwater elevations. This "wet field" condition is one of the project evaluation criteria and is discussed further in the surface water modeling report sections.

Observed groundwater temperatures for B-8w-13 and B-9W-13 ranged from 10.3 to 10.7˚C with an average of 10.4˚C (Figure A-8) for the deeper well (B-8w-13) and 13.1 to 16.0˚C for the shallow well (B-9w-13). Observed temperature and conductivities in the Hayton South groundwater wells are nearly identical to those observed in wells to the north.

Salinity ranged from 11.5 to 15.1 psu with an average of 14.2 psu for the deep well (B-8w-13), which is considered brackish (Figure A-9). Salinity ranged from 0.9 to 3.4 psu, with an average of 2.1 psu in the shallow well, which is considered mildly brackish. It is

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expected that the measured higher salinity conditions in these wells would occur. This is due to their proximity to the Skagit Bay tidal area, and in the deeper (more saline) observation well. The question going forward is if the proposed project will have effects on shallow groundwater elevations and salinity concentrations such that they impact farming operations in the WDFW and Hayton fields.

A.1.3 Surface Water Monitoring

Historic surface water monitoring for the project was performed during the feasibility study in locations similar to current installations, in 2010 and 2011. Monitoring did not continue during the 2012 period. The data loggers were refurbished and reinstalled in new locations and more secure installations in 2013 (Figure 1).

A.1.3.1 Surface Water Level, Temperature, and Salinity Measurements

Surface water data loggers are installed in Dry Slough at positions immediately downstream of the tidegates (SW-DS-1.0-LTC), immediately upstream from the tidegates (SW-DS-1.1-LTC), and approximately 3,000 feet upstream from the tidegates and north of the proposed levee setback and interior drainage storage pond (SW-DS-1.3-LTC). The downstream Dry Slough data logger (SW-DS-1.0-LTC) is measuring Skagit Bay tidal conditions along Dry Slough. The interior drainage data loggers are measuring drainage conditions in Dry Slough, which is mostly disconnected from No Name Slough, except at very high flow conditions where lateral ditches overflow.

During the June through August 2013 period, Dry Slough was under the influence of irrigation operations. The farmers and Consolidated Diking District 22 block drainage from Dry Slough in order to pump water from the slough for irrigation and groundwater management purposes. Normally, without irrigation operations, Dry Slough would drain similarly to the adjacent No Name and Brown Sloughs. Irrigation operations stopped in early September 2013. The average water surface elevation (mean tide) downstream from the tidegate was 5.4 feet (NAVD88) (Figure A-10). The average water surface elevation upstream from the tidegate for SW-DS-1.1-LTC and SW-DS-1.3-LTC was 3.6 feet (NAVD88), which was elevated during this period. The SW-DS-1.3-LTC data gage may have a survey data error that needs to be confirmed with WDFW.

Surface water temperatures in the Dry Slough (SW-DS-1.0-LTC) tidal channel downstream of the tidegates range from 10 to 26˚C in mid-summer (Figure A-11). A temperature spike of 26˚C was observed on June 30, 2013. Surface water temperatures in Dry

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Slough (SW-DS-1.1-LTC) immediately upstream of the levee and tidegates range from 10 to 15˚C.

Surface water temperatures in Dry Slough (SW-DS-1.3-LTC) located further upstream, north of the proposed levee setback, range from 14 to 22˚C. The gage near at the landward side of the levee has lower temperatures than both the downstream tidal and upstream interior drainage channel gages. This is likely because the gage is located directly north of the levee structure and located in the shadow of the levee, providing shade to the channel.

Salinity in Dry Slough (SW-DS-1.0-LTC) ranges from 0.1 to 29 psu (Figure A-12). The Skagit Bay salinity conditions observed at this gage were less than 10 psu until mid-July, when they spiked in late August to nearly 30 psu and then dropped again below 10 psu in late September. The observed salinity conditions match the descriptions and conceptual models of Skagit Bay salinity mixing that is associated with Skagit River freshwater flow contribution and mixing in the deltas and along the Bay front area.

Surface water data loggers are installed in No Name Slough at positions immediately downstream of the tidegates (SW-NNS-2.0-LTC), and further upstream, north of the proposed levee setback and interior drainage storage pond (SW-NNS-2.1-LTC). The downstream Dry Slough data logger (SW-DS-1.0-LTC) is measuring Skagit Bay tidal conditions. The average water surface elevation (mean tide) downstream from the tidegate was 5.6 feet (NAVD88) and the average water surface elevation upstream from the tidegate and north of the proposed levee setback and interior drainage pond was 3.5 feet (NAVD88) (Figure A-13). No Name Slough (SW-NNS-2.1-LTC) exhibited a normal drainage pattern, unlike Dry Slough, which was under irrigation operations.

Surface water temperatures in the No Name Slough (SW-NNS-2.0-LTC) tidal channel downstream of the tidegates range from 10 to 28.3˚C in mid-summer. A temperature spike of 28.3˚C was observed on June 30, 2013 (Figure A-14). Surface water temperatures in No Name Slough (SW-NNS-2.1-LTC) located further upstream, north of the proposed levee setback, range from 14 to 17.5˚C. The measured surface water temperatures in No Name Slough tidal channel are much higher than Dry or Brown Slough. The reason for this is not known.

Salinity in No Name Slough (SW-NNS-2.0-LTC) ranges from 0.0 to 20 psu (Figure A-15). The salinity readings dropped to zero in July 2013, which may indicate a problem with the salinity readings. Salinity in No Name Slough (SW-NNS-1.0-LTC) ranges from 2.5 to 10.2 psu and gradually increases throughout the summer and fall. This gage is

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located in the section of channel flowing directly adjacent to the current WDFW farming areas. Even with the higher salinity concentrations, there are no reported adverse effects on farming, likely due to the elevated grade of the farm area next to the drainage channel.

Surface water data loggers are installed in the Brown Slough at positions immediately downstream of the tidegates (SW-BS-3.0-LTC), and further upstream, north of the Fir Island Road (SW-BS-2.1-LT). The downstream Brown Slough data logger (SW-BS-3.0-LTC) is measuring Skagit Bay tidal conditions along Brown Slough. The average water surface elevation (mean tide) downstream from the tidegate was 5.6 feet (NAVD88) and the average water surface elevation upstream from the tidegate and north of the proposed levee setback and interior drainage pond was 3.2 feet (NAVD88) (Figure A-16). Brown Slough had slightly higher average water surface elevations downstream from the tidegate and slightly lower average water surface elevations upstream from the tidegate than No Name Slough. The lower upstream water surface elevations are a function of the single, vertical slidegate that allows flow into Brown Slough area between the downstream tidegate complex and the Fir Island Road tidegates.

Surface water temperatures in the Brown Slough (SW-BS-3.0-LTC) tidal channel downstream of the tidegates range from 9 to 29˚C in mid-summer (Figure A-17). A temperature spike of 29˚C was observed on June 22, 2013. Surface water temperatures in Brown Slough (SW-BS-3.1-LT) located upstream of Fir Island range from 14.7 to 17.3˚C. The measured surface water temperatures in Brown Slough are similar to No Name Slough and higher than those observed in Dry Slough. The reason for this is not known.

Salinity in Brown Slough was observed at the downstream tidal gage (SW-BS-3.0-LTC), for a short period from June 2013 into July 2013 (Figure A-18). Salinity during that time period ranged from 0.5 psu with a salinity spike of 19.1 psu occurring on June 29, 2013. The data logger was replaced with a level-temperature sensor only in July 2013 to provide an additional seventh data logger for project monitoring. Salinity in upstream Brown Slough (SW-BS-3.1-LTC) was fairly constant and ranged from 7.6 to 10.6 psu.

A.1.3.2 Data Quality Assurance

Data were downloaded from all of the data loggers on July 19, August 23, and October 9, 2013. The data verify that the loggers were installed and operating correctly, except as noted below. The following observations are noted:

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- The water levels in Dry Slough (Figure A-10) were influenced by irrigation operations during the collection period.
- Well B-5 was dry for a portion of the collection period.
- Well B-7 was dry for a portion of the collection period.
- The groundwater level readings at well B-6 did not correlate with values measured manually when the data were downloaded. Diagnostic tests on the data logger indicated the pressure sensor had malfunctioned. The logger was returned to the manufacturer for repair.
- The water level readings at well B-9 appear to drift and the data logger has since been replaced.
- A survey discrepancy was found in SW-DS-1.3-LTC. The elevation values from this data logger should be treated as questionable until the discrepancy is resolved. WDFW survey crews have been notified that resurvey of the data logger well casing is needed.
- Prior to October 9, the SW-BS-3.1-LTC upstream gage may have a slight survey or water measurement error that was corrected when the new LT gage was installed.

A.1.3.3 Future Data Collection Schedule

Data will be downloaded from the data loggers by S&W and WDFW, approximately every three to four months. The next scheduled data download is February 2014. Data downloads need to occur prior to the data loggers exceeding the logger data capacity, which is typically a five-month period collecting data at 15-minute intervals. After the 2014 data collection period, WDFW will be assuming data collection and data reporting responsibilities. These responsibilities include quarterly data logger downloads, data processing and publishing, and repair and maintenance of data logger equipment. If these data monitoring activities do not continue, information needed to make informed management decisions, and to avoid or refute potential landowner claims regarding project effects, could be lost.

A-2 REFERENCES

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.

Shannon & Wilson, Inc., 2014, Draft coastal engineering report WDFW – Fir Island Farm Snow Goose Reserve. Skagit County, Washington: Report prepared by Shannon & Wilson, Inc., Seattle, Wash., January.

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TABLE A-1
GROUNDWATER AND SURFACE WATER DATA LOGGER INFORMATION

ID	Date of Deployment	S/N	Type	Location Description	Northing	Easting	TOC Elevation (NAVD88)	Notes
GW-B-04-13-LTC	27-Jun-13	1E+06	LTC	North of new interior drainage storage area (West, Deep Well)	1,257,925.92	491,729.61	9.20	
GW-B-05-13-LTC	27-Jun-13	1E+06	LTC	North of new interior drainage storage area (East, Shallow Well)	1,257,929.85	491,728.70	9.18	
GW-B-06-13-LTC	27-Jun-13	1E+06	LTC	In Field, approximately 1,000 feet east of new dike at Sta. 40+00 (South, Deep We	1,259,192.70	491,087.87	9.09	
GW-B-07-13-LTC	27-Jun-13	1E+06	LTC	In Field, approximately 1,000 feet east of new dike at Sta. 40+00 (North, Shallow	1,259,189.53	491,091.47	8.77	
GW-B-08-13-LTC	17-Jul-13	1E+06	LTC	Field side of existing dike east of Dry Slough (West, Deep Well)	1,258,897.08	488,241.99	7.50	
GW-B-09-13-LTC	17-Jul-13	1E+06	LTC	Field side of existing dike east of Dry Slough (East, Shallow Well)	1,258,900.88	488,240.05	7.40	4
SW-DS-1.0-LTC	19-Jun-13	1E+06	LTC	Dry Slough - Bay side of existing dike	1,258,201.26	488,322.24	N/A	1
SW-DS-1.1-LTC	19-Jun-13	1E+06	LTC	Dry Slough - Field side of existing dike	1,258,200.41	488,415.86	8.64	
SW-DS-1.3-LTC	19-Jun-13	1E+06	LTC	Dry Slough - Field, downstream of DS/DSW confluence	1,259,107.21	491,757.77	7.42	
SW-NNS-2.0-LTC	20-Jun-13	1E+06	LTC	No Name/COD Slough - Bay side of existing dike	1,256,475.59	489,460.55	N/A	1
SW-NNS-2.1-LTC	20-Jun-13	1E+06	LTC	No Name Slough - Field side of proposed dike	1,257,236.42	492,173.63	9.58	
SW-BS-3.0-LTC	20-Jun-13	1E+06	LTC	Brown Slough - Bay side of tidegates	1,255,955.34	491,077.75	12.62	2
SW-BS-3.1-LTC	20-Jun-13	1E+06	LTC	Brown Slough - North of Fir Island Road	1,256,026.14	493,256.49	7.45	3
BARO	20-Jun-13	2E+06	Baro	Near NNS-2.0, at top of left bank	1,256,461.33	489,408.05	N/A	

Notes:

1. Staff gage is NAVD88.
2. Subtract 2.64 feet from staff gage reading to get NAVD88 elevation.
3. Logger is Solinst Level/Temperature Conductivity (LTC); conductivity is uncalibrated and should be disregarded.
4. Logger pressure data began to drift in October 2013, affecting data and should be disregarded.

COD = Claude O. Davis

DS/DSW= Dry Slough (West)

N/A = not applicable

NAVD88 = North American Vertical Datum of 1988

NNS = No Name Slough

S/N = serial number

Sta. = Station

TOC = top of cap

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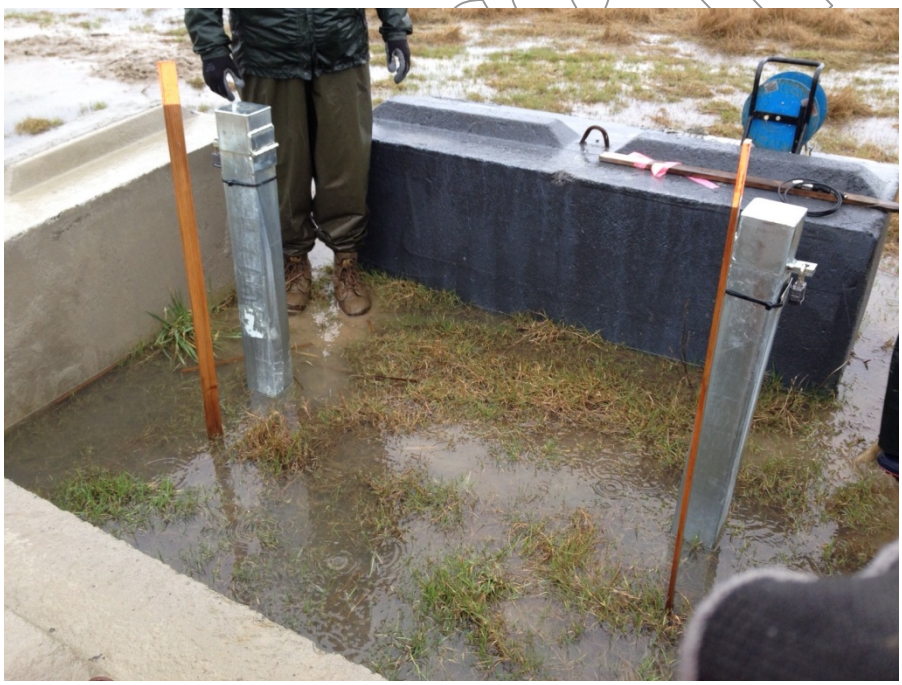
Photograph A-1. Drilling, boring and groundwater observation wells B-4W-13 and B-5W-13

Photograph A-2. Completed groundwater observation wells B-4W-13 and B-5W-13

Photograph A-3. Completed groundwater observation wells B-6W-13 and B-7W-13



Photograph A-4. Completed groundwater observation wells B-8W-13 and B-9W-13

Photograph A-5. Dry Slough (SW-DS-1.0-LTC) surface water datalogger installation on east (left) bank looking south, Skagit Bay side of tidegates.

Photograph A-6. Dry Slough staff gage installation on west (right) tidegate headwall (photo looking west), Skagit Bay side of tidegates.

Photograph A-7. Dry Slough (SW-DS-1.1-LTC) surface water datalogger installation on boardwalk looking north, farm side of tidegates.

Photograph A-8. Dry Slough (SW-DS-1.3-LTC) surface water datalogger installation right (west) bank, photo looking east.

Photograph A-9. Davis (No Name Slough, SW-NNS-2.0-LTC) surface water datalogger installation right side (west) of tidegates, photo looking southwest.

Photograph A-10. Davis (No Name Slough) staff gage installation on timber pile downstream of tidegates, left (east) bank, photo looking southwest.

Photograph A-11. No Name Slough (SW-NNS-2.1-LTC) surface water datalogger installation on left (east) bank, north of WDFW farm road and gate from parking lot, photo looking south.

Photograph A-12. Brown Slough (SW-BS-3.0-LTC) surface water datalogger installation on far (west) side of trash rack screen, photo looking west.

Photograph A-13. Brown Slough (SW-BS-3.1-LT) surface water datalogger installation on left (east) side of channel, north of Fir Island Road, photo looking south.

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APPENDIX B

SEEPAGE ANALYSIS

APPENDIX B

SEEPAGE ANALYSIS

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APPENDIX B

SEEPAGE ANALYSIS

B.1 OBJECTIVE

A seepage analyses using SEEP/W was performed to evaluate seepage effects of the proposed levee setback, including:

- Calculating water seepage through and below the existing and proposed levees. The seepage rates (flux) will be used as inflow parameters for interior drainage surface water modeling, which will be used to predict surface and groundwater conditions on adjacent farm properties;
- Evaluate groundwater levels for the adjacent farm properties; and
- Provide seepage information for salinity mixing calculations of the interior drainage storage pond and adjacent farm fields.

B.1.1 In Situ Hydraulic Conductivity Testing

Shannon & Wilson, Inc. (S&W) performed slug tests at monitoring wells B-4w-13, B-6w-13, and B-8w-13 (the deep wells), which lie in the loose, slightly silty, sand soil layer. The shallow monitoring wells B-5w-13, B-7w-13, and B-9w-13, which lie in the upper soil layer, did not have enough water in them to perform a slug test. Slug testing is a method for estimating the in situ hydraulic conductivity of the saturated material surrounding an observation well. Slug tests have a small radius of influence. As such, they do not provide data regarding large-scale aquifer properties, aquifer geometry, or boundary conditions affecting groundwater flow. Pumping tests are necessary to provide data related to large-scale aquifer properties.

Slug testing involves rapidly raising or lowering the water level in a well and measuring the subsequent change in water level as it recovers to the original static position. Raising the water level in a well is achieved by quickly lowering a slug (in this case a sealed 1.25-inch-diameter polyvinyl chloride pipe filled with silica sand) into the well to displace water within the well casing. The subsequent falling of the water level to the original static position is referred to as a falling head slug test. Removing the slug and monitoring the rising water level constitutes a rising head slug test. A pressure transducer and data logger records the water level in the well during the slug tests.

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The slug test analysis consists of plotting the water level versus time, fitting a line to the data, and using an analytical solution to calculate the hydraulic conductivity based on the fit line (S&W, 2013). Several analytical solutions are available for calculating the hydraulic conductivity from a slug test. The analytical solution used to calculate the hydraulic conductivity depends on the aquifer parameters. We interpret that the aquifer we tested is partially confined, due to the presence of alluvial silts and clayey silts overlying silty sand, which results in higher groundwater pressures in deeper soil layers than observed in shallow soil layers.

We interpret the aquifer has an under-damped response, based on our observations during drilling and the results of the slug tests. An under-damped response is when the water level recovery during a slug test oscillates above and below the initial static water level with decreasing amplitude with time.

Two different solutions were used analyze the slug tests. The two solutions provide a range of hydraulic conductivity values and account for variability of the aquifer parameters. The solutions include the Bouwer and Rice method (Bouwer, 1989), which is used for analyzing slug tests in confined aquifers, and the Butler (1998) method, which is used for analyzing slug tests in a confined aquifer with an under-damped response. We used the computer program AQTESOLV to plot the slug test results, match the fit line to the results, and calculate the hydraulic conductivity using different solutions. A summary of the hydraulic conductivity calculated from the slug tests and the data plots with fit lines was provided in the Geotechnical Data Report (S&W, 2013). The range of hydraulic conductivities for the underlying sand layers is 94 to 192 feet/day using the Bouwer and Rice method (Table B-1). The Bower and Rice-calculated hydraulic conductivities were selected for use in the study. The Bower and Rice hydraulic conductivities and calculated seepage inflow rates better match site-observed surface and groundwater inflows to the tidegates.

B.1.2 Seepage Estimates from Hydrologic Monitoring Data

Hydrologic monitoring data were used to estimate existing condition seepage inflow to the No Name Slough drainage system. The estimate was performed by calculating the change in interior drainage channel storage volume while the tidegates are shut on each cycle. Seepage inflows include both existing levee seepage and upstream groundwater drainage inflows. Using the hydrologic monitoring data for the site, seepage inflows are estimated at 1 cubic foot per second (cfs) (449 gallons per minute [gpm]).

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B.1.3 Seepage Model Development

We constructed three seepage analysis models to evaluate existing and proposed groundwater conditions. Geologic sections A-A' and B-B' from the Geotechnical Data Report (Shannon & Wilson, Inc., 2013) were used, along with soils data along the existing levee and levee setback, to estimate soil properties in the models along various levee zones. Cross section elevation data was obtained from existing ground surveys and proposed levee geometry. Surface water elevations and boundary conditions were obtained from monitoring data obtained at the site.

To represent the heterogeneous conditions in the project area, we divided the existing and proposed levee into three representative areal zones, each represented by generalized geologic sections in these zones (Figure B-1):

- Zone 1 – Existing levee from Brown to Dry Slough
- Zone 2 – Northern section (running east-west) of the proposed setback levee
- Zone 3 – Eastern section (running north-south) of the proposed setback levee

B.2 SEEP/W MODEL

We evaluated groundwater conditions across the levee by constructing a numerical seepage flow model using the two-dimensional, finite-element seepage analysis program SEEP/W, which simulates fluid flow and pressure distribution in saturated and unsaturated porous media. SEEP/W is part of the GeoStudio 2007 software package developed by Geo-Slope International (2007). The following sections of the report describe the SEEP/W model structure, numerical model application, and modeling results

B.2.1 Land Surface

The model land surface is based on the 2003 Light Detection and Ranging data for the site existing conditions, and preliminary design plans developed in the feasibility study (and modified for this study) for proposed levee setback and interior drainage pond conditions.

B.2.2 Soil Layers and Hydraulic Conductivity Estimates

Estimates of hydraulic conductivity were performed for the four representative soil layers in the SEEP/W model. Modeling soil layers include: 1) levee/levee fill, 2) combined upper soil units (Hm and Agricultural) soil layer, 3) underlying Holocene alluvium (Ha), and 4) underlying Holocene estuarine soils (He), as characterized in S&W, 2013.

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The seepage model soil and groundwater properties were based on soil, groundwater, and surface water data collected during the geotechnical field exploration and hydrologic monitoring program. The estimated hydraulic conductivity estimates were based on soil type and grain size analyses collected from previous geoprobe, boring, and test pit soil samples during this phase of study and from previous feasibility phases of study. Slug tests were performed in the deeper groundwater observation wells installed during this final engineering design phase of study. Soil hydraulic conductivities (K) were selected based on soil descriptions, grain size analysis, slug tests, and literature review (Freeze and Cherry, 1979). Porosities of 0.25 and anisotropy ratio 0.5 were assigned to soil based on the literature review.

Averages of hydraulic conductivity estimates of the materials are listed in Table B-2. For sensitivity analyses, we modeled scenarios with a high soil permeability factor (K), which was either double of the averaged K or the higher values measured from slug tests. Table B-3 summarizes the soil permeability factors used for each zone and soil layers used in the SEEP/W model.

B.2.3 Surface and Groundwater Boundary Conditions

Surface and groundwater boundary conditions were developed based on the data collected during this current phase of study. Seepage through and underneath the existing levees is assumed to be a quasi-steady state condition, whereby the exterior average tide is higher than the interior drainage surface water condition, right at the existing levee. Therefore, a seepage gradient exists inland towards the farm areas across the existing levee.

Observed average surface and groundwater elevations from the June through September 2013 period were used as boundary conditions to estimate steady-state seepage inflows for existing and proposed conditions, as summarized below (Figures B-2 through B-4):

- The No Name Slough (SW-NNS-2.0-LTC) average observed tidal water elevation of 5.6 feet (North American Vertical Datum of 1988 [NAVD88]) is the tidal water elevation boundary condition.
- The No Name Slough No Name Slough (SW-NNS-2.1-LTC) interior drainage water elevation of 3.5 feet (NAVD88) is the interior drainage surface water elevation boundary condition.
- The average groundwater elevations in observation wells B-8w-13 were 3.8 feet (NAVD88) for the deep well.
- Soil layers and boundary conditions in the three models are shown in Figures B-5 through B-7.

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B.2.4 Seepage Modeling Scenarios

Steady-state seepage analyses were performed for the three generalize zones as modeled sections. Low- and high-hydraulic-conductivity scenarios were performed for each section. For Ha material, the low K value was derived from grain size analyses, and the high K value was based on the slug test. The ratio of high K to low K of Ha was applied to other material in the same section to obtain the high K values for other materials in the model.

We also performed a scenario to evaluate how the seepage rate might be reduced if the shallower interior drainage pond is not directly connected to the underlying sand layer (Ha) in the northern zone. The analysis involved the low- and high-hydraulic-conductivity cases but two feet of farm soil (silt) maintained below the pond invert.

B.2.5 Seepage Results

Table B-4 and Figures B-8 through B-10 present the seepage modeling results. The results indicate the following:

- For the proposed project, the seepage flows through and underneath the levee to interior drainages will be lower than under existing conditions by between 45 and 132 gpm.
- Existing condition seepage flux across the levee was calculated to range from 91 to 232 gallons per minute. Proposed condition seepage flux across the levee was calculated to range from 62 to 120 gpm, which represent the combined flux of the northern and eastern sections.
- Maintaining the 2-foot silt layer at the bottom of the pond reduces the inflows by a further 2 to 3 gpm.

For the purposes of modeling seepage inflows to the proposed interior drainage system for the surface water hydraulic analysis, the recommended seepage rate to the No Name Slough interior drainage pond will use the calculated existing seepage and groundwater inflow condition of 1 cfs (449 gpm). For Dry Slough, use an increased seepage rate of 100 gpm. These values are conservative, as the SEEP/W model indicates that expected seepage rates to the interior storage pond and Dry Slough will likely be less for proposed conditions than the existing conditions. Also, the proposed condition project has reduced interior drainage channel lengths and drainage areas, as compared to existing conditions, and therefore would likely have less upstream groundwater inflow to the system.

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TABLE B-1
SUMMARY OF SLUG TESTING

Observation Well	Date Tested	Test Number	Static Water Level Depth[a] (feet bgs)	Hydraulic Conductivity Calculated Using the Bouwer and Rice Method		Interpreted Primary Geologic Unit Tested[b]
				ft/day	cm/sec	
B-04W-13	6/26/2013	Falling Head Test 1	2.6	113	4.0E-02	Ha
		Falling Head Test 2		170	6.0E-02	
		Falling Head Test 3		142	5.0E-02	
		Falling Head Tes 4		113	4.0E-02	
		Rising Head Test 1		85	3.0E-02	
		Rising Head Test 2		113	4.0E-02	
		Rising Head Test 3		170	6.0E-02	
		Rising Head Test 4		142	5.0E-02	
		Geomean		**128**	**4.5E-02**	
B-06W-13	6/26/2013	Falling Head Test 1	3.1	57	2.0E-02	Ha
		Falling Head Test 2		113	4.0E-02	
		Falling Head Test 3		142	5.0E-02	
		Falling Head Test 4		57	2.0E-02	
		Rising Head Test 1		85	3.0E-02	
		Rising Head Test 2		113	4.0E-02	
		Rising Head Test 3		113	4.0E-02	
		Rising Head Test 4		113	4.0E-02	
		Geomean		**94**	**3.3E-02**	
B-08W-13	6/26/2013	Falling Head Test 1	1.2	170	6.0E-02	Ha
		Falling Head Test 2		198	7.0E-02	
		Falling Head Test 3		283	1.0E-01	
		Falling Head Test 4		170	6.0E-02	
		Rising Head Test 1		170	6.0E-02	
		Rising Head Test 2		198	7.0E-02	
		Rising Head Test 3		198	7.0E-02	
		Rising Head Test 4		170	6.0E-02	
		Geomean		**192**	**6.8E-02**	

Notes:

[a] Static water level measured just prior to the start of slug testing.

[b] If a well was screened across more than one interpreted geologic unit, the most pervious unit was considered to the the unit tested.

cm/sec = centimeters per second

ft/day = feet per day

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TABLE B-2
SUMMARY OF SOIL SAMPLES AND PROPERTIES, AVERAGE OF HYDRAULIC CONDUCTIVITY CALCULATIONS

Boring	Sample	Depth	USCS Soil Type	Soil Properties: GRAVEL (%)	SAND (%)	FINES (%)	D10 (mm)	D20 (mm)	D50 (mm)	D60 (mm)	Cu Ratio (Coefficient of Uniformity)	Porosity equation (n) from Vukovic and Soro	I_0 (mm)	Hazen (cm/sec)	Kozeny-Carman (cm/sec)	Breyer Equation (cm/sec)	Slitcher (cm/sec)	Alyamani and Sen (1993) (cm/sec)	USBR (U.S.Bureau of Rec.) (cm/sec)	Hydraulic Conductivity - Based on Averages of Equations: (cm/sec)	(ft/day)	(ft/min)
Borings in Zone 1 - Existing Levee																						
B-9w-13	S-1	2	ML	0	14	86	0.0015	0.0035	0.017	0.027	18.0	0.26	0.001	1.4E-06	6.2E-07	1.9E-06	2.8E-07	2.2E-06	1.1E-06	1.2E-06	0.004	2.4E-06
TP-26-13	S-3	3	ML	0	7	93	0.001	0.003	0.009	0.015	15.0	0.27	0.001	6.5E-07	3.0E-07	9.0E-07	1.3E-07	9.1E-07	7.4E-07	6.1E-07	0.002	1.2E-06
TP-37-13	S-3	3	SM	0	78	22	0.035	0.08	0.2	0.25	7.1	0.32	0.023	1.2E-03	7.3E-04	1.3E-03	2.9E-04	1.1E-03	1.4E-03	1.0E-03	2.8	2.0E-03
TP-33-13	S-3	3.5	SM	0	78	22	0.03	0.07	0.21	0.3	10.0	0.29	0.018	7.1E-04	3.8E-04	9.0E-04	1.6E-04	7.9E-04	1.0E-03	6.6E-04	1.9	1.3E-03
TP-32-13	S-3	4.5	SM	0	75	25	0.03	0.05	0.17	0.2	6.7	0.33	0.019	8.9E-04	5.8E-04	9.9E-04	2.3E-04	7.9E-04	4.8E-04	6.6E-04	1.9	1.3E-03
TP-36-13	S-3	5	SM	0	81	19	0.04	0.08	0.17	0.25	6.3	0.33	0.028	1.6E-03	1.1E-03	1.8E-03	4.3E-04	1.5E-03	1.4E-03	1.3E-03	3.7	2.6E-03
TP-23-13	S-3	8.5	ML	0	3	97	0.001	0.003	0.007	0.01	10.0	0.29	0.001	7.9E-07	4.2E-07	1.0E-06	1.8E-07	8.8E-07	7.4E-07	6.7E-07	0.002	1.3E-06
B-8w-13	S-5	10	SP-SM	2	92	6.2	0.15	0.2	0.4	0.5	3.3	0.39	0.117	3.1E-02	3.0E-02	2.9E-02	1.0E-02	2.3E-02	1.2E-02	2.2E-02	63.2	4.4E-02
B-8w-13	S-7	15	SP	0	97	3.5	0.2	0.22	0.33	0.35	1.8	0.44	0.176	6.6E-02	8.8E-02	5.8E-02	2.6E-02	4.9E-02	1.4E-02	5.0E-02	142	9.8E-02
GP-02-10		15	SP-SM	2	93	5	0.15	0.23	0.4	0.52	3.5	0.39	0.117	3.0E-02	2.9E-02	2.9E-02	9.9E-03	2.3E-02	1.6E-02	2.3E-02	64.4	4.5E-02
GP-01-10		16	SP	1	96	3	0.19	0.25	0.4	0.43	2.3	0.42	0.158	5.6E-02	6.6E-02	5.0E-02	2.1E-02	4.0E-02	1.9E-02	4.2E-02	118.8	8.2E-02
GP-01-10	S-6	25	SP-SM	0	91	9	0.1	0.17	0.33	0.36	3.6	0.39	0.074	1.3E-02	1.2E-02	1.3E-02	4.3E-03	9.6E-03	8.0E-03	1.0E-02	28.3	2.0E-02
GP-02-10		25	SP-SM	0	95	5	0.15	0.23	0.4	0.5	3.3	0.39	0.117	3.1E-02	3.0E-02	2.9E-02	1.0E-02	2.3E-02	1.6E-02	2.3E-02	65.3	4.5E-02
Borings in Zone 2 - Northern Section of Proposed Levee																						
TP-4-13	S-1	2	ML	0	3	97	0.001	0.002	0.009	0.015	15.0	0.27	0.001	6.5E-07	3.0E-07	9.0E-07	1.3E-07	9.1E-07	2.9E-07	5.3E-07	0.002	1.0E-06
TP-6-13	S-2	2.5	ML	0	15	85	0.004	0.008	0.035	0.042	10.5	0.29	0.002	1.2E-05	6.4E-06	1.6E-05	2.7E-06	1.4E-05	7.1E-06	9.8E-06	0.03	1.9E-05
TP-7-13	S-2	2.5	ML	0	19	81	0.005	0.01	0.035	0.05	10.0	0.29	0.003	2.0E-05	1.0E-05	2.5E-05	4.4E-06	2.2E-05	1.2E-05	1.6E-05	0.04	3.1E-05
B-5w-13	S-13	3	ML	0	33	67	0.0025	0.006	0.042	0.06	24.0	0.26	0.001	3.6E-06	1.6E-06	4.8E-06	7.1E-07	7.4E-06	3.6E-06	3.6E-06	0.01	7.1E-06
TP-9-13	S-2	3	ML	0	29	71	0.0055	0.015	0.04	0.055	10.0	0.29	0.003	2.4E-05	1.3E-05	3.0E-05	5.3E-06	2.7E-05	3.0E-05	2.1E-05	0.06	4.2E-05
TP-5-13	S-2	3.5	SM	0	85	15	0.04	0.1	0.17	0.2	5.0	0.36	0.028	1.8E-03	1.4E-03	1.9E-03	5.2E-04	1.5E-03	2.4E-03	1.6E-03	4.5	3.1E-03
TP-2-13	S-3	3.5	SP	1	98	1	0.28	0.31	0.45	0.5	1.8	0.44	0.249	1.3E-01	1.7E-01	1.1E-01	5.1E-02	9.6E-02	3.2E-02	9.8E-02	278	1.9E-01
TP-3-13	S-2	3.5	ML	0	11	89	0.0028	0.007	0.021	0.03	10.7	0.29	0.002	6.0E-06	3.1E-06	7.7E-06	1.3E-06	6.9E-06	5.2E-06	5.0E-06	0.01	9.9E-06
TP-11-13	S-3	3.5	SP-SM	0	94	6	0.15	0.17	0.2	0.21	1.4	0.45	0.140	3.9E-02	5.6E-02	3.4E-02	1.6E-02	3.0E-02	8.0E-03	3.0E-02	86.0	6.0E-02
TP-8-13	S-3	4	ML	0	47	53	0.009	0.02	0.07	0.09	10.0	0.29	0.005	6.4E-05	3.4E-05	8.1E-05	1.4E-05	7.2E-05	5.8E-05	5.4E-05	0.15	1.1E-04
TP-10-13	S-3	5	SW-SM	0	90	10	0.08	0.15	0.4	0.5	6.3	0.33	0.053	6.6E-03	4.4E-03	7.2E-03	1.7E-03	5.7E-03	6.0E-03	5.3E-03	14.9	1.0E-02
B-1-13	S-5	10	SP	0	96	4	0.16	0.25	0.38	0.42	2.6	0.41	0.129	3.8E-02	4.2E-02	3.4E-02	1.4E-02	2.7E-02	1.9E-02	2.9E-02	82.1	5.7E-02
GP-06-10		10	SM	0	96	4	0.15	0.2	0.3	0.32	2.1	0.43	0.126	3.5E-02	4.3E-02	3.1E-02	1.3E-02	2.5E-02	1.2E-02	2.7E-02	75.5	5.2E-02
B-4w-13	S-5	10.5	SP	0	97	3	0.15	0.19	0.3	0.33	2.2	0.42	0.126	3.5E-02	4.2E-02	3.1E-02	1.3E-02	2.5E-02	1.0E-02	2.6E-02	74.1	5.1E-02
B-4w-13	S-6	12.5	SP-SM	1	94	5	0.15	0.2	0.4	0.48	3.2	0.40	0.117	3.1E-02	3.1E-02	2.9E-02	1.0E-02	2.3E-02	1.2E-02	2.3E-02	64.2	4.5E-02
B-1-13	S-9	20	SM	2	61	37	0.006	0.025	0.1	0.15	25.0	0.26	0.003	2.1E-05	9.1E-06	2.8E-05	4.1E-06	4.3E-05	9.7E-05	3.4E-05	0.1	6.6E-05
B-1-13	S-13	35	SM	0	75	25	0.022	0.07	0.09	0.1	4.5	0.36	0.015	5.8E-04	4.7E-04	5.8E-04	1.7E-04	4.4E-04	1.0E-03	5.5E-04	1.55	1.1E-03
Borings in Zone 3 - Eastern Section of Proposed Levee																						
B-3-13	S-2	2.5	ML	0	22	78	0.007	0.015	0.04	0.05	7.1	0.32	0.005	4.7E-05	2.9E-05	5.3E-05	1.2E-05	4.3E-05	3.0E-05	3.6E-05	0.101	7.0E-05
TP-9-13	S-2	3	ML	0	29	71	0.0055	0.015	0.04	0.055	10.0	0.29	0.003	2.4E-05	1.3E-05	3.0E-05	5.3E-06	2.7E-05	3.0E-05	2.1E-05	0.061	4.2E-05
TP-13-13	S-3	3.5	SP-SM	0	88	12	0.07	0.09	0.15	0.18	2.6	0.41	0.058	7.3E-03	8.1E-03	6.6E-03	2.6E-03	5.4E-03	1.9E-03	5.3E-03	15.040	1.0E-02
TP-15-13	S-2	3.5	SP-SM	0	94	6	0.1	0.14	0.22	0.3	3.0	0.40	0.082	1.4E-02	1.5E-02	1.3E-02	4.9E-03	1.1E-02	5.1E-03	1.0E-02	29.562	2.1E-02
TP-11-13	S-3	3.5	SP-SM	0	94	6	0.15	0.17	0.2	0.21	1.4	0.45	0.140	3.9E-02	5.6E-02	3.4E-02	1.6E-02	3.0E-02	8.0E-03	3.0E-02	85.973	6.0E-02
GP-08-10		5	SP-SM	1	92	7	0.13	0.15	0.24	0.29	2.2	0.42	0.112	2.6E-02	3.1E-02	2.3E-02	9.8E-03	2.0E-02	6.0E-03	1.9E-02	54.862	3.8E-02
TP-10-13	S-3	5	SW-SM	0	90	10	0.08	0.15	0.4	0.5	6.3	0.33	0.053	6.6E-03	4.4E-03	7.2E-03	1.7E-03	5.7E-03	6.0E-03	5.3E-03	14.872	1.0E-02
B-2-13	S-4	7.5	SP	1	95	4	0.15	0.25	0.5	0.65	4.3	0.37	0.111	2.8E-02	2.3E-02	2.7E-02	8.3E-03	2.2E-02	1.9E-02	2.1E-02	59.997	4.2E-02
GP-04-10		10	SP	1	97	2	0.2	0.33	0.6	0.7	3.5	0.39	0.152	5.4E-02	5.1E-02	5.1E-02	1.7E-02	3.9E-02	3.7E-02	4.1E-02	117.232	8.1E-02
B-3-13	S-6	12.5	SP	0	96	4	0.18	0.25	0.4	0.45	2.5	0.42	0.147	4.9E-02	5.5E-02	4.4E-02	1.8E-02	3.5E-02	1.9E-02	3.7E-02	103.632	7.2E-02
GP-03-10		14.5	SP	0	96	4	0.2	0.28	0.4	0.5	2.5	0.42	0.168	6.0E-02	6.8E-02	5.4E-02	2.2E-02	4.5E-02	2.5E-02	4.6E-02	129.313	9.0E-02
GP-03-10		21	SP	0	97	4	0.15	0.2	0.3	0.33	2.2	0.42	0.126	3.5E-02	4.2E-02	3.1E-02	1.3E-02	2.5E-02	1.2E-02	2.6E-02	74.735	5.2E-02
B-2-13	S-11	30	SP-SM	0	90	10	0.08	0.1	0.18	0.19	2.4	0.42	0.065	9.7E-03	1.1E-02	8.7E-03	3.6E-03	6.9E-03	2.4E-03	7.1E-03	20.127	1.4E-02
B-3-13	S-12	35	SM	1	66	33	0.007	0.03	0.13	0.15	21.4	0.26	0.003	2.9E-05	1.3E-05	3.9E-05	5.7E-06	6.3E-05	1.5E-04	4.9E-05	0.140	9.7E-05
B-2-13	S-13	40	ML	0	13	87	0.0025	0.008	0.035	0.04	16.0	0.27	0.001	4.0E-06	1.8E-06	5.5E-06	8.1E-07	6.7E-06	7.1E-06	4.3E-06	0.012	8.5E-06

Notes:

cm/sec = centimeters per second

ft/day = feetper day

ft/min = feet per minute

USBR = U.S. Bureau of Reclamation

USCS = Unified Soil Classification System

% = percent

TABLE B-3
SEEP/W MODEL SELECTED HYDRAULIC CONDUCTIVITY BY SOIL LAYER

ID	Sample	Depth (ft)	USCS	K (cm/sec)	K (ft/day)	K (ft/min)	Kz/Kh Ratio	Porosity	Formation	Averaged K (ft/day)
Borings in Zone 1 - Existing Levee										
B-9w-13	S-1	2	ML	1.24E-06	0.00	2.43E-06	0.5	0.25		
TP-37-13	S-3	3	SM	1.00E-03	2.83	1.97E-03	0.5	0.25		
TP-33-13	S-3	3.5	SM	6.63E-04	1.88	1.30E-03	0.5	0.25	Topsoil and	
TP-23-13	S-3	8.5	ML	6.68E-07	0.00	1.31E-06	0.5	0.25	Hm	1.18
B-8w-13	S-5	10	SP-SM	2.23E-02	63	4.39E-02	0.5	0.25		
B-8w-13	S-7	15	SP	5.00E-02	142	9.83E-02	0.5	0.25		
GP-02-10		15	SP-SM	2.27E-02	64	4.47E-02	0.5	0.25		
GP-01-10		16	SP	4.20E-02	119	8.25E-02	0.5	0.25		
GP-01-10	S-6	25	SP-SM	1.00E-02	28	1.97E-02	0.5	0.25		
GP-02-10		25	SP-SM	2.31E-02	65	4.54E-02	0.5	0.25	Ha	80
B-08-w13	Slug Test				192				Ha	192
									He	??
Borings in Zone 2 - Northern Section of Proposed Levee Along Interior Storage Pond										
TP-4-13	S-1	2	ML	5.30E-07	0.002	1.04E-06	0.5	0.25		
TP-6-13	S-2	2.5	ML	9.79E-06	0.03	1.92E-05	0.5	0.25		
TP-7-13	S-2	2.5	ML	1.56E-05	0.04	3.06E-05	0.5	0.25		
B-5w-13	S-13	3	ML	3.64E-06	0.01	7.15E-06	0.5	0.25		
TP-9-13	S-2	3	ML	2.15E-05	0.06	4.22E-05	0.5	0.25		
TP-3-13	S-2	3.5	ML	5.03E-06	0.01	9.89E-06	0.5	0.25	Topsoil and	
TP-8-13	S-3	4	ML	5.39E-05	0.15	1.06E-04	0.5	0.25	Hm	0.04
TP-5-13	S-2	3.5	SM	1.58E-03	4.46	3.10E-03	0.5	0.25		
TP-2-13	S-3	3.5	SP	9.82E-02	278	1.93E-01	0.5	0.25		
TP-11-13	S-3	3.5	SP-SM	3.04E-02	86	5.97E-02	0.5	0.25		
TP-10-13	S-3	5	SW-SM	5.26E-03	15	1.03E-02	0.5	0.25		
B-1-13	S-5	10	SP	2.90E-02	82	5.70E-02	0.5	0.25		
GP-06-10		10	SM	2.67E-02	76	5.24E-02	0.5	0.25		
B-4w-13	S-5	10.5	SP	2.62E-02	74	5.15E-02	0.5	0.25		
B-4w-13	S-6	12.5	SP-SM	2.27E-02	64	4.46E-02	0.5	0.25	Ha	85
B-06-w13	Slug Test				99				Ha	99
B-1-13	S-9	20	SM	3.35E-05	0.09	6.59E-05	0.5	0.25		
B-1-13	S-13	35	SM	5.48E-04	1.55	1.08E-03	0.5	0.25	He	0.82
Borings in Zone 3 - Eastern Section of Proposed Levee Along Dry Slough										
B-3-13	S-2	2.5	ML	3.56E-05	0.10	7.00E-05	0.5	0.25	Topsoil and	
TP-9-13	S-2	3	ML	2.15E-05	0.06	4.22E-05	0.5	0.25	Hm	0.08
TP-13-13	S-3	3.5	SP-SM	5.31E-03	15	1.04E-02	0.5	0.25		
TP-15-13	S-2	3.5	SP-SM	1.04E-02	30	2.05E-02	0.5	0.25		
TP-11-13	S-3	3.5	SP-SM	3.04E-02	86	5.97E-02	0.5	0.25		
GP-08-10		5	SP-SM	1.94E-02	55	3.81E-02	0.5	0.25		
TP-10-13	S-3	5	SW-SM	5.26E-03	15	1.03E-02	0.5	0.25		
B-2-13	S-4	7.5	SP	2.12E-02	60	4.17E-02	0.5	0.25		
GP-04-10		10	SP	4.14E-02	117	8.14E-02	0.5	0.25		
B-3-13	S-6	12.5	SP	3.66E-02	104	7.20E-02	0.5	0.25		
GP-03-10		14.5	SP	4.57E-02	129	8.98E-02	0.5	0.25		
GP-03-10		21	SP	2.64E-02	75	5.19E-02	0.5	0.25		
B-2-13	S-11	30	SP-SM	7.11E-03	20	1.40E-02	0.5	0.25	Ha	64
B-04-w13	Slug Test				128				Ha	128
B-3-13	S-12	35	SM	4.95E-05	0.14	9.73E-05	0.5	0.25		
B-2-13	S-13	40	ML	4.31E-06	0.01	8.46E-06	0.5	0.25	He	0.08

Notes:

cm/sec = centimeters per second; ft/day = feet per day; ft/min = feet per minute; ID = identification; USCS = Unified Soil Classification System

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TABLE B-4
SEEP/W MODEL RESULTS

Zone	Permeability[1]	Hydraulic Conductivities				Kz/Kh Ratio	Porosity	Water Level		Seepage - Flux			Velocity at Center of Levee	Gradient at Toe of Levee	Water Level at Center of Levee
		Dike Fill	Ag. Layer Hm	Ha	He			Bay Side	Land Side	Per linear ft	Levee Length	Entire Levee[2]			
		(ft/day)				All Material		(ft)		(ft^3/d/ft)	(ft)	gpm	(ft/day)	(ft/ft)	(ft)
Existing (Zone 1)	Low (k)	1.50	1.50	80	0.80	0.5	0.25	5.6	3.5	15.96	1100	91	0.70	0.04	4.00
	High (k)	3.60	3.60	192	1.92	1.20	0.25	5.6	3.5	40.60	1100	**232**	1.80	0.04	4.00
Northern (Zone 2)	Low (k)	1.50	0.04	85	0.80	0.5	0.25	5.85	3.50	1.32	2400	16	0.07	0.03	3.60
	High (k)	1.75	0.05	99	0.93	1.20	0.25	5.85	3.50	1.63	2400	**20**	0.08	0.01	3.60
Northern (Zone 2)	Low (k) - 2 ft of Hm at bottom of pond	1.50	0.04	85	0.80	0.5	0.25	5.85	3.50	1.09	2400	14	0.06	0.30	3.60
	High (k) - 2 ft of Hm at bottom of pond	1.75	0.05	99	0.93	1.20	0.25	5.85	3.50	1.35	2400	17	0.07	0.30	3.60
Eastern (Zone 3)	Low (k)	1.50	0.08	64	0.10	0.5	0.25	5.85	3.50	3.03	2900	46	0.15	0.01	3.60
	High (k)	3.00	0.16	128	0.20	1.20	0.25	5.85	3.50	6.61	2900	**100**	0.30	0.01	3.60

Notes:

[1] K was based on grain size analysis and slug test.

[2] Values in **BOLD** were used as seepage inflow to surface water hydrology and hydraulic models.

ft^3/d/ft = cubic feet per day per foot

ft/day = feet per day

gpm = gallons per minute

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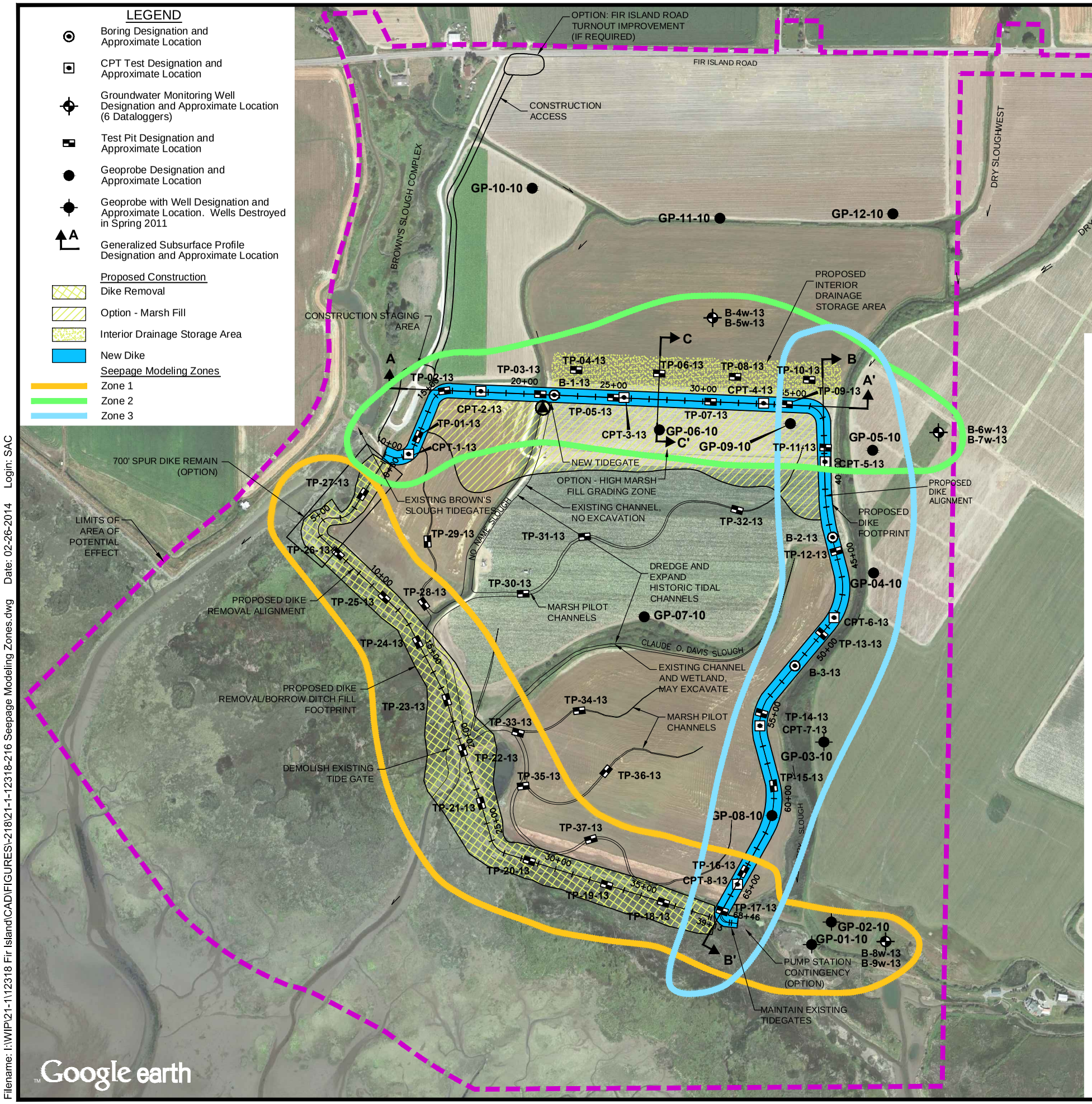

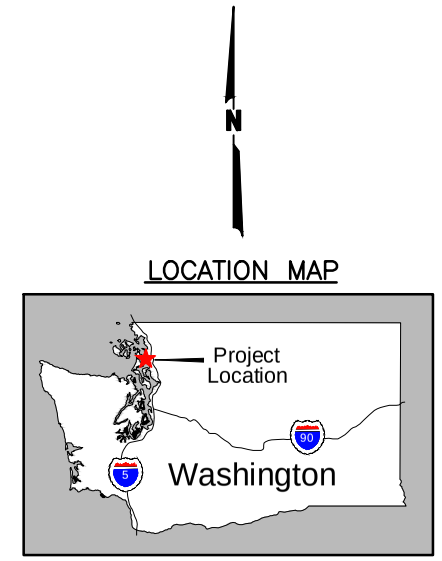

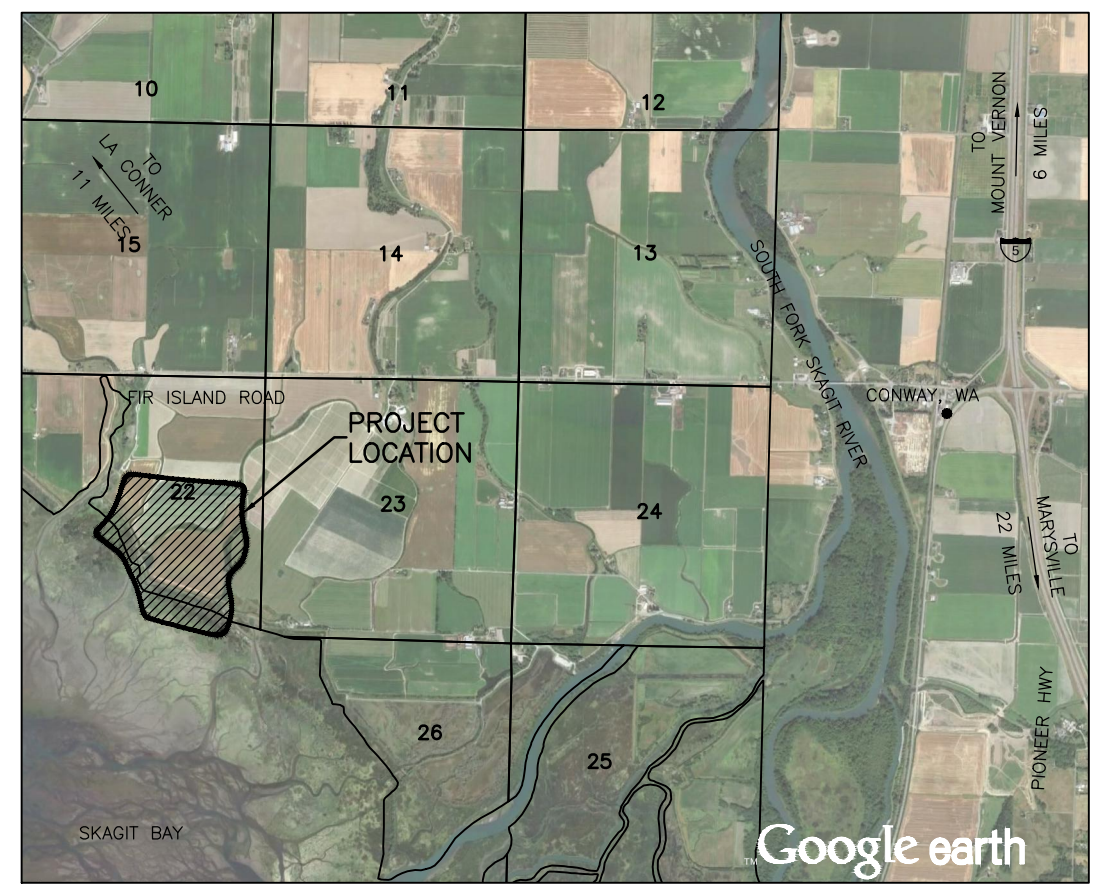

VICINITY MAP
SCALE: 1" = 2000'

0 600 1200
Scale in Feet

NOTE

This figure is adapted from *R004113c004.dwg*, dated December 2011. Aerial imagery provided by Google Earth Pro, reproduced by permission granted by Google Earth ™ Mapping Service.

Fir Island Farm Restoration
Skagit Wildlife Area
Skagit County, Washington

SEEPAGE MODELING ZONES

February 2014 21-1-12318-216

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FIG. B-1

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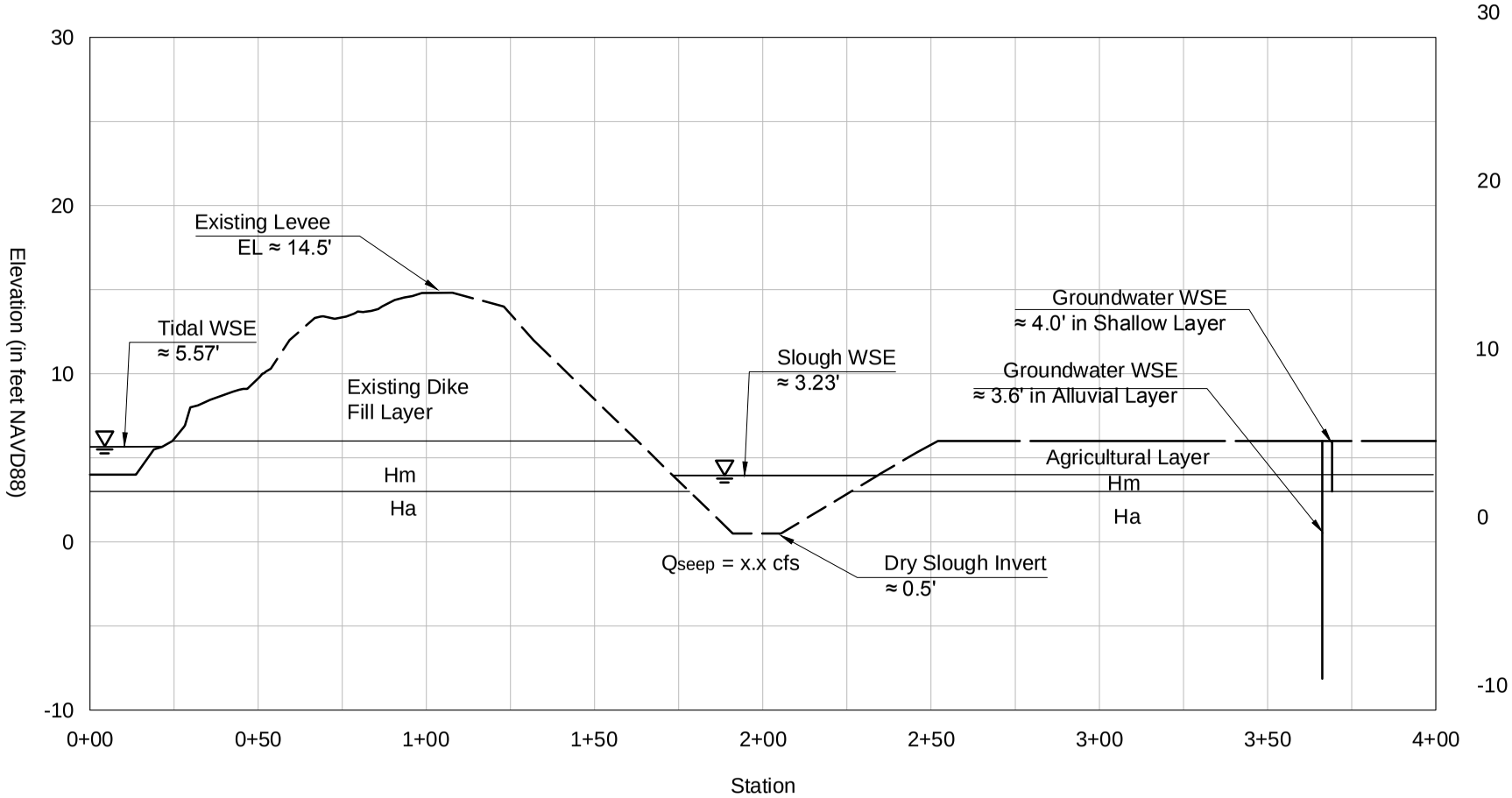

PROFILE VIEW

NOTES

1. Tidal WSE is based on average from NNS-2.0 for period 6-19-2013 through 10-9-2013
2. Slough WSE is based on average from NNS-2.1 for period 6-19-2013 through 10-9-2013
3. Groundwater WSE is based on average from B-8 and B-9 for period 6-19-2013 through 10-9-2013
4. Geologic profile is based on TP-18 and TP-19

Fir Island Snow Goose Preserve
Restoration Project
Skagit County, Washington

SEEPAGE ANALYSIS
EXISTING CONDITIONS
CALIBRATION RUN

February 2014 21-1-12318-216

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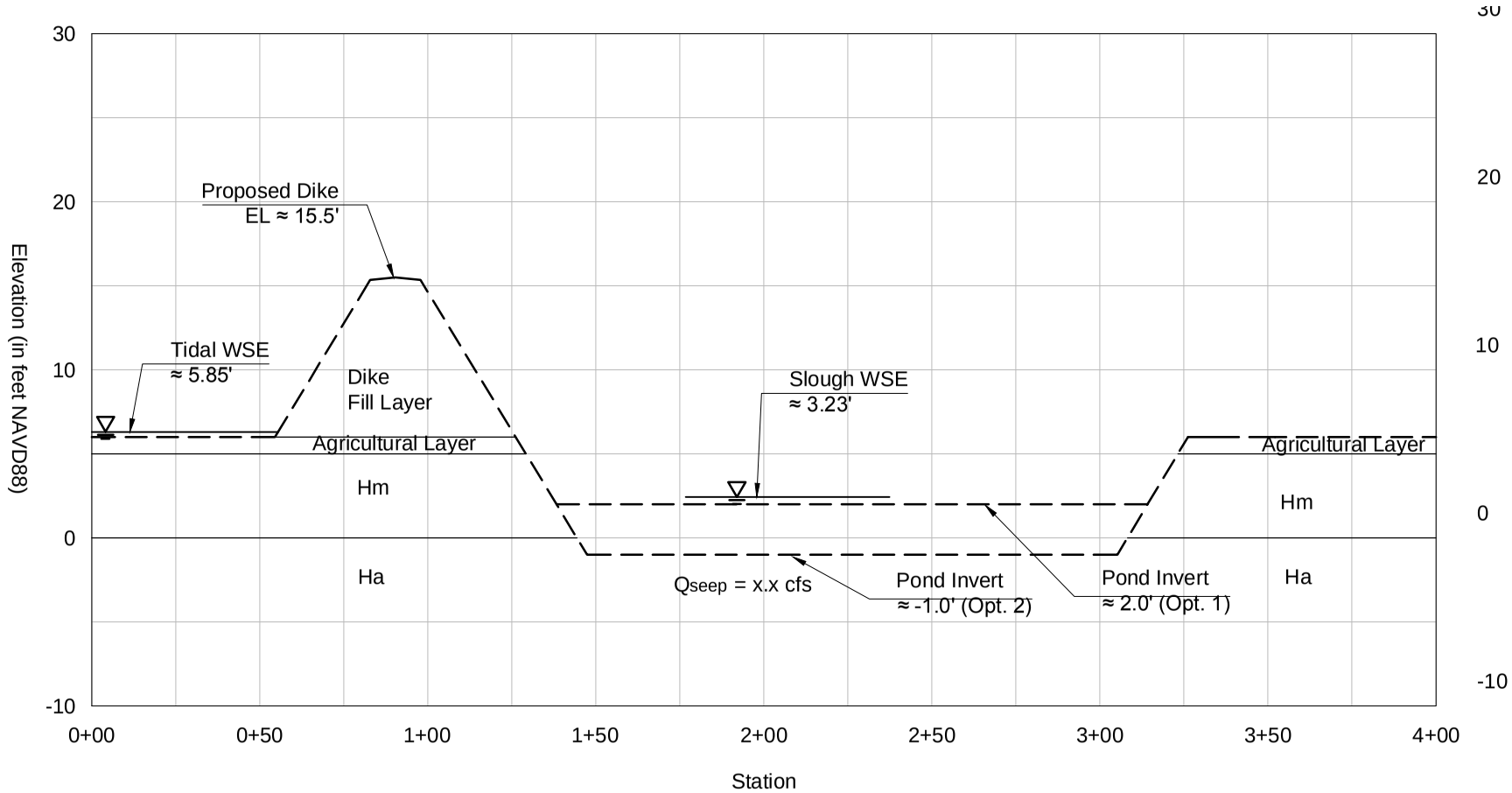
FIG. B-2

Filename: I:\WIP\21-1\12318 Fir Island\CAD\FIGURES\-216\21-1-12318-216-Fig_B-2 to B-4.dwg Date: 02-26-2014 Login: SAC



PROFILE VIEW

NOTES

1. Tidal WSE is based on average from NNS 2.0 for period 6-19-2013 through 10-9-2013, with troughs raised 0.75 feet based on Battelle modeling results
2. Slough WSE is based on average from NNS-2.1 for period 6-19-2013 through 10-9-2013
3. Groundwater WSE is based on average from B-8 and B-9 for period 6-19-2013 through 10-9-2013
4. Geologic profile is based on TP-18 and TP-19

Fir Island Snow Goose Preserve
Restoration Project
Skagit County, Washington

SEEPAGE ANALYSIS
PROPOSED CONDITIONS
STORAGE POND

February 2014 21-1-12318-216

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FIG. B-3

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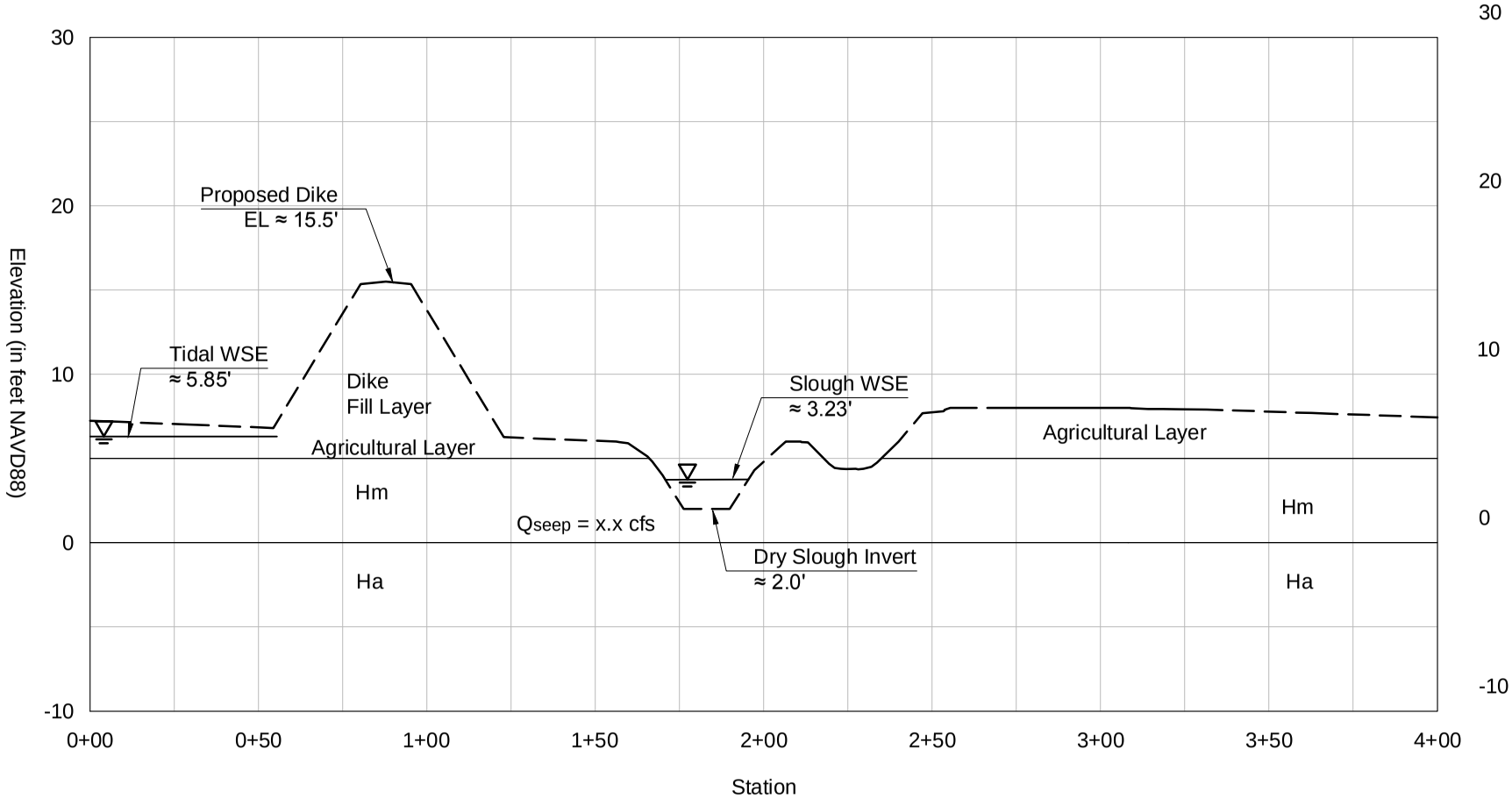

PROFILE VIEW

NOTES

1. Tidal WSE is based on average from NNS 2.0 for period 6-19-2013 through 10-9-2013, with troughs raised 0.75 feet based on Battelle modeling results
2. Slough WSE is based on average from NNS-2.1 for period 6-19-2013 through 10-9-2013
3. Groundwater WSE is based on average from B-8 and B-9 for period 6-19-2013 through 10-9-2013
4. Geologic profile is based on TP-18 and TP-19

Fir Island Snow Goose Preserve
Restoration Project
Skagit County, Washington

SEEPAGE ANALYSIS
PROPOSED CONDITIONS
DRY SLOUGH

February 2014 21-1-12318-216

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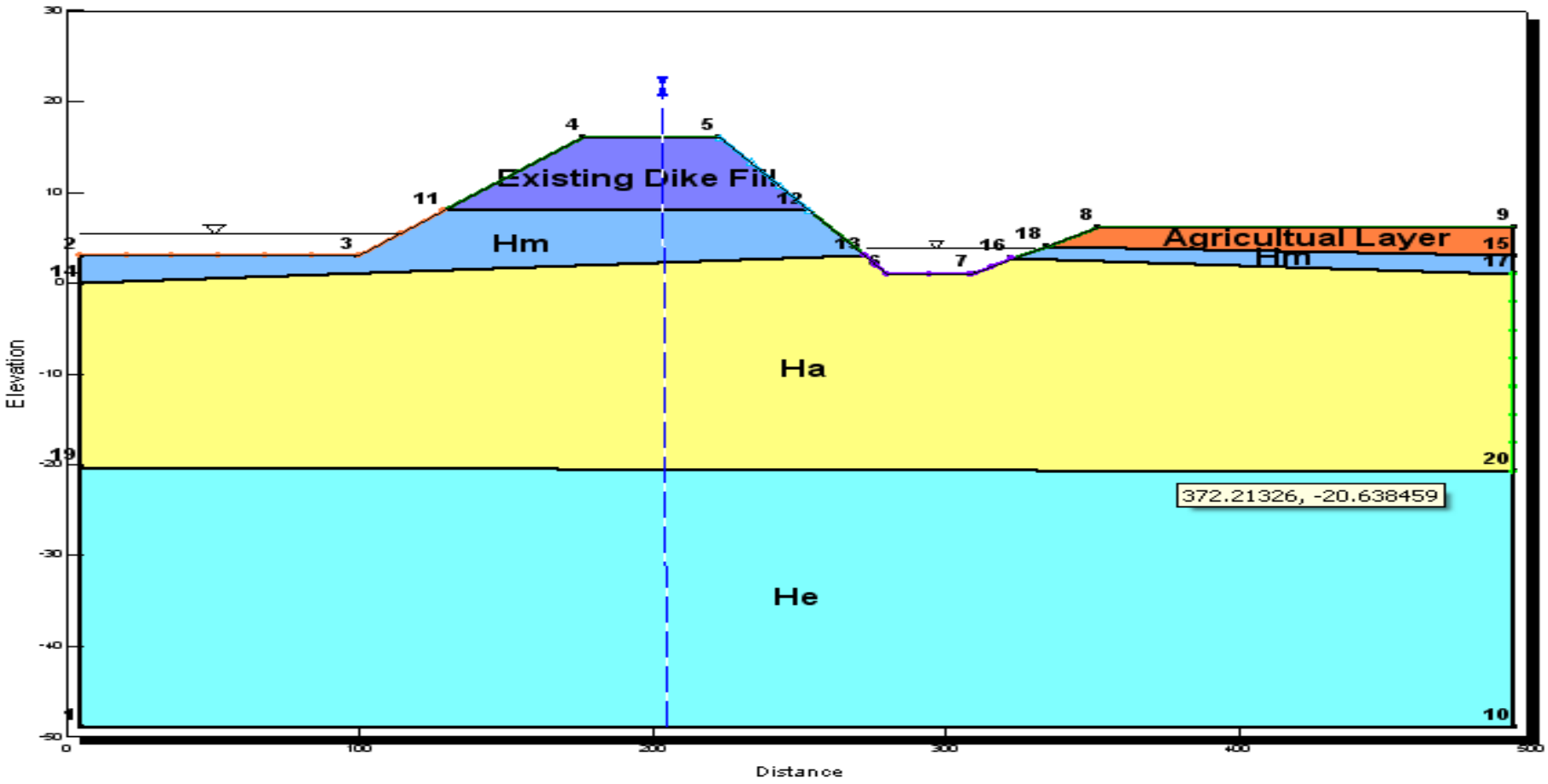
FIG. B-4



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Fir Island Farms Restoration

Skagit County, WA

SEEP/W
MODELED SOIL PROFILE
EXISTING LEVEE

February 2014 21-1-12318-216

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FIG. B-5

FIG. B-5

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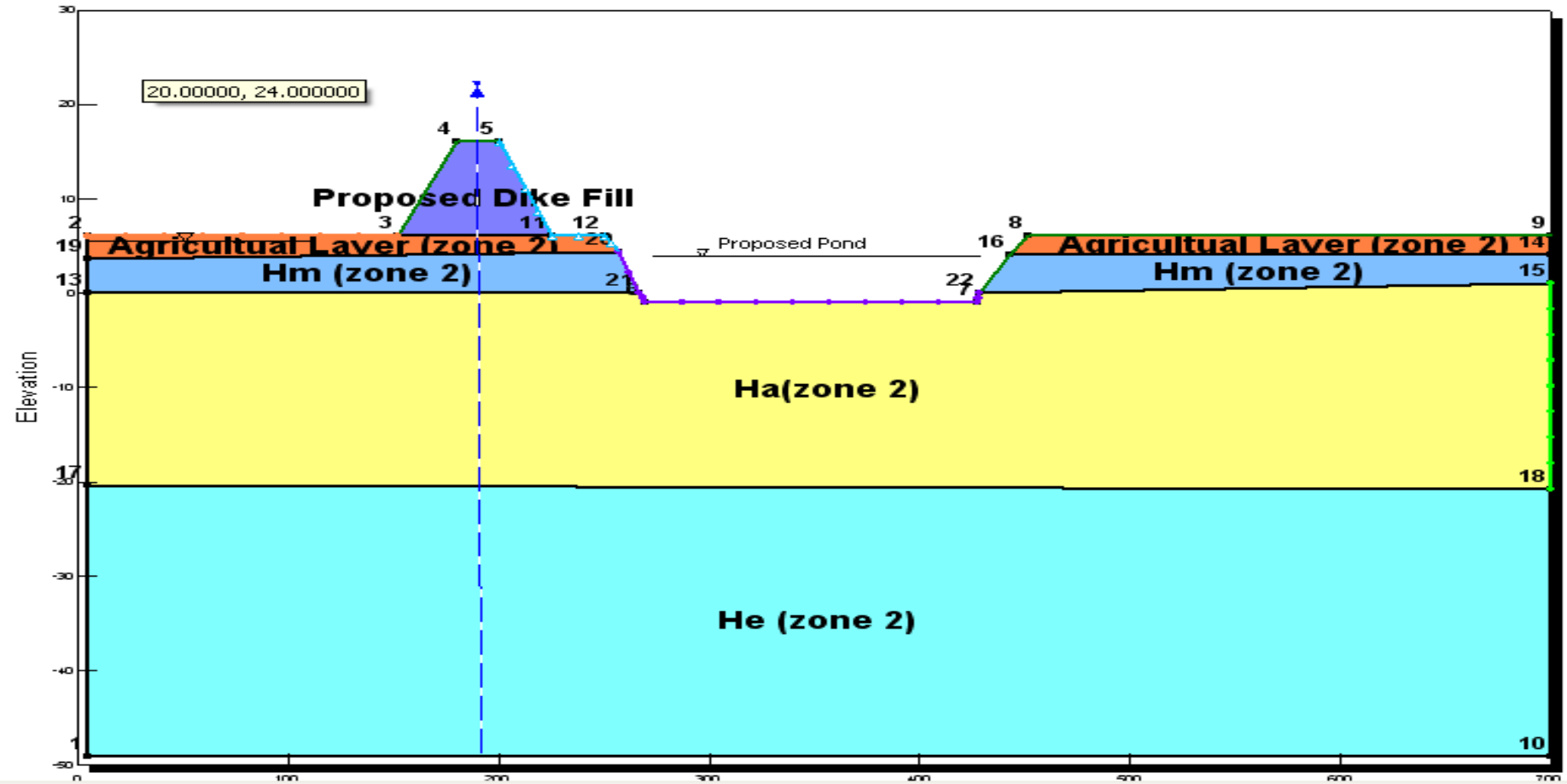

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Fir Island Farms Restoration

Skagit County, WA

SEEP/W
MODELED SOIL PROFILE
PROPOSED LEVEE N. SECTION

February 2014 21-1-12318-216

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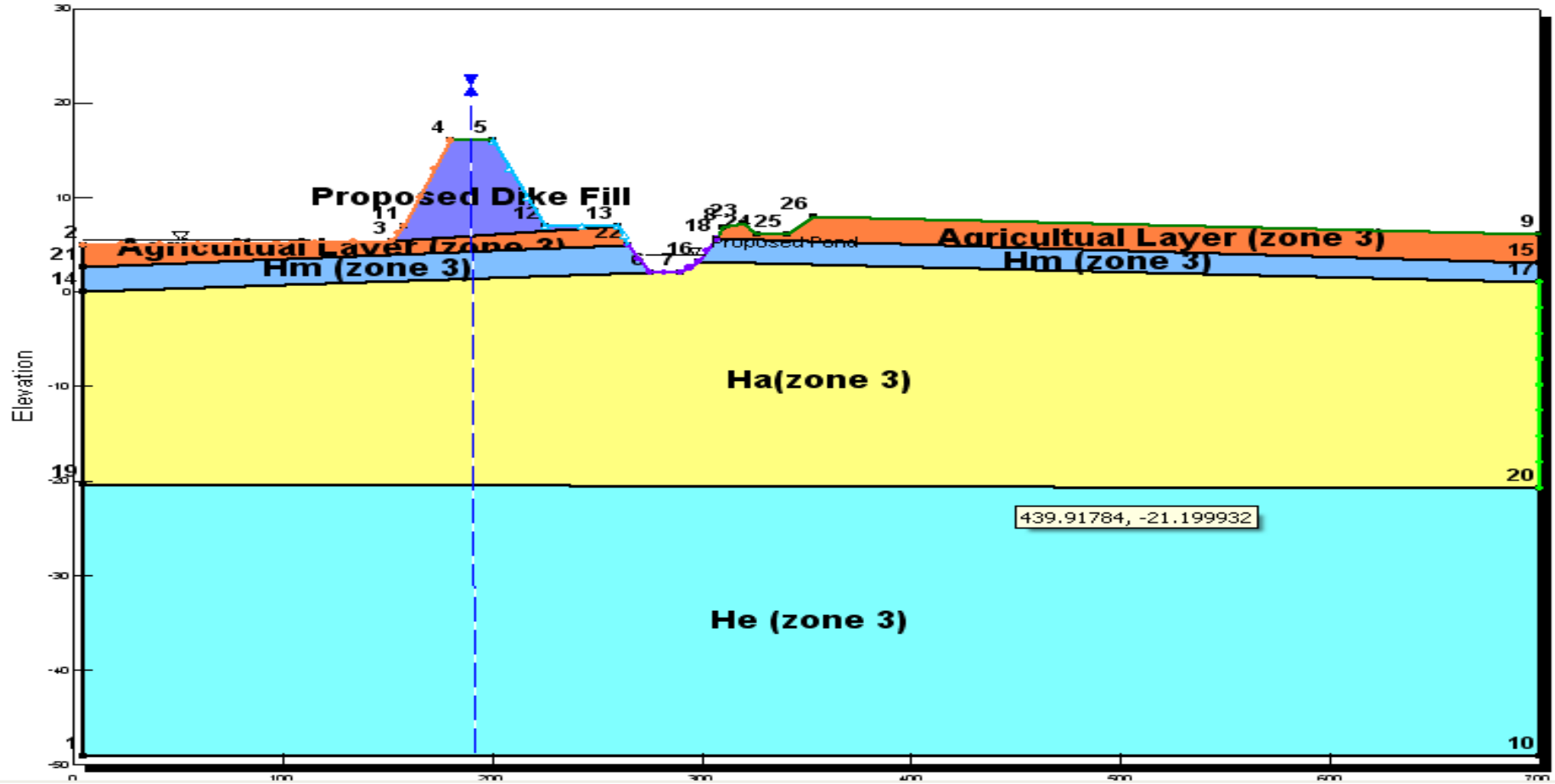
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

FIG. B-6

FIG. B-6

I:\WIP\21-1\12318 FIR ISLAND\216_GW-INT DRAINAGE\REPORT\21-1-12318-216-APP_B\21-1-12318-216-R1-Figs-AB.xlsx <FIGB6.SEEP-GEO-NORTH>



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Fir Island Farms Restoration

Skagit County, WA

SEEP/W
MODELED SOIL PROFILE
PROPOSED LEVEE E. SECTION

February 2014 21-1-12318-216

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FIG. B-7

FIG. B-7

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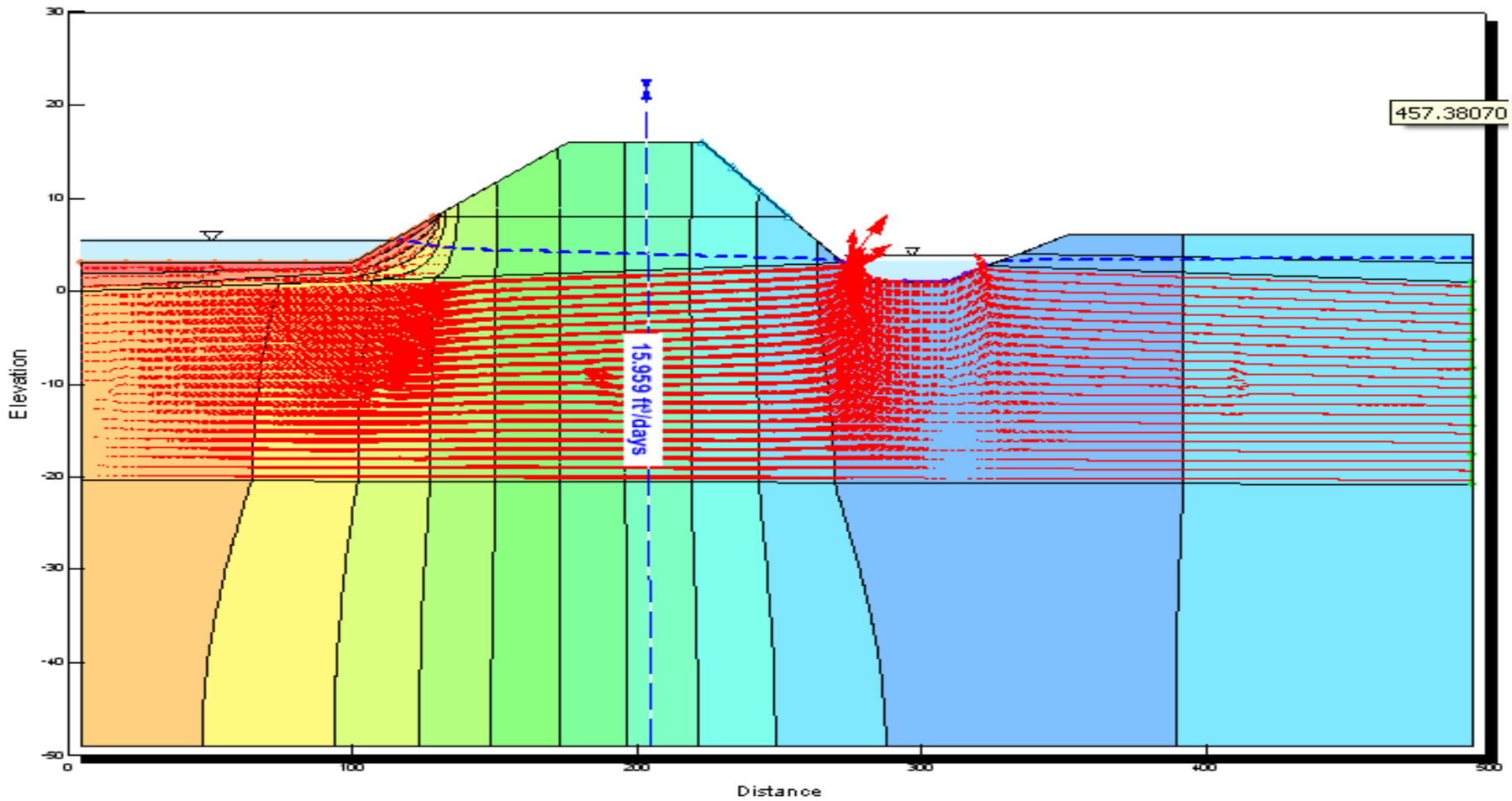

Notes:

Hydraulic Velocity Vectors Magnification = 5

→ Hydraulic Velocity Vector (ft/d)

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Fir Island Farms Restoration

Skagit County, WA

SEEP/W
MODELED SEEPAGE FLUX
EXISTING LEVEE

February 2014 21-1-12318-216

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GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

FIG. B-8

FIG. B-8

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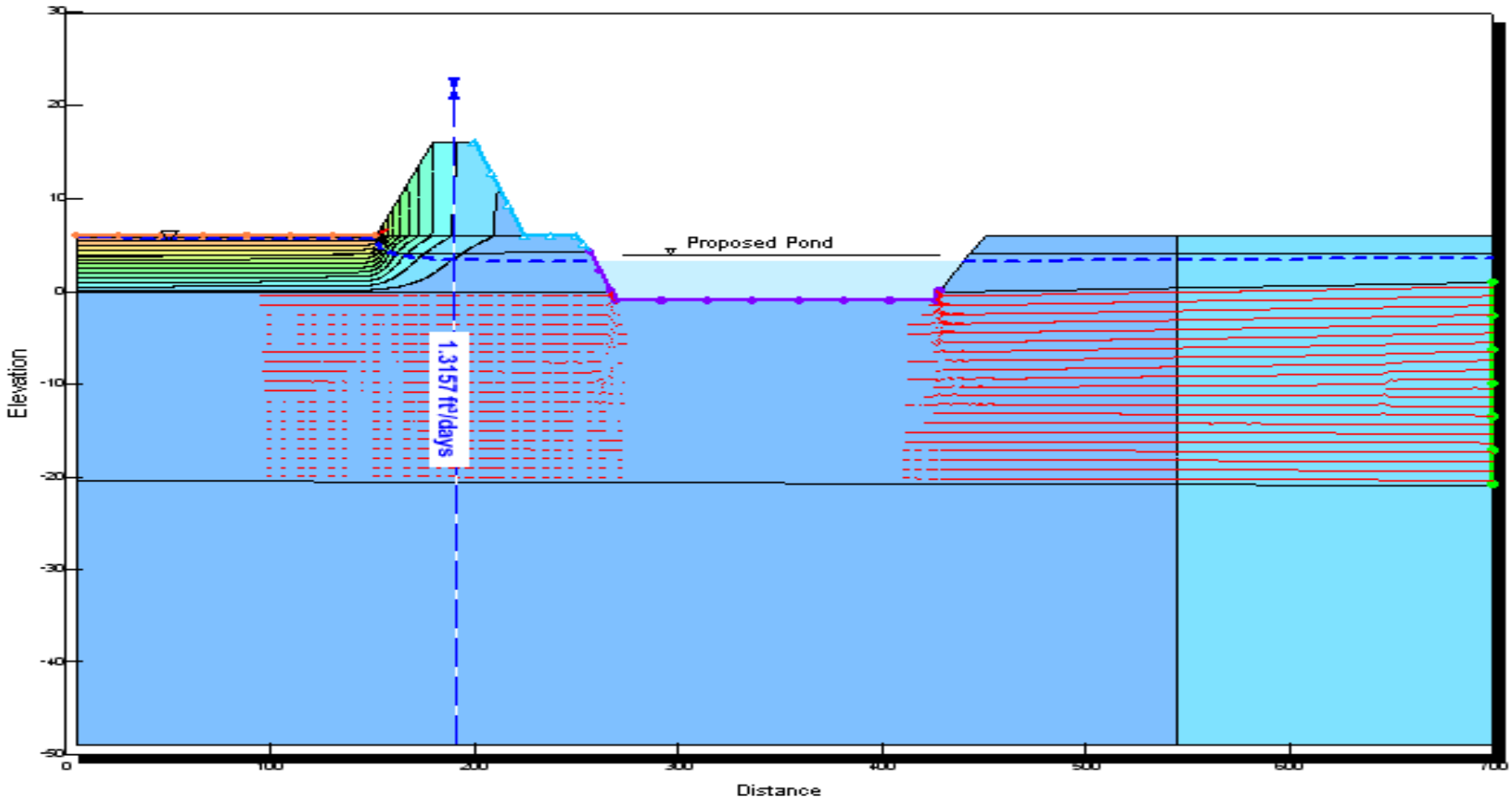

Notes:

Hydraulic Velocity Vectors Magnification = 5

Hydraulic Velocity Vector (ft/d)

Fir Island Farms Restoration

Skagit County, WA

MODELED SEEPAGE FLUX
PROPOSED LEVEE - N. SECTION

February 2014 21-1-12318-216

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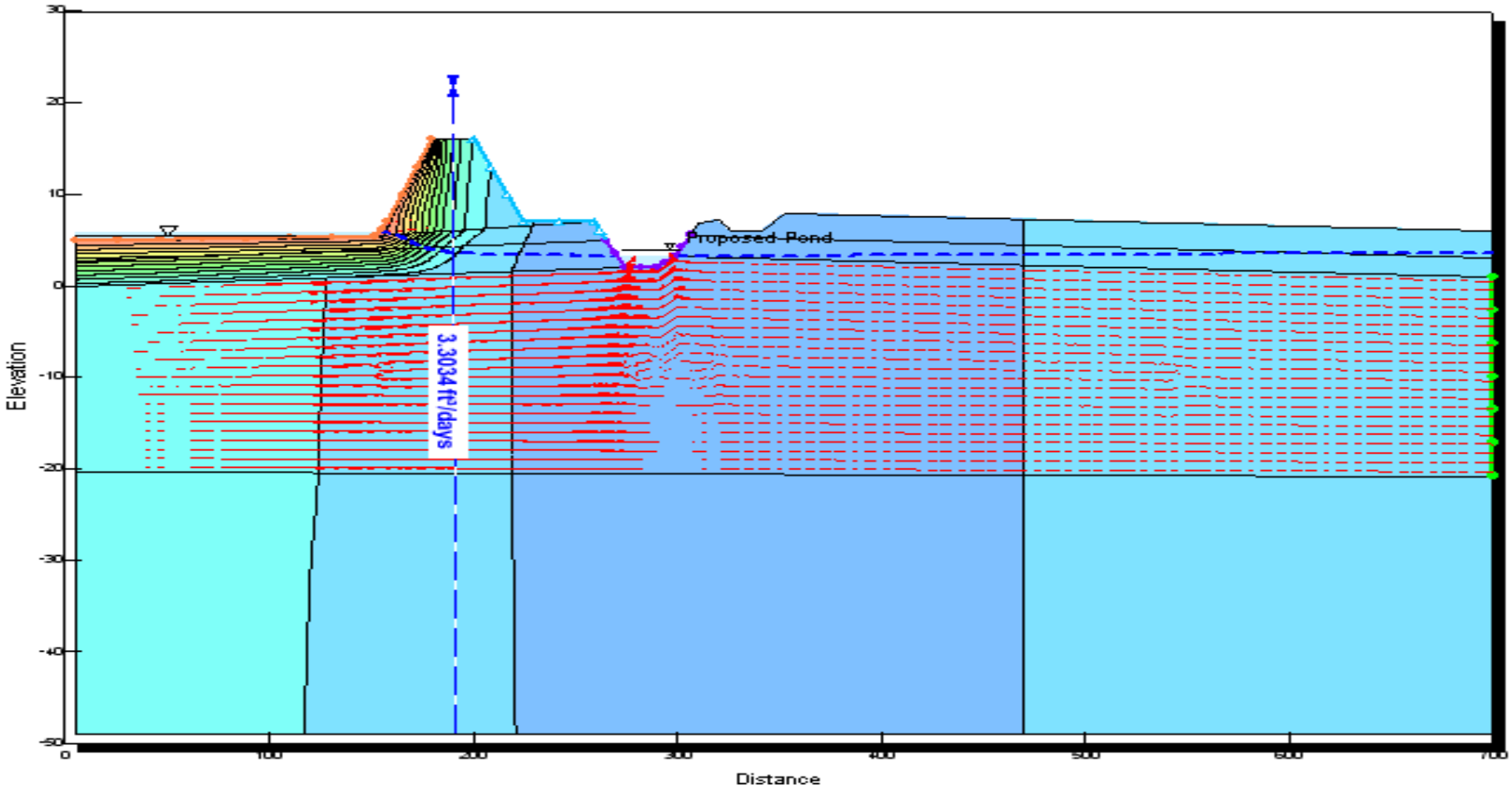
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

FIG. B-9

FIG. B-9

I:\WIP\21-1\12318 FIR ISLAND\216_GW-INT DRAINAGE\REPORT\21-1-12318-216-APP_B\21-1-12318-216-R1-Figs-AB.xlsx <FIGB9.SEEP-RESULT-NORTH>



Notes:

Hydraulic Velocity Vectors Magnification = 5

Hydraulic Velocity Vector (ft/d)

Fir Island Farms Restoration

Skagit County, WA

MODELED WATER FLUX
PROPOSED LEVEE
WEST SECTION

February 2014 21-1-12318-216

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FIG. B-10

FIG. B-10

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APPENDIX C

SURFACE WATER MODELING

APPENDIX C

SURFACE WATER MODELING

TABLE OF CONTENTS

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APPENDIX C

SURFACE WATER MODELING

Surface water modeling for the project involves hydrologic runoff modeling combined with hydraulic open channel flow modeling. These models are used to calculate interior drainage and pond water surface elevations that occur upstream from the system drainage tidegates. Existing "Without Project" and proposed "Project" conditions modeling was performed to compare average pond elevations and salinity conditions during key farm planting and growing seasons. The modeling analyses evaluated a 50-year levee and drainage lifecycle period of 2013 through 2063. A variety of factors was also analyzed as part of a sensitivity analysis. These factors include Sea Level Rise (SLR), marsh erosion, sedimentation and vegetation effects on drainage tailwater conditions, and possible changes to interior drainage pond vegetation and roughness conditions that may affect storage pond capacity over time with varying degrees of drainage maintenance.

C.1 HYDROLOGIC RUNOFF MODELING

Hydrologic runoff modeling of the drainage basins was performed using the Western Washington Hydrology Model 2012 (WWHM2012) (Figure 2 – main report). WWHM is a continuous-simulation hydrology model developed for Western Washington by the Washington Department of Ecology. The model utilizes 60 years of recorded rainfall data and is calibrated for typical watersheds in the region. The WWHM model was used to estimate surface water inflows to the No Name Slough and Dry Slough systems. Seepage inflows, discussed in Appendix B, were added as inflow to the surface water runoff flows to the interior drainage system. The seepage and groundwater inflow of 1 cubic foot per second was used and is based on hydrologic data collection and measurements of base flows during daily tidal cycles.

Brown Slough was not included in the study, as it was determined during the feasibility study that the primary effects that could occur in Brown Slough were associated with sedimentation and erosion in the Brown Slough tidal channel downstream from the tidegates. These conditions were evaluated in the Shannon & Wilson, Inc. (S&W) (2013) and Battelle (2013) Coastal Hydrodynamic Modeling and Coastal Engineering Recommendations Reports.

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C.1.1 Drainage Basin Delineations

Drainage basins were delineated for No Name Slough, Claude O. Davis Slough, and Dry Slough (East and West) using Light Detection and Ranging (LIDAR) topography data (Figure 2 – main report). The drainage basins were imported to Watershed Modeling Software 9.1 (WMS) (Aquaveo, LLC, 2013) and overlaid onto soils and land use geographic information system data. The land use data were obtained from Lakes Environmental Software (1983) and the soil data was obtained from the Natural Resources Conservation Service (NRCS) (2012), which generally matches the soil types and observed conditions made during S&W field data studies. WMS was used to calculate areas of combined land uses and soil types within each drainage basin. The resulting output from WMS was used to develop a WWHM2012 input file. Basin parameters and WWHM2012 inputs are summarized in Table C-1.

C.1.2 Western Washington Hydrology Model (WWHM) Modeling Results

The WWHM model provides continuous hydrologic runoff flow rate estimates, which were used as input to the hydraulic model for a 50-year time period. Table C-2 is a flood frequency annual exceedance table for the project's contributing and adjacent drainage basins.

C.2 INTERIOR DRAINAGE HYDRAULIC MODELING

An unsteady state HEC-RAS (U.S. Army Corps of Engineers [USACE], 2010) model was created for the No Name/Claude O. Davis Slough and Dry Slough interior drainage systems. HEC-RAS is a one-dimensional hydraulic analysis program designed to model flow through channels. The hydraulic model was used to evaluate the effects of the levee setback on drainage and storage conditions behind the levee. The original model setup and calibration was developed as part of the S&W Fir Island Farm Feasibility Study (S&W, 2011).

For this phase of study, "Without Project" and "Project" conditions were modeled over a 50-year time period to evaluate current and long-term effects on the interior drainage system and adjacent farm properties. A sensitivity analysis was performed by varying modeling parameters and boundary conditions to evaluate the effects of SLR, vegetation and sedimentation in the restored marsh, and vegetation and maintenance conditions on the interior drainage system. The sensitivity analyses includes both "Without Project" (i.e., a hypothetical future scenario where the project is not built) and "Project" conditions as described below.

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C.2.1 "Without Project" Conditions Model

The "Without Project" conditions HEC-RAS model geometry was developed using several available data sources, with the following corrections and adjustments:

- Floodplain geometry used data from a triangulated irregular network developed from LIDAR data collected in 2003 and made available by the Skagit River System Cooperative. S&W transformed the original data from North American Datum of 1927, National Geodetic Vertical Datum of 1929 to North American Datum of 1983, and North American Vertical Datum of 1988 (State Plane Washington North).
- Dry Slough East bathymetric and culvert data use Skagit Conservation District 2009 survey data adjusted to a NAVD88 vertical datum.
- Dry Slough West bathymetric and culvert data use general thalweg adjustments based on comparison of LIDAR and S&W, 2010 surveys of vegetated cross sections in the project area and surveys performed within the project study area. Upstream from Fir Island Road, channel thalweg adjustments and culvert sizes and locations are approximate as no survey data were available in these areas.
- No Name and Claude O. Davis Slough bathymetric and culvert data use general thalweg adjustments based on comparison of LIDAR and S&W, 2010 surveys of vegetated cross sections in the project area and surveys performed within the project study area. Upstream from Fir Island Road, channel thalweg adjustments and culvert sizes and locations are approximate only, as no survey data were available in these areas.

The model was set up to run for the 61-year time span of the WWHM model, which is September 1948 through September 2009. The modeling assumption is that land use and rainfall runoff characteristics for the 1948 through 2009 period will be similar going forward 50 years into the future. Daily inflow rates from the WWHM hydrology model were used as upstream inflow boundary conditions. Because the WWHM data only represent surface water flow, a base flow was added to the WWHM inputs to represent groundwater influences. The amount of the base flow estimated in the 2011 feasibility study was used in the model. The base flow estimates were made using surface water monitoring data. The base flow rates used in the model are higher than the seepage rates estimated from the SEEP-W modeling along the levee only. This is because they represent groundwater inflow along the length of the interior drainage channels, not just from seepage along the existing levee.

Boundary conditions on the downstream end of the model were created from tidal data at the site from October through December 2010 using a one-hour time step. The tidal data were then extrapolated out for the 61-year time period, to match the WWHM modeling period. This

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assumes typical tidal cycling and no storm surge conditions in the model. The model downstream boundary conditions were then adjusted for SLR only over the modeling period for the "Without Project" condition. More information regarding boundary condition adjustments is provided in the sensitivity analysis section of the report.

C.2.2 "Project" Conditions Model

The proposed conditions or "Project" conditions model was created by modifying the "Without Project" conditions model to reflect the revised geometry and seepage conditions of the existing levee removal and new setback levee with an interior drainage storage pond. The geometry was modified by moving the tidegates from the current No Name Slough and Davis Slough confluence at the levee upstream, to the proposed No Name Slough crossing location of the setback levee. An interior storage pond was added north of the setback levee. The size of this pond was determined in the 2011 feasibility study with the objective of reducing flood impacts to zero rise for the 25-year flood event. Claude O. Davis Slough was removed from the "Project" conditions model as the levee setback lies to the north of this channel.

Boundary condition adjustments for the "Project" condition model include the following items in the sensitivity analysis:

- Increase in low tide tailwater elevation of 0.75 foot, in accordance with the hydrodynamic effects identified in the Coastal Engineering Recommendations Report (S&W, 2014).
- Increase in seepage along the Dry Slough levee segment (east zone, station 37+00 to 67+00) to 100 gallons per minute. Maintain seepage rates No Name Slough from the site observed hydrologic monitoring of base flow conditions along the northern zone (station 22+00 to 37+00) levee segment along the interior storage pond. These are conservative assumptions and higher than the predicted SEEP/W seepage modeling results. The Dry Slough (east zone) addition was made using the maximum predicted seepage rate from the modeling, and the northern zone uses a seepage based on hydrologic observations that is higher than the seepage modeling predictions.
- Increase tailwater tidal conditions for a range of predicted SLR conditions based on the Coastal Engineering Recommendations Report (see Figure C-1).
- Modify tailwater tidal conditions for a range of predicted marsh erosion and sedimentation characteristics based on the Coastal Engineering Recommendations Report (see Table C-3).
- Reduce interior storage pond volumes for potential cattail (emergent) wetland vegetation growth and/or reduction of maintenance on the system over time.

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More information is provided below in the following sensitivity analysis section of the report.

C.2.1 Project Effects Evaluation Metrics

The key concern of the adjacent property owners and farmers is that the project will raise water surface elevations in the drainage ditches, thereby impacting farming on adjacent property. This study evaluated interior storage pond elevations during early spring (April) planting periods when groundwater tables are highest and most likely to impact planting operations and root zones.

Critical root zone depths depend upon crop types, soil type, drainage, and groundwater conditions. Crops grown on the adjacent Hayton Farm include strawberries, raspberries, blackberries, blueberries, and other berry crops such as marionberries and loganberries. Crops grown on the Washington Department of Fish and Wildlife Snow Goose Reserve property are subject to snow goose foraging winter crop rotations. Crops typically include spring-planted vegetable seed crops such as spinach, red beets, and radish, or annual summer crops such as potatoes and broccoli. Root zone depths for the crops listed above range from 6 to 18 inches (NRCS, 2005). The study selected a critical root zone depth of 24 inches (2 feet) to conservatively estimate potential groundwater effects on adjacent farm properties and crops.

The second aspect of the root zone criteria is the duration of root zone inundation. The study assumes that crops can withstand minor increases in root zone inundation. The inundation criteria selected increase the period of inundation of the critical root zone elevation by more than 10 percent of the month (three to four days) during April, comparing “Without Project” to “Project” conditions. If the inundation period increases by more than 10 percent, it would be flagged as a “Project” effect.

Figure C-2 shows the upstream and adjacent farm areas that may be affected by changes in the interior drainage average April (or early spring) water surface elevations. The “Project” root zone criteria were flagged when the pond water elevations exceed the critical root zone elevation criteria, and when the inundation period increases more than 10 percent of the time as compared to the “Without Project” condition.

Increases in pond and ditch salinity are the second project metric being evaluated for potential farm and property effects. If salinity increases in the pond and ditches, and water surface elevations are above the critical root zone elevation, then there may be project effects. The study considers salinity a secondary (or dependent) criterion because salinity levels in the

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existing ditches are fairly high and, for impacts to occur, the groundwater elevations need to be higher than the critical root zone elevation criteria. Typically, farm drainage operations focus on keeping the groundwater table low rather than preventing salt water intrusion.

C.2.2 Hydraulic Modeling Results – Storage Pond Water Surface Elevations

The hydraulic modeling results for SLR scenarios and effects in No Name Slough are summarized in Tables C-4 and C-5. The project effects are limited primarily to No Name Slough, as this is the location subject to the tidal hydrodynamic effect and the sensitivity parameters discussed in Appendix D. Seepage effects are not great enough alone to result in effects on adjacent and upstream farm areas in No Name Slough. Dry Slough will not likely have the same tidal hydrodynamic or sensitivity factor effects, as it is mostly isolated. Minor increases in seepage can be accommodated by an additional 48-inch tidegate to the existing drainage system.

These results indicate that the proposed project will likely increase storage pond water surface elevations in No Name Slough and have an effect on farm properties in the No Name Slough Basin, for "Project" conditions. The results show that farm properties will be affected by SLR for both "Without Project" and "Project" conditions. However, the "Project" SLR and hydrodynamic conditions could have effects on an additional 106 acres in 2013 and 319 acres in 2063. This is 11 to 32 percent of the drainage basin farm properties. These effects do not consider the uncertainty associated with the SLR estimates or the key sensitivity factors such as marsh erosion and sedimentation, and storage pond capacity conditions discussed further in Appendix D.

C.2.3 Salinity

A mass balance model was used to estimate salinity effects on the interior drainage storage pond. The mixing parameters included seepage inflow rates along the length of the "Without Project" and "Project" levee sections, base flow groundwater inflows to the storage pond, and average Skagit Bay and No Name Slough salinity concentrations recorded during the 2013 data-collection period. The calculation estimates that salinities in the pond will be slightly lower (Table C-6).

Decreases in seepage rates are based on the observations, and sampling and testing of soil properties along the existing levee and the proposed levee setback alignment. This finding indicates that concerns regarding salinity may not be a major factor and that the primary concern should be focused on limiting effects on storage pond water surface elevations only. It should be

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noted that the proposed project objectives are to generally maintain groundwater levels below the root zone of the field, which incidentally mitigates salinity impacts. Another item to note is that observed salinity levels in the No Name Slough ditch are relatively high for the current "Without Project" condition. Farming persists in the area and is sustained by keeping ditch water surface and groundwater elevations low enough to protect the crop root zones. This topic is related to seepage related questions made by Consolidated Diking District 22, and requests for additional review of project levee seepage estimates and the need to evaluate seepage cutoff measures.

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TABLE C-1
DRAINAGE BASIN PARAMETERS

Basin	Soil Type	Land Use Description	WWHM Category	Area (acres)
No Name Slough	B	Cropland and Pasture	A/B, Pasture, Flat	857.7
	C	Streams and Canals	Pond	35.3
	C	Cropland and Pasture	C, Pasture, Flat	60
	B	Nonforested Wetlands	Saturated, Pasture, Flat	4.2
	B	Streams and Canals	Pond	3.5
	D	Cropland and Pasture	Saturated, Pasture, Flat	0.4
		Total		**961.1**
Claude O Davis Slough	B	Nonforested Wetlands		3.7
	B	Cropland and Pasture		42
		Total		**45.7**
Dry Slough West	C	Streams and Canals	Pond	51
	B	Cropland and Pasture	A/B, Pasture, Flat	813.8
	C	Cropland and Pasture	C, Pasture, Flat	97.9
	B	Residential	B, Lawn, Flat	4.9
	B	Streams and Canals	Pond	7
	C	Residential	C, Lawn, Flat	1.1
	D	Cropland and Pasture	Saturated, Pasture, Flat	0.4
		Total		**976.1**
Dry Slough East	B	Nonforested Wetlands	Saturated, Pasture, Flat	6.4
	B	Cropland and Pasture	A/B, Pasture, Flat	198.1
	D	Cropland and Pasture	Saturated, Pasture, Flat	11.4
	C	Cropland and Pasture	C, Pasture, Flat	120.4
	C	Residential	C, Lawn, Flat	19.2
	B	Residential	A/B, Lawn, Flat	4.3
	C	Other Agricultural Land	C, Pasture, Flat	2.5
	C	Streams and Canals	Pond	24.5
		Total		**386.7**

Note:

WWHM = Western Washington Hydrology Model

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TABLE C-2
WESTERN WASHINGTON HYDROLOGY MODEL VERSION 3 - FLOOD FREQUENCY OUTPUT

Return Interval - Annual Exceedance (%)	Flow Rate (cfs)			
	No Name Slough	Claude O. Davis	Dry Slough West	Dry Slough East
2-year (50%)	14.2	0.0	21.3	10.4
5-year (20%)	19.9	0.1	29.8	15.4
10-year (10%)	24.0	0.1	36.1	19.5
25-year (4%)	29.9	0.1	45.0	25.6
50-year (2%)	34.7	0.1	52.3	31.0
100-year (1%)	39.9	0.2	60.3	37.2

Note:

cfs = cubic feet per second

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TABLE C-3
SEA LEVEL RISE VALUES

Year	SLR - Low[1,2] (feet)	SLR - Average[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 linearly interpolated for years 2013, 2033, and 2063 from published NAS values in years 2000, 2030, 2050, and 2100.

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TABLE C-4
HYDRAULIC MODEL OUTPUT
INTERIOR POND AVERAGE (APRIL) AND MAXIMUM WATER SURFACE ELEVATIONS

2013	Without Project	Project	Change	Without Project	Project	Change	Without Project	Project	Change
	Low			Average			High		
SLR (ft)	0.0	0.0	n/a	0.1	0.1	n/a	0.2	0.2	n/a
Average WSE (ft)	3.3	4.1	0.8	3.4	4.2	0.8	3.5	4.3	0.9
Maximum WSE (ft)	3.8	4.7	0.9	3.9	4.8	0.9	4.0	4.9	0.9
2033	**Low**			**Average**			**High**		
SLR (ft)	0.1	0.1	n/a	0.3	0.3	n/a	0.5	0.5	n/a
Average WSE (ft)	3.4	4.2	0.8	3.6	4.4	0.9	3.8	4.6	0.9
Maximum WSE (ft)	3.9	4.8	0.9	4.1	5.0	0.9	4.3	5.1	0.8
2063	**Low**			**Average**			**High**		
SLR (ft)	0.5	0.5	n/a	0.9	0.9	n/a	1.5	1.5	n/a
Average WSE (ft)	3.8	4.6	0.9	4.2	5.0	0.8	4.8	5.6	0.8
Maximum WSE (ft)	4.3	5.1	0.8	4.7	5.5	0.8	5.2	5.9	0.7

Notes:

ft = foot

n/a = not applicable

SLR = sea level rise

WSE = water surface elevation

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TABLE C-5
HYDRAULIC MODELING RESULTS - 2 FEET CRITICAL ROOT ZONE FARM AREA EFFECTS

Field	Model Node	Elevation Range Low (ft)	Elevation Range High (ft)	Critical Root Zone Depth (ft)	Field Elevation (ft)	Field Elevation Area (acres)	% Total Area	2013 Average SLR % of Time Exceeded (April) w/o Project SLR Only 5.4 ft	2013 Average SLR % of Time Exceeded (April) Project SLR+Hyd 6.2 ft	2013 Average SLR % of Time Exceeded (April) Increase %	2013 Average SLR Area Affected (acres)	2063 Average SLR % of Time Exceeded (April) w/o Project SLR Only 6.2 ft	2063 Average SLR % of Time Exceeded (April) Project SLR+Hyd 7.0 ft	2063 Average SLR % of Time Exceeded (April) Increase %	2063 Average SLR Area Affected (acres)
North Field #2	NNS XS 11193	6	6.5	2	4	18.4	6%	35%	100%	65%	18.4	100%	100%	0%	0.0
		6.5	7		4.5	32.7	11%	2%	21%	19%	32.7	39%	100%	61%	32.7
		7	7.5		5	51.1	18%	0%	1%	0%	0.0	1%	100%	99%	51.1
		7.5	8		5.5	52.7	18%	0%	0%	0%	0.0	0%	1%	1%	0.0
		8	8.5		6	33.2	12%	0%	0%	0%	0.0	0%	0%	0%	0.0
		8.5	9		6.5	25.7	9%	0%	0%	0%	0.0	0%	0%	0%	0.0
		9	9.5		7	22.9	8%	0%	0%	0%	0.0	0%	0%	0%	0.0
		9.5	10		7.5	14.3	5%	0%	0%	0%	0.0	0%	0%	0%	0.0
		10	12		8	28.6	10%	0%	0%	0%	0.0	0%	0%	0%	0.0
North Field #1	NNS XS 6622	6	6.5	2	4	26.1	6%	0%	100%	100%	26.1	91%	100%	9%	0.0
		6.5	7		4.5	62.7	15%	0%	0%	0%	0.0	3%	100%	97%	62.7
		7	7.5		5	93.8	23%	0%	0%	0%	0.0	0%	58%	58%	93.8
		7.5	8		5.5	105.3	26%	0%	0%	0%	0.0	0%	0%	0%	0.0
		8	8.5		6	68.9	17%	0%	0%	0%	0.0	0%	0%	0%	0.0
		8.5	9		6.5	32.5	8%	0%	0%	0%	0.0	0%	0%	0%	0.0
		9	9.5		7	5.7	1%	0%	0%	0%	0.0	0%	0%	0%	0.0
WDFW Field	NNS XS 3386	6	6.5	2	4	2.6	2%	0%	100%	100%	2.6	89%	100%	11%	2.6
		6.5	7		4.5	19.1	17%	0%	0%	0%	0.0	3%	100%	97%	19.1
		7	7.5		5	57.1	51%	0%	0%	0%	0.0	0%	55%	55%	57.1
		7.5	8		5.5	25.2	23%	0%	0%	0%	0.0	0%	0%	0%	0.0
		8	8.5		6	5.0	4%	0%	0%	0%	0.0	0%	0%	0%	0.0
Hayton North	DS XS 4899	6.5	7	2	4.5	1.0	2%	25%	37%	12%	1.0	90%	94%	4%	0.0
		7	7.5		5	5.7	14%	1%	1%	0%	0.0	4%	7%	2%	0.0
		7.5	8		5.5	18.5	45%	0%	0%	0%	0.0	0%	0%	0%	0.0
		8	8.5		6	10.2	25%	0%	0%	0%	0.0	0%	0%	0%	0.0
		8.5	9		6.5	1.9	5%	0%	0%	0%	0.0	0%	0%	0%	0.0
		9	9.5		7	1.4	3%	0%	0%	0%	0.0	0%	0%	0%	0.0
		9.5	10		7.5	0.8	2%	0%	0%	0%	0.0	0%	0%	0%	0.0
Hayton Mid-North	DS XS 4899	5.5	6	2	3.5	4.2	5%	100%	100%	0%	0.0	100%	100%	0%	0.0
		6	6.5		4	18.6	20%	100%	100%	0%	0.0	100%	100%	0%	0.0
		6.5	7		4.5	25.5	28%	25%	37%	12%	25.5	90%	94%	4%	0.0
		7	7.5		5	24.5	27%	1%	1%	0%	0.0	4%	7%	2%	0.0
		7.5	8		5.5	10.3	11%	0%	0%	0%	0.0	0%	0%	0%	0.0
		8	8.5		6	5.2	6%	0%	0%	0%	0.0	0%	0%	0%	0.0
		8.5	9		6.5	2.1	2%	0%	0%	0%	0.0	0%	0%	0%	0.0
Hayton South	DS XS 996	4.5	5	2	2.5	1.5	2%	100%	100%	0%	0.0	100%	100%	0%	0.0
		5	5.5		3	5.1	7%	97%	98%	0%	0.0	100%	100%	0%	0.0
		5.5	6		3.5	20.0	27%	66%	67%	1%	0.0	100%	100%	0%	0.0
		6	6.5		4	31.5	43%	34%	37%	3%	0.0	93%	93%	0%	0.0
		6.5	7		4.5	11.5	16%	6%	9%	3%	0.0	50%	52%	3%	0.0
		7	7.5		5	2.4	3%	0%	0%	0%	0.0	3%	4%	2%	0.0
Total						985.7				11%	106.3			32%	319.1

Note:
ft = foot
SLR = sea level rise
% = percent

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TABLE C-6
SALINITY MIXING
MASS BALANCE MODEL RESULTS

No Name Slough

Scenario	Tidal Seepage (cfs)	Tidal Seepage (ppt)	Upstream Baseflow (cfs)	Upstream Baseflow (ppt)	Total Flow (cfs)	Average Salinity at Tidegate (ppt)
Existing						
Low	0.20	20	1.00	7.2	1.20	9.4
High	0.52	25	1.00	7.2	1.52	13.3
Proposed						
Low	0.04	20	1.00	7.2	1.04	7.6
High	0.04	25	1.00	7.2	1.04	8.0

Dry Slough

Scenario	Tidal Seepage (cfs)	Tidal Seepage (ppt)	Upstream Baseflow (cfs)	Upstream Baseflow (ppt)	Total Flow (cfs)	Avg Salinity at Tidegate (ppt)
Existing						
Low	0.20	20	1.00	7.2	1.20	9.3
High	0.30	25	1.00	7.2	1.30	11.3
Proposed						
Low	0.10	20	1.00	7.2	1.10	8.4
High	0.22	25	1.00	7.2	1.22	10.4

Notes:

cfs = cubic feet per second

ppt = parts per thousand

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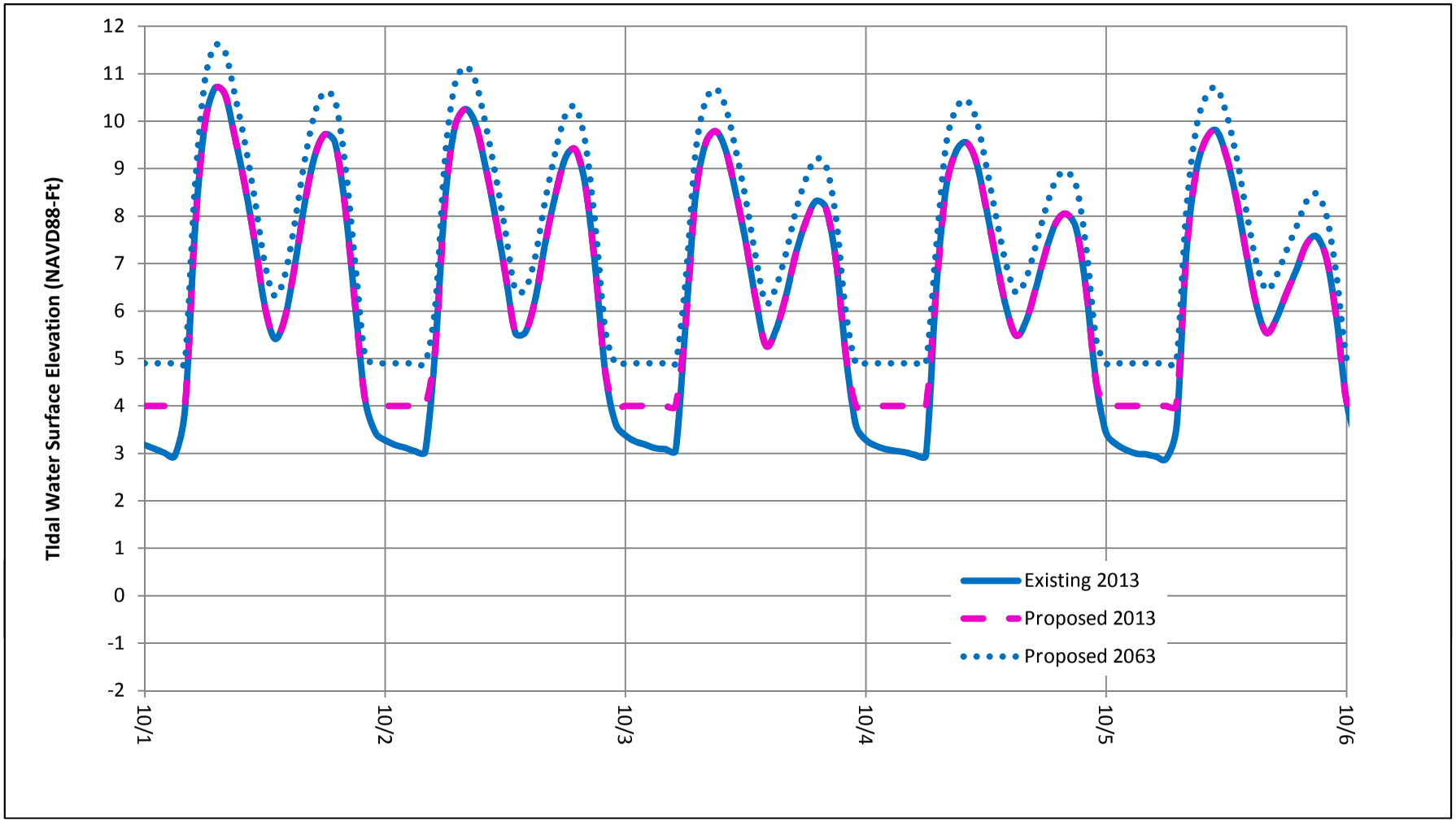

Date

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Fir Island Farms Restoration

Skagit County, WA

Without Project SLR and With Project SLR and Hydrodynamic Effect

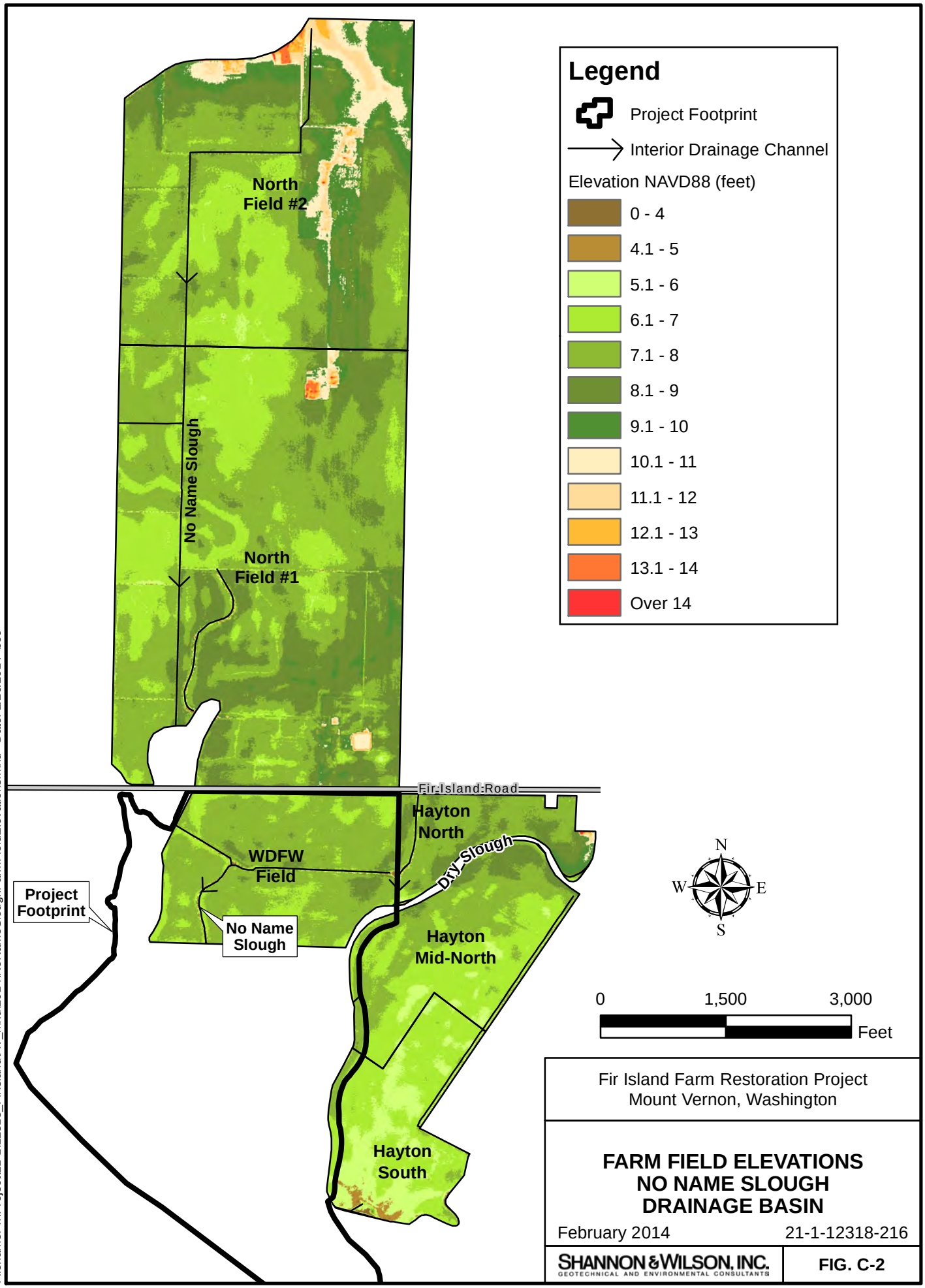
February 2014 21-1-12318-216

SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

Fig. C-1

Fig. C-1

I:\WIP\21-1\12318 FIR ISLAND\216_GW-INT DRAINAGE\REPORT\21-1-12318-216-APP_C\21-1-12318-216-R1-Fig-C-1.xlsx <FIG_C1>



Fir Island Farm Restoration Project
Mount Vernon, Washington

FARM FIELD ELEVATIONS
NO NAME SLOUGH
DRAINAGE BASIN

February 2014 21-1-12318-216

SHANNON & WILSON, INC.
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FIG. C-2

Filename: T:\Project\21-1\12318_FirIsland\AV_mxd\2014\NoNameSloughFarmFieldElevations.mxd Date: 2/26/2014 beo

APPENDIX D

SENSITIVITY ANALYSIS

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APPENDIX D

SENSITIVITY ANALYSIS

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APPENDIX D

SENSITIVITY ANALYSIS

A sensitivity analysis was performed on the interior drainage system, to evaluate the effects of coastal hydrodynamics, marsh erosion, sedimentation and vegetation, and interior storage pond vegetation and maintenance conditions on its performance. The sensitivity analysis considers how changes in these conditions may occur over a design life period of 50 years. The study uses a Monte Carlo analysis to perform the sensitivity analysis.

D.1 MONTE CARLO METHOD

The Monte Carlo method is a statistical technique used to model the range of expected sensitivity factors (inputs) to characterize the uncertainty of the pond water surface elevation (output). For the Fir Island project, three key sensitivity factors of concern are assumed. These factors are the most likely to affect the interior drainage and storage pond water surface elevations, and the adjacent groundwater elevations (i.e., the primary evaluation metric). The sensitivity analysis is performed by evaluating how changes in each of these factors (independently and combined) can affect the interior drainage storage pond water surface elevations during critical early season growing period water surface elevations. The analysis evaluates the effects over a 50-year project design period.

The following are the project key sensitivity factors of concern:

- Sea level rise (SLR)
- Erosion, sedimentation, and vegetation conditions in the restored marsh that can affect interior drainage system tailwater conditions (ESV)
- Vegetation and maintenance conditions in the interior storage pond that can affect storage pond capacity (SPC)

The effect of each of these factors can be determined from the results of the surface water and hydraulic modeling described in Sections 6.1 and 6.2 of the main report. For example, the effect of a SLR of 0.2 foot on interior storage pond average early growing season water surface elevations can be calculated. However, the magnitude and timing of the potential SLR related to the pond water surface elevation effect is uncertain. The sensitivity factors of concern are assumed to be independent and, therefore, the combined effect of the various sensitivity factors can be calculated by summing the individual factor effects.

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The general procedure used to perform the Monte Carlo analyses was as follows:

1. Generate independent SLR, ESV, and SPC log-normal, normal or best fit distributions. SLR and ESV input values are those presented in the Shannon & Wilson, Inc. (S&W) Coastal Engineering Recommendations Report (S&W, 2014).
2. Use a random number generator and select a probability of occurrence for the input value based on the probability distributions defined above.
3. Calculate output value (storage pond elevation) resulting from the selected probabilistic input event.
4. For the "Without Project" condition, repeat steps 2) and 3) for SLR (only) for 10,000 iterations.
5. For the "Project" condition, repeat steps 2) and 3) for SLR (plus the hydrodynamic effect), ESV, and SPC for 10,000 iterations. The independent output values are summed at each iteration.
6. Perform the same steps for each year 2013, 2033, 2063 to generate output values over a 50-year project design timeframe.

The calculated results were analyzed statistically to evaluate the effect of input uncertainty (SLR, ESV, or SPC) on the resulting calculated output uncertainty (interior pond water surface elevations). When the 10,000 iterations were complete for the "Without Project" and "Project" conditions, descriptive statistics of average, standard deviation, skewness, and the average relative contribution of each factor were calculated. A cumulative distribution function curve of interior drainage storage pond water surface elevation versus cumulative probability was plotted at each discrete time interval (2013, 2033, 2063). The Monte Carlo analysis was completed using Microsoft Excel 2007.

D.2 SENSITIVITY FACTORS OF CONCERN

The input parameters that are considered the key factors of concern for the study have been identified as SLR, ESV effects, and SPC volume effects. The uncertainties associated with each of the factors of concern were generated based on data, monitoring, studies, and other anecdotal site information. Many of these were presented in the S&W Coastal Engineering Recommendations Report (S&W, 2014) and are summarized herein.

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D.2.1 Sea Level Rise (SLR) Effects

The effects of potential SLR were evaluated for a 50-year levee design lifecycle (the period 2013 through 2063), based on information and predictions provided in the National Academy of Sciences (NAS) (2012) Sea Level Rise report (Table D-1).

Sea level rise effects could be significant at Fir Island because many of the crops grown in the farm fields have root zones that extend near or below the groundwater table elevation on the island. As the sea level rises, the groundwater table will also rise. If the groundwater tables rise and inundate the root zones for too long, crop damage could occur. Groundwater tables are managed at the site through drainage ditches and tidegate systems. SLR will raise the tailwater elevations on the tidegates, which then affects the amount of water that can drain through the tidegate. The negative effects of SLR are expected to occur for both "Without Project" and "Project" conditions.

The "Without Project" uses SLR (only) to the existing, observed tidal tailwater conditions. The "project" conditions use a combination of SLR tidal increases and the 0.75-foot hydrodynamic (water surface elevation increase described in the Fir Island Hydrodynamic Modeling Report [Battelle, 2013] and the Coastal Engineering Recommendations Report [S&W, 2014]). The hydrodynamic effect is on the low-tide trough (shown conceptually in Figure D-1). Results of the hydraulic modeling of the "Without Project" and "Project" alternatives for the average spring (April) period and the maximum predicted water surface elevations are shown in Table D-2.

Table D-3 shows how the hydraulic modeling outputs relate to critical root zone depth (elevation) criteria for the adjacent farm fields. Fields north of the setback levee (i.e., Washington Department of Fish and Wildlife North Field, North Field #1 and North Field #2, and the Hayton Mid-north fields) could have increased water surface elevations above the critical root zone elevation, increasing by more than 10 percent of the time. For the 2013 scenario (if the project were built today), the model predicts that up to 106 acres could be affected by the project, mostly as a result of the hydrodynamic tailwater component of the SLR + Hydrodynamic input variable to the sensitivity analysis. For the 2063 scenario, up to 319 acres could be affected, which is a combination of both SLR and the hydrodynamic tailwater effect.

Pond water surface elevations could be more or less than calculated or predicted as described above due to uncertainty. To address SLR-related uncertainty, the sensitivity analysis uses the low, average, and high data inputs and the resulting hydraulic modeling output for April

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water surface elevations at the yearly study intervals (2013, 2033, and 2063). Figure D-2 shows the SLR input values derived from the NAS (2012) study and the log-normal curve fit to the SLR input data. The curve fitting allows for assignment of a probability distribution function to the SLR input values, as shown in Figure D-3. Both "Without Project" and "Project" conditions have similar input and probability distribution functions related to SLR. The difference between the two is the "Project" condition has an additional 0.75-foot hydrodynamic tailwater effect on the low tide tailwater. These output pond water surface elevation relationships are shown in Figures D-4 and D-5. Computations were then performed to estimate the effect of SLR input uncertainty on corresponding pond water surface elevation outputs. The SLR effects and probabilistic outputs were then combined with other sensitivity factors ESV and SPC for the "project" condition. The combined effects of all of the contributing factors are discussed in the following report sections

D.2.2 Erosion, Sedimentation, and Vegetation Effects (ESV)

The project has the potential for marsh sediment erosion, sedimentation, and vegetation establishment that could affect tidal drainage and marsh drainage conveyance. Very few tools are available for accurately predicting large-scale tidal marsh restoration erosion, sedimentation, and vegetation trends, and their corresponding effects on the interior drainage system water elevations, hence the uncertainty associated with the project.

Project hydrodynamic modeling indicates that the tidal prism exchange to the marsh restoration site will provide significant flood and ebb tidal flows, and will have flow conditions along the No Name Slough tidal channel that will mobilize sediment in the bed and banks of the channels. Shear stress modeling indicates that the shear stresses exceed the threshold for mobilizing fine silts and sands present in the Skagit Bay area. If sediment supplies are low, erosion and expansion of the primary tidal channel could occur, which could lower the tidal tailwater elevations. Erosion expansion and degradation of the primary tidal channel was a reported observation at the Nisqually restoration project. There is little information on how tidal channel erosion and scour effects relate to tidal tailwater elevations. For this study, it was assumed that erosion of a larger tidal channel would increase tidal drainage conveyance and the reductions in channel elevation would correlate to reductions in tidal tailwater elevations.

This effect would likely be offset by other project effects that could include sedimentation in the tidal channel and on the marsh surfaces, thereby reducing drainage conveyance. Likely sources of sedimentation include sediment eroded and transported from the newly restored marsh areas, and sediments transported from shoreline drift from mudflat and

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South Fork Skagit River distributary areas. Excavation of the tidal channels and inlet area will be part of the project, which will reduce the potential for sedimentation. Also, the amount of sediment supply from shoreline drift appears to be low, as described in the Coastal Engineering Recommendations report. Sedimentation of tidal channels and marshes could result in increases of tidal tailwater elevations. Vegetation establishment on the marsh could also reduce tidal drainage conveyance and contribute to elevated tidal tailwater conditions. The Fir Island ESV parameter was based on the Nisqually project marsh sedimentation monitoring data. The Fir Island ESV assumes that Nisqually-type marsh sedimentation rates correlate to effects on tidal tailwater conditions, as the basis for estimating ESV effects (Table D-4). These are described further in the S&W Coastal Engineering Recommendations Report (S&W, 2014).

Figures D-6 through D-8 are the numerical transformations of these recommendations into manual (normal) curve fits, probability distribution functions, and hydraulic modeling output regression relationships used for the sensitivity analysis for the ESV factor. The findings and outcomes related to ESV effects to the drainage system are considered in the context of multiple contributing factors and are presented together in the following Monte Carlo report section.

D.2.3 Storage Pond Capacity (SPC) – Vegetation Effects

The design assumes that the Consolidated Diking District 22 will maintain the storage pond and will control establishment of emergent wetland vegetation in the pond to maximize storage capacity and conveyance. This will involve periodic mowing, dredging, and vegetation removal from the storage pond and ditches.

However, certain factors limit these maintenance activities (such as lack of funding), whereby wetland and pond vegetation growth could occur and encroach into the pond and reduce storage pond volume, capacity, and conveyance. A number of existing drainage “ditch” pond conditions were evaluated to represent this potential effect (uncertainty) on pond performance. The encroachment criteria developed for the project study include varying degrees of vegetation encroachment, described as follows:

- Vegetation-free condition (0 percent encroachment across open water area)
- Minor vegetation encroachment positioned along the channel banks (25 percent encroachment across open water area)
- Major vegetation encroachment into pond beyond the channel banks (50 percent encroachment across open water area)

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For the purposes of sensitivity analyses for this study, the proposed interior drainage pond sensitivity analysis assumes the levels of vegetation encroachment gradually increase over the 50-year life of the project (Table D-5). Vegetation encroachment into the pond was modeled as obstructions in pond flow areas.

Figures D-9 through D-11 are the numerical transformations of the recommendations from the Coastal Engineering Recommendations Report (S&W, 2014) into log-normal curve fits, probability distribution functions, and hydraulic modeling output regression relationships used for the sensitivity analysis for the SPC factor. The findings and outcomes related to SPC effects to the drainage system are considered in the context of multiple contributing factors and are presented together in the following Monte Carlo report section.

D.3 MONTE CARLO RESULTS

The "Without Project" SLR Only and "Project" SLR+Hydrodynamic, ESV, and SPC combined effect probability distributions were randomly sampled and analyzed using a Monte Carlo simulation. The Monte Carlo simulation generates 10,000 random events (samples) to generate the output probability distributions. Each random event has a corresponding input probability and output value (pond water surface elevation) based on methods and data described above. Performing the full set of sampling and calculations presents the expected range of probable storage pond water surface elevations as a function of SLR, ESV, and SPC inputs. The resulting range of probable storage pond water surface elevation outputs and statistics are shown as a cumulative distribution functions (Tables D-6 and D-7, Figures D-12 through D-14).

The outcomes characterize the uncertainty associated with project design and the modeling predictions. Also, the uncertainty analysis provides information on the relative proportion (or weight) of the SLR, ESV, and SPC effects. The following is a summary of observations regarding the sensitivity analysis results:

- For 2013, the expected range (10 to 90 percent cumulative probability) of average April pond water surface elevations is:
  - 3.3 to 3.6 feet for the "Without Project," 100 percent of the effect is SLR
  - 4.1 to 4.4 feet for the "Project," 98 percent of the effect is related to SLR plus the hydrodynamic effect
- For 2033, the expected range (10 to 90 percent cumulative probability) of average April pond water surface elevations is:
  - 3.4 to 3.8 feet for the "Without Project," 100 percent of the effect is SLR

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  - 4.1 to 4.9 feet for the "Project," 88 percent of the effect is related to SLR plus the hydrodynamic effect
- For 2063, the expected range (10 to 90 percent cumulative probability) of average April pond water surface elevations is:
  - 3.7 to 5.1 feet for the "Without Project," 100 percent of the effect is SLR
  - 4.4 to 6.2 feet for the "Project," 88 percent of the effect is related to SLR plus the hydrodynamic effect

SLR is expected to affect interior storage pond water surface elevations in early spring for the near term and foreseeable future, for the "Without Project" condition. SLR represents 100 percent of the effect in this analysis. These effects will likely impact drainage functions and farming operations.

The combined effects (SLR+hydro, ESV, and SPC) for the project are expected increase pond water surface elevations during early spring season on the order of 0.8 to 1.2 feet higher than the "Without Project" condition. The primary contributing factor appears to be SLR plus the tidal hydrodynamic effect. ESV and SPC effects are likely only moderate contributing factors to the anticipated tailwater increases. Additional drainage structures are necessary to mitigate these effects.

D.4 REFERENCES

National Academy of Sciences (NAS), 2012, Sea level rise for the Coasts of California, Oregon, and Washington, Past, Present, and Future.

Shannon & Wilson, Inc., 2014, Draft coastal engineering report WDFW – Fir Island Farm Snow Goose Reserve. Skagit County, Washington: Report prepared by Shannon & Wilson, Inc., Seattle, Wash., January.

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TABLE D-1
SEA LEVEL RISE VALUES

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] 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.

SLR = sea level rise

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TABLE D-2
HYDRAULIC MODEL OUTPUT
INTERIOR POND AVERAGE (APRIL) AND MAXIMUM WATER SURFACE ELEVATIONS

2013	Without Project	Project	Change	Without Project	Project	Change	Without Project	Project	Change
	Low			Average			High		
SLR (ft)	0.0	0.0	n/a	0.1	0.1	n/a	0.2	0.2	n/a
Average WSE (ft)	3.3	4.1	0.8	3.4	4.2	0.8	3.5	4.3	0.9
Maximum WSE (ft)	3.8	4.7	0.9	3.9	4.8	0.9	4.0	4.9	0.9
2033	**Low**			**Average**			**High**		
SLR (ft)	0.1	0.1	n/a	0.3	0.3	n/a	0.5	0.5	n/a
Average WSE (ft)	3.4	4.2	0.8	3.6	4.4	0.9	3.8	4.6	0.9
Maximum WSE (ft)	3.9	4.8	0.9	4.1	5.0	0.9	4.3	5.1	0.8
2063	**Low**			**Average**			**High**		
SLR (ft)	0.5	0.5	n/a	0.9	0.9	n/a	1.5	1.5	n/a
Average WSE (ft)	3.8	4.6	0.9	4.2	5.0	0.8	4.8	5.6	0.8
Maximum WSE (ft)	4.3	5.1	0.8	4.7	5.5	0.8	5.2	5.9	0.7

Notes:

ft = foot

n/a = not applicable

SLR = sea level rise

WSE = water surface elevation

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TABLE D-3
HYDRAULIC MODELING RESULTS - 2 FEET CRITICAL ROOT ZONE FARM AREA EFFECTS

Field	Model Node	Elevation Range Low (ft)	Elevation Range High (ft)	Critical Root Zone Depth (ft)	Field Elevation (ft)	Field Elevation Area (acres)	Percent Total Area	2013 Average SLR Percent of Time Exceeded (April) Without Project SLR Only 5.4 ft	2013 Average SLR Percent of Time Exceeded (April) Project SLR+Hyd 6.2 ft	2013 Average SLR Percent of Time Exceeded (April) Increase %	2013 Average SLR Area Affected (acres)	2063 Average SLR Percent of Time Exceeded (April) Without Project SLR Only 6.2 ft	2063 Average SLR Percent of Time Exceeded (April) Project SLR+Hyd 7.0 ft	2063 Average SLR Percent of Time Exceeded (April) Increase (%)	2063 Average SLR Area Affected (acres)
North Field #2	NNS XS 11193	6	6.5	2	4	18.4	6%	35%	100%	65%	18.4	100%	100%	0%	0.0
		6.5	7		4.5	32.7	11%	2%	21%	19%	32.7	39%	100%	61%	32.7
		7	7.5		5	51.1	18%	0%	1%	0%	0.0	1%	100%	99%	51.1
		7.5	8		5.5	52.7	18%	0%	0%	0%	0.0	0%	1%	1%	0.0
		8	8.5		6	33.2	12%	0%	0%	0%	0.0	0%	0%	0%	0.0
		8.5	9		6.5	25.7	9%	0%	0%	0%	0.0	0%	0%	0%	0.0
		9	9.5		7	22.9	8%	0%	0%	0%	0.0	0%	0%	0%	0.0
		9.5	10		7.5	14.3	5%	0%	0%	0%	0.0	0%	0%	0%	0.0
		10	12		8	28.6	10%	0%	0%	0%	0.0	0%	0%	0%	0.0
North Field #1	NNS XS 6622	6	6.5	2	4	26.1	6%	0%	100%	100%	26.1	91%	100%	9%	0.0
		6.5	7		4.5	62.7	15%	0%	0%	0%	0.0	3%	100%	97%	62.7
		7	7.5		5	93.8	23%	0%	0%	0%	0.0	0%	58%	58%	93.8
		7.5	8		5.5	105.3	26%	0%	0%	0%	0.0	0%	0%	0%	0.0
		8	8.5		6	68.9	17%	0%	0%	0%	0.0	0%	0%	0%	0.0
		8.5	9		6.5	32.5	8%	0%	0%	0%	0.0	0%	0%	0%	0.0
		9	9.5		7	5.7	1%	0%	0%	0%	0.0	0%	0%	0%	0.0
WDFW Field	NNS XS 3386	6	6.5	2	4	2.6	2%	0%	100%	100%	2.6	89%	100%	11%	2.6
		6.5	7		4.5	19.1	17%	0%	0%	0%	0.0	3%	100%	97%	19.1
		7	7.5		5	57.1	51%	0%	0%	0%	0.0	0%	55%	55%	57.1
		7.5	8		5.5	25.2	23%	0%	0%	0%	0.0	0%	0%	0%	0.0
		8	8.5		6	5.0	4%	0%	0%	0%	0.0	0%	0%	0%	0.0
Hayton North	DS XS 4899	6.5	7	2	4.5	1.0	2%	25%	37%	12%	1.0	90%	94%	4%	0.0
		7	7.5		5	5.7	14%	1%	1%	0%	0.0	4%	7%	2%	0.0
		7.5	8		5.5	18.5	45%	0%	0%	0%	0.0	0%	0%	0%	0.0
		8	8.5		6	10.2	25%	0%	0%	0%	0.0	0%	0%	0%	0.0
		8.5	9		6.5	1.9	5%	0%	0%	0%	0.0	0%	0%	0%	0.0
		9	9.5		7	1.4	3%	0%	0%	0%	0.0	0%	0%	0%	0.0
		9.5	10		7.5	0.8	2%	0%	0%	0%	0.0	0%	0%	0%	0.0
Hayton Mid-North	DS XS 4899	5.5	6	2	3.5	4.2	5%	100%	100%	0%	0.0	100%	100%	0%	0.0
		6	6.5		4	18.6	20%	100%	100%	0%	0.0	100%	100%	0%	0.0
		6.5	7		4.5	25.5	28%	25%	37%	12%	25.5	90%	94%	4%	0.0
		7	7.5		5	24.5	27%	1%	1%	0%	0.0	4%	7%	2%	0.0
		7.5	8		5.5	10.3	11%	0%	0%	0%	0.0	0%	0%	0%	0.0
		8	8.5		6	5.2	6%	0%	0%	0%	0.0	0%	0%	0%	0.0
		8.5	9		6.5	2.1	2%	0%	0%	0%	0.0	0%	0%	0%	0.0
Hayton South	DS XS 996	4.5	5	2	2.5	1.5	2%	100%	100%	0%	0.0	100%	100%	0%	0.0
		5	5.5		3	5.1	7%	97%	98%	0%	0.0	100%	100%	0%	0.0
		5.5	6		3.5	20.0	27%	66%	67%	1%	0.0	100%	100%	0%	0.0
		6	6.5		4	31.5	43%	34%	37%	3%	0.0	93%	93%	0%	0.0
		6.5	7		4.5	11.5	16%	6%	9%	3%	0.0	50%	52%	3%	0.0
		7	7.5		5	2.4	3%	0%	0%	0%	0.0	3%	4%	2%	0.0
Total						985.7				11%	106.3			32%	319.1

Note:
ft = foot
SLR = sea level rise

TABLE D-4
MARSH AND TIDAL CHANNEL
EROSION, SEDIMENTATION, AND VEGETATION TAILWATER INPUTS

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

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TABLE D-5
INTERIOR DRAINAGE STORAGE POND
VEGETATION ENCROACHMENT AND
STORAGE POND CAPACITY INPUTS

Year	Vegetation Encroachment		
	Low (%)	Average (%)	High (%)
2013	0%	0%	0%
2033	5%	10%	25%
2063	10%	25%	50%

Note:

% = percent

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TABLE D-6
MONTE CARLO SENSITIVITY ANALYSIS STATISTICS

2013 - Without Project				2013 - Project			
Statistics	**Average Effect on WSE**			**Statistics**	**Average Effect on WSE**		
Average	3.43	SLR	100.0%	Average	4.28	SLR+Hydro	97.6%
Std Dev	0.13	ESV	0.0%	Std Dev	0.16	ESV	0.4%
Skewness	3.53	SPC	0.0%	Skewness	1.65	SPC	2.1%

2033 - Without Project				2033 - Project			
Statistics	**Average Effect on WSE**			**Statistics**	**Average Effect on WSE**		
Average	3.63	SLR	100.0%	Average	4.52	SLR+Hydro	87.9%
Std Dev	0.18	ESV	0.0%	Std Dev	0.34	ESV	9.5%
Skewness	1.88	SPC	0.0%	Skewness	0.32	SPC	2.5%

2063 - Without Project				2063 - Project			
Statistics	**Average Effect on WSE**			**Statistics**	**Average Effect on WSE**		
Average	4.33	SLR	100.0%	Average	5.32	SLR+Hydro	87.6%
Std Dev	0.61	ESV	0.0%	Std Dev	0.77	ESV	7.9%
Skewness	1.94	SPC	0.0%	Skewness	1.18	SPC	4.5%

Notes:

ESV = erosion, sedimentation, and vegetation

SLR = sea level rise

SPC = storage pond capacity

WSE = water surface elevation

% = percent

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TABLE D-7
MONTE CARLO SENSITIVITY ANALYSIS
COMPARISONS OF STORAGE POND WATER SURFACE ELEVATIONS

Year	Cumulative Probability	Without Project		Project		Difference (Project to Without Project) (ft)
		April Average Pond WSE	Range (ft) (10 - 90%)	April Average Pond WSE	Range (ft) (10 - 90%)	
	10%	3.3		4.1		0.7
	50%	3.4		4.2		0.8
2013	90%	3.5	0.2	4.4	0.4	0.9
	10%	3.4		4.1		0.6
	50%	3.6		4.5		0.9
2033	90%	3.8	0.4	4.9	0.8	1.1
	10%	3.7		4.4		0.7
	50%	4.2		5.2		1.1
2063	90%	5.1	1.4	6.2	1.8	1.2

Notes:

ft = feet

WSE = water sureface elevation

% = percent

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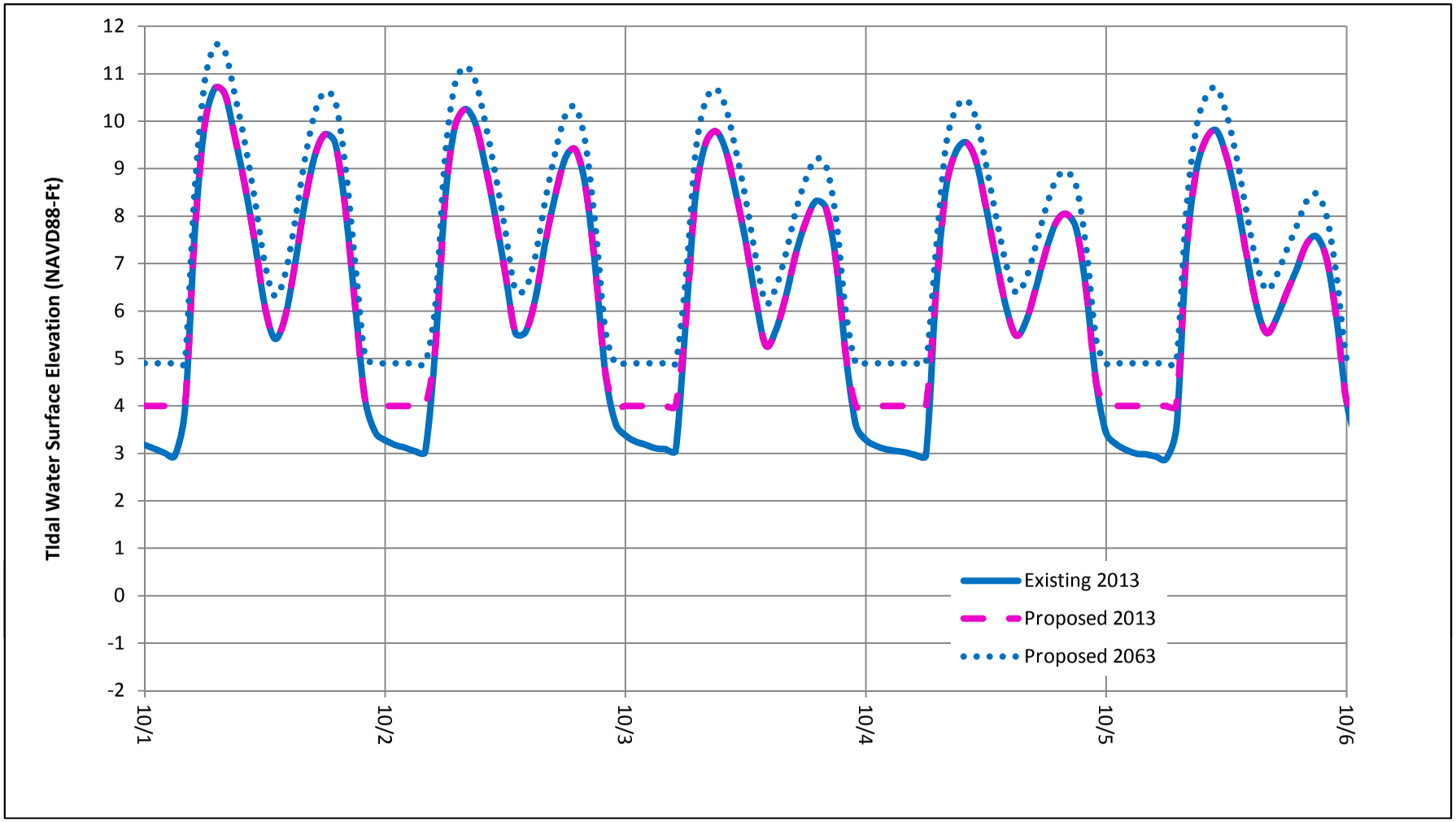

Date

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Fir Island Farms Restoration

Skagit County, WA

Without Project SLR and With Project SLR and Hydrodynamic Effect

February 2014 21-1-12318-216

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GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

Fig. D-1

Fig. D-1

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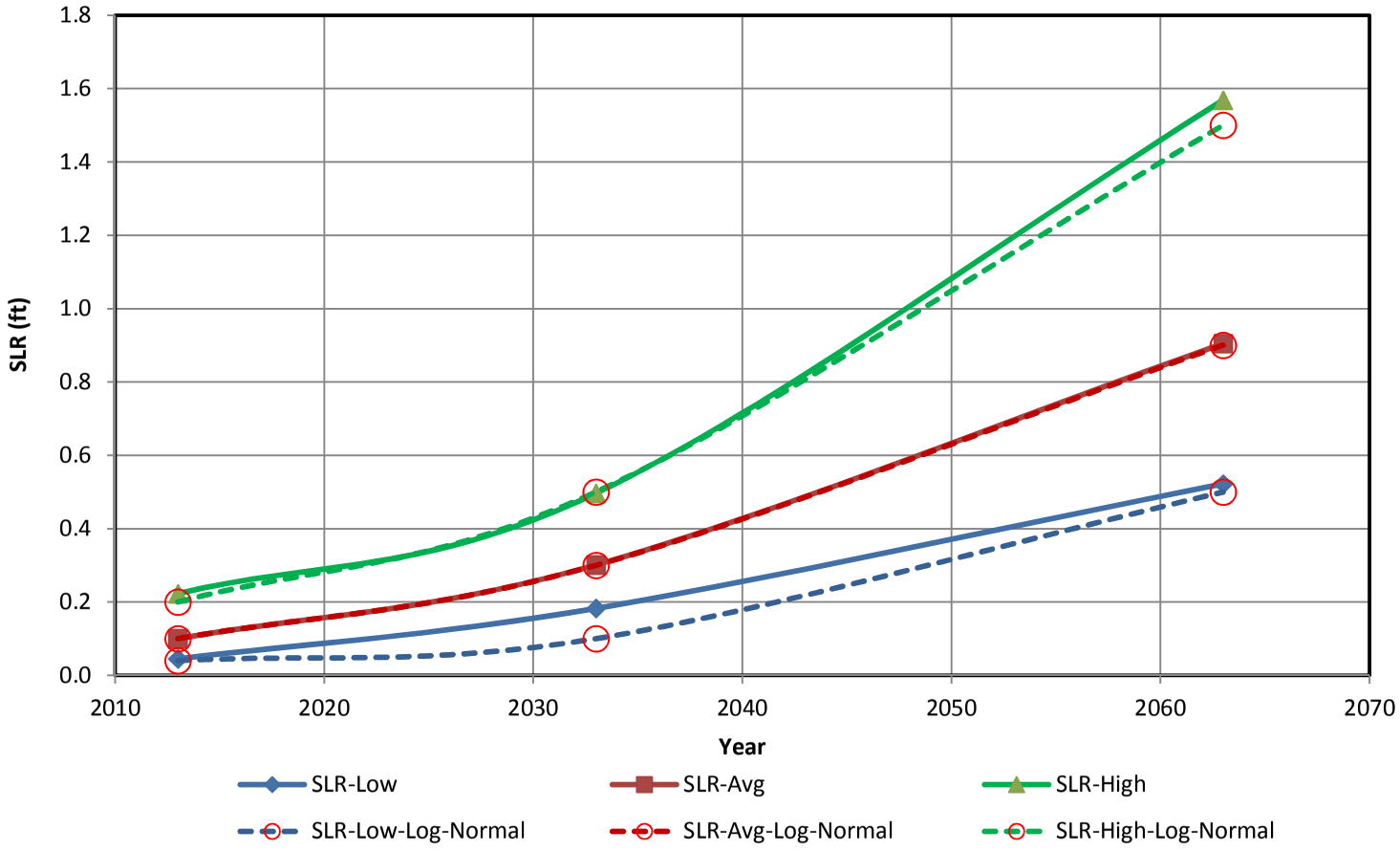

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Fir Island Farms Restoration

Skagit County, WA

SLR INPUT VALUES
LOG-NORMAL CURVE FIT

February 2014 21-1-12318-216

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Fig. D-2

Fig. D-2

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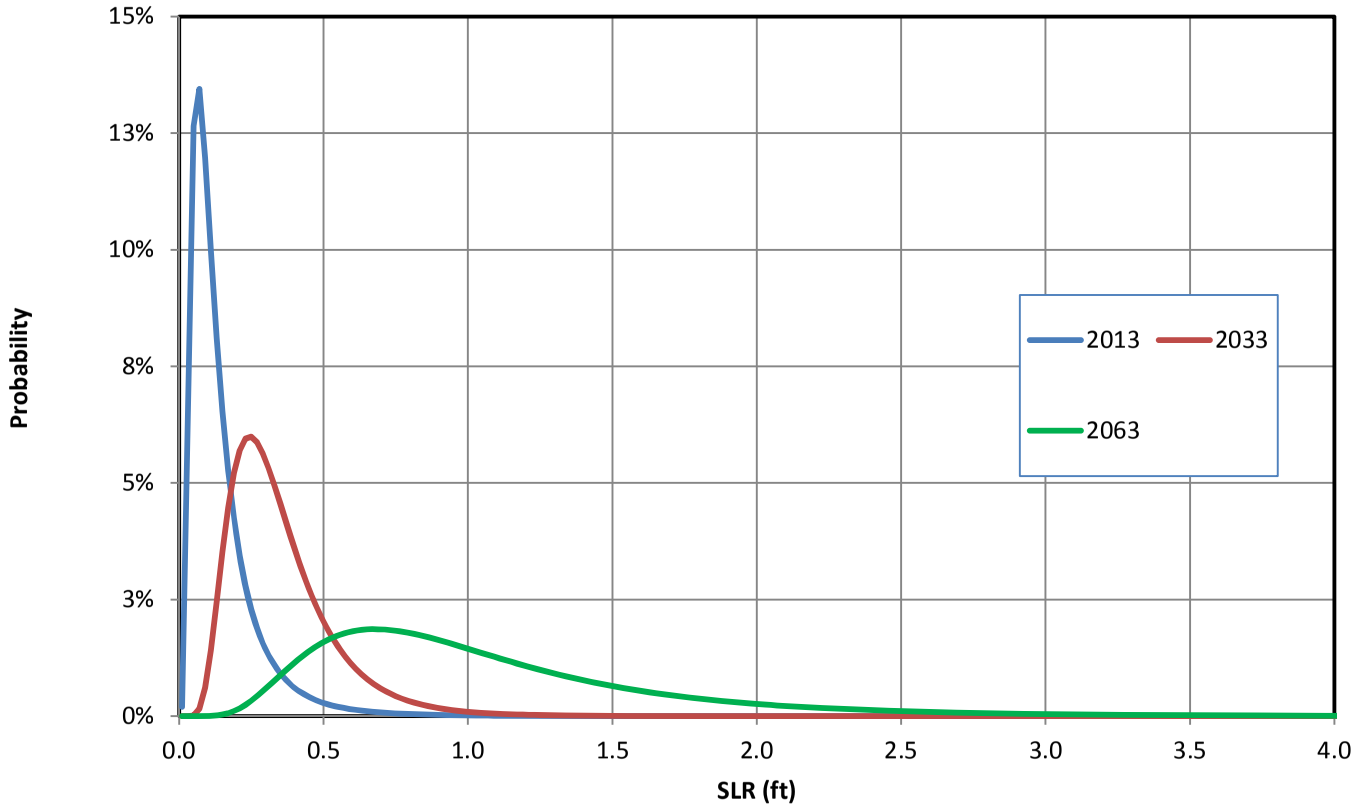

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Fir Island Farms Restoration

Skagit County, WA

SLR DISTRIBUTION

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Fig. D-3

Fig. D-3

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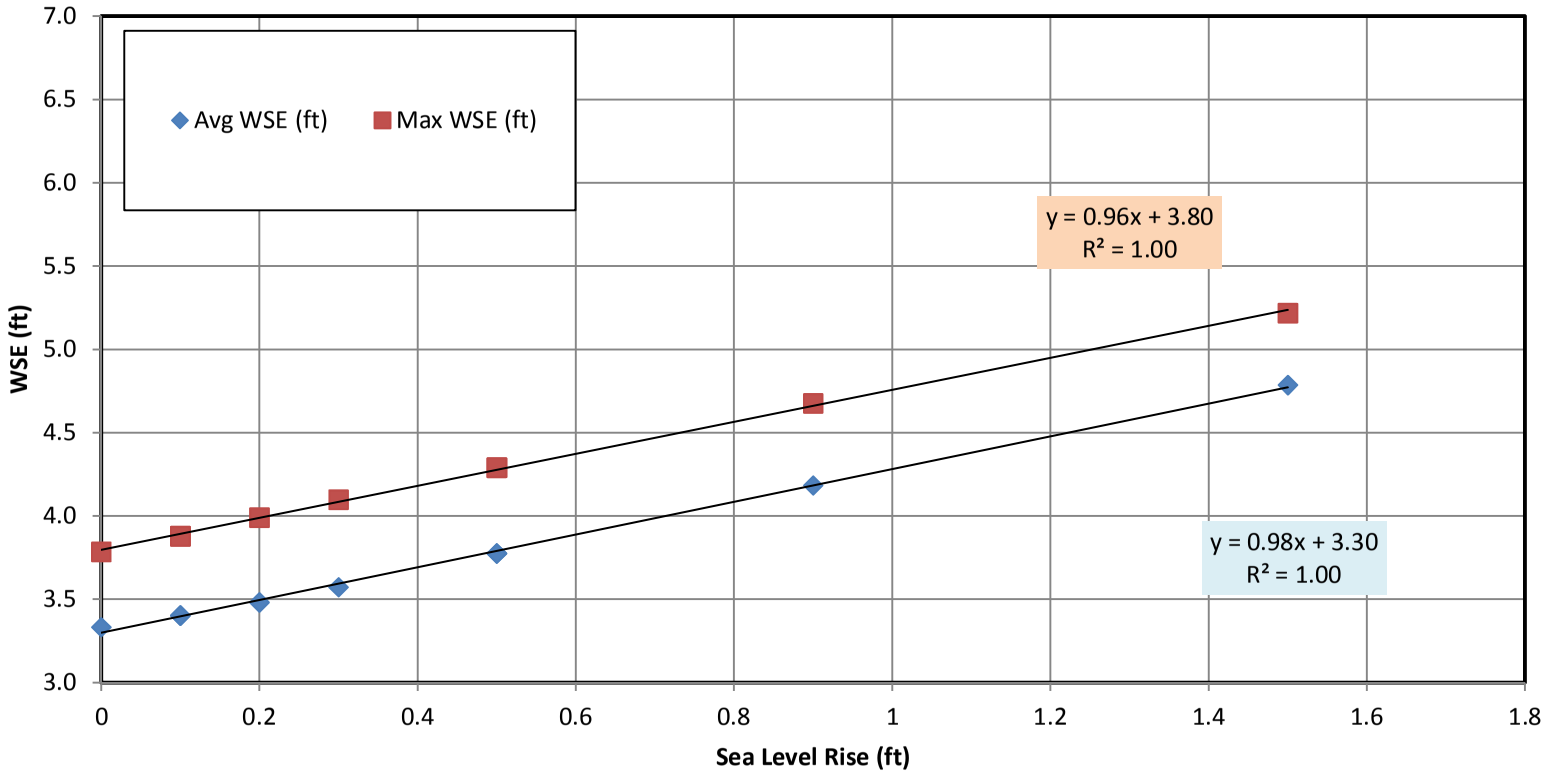

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Fir Island Farms Restoration

Skagit County, WA

WITHOUT PROJECT
SLR (ONLY)
POND (WSE) OUTPUT VALUES

February 2014 21-1-12318-216

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Fig. D-4

Fig. D-4

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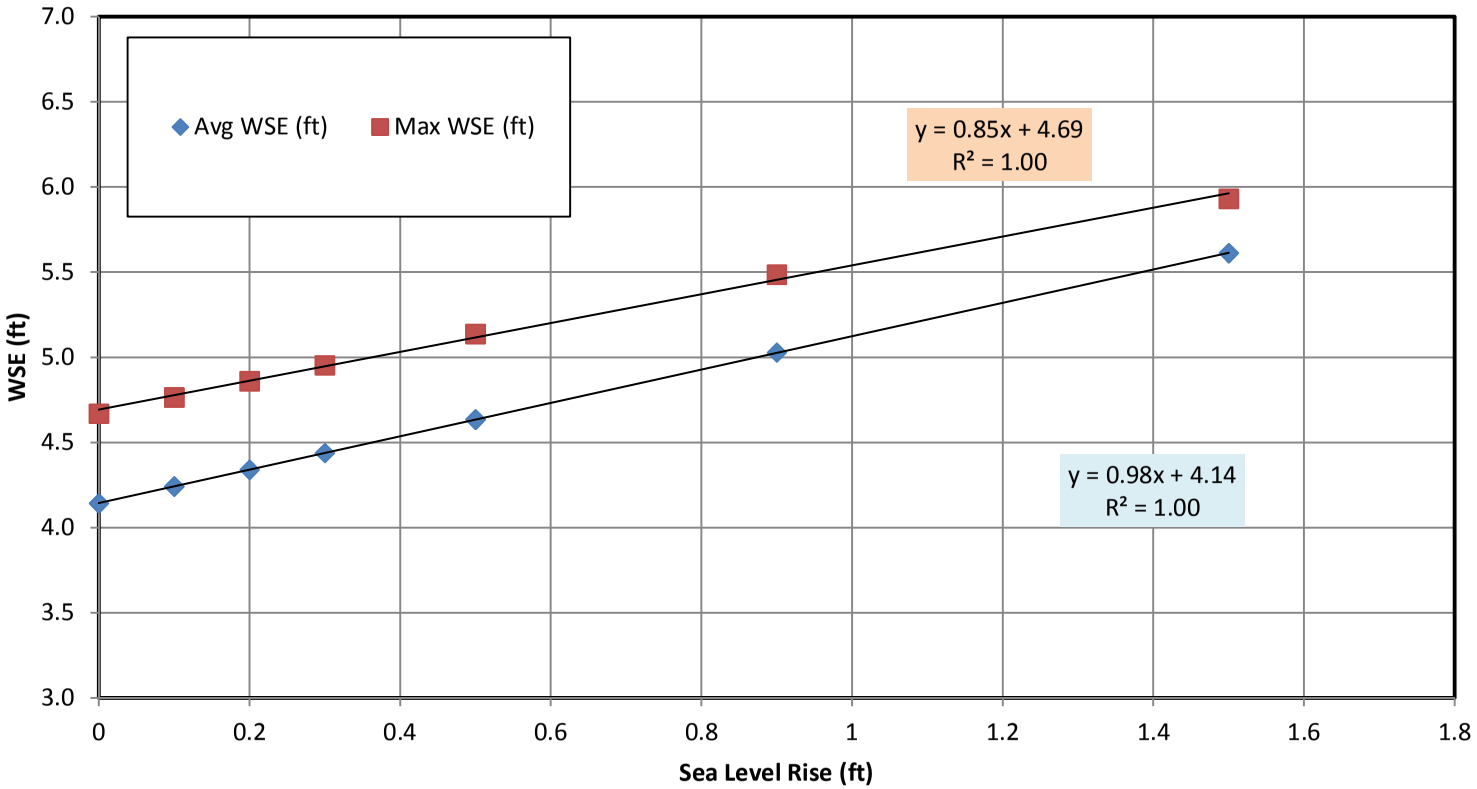

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Fir Island Farms Restoration

Skagit County, WA

PROJECT

SLR + HYDRODYNAMIC EFFECT

POND (WSE) OUTPUT VALUES

February 2014 21-1-12318-216

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GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

Fig. D-5

Fig. D-5

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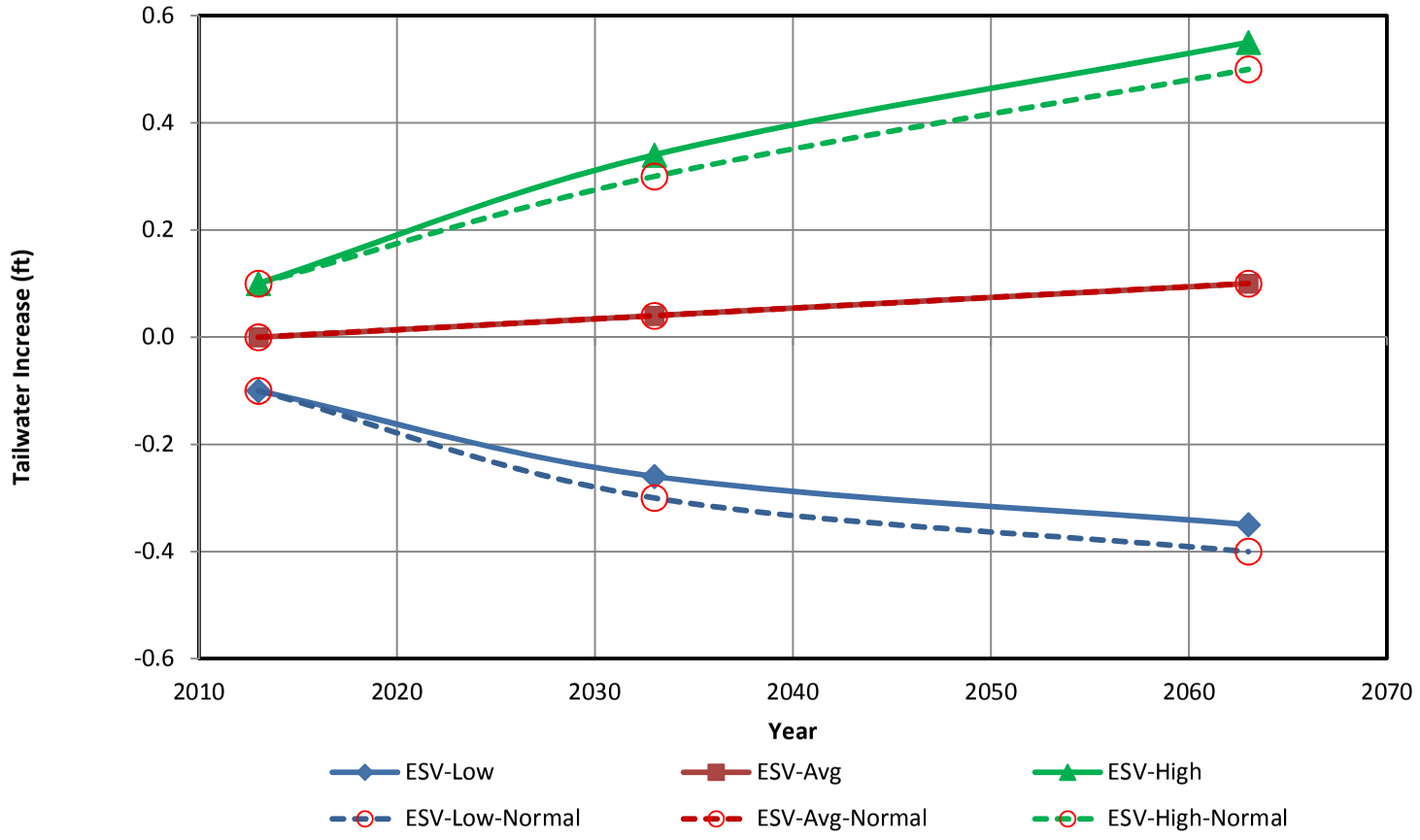

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Fir Island Farms Restoration

Skagit County, WA

PROJECT
ESV INPUT VALUES
MANUAL CURVE FIT

February 2014 21-1-12318-216

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Fig. D-6

Fig. D-6

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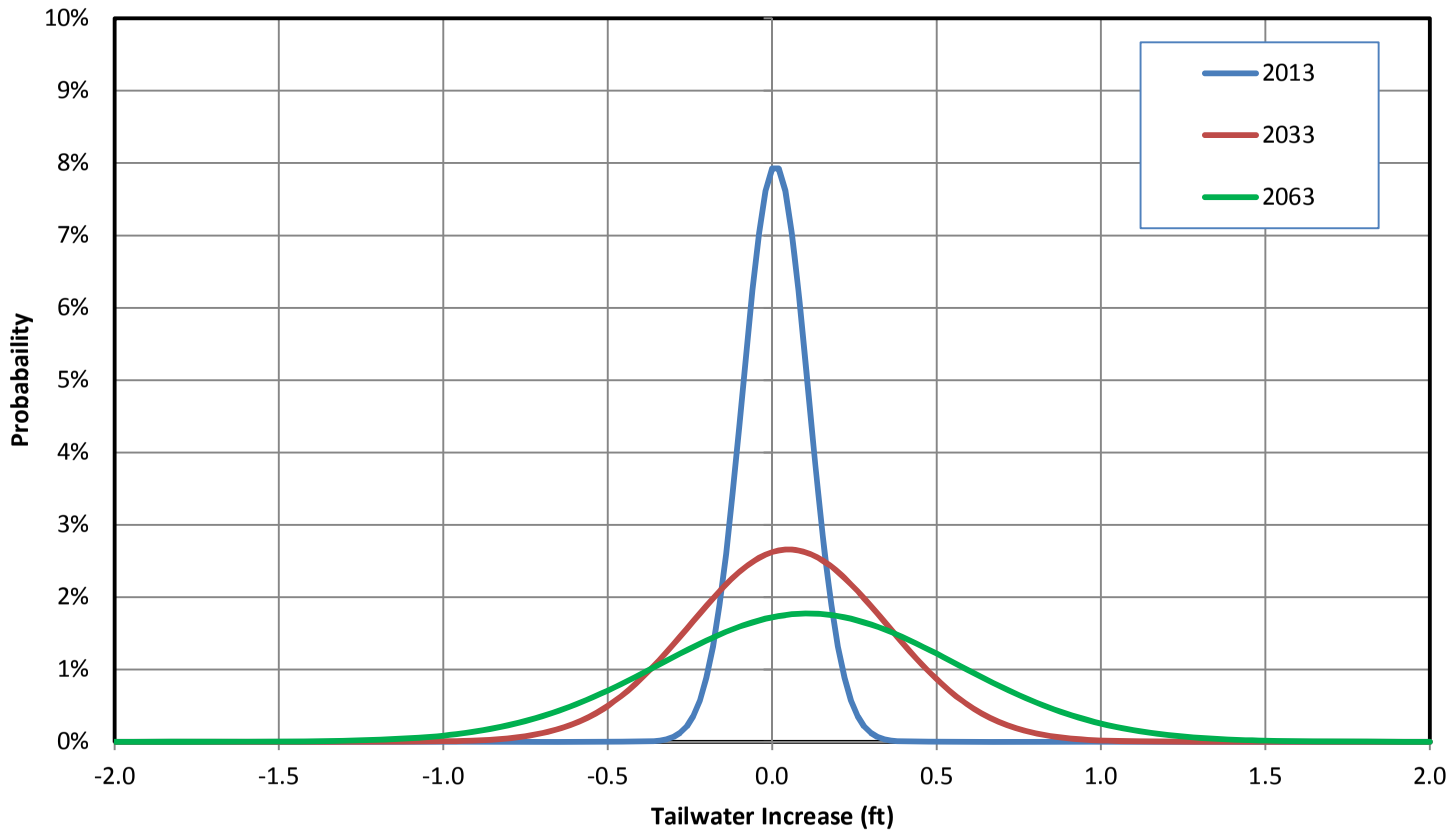

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Fir Island Farms Restoration

Skagit County, WA

PROJECT
ESV DISTRIBUTION

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Fig. D-7

Fig. D-7

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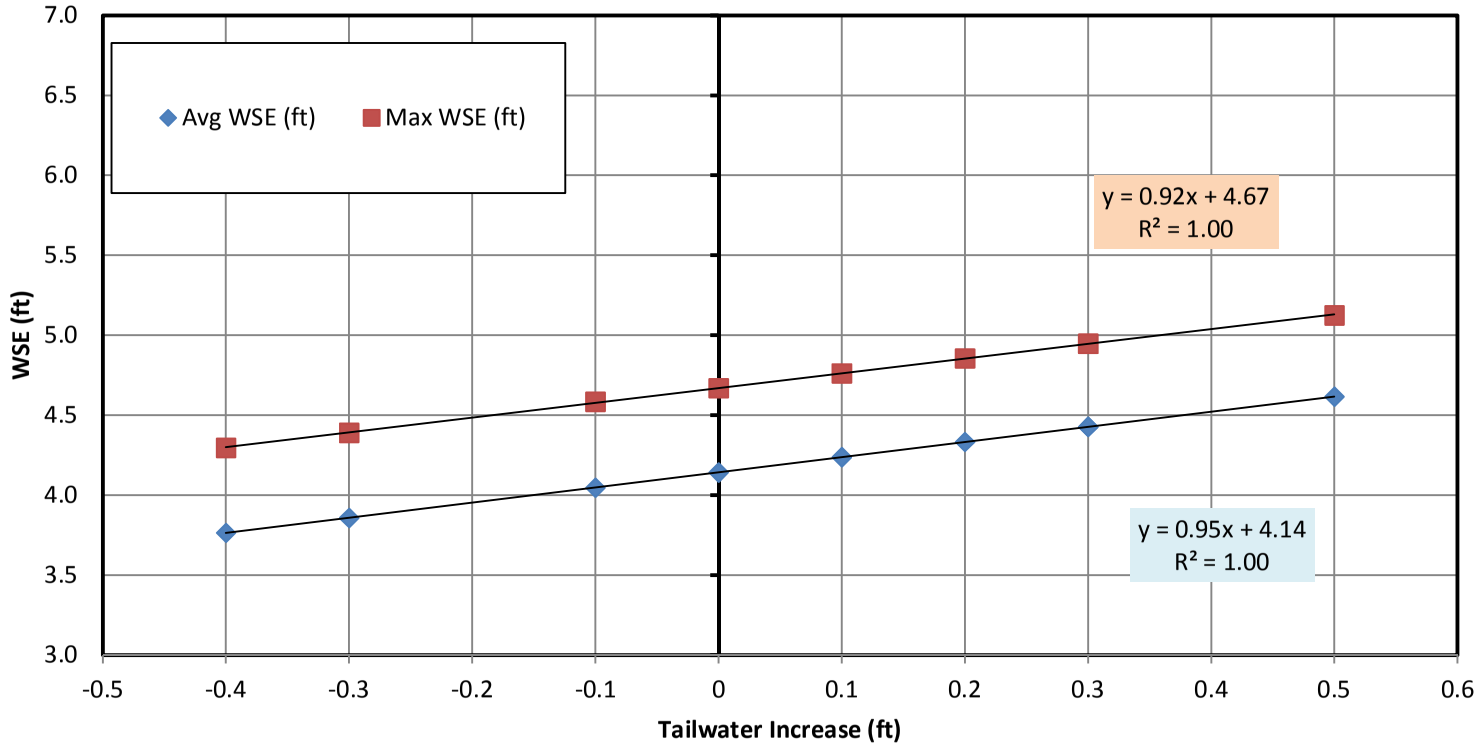

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Fir Island Farms Restoration

Skagit County, WA

PROJECT
ESV
POND (WSE) OUTPUT VALUES

February 2014 21-1-12318-216

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Fig. D-8

Fig. D-8

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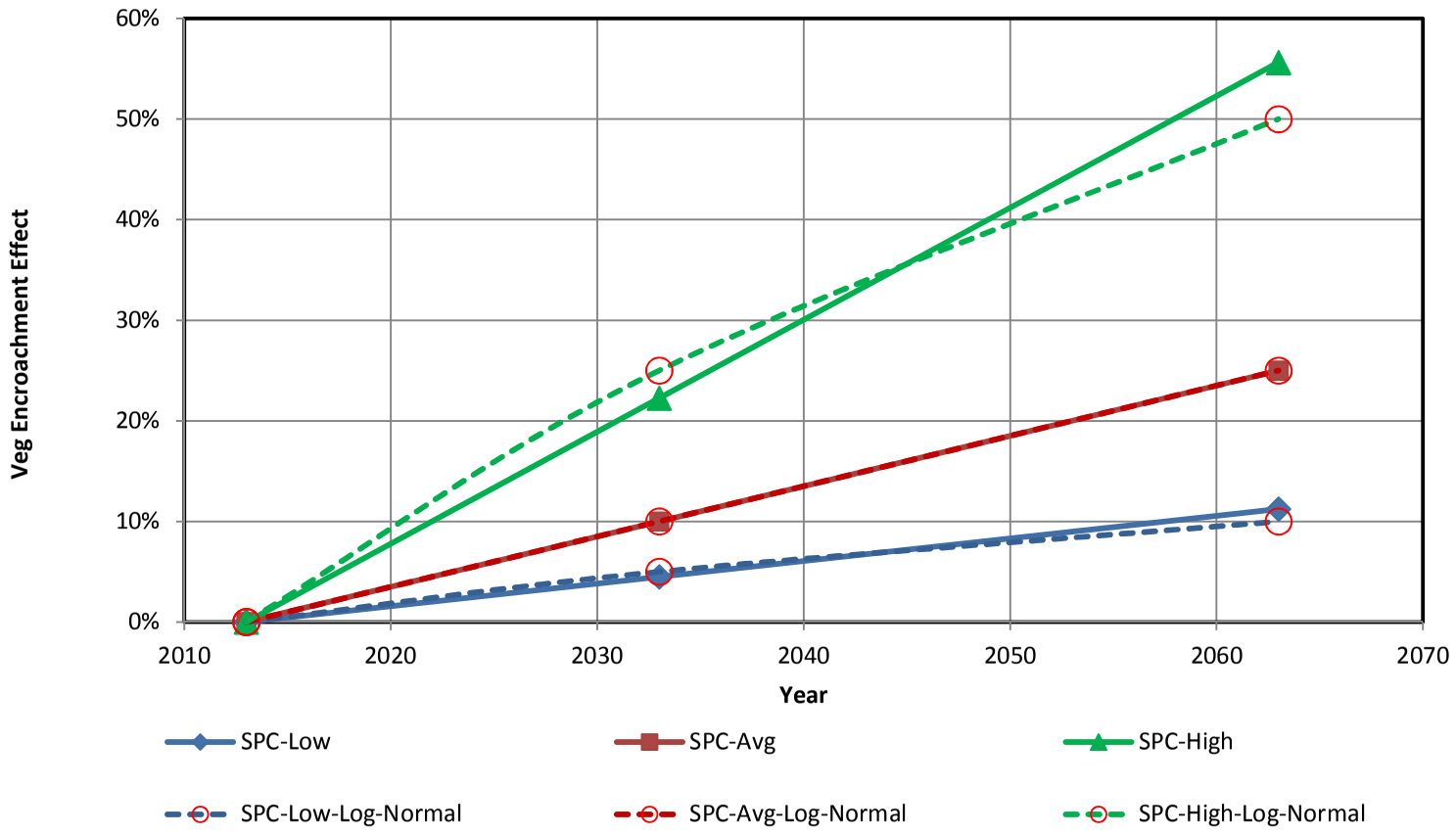

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Fir Island Farms Restoration

Skagit County, WA

PROJECT
SPC INPUT VALUES
LOG-NORMAL CURVE FIT

February 2014 21-1-12318-216

SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

Fig. D-9

Fig. D-9

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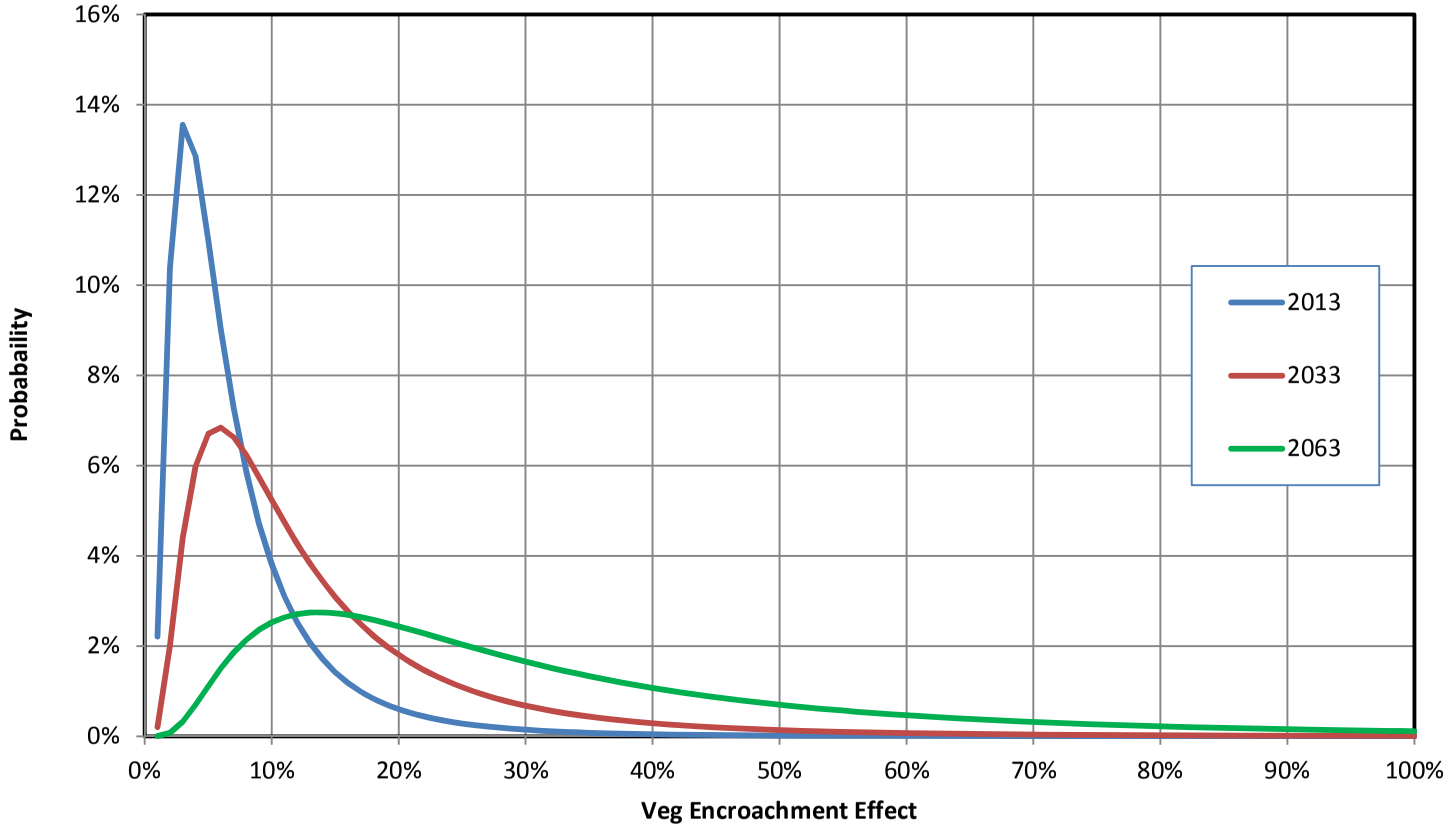

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Fir Island Farms Restoration

Skagit County, WA

PROJECT
SPC DISTRIBUTION

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Fig. D-10

Fig. D-10

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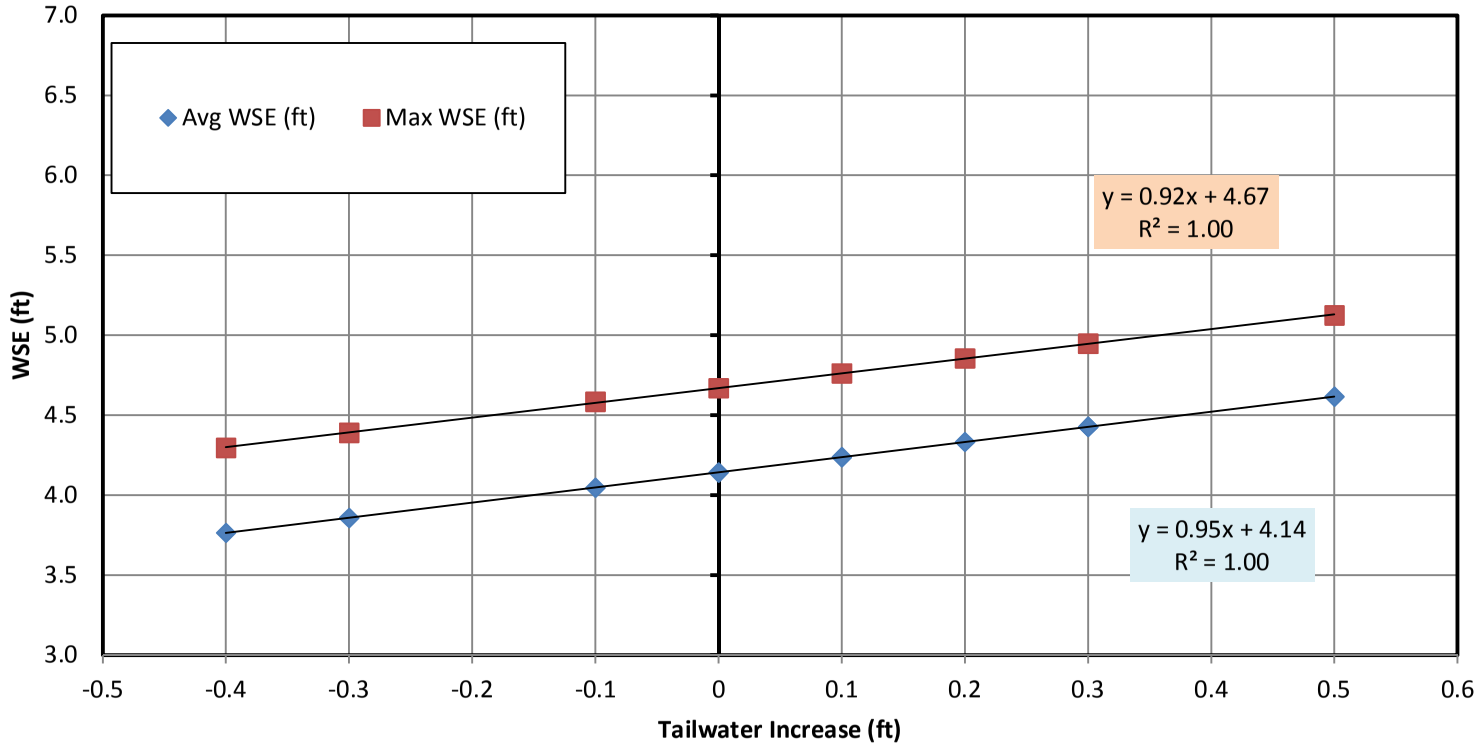

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Fir Island Farms Restoration

Skagit County, WA

PROJECT
ESV
POND (WSE) OUTPUT VALUES

February 2014 21-1-12318-216

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GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

Fig. D-11

Fig. D-11

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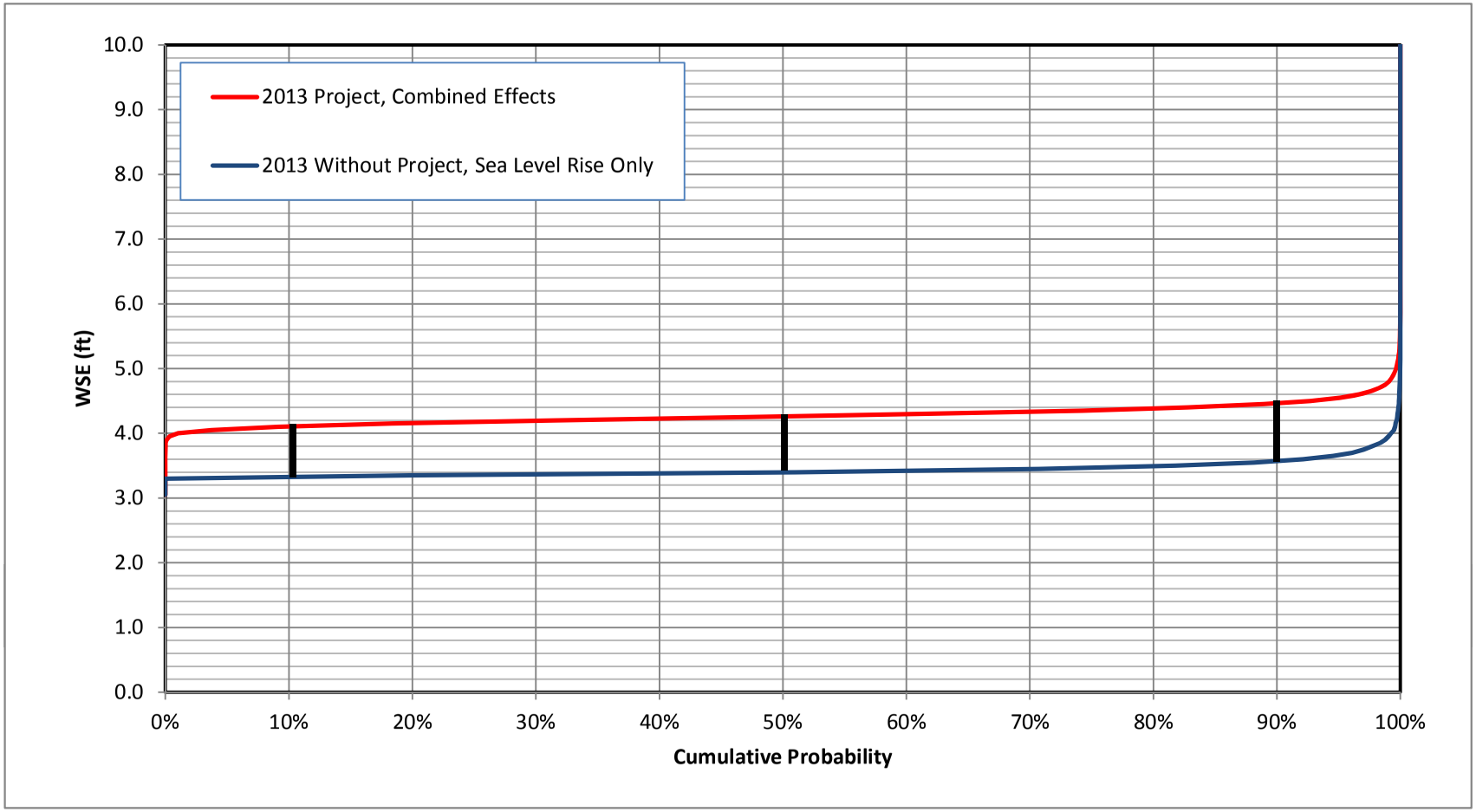

Fir Island Farms Restoration

Skagit County, WA

MONTE CARLO

2013 Cumulative Distribution Function

February 2014 21-1-12318-216

SHANNON & WILSON, INC.
GEOTECHNICAL AND ENVIRONMENTAL CONSULTANTS

Fig. D-12

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Fig. D-12

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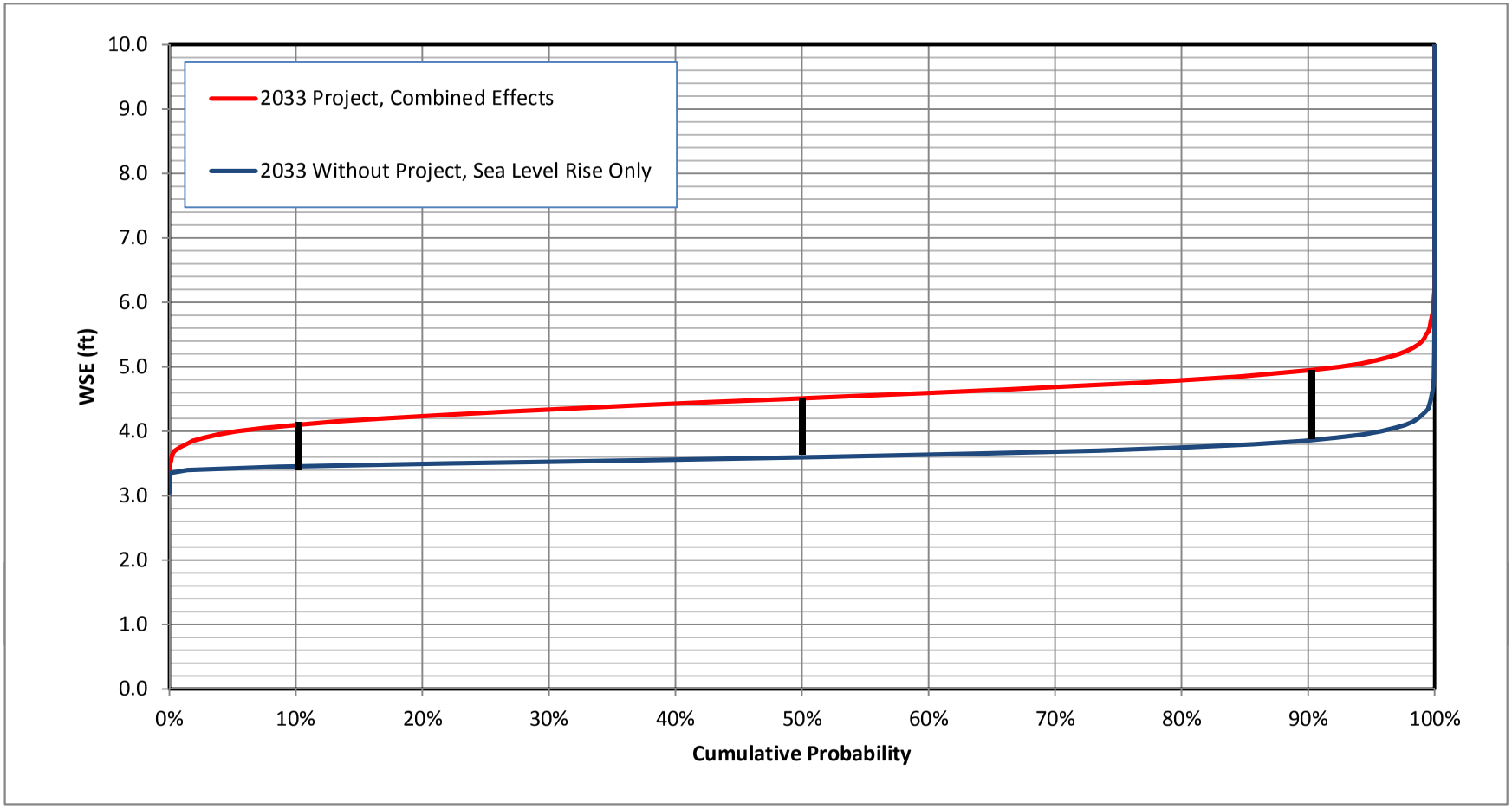

Fir Island Farms Restoration

Skagit County, WA

MONTE CARLO

2033 Cumulative Distribution Function

February 2014 21-1-12318-216

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Fig. D-13

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Fig. D-13

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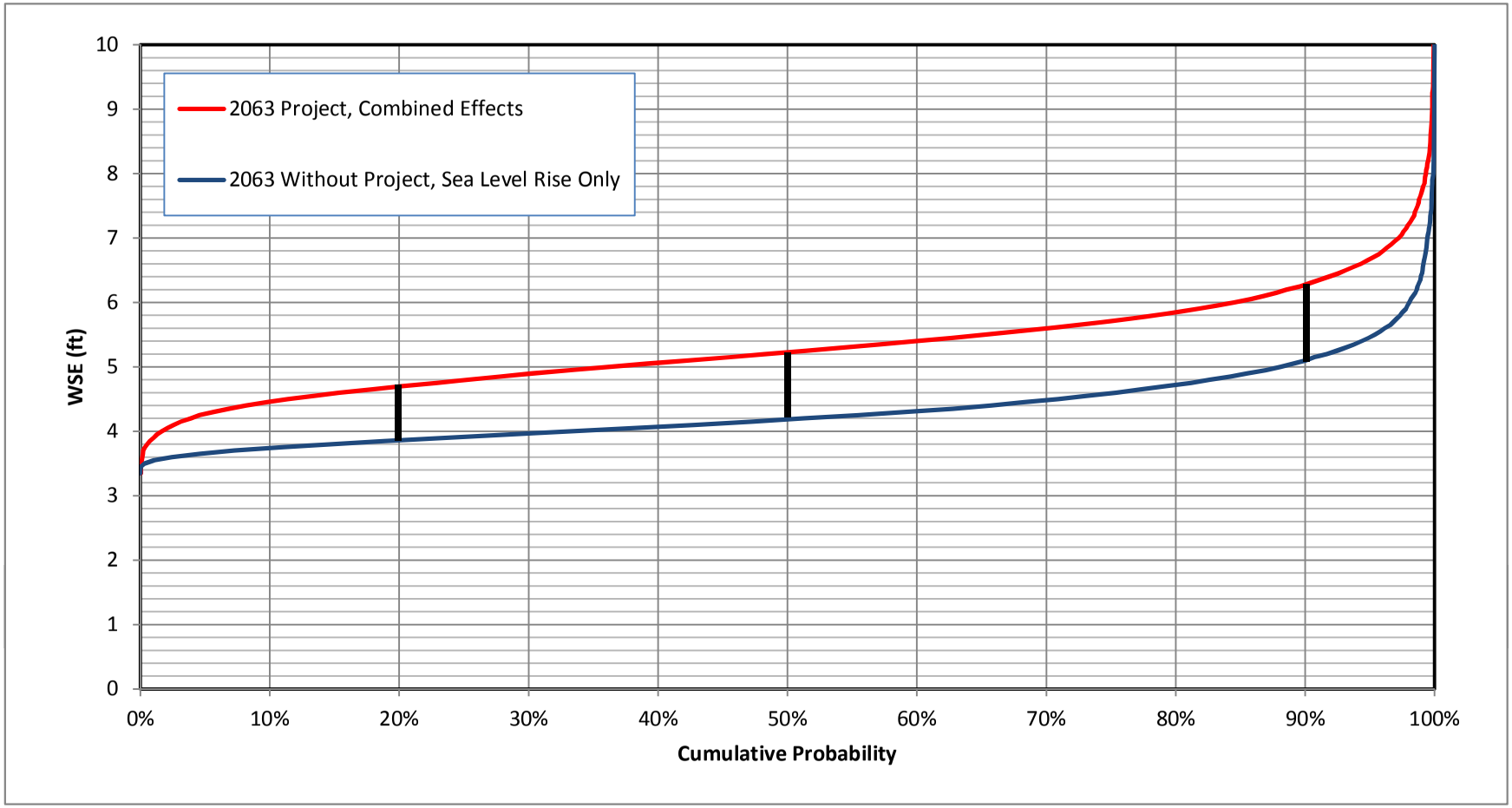

Fir Island Farms Restoration

Skagit County, WA

MONTE CARLO

2063 Cumulative Distribution Function

February 2014 21-1-12318-216

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Fig. D-14

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Fig. D-14

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