Technical Memorandum 1.1.2 – Geomorphologic Characterization
Fir Island Farm, Snow Goose Reserve Restoration Feasibility Study
Fir Island, Washington

March 7, 2011

Submitted To:
Washington Department of Fish and Wildlife
Attn: Mr. Brian Williams
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Attn: Mr. Brian Williams

RE: TECHNICAL MEMORANDUM 1.1.2 – GEOMORPHOLOGIC CHARACTERIZATION, FIR ISLAND FARM, SNOW GOOSE RESERVE RESTORATION FEASIBILITY STUDY, FIR ISLAND, WASHINGTON

This technical memorandum presents a general geomorphologic characterization of the Fir Island Farm, Snow Goose Reserve, Restoration Feasibility Study. The intent of this memorandum is to provide a basis of understanding of the major landforms and processes that contribute to the geomorphologic formation and functions of the existing and proposed tidal marsh restoration future conditions. The contents of the memorandum include the following information:

- Geomorphologic characterization of Skagit River Delta and Skagit Bay Front geomorphologic landforms and processes.
- Conceptual geomorphologic process model of the project site.
- Potential change and response analysis of changes in functional processes, and document changes in site conditions over time.
- Restoration recommendations.

PROJECT BACKGROUND

The project is located in the Skagit River Delta on Fir Island along Skagit Bay between the North and South Forks of the Skagit River Delta (Figure 1). Fir Island is a 12-square-mile island within the Skagit Delta. A majority of Fir Island is farmland on the fertile Skagit Delta. The Washington Department of Fish and Wildlife (WDFW) Snow Goose Preserve is located 3 miles east of Conway, Washington. The Snow Goose Preserve encompasses the farmland between the two sloughs and bordered by Fir Island Road to the north and the Bay Front coastal flood protection dike (levee) to the south. East of the preserve is a farm owned by the Haytons. Currently, the WDFW Snow Goose Preserve is actively farmed with special crop rotations and plantings that allow for Snow Goose foraging during winter migrations. The Hayton family acts

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as the farm operators for the WDFW Snow Goose Preserve and also provide in-kind farming match on their own property. The project footprint encompasses 392 acres, including existing Bay Front marsh areas within the study area, 270 acres of WDFW farmland preserve, sloughs, and additional adjacent private farm land owned by the Haytons that falls within the proposed footprint of the project. Additional details regarding the Snow Goose Preserve establishment, operations, and functions for Snow Goose habitat are included in Technical Memo 1.8.

RESTORATION FRAMEWORK

The restoration project goals and objectives are to restore critical nearshore and river delta juvenile Chinook habitat. Understanding the existing and historic geomorphologic processes and conditions of the project will allow for establishment of a project baseline, which will then be used in developing a conceptual process-response model. This model will then be used as a framework for understanding how the project site may respond to restoration actions.

Beechie and others (2009) present principles and a "framework" for implementing process-based restoration. The principles put forth assert that restoration actions must:

- Address root causes of degradation.
- Be consistent with physical and biological potential of the site.
- Work at a scale commensurate with the environmental problems.
- Clearly articulate outcomes for restored ecosystem dynamics.

The Puget Sound Nearshore Partnership has also developed a set of guiding principles to be utilized on nearshore restoration projects (PSNP, 2006), which include:

- Restoration actions should be based explicitly stated hypotheses;
- Initial restoration projects should be designed as experiments to address information needs;
- Project implementation should be preceded by restoration planning;
- Restoration must consider "ecological succession";
- Project proponents should recognize the limits on ecosystem potential constrained or limited by irreversible change; and
- Restoration projects should be based on carefully developed goals and objectives.

Slocum (2010) presents an alternative strategy for developing restoration projects that focus on habitat creation that consider the limitations and constraints that are frequently encountered in a project. This approach considers that not all restoration actions are feasible or practical to achieve process-based restoration.

The Fir Island Farm restoration project is utilizing a process-based framework, similar to those prescribed by Beechie and others and PSNERP. However, the project team and steering committee recognize that there may be constraints and limitations for the levee setback project alternatives, and that other habitat creation approaches (namely self-regulating tidegate retrofits) are being evaluated as possible project alternatives. The project alternatives are described further in Memorandum 2.1, Concept Design Alternatives. In general, the project goals and objectives are to restore existing farm lands into tidal marsh areas by setting back existing levees. This type of approach is generally considered a process-based approach. However, there may be some limitations on which particular processes can be restored. The conceptual process-based model is used to describe some of the potential limitations for the setback projects.

For the self-regulating tidegate retrofit alternatives, the primary restoration mechanism is to allow for increase the period of time for juvenile Chinook fish passage, access to previously blocked tidal channels. The regulating tidegates will provide access and partial restoration of tidal flow and associated sediment and nutrient inputs to the system. These alternatives do not fully restore processes and are more focused on providing fish passage that need consideration due to budget and funding limitations as the levee setback projects are an order-of-magnitude more costly.

In applying the process based principles from Beechie and others and PSNERP listed above, the first step is to identify goals and objectives of the restoration project. The project goals and objectives are stated in the Salmon Recovery Funding Board grant application (WDFW, 2009).

- Restore tidal flooding (natural process).
- Restore unrestricted movement of water, sediments, nutrients, detritus, and organisms.
- Restore native tidal marsh habitat.
- Restore tidal channel habitat.
- Restore fish passage.
- Restore estuary rearing habitat for Endangered Species Act-listed species.
- Restore estuary habitat for fish and wildlife species.

The memorandum provides a basis for understanding geomorphologic processes (historical and existing), and the potential range of tidal marsh responses to restoration actions. Of particular concern are questions related to tidal marsh responses as they relate to the predictive methods being used for estimating tidal marsh restoration response. Later in this technical memorandum, the conceptual process model will be utilized to evaluate if the proposed actions will restore the degraded processes that will result geomorphologic responses and the associated restoration of functional habitats, as well as the applicability of the geomorphologic predictive tools being used for the project. The application of the model will also allow the project team to evaluate possible constraints, risks, and outcomes to the alternatives that will become more apparent through application of the conceptual process model.

GEOMORPHOLOGIC CHARACTERIZATION

The following geomorphologic characterization was developed considering the spatial scale of the proposed project, as well as considering the historical changes in Skagit River and Skagit Bay Front shoreline processes. The Skagit River Delta is one of four major landscape types found along the margins of the Puget Sound nearshore, which include rocky coasts, beaches, embayments, and large river deltas. Large river deltas in the Puget Sound represent marine extensions and fill of alluvial floodplains into glacially carved troughs (Shipman, 2008).

The Skagit River Delta is part of the Skagit Bay in the Puget Sound Whidbey Basin. Skagit Bay and is bounded by the Skagit River Delta to the north and east, Camano Island to the south, and Whidbey Island to the west and north (Figure 1). River inflow to Skagit Bay are from the North and South Forks of the Skagit River, the Swinomish channel between Skagit and Padilla Bays near La Conner, and the West Pass distributary of the Stillaguamish River in the southernmost portion of the Bay near Stanwood, Washington. Tidal inflow and drainage to the Skagit Bay is through the Saratoga Passage from the south between Camano and Whidbey Islands and Deception Pass from the north between Whidbey and Fidalgo Islands.

The geomorphologic scale of interest to the project is at the river reach and shoreline bedform feature scale. We are interested in features such as river delta distributary and avulsion channels, tidal marshes and their associated blind channels, sand bars, and mudflat complexes. Ultimately, the Fir Island Farm restoration feasibility study evaluates the potential restoration of these features and estimate the potential habitat areas and juvenile Chinook smolt production that will

result from the project restoration alternatives and actions. The following characterization and development of a process-based conceptual model will be used to assess how project alternatives will affect river delta and Bay Front shoreline processes. Then we will evaluate how the project may respond to future restoration actions, and identify the associated constraints, limitations, and risks to the proposed project alternatives.

Skagit River Delta Features and Processes

The Fir Island Farm restoration project site is located on the Skagit Bay Front along the southern shoreline of the Skagit River Delta. This site is mid-way between the North and South Fork Skagit River distributaries. The Skagit River Delta is comprised of the north and south fork channels with Fir Island area located in between.

River deltas are landforms that form as rivers flow into large water bodies and experience a change in profile, slope and floodplain confinement. The deltaic land feature formed over time from sedimentation that occurred as flowing river enters the open areas of the coastal embayment or glacial trough. Both the change in river slope at is encounters the marine level and the expansion of the embayment contribute to reductions in river velocities and energy, which correspond to active deposition and sedimentation. As sedimentation occurs, alluvial surfaces build upward and extend outward (prograde) into the marine trough, creating a fan or delta-shaped feature.

The Skagit River delta is located in the northern portion of the Puget Lowland. The Puget Lowland was subjected to six or more major glacial advances over the past several million years, including the most recent Vashon advance, which occurred between about 18,000 and 13,500 years ago. Extensive erosion and sedimentation during the Vashon glaciation produced many of the deposits and landforms that make up the surface of the Puget Lowland (see Technical Memorandum 1.3).

Among the more prominent glacially derived landforms in the Puget Lowland are north-south-trending troughs like those now occupied by Puget Sound and Lake Washington. These troughs were scoured by meltwater streams that flowed beneath Vashon ice (Booth, 1994). The Skagit River deltaic deposits occupy a trough eroded by subglacial meltwater streams between the Devil's Mountain and Bulson Creek complex to the east, and the Pleasant Ridge and Rexville

bedrock complex to the west (Dragovich and others, 2002). Trough sedimentation and delta formation (progradation) occurred in a relatively rapid fashion (approximately 5,000 years) through post-glacial alluvial sedimentation, with major sediment contributions from volcanic input and debris flows (lahars) originating from Glacier Peak volcano (Dragovich and others, 2000 and 2002).

Isolated bedrock knobs protrude above the surface of the Skagit River Delta deposits. These can be observed near Pleasant Ridge and Rexville to the west of the delta and Bulson Creek to the east of the delta. Bedrock protrusions consist of Tertiary sedimentary rocks of Bulson Creek (Dragovich and others, 2002). Locally, the bedrock knobs are mantled by Vashon till and recessional glaciomarine deposits.

In river delta environments, long-term alluvial sedimentation processes create and sustain systems of distributary channels.

> *River delta is defined as a fan-shaped landform of fluvial sediment deposited at and beyond the mouth of a stream, usually a river, as it debouches into a body of standing or low-velocity water, generally an ocean or lake, or some other water body and embayment of reduced or stagnant flow. As a delta continues to form and grow outward from the mouth of the stream into the standing water, channel gradient is minimized and the stream typically separates into a complex of relatively straight channel distributaries that are poorly capable of carrying the coarser fractions of their total sediment loads to the distal edge of the delta (U.S. Geological Survey [USGS], 2008).*

In general, mainstem river bed profiles rise due to sedimentation. As the bed of the channel rises, the river will overflow its banks, into adjacent low lying floodplain areas, thereby forming distributary channels. This process of distributary formation is termed “bifurcation” and is commonly associated with river delta environments. Distributaries, similar to larger mainstem river channels, deliver flow, sediment, nutrients, detritus, and woody debris to downstream river delta and Bay Front areas. Distributaries are ephemeral features that flow and fill in over relatively short periods of time, creating a mosaic of channel patterns along shoreline of the river delta.

Distributary and cross island channel connectors have been identified as restoration alternatives in multiple studies (Chinook Recovery Plan - SRSC 2005, Restoration Pathways - PWA 2003, Skagit River Flood Damage Reduction Study Preliminary Measures – U.S. Army Corps of Engineers [Corps], 2008, Solutions for Landowners and Salmon on Dry Slough – Northwest Chinook Recovery [NCR], 2002). The importance of discussing the role of distributaries for the Fir Island Farm restoration project is due to the relationship of the two historical distributary connections at the project site, namely Browns Slough and Dry Sloughs. These historic distributaries are currently disconnected from the Skagit River and Skagit Bay due to the existence of the flood protection levee and dike systems. Distributary connections are not currently elements of Fir Island Farm restoration feasibility study, but future linkages could provide benefits and improve restoration of physical and biological processes in the Fir Island farm study area.

Another major physical process is the transport and deposition of large woody debris along the Skagit River Delta. Transport of large woody debris contributes to channel forming processes and is a key factor in development, maintenance, blockage, and abandonment of both distributary and avulsion channels. We distinguish between distributary channels and avulsions whereby avulsions typically involve channel abandonment and occupation of a new or historical channel alignment that can form for by a variety of alluvial processes and will frequently involve abandonment of the former channel, whereas distributaries refer to splitting and formation of multiple channels typically found on river delta areas.

> *Avulsion is defined for fluvial processes as a rapid change in the course or position of a stream channel, especially by incision (erosion) of lowland alluvium, to bypass a meander and thereby shorten channel length and increase channel gradient; avulsion commonly occurs during floods but also can occur by normal processes of lateral migration of a stream channel during non-flood discharges (USGS, 2008).*
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> *Distributary is defined as a fluvial-geomorphic term, typically referring to the spitting of a stream channel into two or more segments that leave the main channel and do rejoin it, as generally occurs on deltas (USGS, 2008).*

One of the most typical types of avulsion occurs across the inside of a meandering river bend, termed “meander cutoff.” As an alluvial river meander develops, there are instances whereby the

radius of curvature of the meander bend decreases and "tightens", and a channel avulsion will occur across the short inside section of the bend (Slingerland and Smith, 2004). Meander cutoff avulsions, albeit fairly common in low gradient, alluvial meandering river systems, are not typical types of avulsion process observed in the Skagit River Delta.

The role of large wood debris transport and deposition is a major factor for both distributary and rapid river avulsion formations on the Skagit River Delta. Large wood debris formations historically and currently contribute to the periodic formation and abandonment of delta distributaries. However, the historical Skagit River was also observed to have major, full river log jam blockages , which would create major avulsions and abandonment of mainstem channels. Reductions in large wood debris inputs to the river through river channelization, bank stabilization, and armoring and losses in riparian inputs to urbanization, as well as wood debris removal from the river have reduced the potential and frequency major river avulsions in the Skagit River Delta.

Another unique type of distributary channel avulsion process has been observed along the North Fork Skagit Delta (Hood, 2010a). In this particular case, the North Fork Skagit Delta is migrating southward, and the outside bed of the meander has eroded into and occupied several smaller distributary and tidal channels. This is another potential mechanism for channel development and formation in the Skagit River Delta, and is slightly different from the processes described above.

In the Skagit River Delta, it is observed that there are fairly significant differences in historical and current flow distribution and sedimentation patterns. The importance of overflow into distributary channels, whether they are derived from delta distributary processes, influenced by log jam blockages or meander bend processes, is that distributaries provide important flow, sediment, nutrients, and detritus delivery mechanisms to the Skagit Bay Front area. These historical processes were important in the development and maintenance of downstream tidal marsh areas, which historically provided functional juvenile Chinook habitat, in the Skagit River Delta and Bay Front areas, including the Fir Island Farm Snow Goose Reserve site.

Skagit Bay Front Tidal Marsh Features and Processes

In addition to the river delta sedimentation and wood transport processes as described above, the Skagit River Delta is also subject to coastal and tidal processes. Tidal marsh geomorphologic features are influenced by tidal prism exchange, storm surges and wave action, large wood debris and longshore sediment transport and deposition patterns, and vegetation establishment, as well as influenced by other biological factors (such as Snow Goose foraging). While not wholly separable from river flow conditions, certain areas of the Delta may have less influence by river processes that result in different geomorphologic conditions and potential restoration trajectory.

A characterization of the Skagit Delta and Bay Front areas was performed to describe the different morphologic features observed in the river delta and coastal Bay Front areas. There are numerous methods for describing coastal morphologies using a similar scale to the river reach and bedform scale. The terminology used in this study is similar to the terms and features identified in nearshore habitat mapping studies along Skagit Bay (McBride and others, 2006). Within Skagit Delta and Bay Front areas, there are five observed marsh and channel bedform morphologies (Figure 2).

- Intertidal vegetated marshes with distributary and blind channels and interspersed large wood debris accumulations (river and tidal/coastal influences).
- Intertidal, unvegetated sand and mudflats with complex delta channel networks and little to no wood debris accumulations (river and tidal/coastal influences).
- Intertidal vegetated marshes with numerous blind tidal channels, no distributaries, and massive accumulations of large wood debris lateral to the shoreline and bay dikes (tidal/coastal influences).
- Intertidal, unvegetated mud flats with little complexity and few sand channels (tidal/coastal influences).
- Subtidal vegetated eel-grass beds bayward of both Bay Front and delta channels (tidal/coastal influences).

The North and South Fork Deltas are observed to have a complex mosaic of overlaying distributaries and blind tidal channels. Further into the bay, these channels diffuse into a complex network of unvegetated sand bars, channels, and mudflat areas. The influence of river sediments is very much apparent in these delta areas. Another notable observation is that large

wood debris accumulations appear to be more sporadic, and less dense as compared with the large wood debris accumulations observed along the Skagit Bay Front areas. The sporadic wood accumulations may indicate that wood debris in the delta areas is subject to transport rather than long term deposition or accumulation conditions.

Along the Bay Front areas, which are now primarily tidally influenced as historic distributaries have been removed, the observed geomorphologic features are described as vegetated marshes with numerous blind channels and large wood debris accumulations. The blind channels transition downstream into the bay as unvegetated mud flats with few sand bars and far less channel complexity than the river delta areas. The areas are described as broad, open, unvegetated mudflats. A notable distinction between the Bay Front and delta areas is the occurrence of numerous, dense, large wood debris accumulations along the vegetated marsh areas parallel to the Bay Front dikes. These types of accumulations would tend to indicate a depositional and accumulation environment along the bay front.

The patterns of sediment and wood transport and deposition in the bay appear to diverge along the bay front. Sedimentation patterns tend to diffuse in a linear fashion into Skagit Bay. This would indicate that sediment supply and transport is influenced by river flows a further distance out into the bay along the bed.

In contrast, wood accumulation patterns may indicate that as wood is supplied to the bay area, wind and wave forces at the water surface become more dominant transport mechanisms and move wood materials along and into accumulation and depositional bay front and shoreline areas.

Skagit Delta and Bay Front Area Geomorphologic Segregation

Previous studies on the Skagit Delta have identified three distinct areas along the Skagit Delta, Skagit Bay Front area (Hood, 2010b). These areas are described as (Figure 2):

- South Fork Skagit Delta – Active alluvial deposition, existence of overflow delta distributary channels, intermingled with blind tidal channels, and connected to unvegetated, sedimentary tidal channel, sand bars and mudflat complexes out in the Skagit Bay area.

- North Fork Skagit Delta – Active alluvial deposition, mainstem river meander bend channel migration, connection and occupation of blind tidal channels on the outside of the meander bend causing formation of periodic distributary channels, and sedimentary tidal channel, sand bars, and mudflat complexes out in the Skagit Bay area (albeit less complex than the South Fork Delta).
- Skagit Bay Front Area –The current Bay Front has multiple blind tidal channels and marsh areas with no current delta distributary channel connections, which were formerly connected at Browns and Dry Sloughs. The current drainages are connected upstream to interior agricultural drainage channels. The marsh along the Bay Front is bordered by a broad mudflat complex and does not have the same tidal channel and sand bar complexity as are observed in the South and North Fork Deltas.

One significant difference noted between these three delta regions are the level of channel complexity observed in the delta distributaries as compared with the Bay Front area. The delta distributaries receive continual inflow, alluvial sediment transport, and large wood debris, which contribute to the channel complexity and provide the formation processes necessary to sustain the continual development and formation of the tidal channel system. The Bay Front areas have tidal exchange only, large wood debris transport, and large jam accumulations along the marshes and longshore sediment transport processes occurring (not river distributary processes). These processes result in different tidal channel morphology where the Bay Front areas have less channel complexity and smaller channels.

CONCEPTUAL GEOMORPHIC PROCESS RESPONSE MODEL

Conceptual geomorphic and habitat functional response models are recommended by the Puget PSNERP in the Technical Report 2006-03, Conceptual Model for Assessing Restoration of Puget Sound Nearshore Ecosystems. The report describes a framework that can be applied and evaluated for an array of landform features. The framework outlines a method for:

- Characterizing restored processes.
- Assess structural and physical responses (change analysis).
- Assess functional habitat responses (future habitat response).
- Identifying critical risks or constraints to the restoration actions and alternatives.

In this section of the memorandum, identify physical processes influencing these geomorphic properties. The characterization and description of physical processes influencing the site is

ermed the Conceptual Geomorphic Process Model. A change analysis (historical, existing, and future) is then used in combination with the Conceptual Geomorphic Process Model to understand potential responses to restoration actions and the potential risks and limitations for the alternatives as they relate to restoring physical processes and the resulting functional habitat responses.

The primary processes involved are shown as scalar arrows in Figure 1 and Table 1. We note that the scalars shown in Figure 1 along the Bay Front represent the conditions on the outside of the dikes that will be restored for the project in its current formulation. Processes are broken into tidal and river processes. If, in the future, distributary flows were to be associated with the project, the process model would be updated to show river inputs from distributary connections.

Constraints (manmade features or boundaries) and anthropomorphic effects are generally shown for existing conditions in Figure 1. Both river and coastal constraints are the structures (roads, levees, tidegates, and stabilized banks), land use practices (adjacent farming), and regulations or zoning that are in place that will affect conditions, processes, and functions of the river delta and coastal system. An example of a physical constraint would be a highway adjacent to an area that cannot be moved. An example of zoning would be an area designated as Agricultural Land that may or may not be changed to a restored condition.

Evaluation of risks can be included in a conceptual model framework, but are not specifically evaluated in this geomorphologic memorandum. Risks are defined as potential for adverse conditions or outcomes that may or may not cause harm and damages to humans, infrastructure and ecosystems as a result of existing or proposed project conditions. Risks are not evaluated in this geomorphologic memorandum, and will need to be considered as part of the overall project review.

CHANGE ANALYSIS

We reviewed a number of documents, maps, and aerial photographs to generally characterize the likely historical condition, changes through time, and the resulting geomorphologic response. Our historical change analysis includes the following periods:

- Skagit Delta pre-development conditions as described by Collins and others (2002).

- Late 1800s conditions as observed on 1889 T-sheets (original GLO survey sheets).
- 1937 historical aerial photographs provided by Skagit County.
- 1956 historical aerial photographs provided by the Natural Resource Soil Conservation Service (no map or figure included).
- 2006/2009 aerial photographs provided by Skagit County.

Historical Skagit Delta Reconstruction

Collins and others (2002) developed a historical interpretation of the Skagit River Delta using a variety of historical maps, reports, ethnology, landscape ecology, ethnobotany, and palynology data and techniques to develop a pre-develop model of the Skagit River Delta landscape. The landscape scale characterization of the Skagit Delta and Fir Island Farm project site as tideflats and emergent estuarine marsh areas is shown in Figure 3. Figure 3 indicates that both Browns Slough and Dry Slough were connected as distributary overflow channels originating from the North Fork Skagit River with deltas occurring in the project dike setback area. The interior drainage (Claude O'Davis [COD] and No Name Sloughs) are shown as large and long blind channels that may or may not have been historical flow through channels. It is noted that in the historical interpretation, more channel density is shown along the South Fork Skagit Delta than the Bay Front or North Fork Delta areas. It is also noted that both Browns and Dry Slough are shown as having small deltaic network features with channel bifurcations along the emergent estuary, tideflat boundary. Using this type of interpretation, the indication is that all processes described in the conceptual process model including tidal and river distributary flows, sediment transport, large wood debris transport, as well as biological influences, would be occurring at the project site in the pre-settlement period (Table 2).

1889 T-Sheet Map

The 1889 T-Sheet map and Skagit historical records (History Link.org, 2010) were reviewed to understand the early agricultural development activities, and changes to the landscape that were occurring. Settlement of Skagit County and the Fir Island area began around the 1860s. Two settlers, Sullivan and Calhoun, started diking and draining marshy flatlands in the Skagit Delta to develop land for agricultural uses. As Skagit County grew, so did agricultural operations in the Fir Island area. In the late-1800s several important river stops were built along the South Fork of the Skagit River and near Skagit City (near the Skagit Forks and Conway, Washington). These

stops supported the agricultural interests, crossing to Fir Island by ferry, and local logging activities. The ability for steamboat access up the Skagit River to Skagit City (on Fir Island) was accessible in the 1860s. However, economic interests upstream from Fir Island drove the decision for river maintenance activities such as clearing of log jams and debris to allow for commerce and travel along the river (History Link.org, 2010). Clearing of the log jams occurred in the 1870s allowing for upstream navigation, commerce, and development.

The 1889 T-Sheet shows that diking and drainage had occurred along the margins of Browns and Dry Sloughs (Figure 4). Most diking and agricultural development on Fir Island was focused on the southwestern portion of the island, in and around Rawlins (to the west of the site), Browns and Dry Slough. The Browns Slough distributary is shown to bifurcate and split into Rawlins and Brown. Dry Slough is also shown to split into Dry, COD, and MacDonald Sloughs with additional intertidal distributaries downstream from the dikes. The dikes did not extend as far south into the Bay as today, but roughly ended near the current WDFW parking area. A drawbridge is shown on the T-Sheet map and is located at the current Dry Slough/Fir Island Road crossing, which today is near the Hayton Farm entrance. Vast areas to the north and east of Fir Island Road are shown as scrub shrub wetlands on Fir Island.

Considering the initial diking and drainage land reclamation activities, the site would experience disconnection and fragmentation of the marsh from the marsh floodplain and habitat functions. In addition, areas outside the dikes would have reductions in flood flows, reductions in sediment transport and large wood debris, as well as biological influences (Table 2). The Bay Front area did still have connectivity to river distributary flows and sediment, albeit less as a result of ring dikes around the island farms. It was likely that wood debris was removed from the river and distributaries as no major jams where shown on the maps. Biological inputs were also likely decreasing as local river and floodplain nutrients and detritus were contained within interior areas of the adjacent farm berms and dikes.

1937 Aerial

The 1937 aerial shows that the Fir Island dikes are in nearly the same location, along the WDFW Snow Goose Preserve, as they are today in 2010 (Figure 5). The primary difference is that both Browns and Dry (Deer) Slough appear to remain open as distributaries. Fir Island Road crosses both sloughs over bridges. It is likely that the adjacent farm lands were protected with berms and

small levees running along the length of Browns and Dry Slough. The remaining northeastern portions of the island are fully converted to farmland in 1937 from their historic shrub scrub wetland vegetation composition. When the Bay Front dikes were extended to this alignment, COD Slough was closed along the Bay Front with a set of tidegates (likely wood box culvert with a steel flapgate). Interviews with Dike District 22 place the COD closure and tidegate installation circa approximately 1913.

The extension of the diking and drainage contributed to the decline of tidal marsh connectivity and river distributary processes. Interior dike areas have little natural processes occurring. Outside of the dikes, there are reductions in tidal and river flows, with corresponding reductions in sediment transport and large wood debris, as well as biological influences (Table 2).

The Bay Front area did still have some level of connectivity and contributions from river distributary flows and sediment. It was likely that wood debris was removed from the system as none was observed in the aerial photos. Biological inputs were also likely decreased as local river and floodplain nutrients and detritus were contained within interior areas of the adjacent farm berms and dikes. Closure of COD Slough did reduce the amount of tidal inflow and river drainage to the Bay Front area. In 1937, a sedimentary delta feature remained in the aerial photograph at along the Bay Front at Browns and Dry Sloughs. It was likely experiencing reductions in distributary channel sediments at this point in time.

1956 Aerial (Partial)

A partial 1956 aerial photograph was reviewed by Shannon & Wilson and WDFW as part of ongoing discussions regarding tidal channel morphologic predictions of channel will be likely to occur. This period was reviewed as representative tidal inflow only to the Bay Front area, just prior to the 1962 tidal closure and tidegate installation of Dry Slough. The 1956 condition would be somewhat similar to the conditions proposed for the dike setback being evaluated for this study. In this photograph, Browns Slough and upstream Dry Slough appear to have tidegates installed at Fir Island Road to protect interior drainage areas, thereby indicating that river distributary flow was no longer present, but that tidal flows due occur in the Slough channels and adjacent marshes. It is thought that this scenario will be similar to the proposed restoration scenarios for the restoration project. The processes and changes are similar to those described in

1937. There is a question regarding the exact period of upstream closure of Browns and Dry Slough, whether or not it had actually occurred by the time of the 1937 aerial photograph.

2006/2009 Aerial Composite

The 2006/2009 aerial composite shows the configuration of the dikes since 1962 with full closure of Dry Slough (Figure 6). Some minor alterations have occurred during the 1960 to 2010 period mostly related to repairs from levee overtopping and breaching, namely in the 1990 floods.

There is little tidal or river inflow to the project site with some tidal flow occurring at Browns Slough through the screw gate. There is little to no river distributary flows, nor the formation of a sediment delta along the Bay Front area. The primary drainage appears to have been dredged along No-Name Slough. All wood and sediment sources are excluded from the site. Along the Bay Front area, there remains tidal inflow, but the reductions in sediment are notable, with primary evidence being the retreat of tidal marsh vegetation line. Measurements of the retreat of vegetation lines indicate that the vegetated marsh areas along the exterior margins of the Fir Island Farm dike have retreated distance between 400 and 1,000ft as observed on the 1937 and 2010 aerial photographs. This corresponds to a loss of 75 acres of tidal marsh area along the Fir Island Farm Bay Front over the past 73 years.

This observation reflects those made by many others regarding marsh vegetation losses in the Skagit Bay Front area. Hood (2010a) emphasizes the need to evaluate and understand the effects of diking and levee projects on seaward side of the structures. The study asserts that losses in sediment delivery is a primary factor in loss of marsh areas and channel vegetation. The study also indicates that the reduction in tidal prism also plays a significant role in channel marsh formation processes (within and outside the dikes). This would tend to indicate that alternatives that include dike removal would create additional tidal marsh habitat restoration benefits on the seaward side of the dikes, and that the do nothing alternative would continue to experience losses and degradation of habitat along exterior marsh areas.

With respect to large wood debris, there remains quite a bit of large wood debris along the Bay Front area, which is likely derived from the North and South Fork Delta channels. However, at this point in time, there is little to no wood or biological, organic, nutrient, or detritus that would

be recruited from the Fir Island interior areas. The amount of wood debris along the Bay Front is significant, and we would expect that this material will mobilize into the restore marsh areas. Per a previous section of the memorandum, it may be worthwhile to consider large wood debris installations within the levee setback marsh restoration area as protective and energy dissipation features.

Another observation is the accumulation of large algal mats along the interior drainage channels during the summer months. This tends to indicate high levels of nutrients (possibly crop fertilizers) and little flushing or drainage of interior drainage channels. The buildup of nutrients in the water column allows for bacterial algae consumption and processing.

Climate Change

Landscape scale processes, climate change, and sea level rise (SLR) will influence the overall trajectory of the Fir Island Farm, tidal marsh restoration project. Evaluating the influence and potential changes of these external controls is necessary to provide context of the underlying processes that will influence the site over the long term and likely affect the overall trajectory of the site. The following large-scale external processes are reviewed within the framework of the project restoration objectives.

- Climate change affects
- SLR
- Landscape and large scale river processes in the Skagit Delta
- Skagit Delta land use changes

A recent report was published by the University of Washington, Climate Impacts Group (WCCIA, 2009). The executive summary report provides an overview of potential effects of climate change in the State of Washington, including the Puget Sound Area. Temperature is expected to increase by 2.2°F by 2020, 3.5°F by the 2040s, and 5.9°F by the 2080s. These increases in temperatures will affect the changes in mountain snowpack, water storage supply, and flooding. Overall, precipitation is projected to increase by 1 to 2 percent annually. Within that annual period, some models predict wetter winter periods and flooding, with drier summers. Annual snowpack is expected to decrease, and rising temperatures will likely reduce the quality and extent of salmon habitat.

The change in precipitation patterns and reduction in snowpack has significant implications for the hydrology of Skagit River. First, it is expected that more frequent flooding will occur during the fall/winter period. In addition, higher flows are expected during late winter and early spring as a result of flooding from rainfall runoff that historically would have been stored as snowpack in upper watershed areas. For juvenile fish, this would indicate that marsh habitat in the delta will continue to be an important area for early migrant rearing and cover of those individuals that are transported downstream to the Bay Front areas. For later spring and summer periods, there will likely be less flooding from excessive snowmelt runoff and also lower Skagit River flows during these periods. This may have an effect on Skagit Bay salinity, which is also related to juvenile rearing habitat characteristics and could be linked to the need for distributary and cross island connector options.

A key finding in the WCCIA report is that rising temperatures will reduce the quality and quantity of freshwater salmon habitats. Water temperature increases are expected and will continue to degrade and stress salmon. Summer low flows will likely decrease as a result of higher summer time temperatures and lower snowpack. The effects will be significant for populations of rearing salmon that spend time in freshwater areas during summer months such as coho, steelhead, and stream-type chinook that require one year of freshwater juvenile rearing.

Long-term SLR is expected in the Puget Sound area as a result of climate change. SLR projections for the Puget Sound area range from 3 to 22 inches by 2050 to 6 to 50 inches by 2100 (Mote and others, 2008), considering SLR will affect the design criteria for dike setback profile elevations. The effects from SLR are expected to result in the following conditions in the Skagit Delta.

- More frequent inundation and rising of high tides.
- Compounded flooding from increased tidal inundation, storm surge height, and river flood precipitation runoff effects.
- Potential loss of existing Bay Front tidal marshes from rising tide, inundation, and erosion.
- Increases in spring and summer salinity conditions along the Bay Front area.
- Localized increases in erosion and sedimentation.

The research regarding impacts and effects from SLR in coastal estuary systems are not well understood at this time and have a high level of uncertainty. It is likely that more frequent flooding from rainfall runoff (interior drainage and winter time Skagit River flooding) will occur at the site. Also, spring and summer low flows and groundwater conditions will likely decrease, thereby allowing for more intrusion of saltwater in the Delta.

Another related item to the climate change and SLR discussion is the potential effects of large-scale changes in Skagit Delta morphology, tidal channel, and distributary channel flow conditions. As SLR occurs, previous intertidal zones will become more frequently inundated and have less vegetation establishment, thereby becoming sub-tidal zones. This, combined with the potential for more frequent winter flooding and storm surge heights, could increase and promote Bay Front marsh erosion.

Long-term climate change and SLR will likely increase the period of time and level of inundation at the site. This combined with the reduction in summer time flows could increase the extent of brackish water inflow and saltwater intrusion through the dike systems to the farm areas.

Consideration of marsh elevations, ponding and the projected types of vegetation that will likely occur at the site can be screened for their ability to sequester carbon (Trulio, 2007). Tidal marshes (saltwater) are known to release less methane than for freshwater marshes. However, methane releases can often offset the amount of soil carbon sequestration. Anaerobic sequestration deep in tidal marsh vegetative beds (permanent inundation and saturation) is more effective than periodic draining. Increasing the salt marsh footprint and expanding tidal marsh areas will likely contribute to additional sequestration of carbon emissions.

Change Analysis Summary

A summary table has been assembled that shows each of the selected time periods (historical through 2009) and what geomorphologic processes have been modified and which ones will be restored with current proposed actions (Table 2). It is evident that the dike setback will restore tidal-related processes to the marsh. However, it is noted that the lack of reconnection of historical distributaries can limit the potential response of the tidal marsh restoration project. The historical distributaries (Browns and Dry Sloughs) provided freshwater flow, sediment and

nutrient delivery, as well as fisheries habitat connectivity to the Bay Front area. One technical consideration related to distributaries is the different potential for tidal marsh density and total channel areas may be affected by the lack of sedimentation on the Bay Front area. More discussion is provided in the following section of this memorandum regarding the application of tidal marsh regression models for predicting marsh restoration response.

The exterior marsh areas will benefit from the dike setback projects by providing increases in tidal exchange, sediment transport, and nutrient delivery, which will improve physical processes in the exterior marsh areas. The no action, current conditions project will allow for continued erosion and degradation of the Bay Front marsh areas.

The process chart in Table 2 is for dike setback alternatives only. Self-regulating tidegate alternatives for Dry and Brown's Slough provide partial tidal flow restoration and fish passage and are assumed not to significantly affect tidal prism, sediment or wood transport processes, nor result in establishing function tidal marsh channel habitat above and beyond what already exists within the Sloughs. Restoration benefits, therefore, should be estimated and limited to the area of tidal inundation, as allowed by the operation of the tidegate (which has been identified as a gate closure setting of the Mean Tide Level (MTL) of approximately 4.5 feet NAVD88. This limitation is specific to the Fir Island project as the tidegate settings are very low and do not allow for full, or large tidal exchanges. Other projects that have larger tidegate operational ranges allow for more inundation of tidal marsh areas and, therefore, provide increased benefit to habitat and marsh restoration response.

A final consideration with respect to restoration is that the use of large wood debris is recommended for the project. The large wood debris accumulations along the outside of the dike are significant and provide habitat complexity (for fish and birds), as well as dissipate coastal wave energy and provide natural protection to the dikes. Wood debris can also damage dikes when wood impinges on the dike structure, or floats over the top into the protected areas. Therefore, we recommend anchoring large wood debris accumulations (or jams) in rows of linear alignments using driven pile anchors to simulate the accumulations outside the existing dike, as well as trap wood debris, dissipate energy, and protect from waves and wood transport damages to the dikes.

GEOMORPHOLOGIC PREDICTIONS OF TIDAL MARSH CHANNEL HABITAT

The Fir Island Farm restoration feasibility study is utilizing existing tidal marsh channel geomorphologic predictive models to evaluate the potential restoration response of the project. The geomorphologic model tools that are being utilized for predicting marsh vegetation and tidal channel response combine the application with empirical models developed by (Hood, 2010b).

The geomorphologic predictions will be supplemented in the future for the preferred alternative by examining the three-dimensional (3D) hydrodynamic modeling results that are under development as part of this study. This study does not however evaluate each different alternative using the 3D hydrodynamic model, rather we evaluate the alternative using empirical relationships to understand the potential restoration response and habitat conditions, and then model the preferred alternative to examine in more detail the project's effects.

Another important aspect of tidal marsh restoration and channel development is to understand the likely patterns of vegetation establishment and thresholds related to establishment below the mudline, as this plays a major role in tidal marsh channel development. This study also identifies the likely mudline areas where fewer tidal channels will occur based on review of local databases that document the establishment and occurrence of Skagit Delta marsh vegetation (Hood, 2009).

A final step in the preliminary geomorphologic predictive assessments includes assessment of historical and existing primary tidal channels. Tidal channel size relationships were also compared to existing interior drainage channels to evaluate potential expansion or reduction using the relationships that were modified for Puget Sound nearshore restoration planning (PSNERP, 2010). The importance of this step relates to the size of channels in the along the Skagit Delta. Historically, these channel sizes were a function of river distributary processes. These channels are much larger than channels that would develop as a result of tidal only processes. Tidal channel sizes can also be predicted by examining the results of the 3D hydrodynamic model for the preferred alternative. If the existing drainage channels have daily tidal flow conditions that exceed stable channel thresholds (such as maximum permissible velocities approximately 1.0 to 2.0 feet per second), it is expected that the channels will erode and expand until their geometry is such that the flow rates and resulting velocities are at or below

equilibrium thresholds. This analysis will be performed for the preferred restoration alternative and not each individual alternative.

Geomorphologic Relationships for Tidal Marsh Channel Response

Numerous investigators have evaluated methods for predicting the morphologic composition and formation of intertidal channels within the vegetated marshes (Coats and others, 2005; Fagherazzi and others, 2006; Hood 2010b; Hood 2007; Kirwan and others, 2007; Rinaldo, 1999). These studies are generally segregated into empirical and numerical methods. The empirical modeling methods evaluate geomorphologic characteristics, data, and marsh morphologic parameters of existing tidal marsh channel systems and develop statistical regression models based on measurable parameters (such as drainage area and resulting tidal channel areas). Numerical methods utilize the development of mathematical algorithms that represent and describe physical processes and then modify numerical coefficients to match empirical data.

This study evaluated three empirical models for predicting the potential for tidal channel surface area for the restoration alternatives, which is then used to predict juvenile Chinook smolt production. Three geomorphologic tidal channel prediction models were evaluated to assess channel response, namely:

- Historic Channel Conditions (Analysis performed by WDFW)
- Marsh Island Regression Model – South Fork Channels (Hood, 2007)
- Marsh Island Regression Model – Skagit Bay Front Channels (Hood, 2007)

First, we noted that the Fir Island Farm project site has unique conditions that are currently (and will be for the dike setback restoration) primarily tidally driven processes and that the historic delta distributaries are, and will remain disconnected. Therefore, the Historic Channel Condition estimates were not considered appropriate estimates of channel restoration potential due to the existing conditions and reductions in distributary flow and sediment.

We then compared the two Marsh Island Regression model equations (South Fork and Bay Front) to an existing tidal drainage area delineation performed along the existing Bay Front tidal marsh area just southeast of the Dry Slough tidegate complex (near McDonald Slough). The test area point compared well with the Marsh Island Regression Model using the South Fork channel, as compared with the Bay Front model regression parameters (Figures 7 and 8). Based on this

simple comparison of the two models and the existing condition of a nearby tidal marsh area, this study applies the Marsh Island Regression Model – South Fork channel parameters for estimating tidal marsh channel surface areas, with the following caveats:

- The South Fork regression model will be applied to the current farm areas and filled drainage ditches that will become restored tidal marsh areas as a result of the dike setback and not along existing interior drainage channels. The South Fork regression model will be applied to converted farm areas and existing wetlands and not in the existing "primary" ("1st" order) tidal/interior drainage channels.
- This study assumes that the existing primary drainage channels (Dry Slough, COD, and No Name Slough) are somewhat representative of future channel sizes (at least for the purposes of comparing alternatives). Historically, these channels were much wider as a result of distributary flows and sediment from the Skagit River. Over time, the interior channels have been modified through filling, channelization, and dredging. An evaluation was performed using hydraulic geometry relationships to estimate tidal channel cross section area along Dry and No Name Slough using modified equations developed for ongoing PSNERP studies (Barnard, 2011). These predicted channel cross section areas were then compared with existing interior drainage channel cross section areas. Both Dry and No Name Slough interior drainage channels existing cross section areas were much larger (and for Dry Slough an order-of-magnitude larger) than the predicted tidal channel cross section area as predicted using the regression equations as a function of tidal marsh drainage area. This finding supports the idea that the historic distributary channels were much larger, and the remaining channels are larger (and oversized) as compared with what would likely develop as a function of tidal prism inflows only. Therefore, in this project's analysis of tidal marsh new channel areas, the "1st order" primary tidal channels along the site use existing channel area as it is not anticipated that Dry and No Name Sloughs will expand significantly due to their history as larger delta distributaries. It is expected that COD may expand somewhat, as it is nearly fully filled with sediment and vegetation, but we did not model this expansion for tidal channel area.
- The South Fork regression model was developed on blind channels in areas influenced by delta distributary flows and increased sediment supplies along the South Fork Skagit River Delta, which has been identified as having more complexity and larger tidal channels as compared with the Bay Front area. We interpret this difference between the Delta and Bay Front areas as the Bay Front having less energy and sediment inputs and less potential to develop channels. This may indicate that the South Fork regression model may over predict the tidal marsh channel surface areas, (likely in the short term). In other words, it may take more time to develop channels predicted by the South Fork

model, due to reduced sediment deposition rates and corresponding tidal channel development. The shorter term response could result in fewer channels, more mudflats, and lagoon-type conditions until the marsh plain sedimentation and vegetation establishment condition is such to promote development of complex tidal channels.

- A second consideration is the low lying farm areas that are being restored that are at/or below or near the MTL. These areas will likely have lower rates of establishment of tidal marsh vegetation. It is noted that these mudflat and mud channel areas have fewer and less complex tidal drainage channel networks, as establishment of vegetation plays a significant role in development of dendritic channel networks. We have observed mudflats and mud channels along the Bay Front area at elevations less than approximately 5 feet NAVD88 (near the MTL of 4.5 feet NAVD88). This elevation is similar to data published for vegetation monitoring database for the Skagit River Delta (Figure 9., Hood, 2009). It is likely that the South Fork model will likely over predict tidal marsh channel surface areas for future restoration areas with elevations lower than approximately 5.0 feet NAVD88. These areas typically occur along the southern side of the site near the existing dike and interior drainage channels and are a fairly significant area for each restoration alternative.

Using this approach, the following tidal channel surface areas were predicted for comparison of alternatives, and use in estimating Chinook smolt production as described in the alternatives analysis, separate from this memo.

CONCLUSIONS AND RECOMMENDATIONS

We provide the following conclusions and recommendations for consideration in the greater context of the Fir Island Farm, Snow Goose Reserve, Restoration Feasibility Study.

- All project alternatives, in their current state, address tidal processes only. We recommend that the Fir Island Farm Project develop recommendations and strategies for linkages to other projects that would enhance and improve the restoration potential of the Fir Island Farm site as it relates to restoring river delta connectivity, specifically distributary flows of Browns and Dry Sloughs.
- Sediment processes for the restoration alternatives are not likely sufficient to fully restore processes in the marsh for tidal restoration alone. These will be improved in part through tidal inflow to the site, but may not be adequate to overcome historical losses of river distributary inputs. Additional restoration actions or strategies should be considered that account for these long-term sediment reductions to the site. These would include long-term goals to provide river sediment inputs through distributary flow and delta

connectivity and other prescriptive measures to offset interior farm topsoil erosion and subsidence. Options may include channel dredging and filling farm (marsh restoration) areas in advance of the dike setback to simulate and restore the losses in soil surfaces. Raising existing farm grades that will be restored could be done to match historical marsh plain surface elevations that have been lowered over the past 100 years. Current discussions with the Fir Island Farm Steering Committee have identified agricultural drainage channel dredging spoils as a potential source for soil import.

- More detailed evaluation of project flow, sediment, wood and biological processes should be included at the outset of the engineering design phase of work. This would include additional model runs to evaluate coastal wave and sediment dynamics and distributary flow through scenarios to demonstrate the benefit of such projects to this project. Also, evaluation of hydrodynamics, sediment deposition and subsequent channel erosion rates should be evaluated for tidal restoration and tidal with distributary flows to assess the estimated timeframes involved with full restoration of the marsh. Estimates of tidal marsh channel morphologic development currently use the Marsh Island – South Fork regression model. We have identified some potential drawbacks to using the South Fork model in that it may over predict the number of channels that will become established at the site (especially in the near term). We recommend during the next phase of study to evaluate the potential for tidal marsh channel development and time frames as they relates to sediment deposition and channel erosion processes, and to also evaluate the affects of linking distributary flows to the study site. Dredging and fill options could also be evaluated to see if they improve the potential for tidal marsh vegetation establishment and accompanying development of interior tidal drainage channels. Evaluation and inclusion of these studies would provide additional assurances that the project restoration goals and time frames will occur as anticipated.
- Self-regulating tidegate alternatives analysis should allow inclusion and evaluation of existing tidal channels only and not the associated marsh areas, as the likely gate settings as described in the Dry Slough Tidegate Replacement, Hydraulic and Geomorphic Assessment report will likely be set at the MTL, thereby only allowing inundation of the tidal channels only and not the adjacent marsh areas.
- Farm drainage effects on water quality degradation could affect the restoration potential of the marsh. We, therefore, recommend linking project objectives and actions to farm water quality treatment alternatives and initiatives on Fir Island. Examples would be treatment measures and farm Best Management Practices to reduce pollutant inputs to the interior drainages.

- Restoration alternatives should also consider the beneficial effects of levee setback on exterior marsh areas. This involves recognition of increased habitat on the exterior marsh as a secondary benefit as a result of increasing tidal marsh drainage areas.
- Alternatives 2 and 3 will likely have larger portions of mudflats along their southern margins as compared with Alternative 1. The predictive models for this study do not directly account for these differences, but should be "qualitatively" considered in evaluating the restoration potential of the project.
- Climate change and SLR have a significant potential to affect the project site. Climate change scenarios, such as SLR effects and corresponding dike profile design elevations and inundation characteristics of the marsh plain, should be further evaluated in the following engineering design phases of study.

CLOSURE

The conclusions and recommendations documented in this technical memorandum have been prepared for specific application to this project and have been developed in a manner consistent with that level of care and skill normally exercised by members of the environmental science profession currently practicing under similar conditions in the area, and in accordance with the terms and conditions set forth in our agreement. The conclusions and recommendations presented in this technical memorandum are professional opinions based on interpretation of information currently available to us, and are made within the operational scope, budget, and schedule constraints of this project. No warranty, express or implied, is made.

Prediction of future geomorphologic conditions is an inexact science. The scope of this document was to provide a baseline understanding of geomorphologic processes and not to predict likely responses and geomorphologic configurations of the restoration alternatives. This document provides preliminary characterization and discussion of broad conceptual process models only. Due to the limitations in scope has a high level of uncertainty on the outcome of morphologic response conditions regarding restoration actions and resulting tidal marsh characteristics.

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

This technical memorandum 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 Shannon & Wilson, Inc.

Sincerely,

SHANNON & WILSON, INC.

David R. Cline, P.E.
Associate

DRC/drc

Enc: References
Table 1 – Scalar Descriptions of Skagit River Primary Geomorphologic Processes (also shown in Figure 1 for existing conditions)
Table 2 – Scalar Descriptions of Skagit River Primary Geomorphologic Processes
Figure 1 – Skagit River Delta Geomorphologic Processes
Figure 2 – Skagit River Delta Distributary and Tidal Channel Morphology
Figure 3 – Skagit River Delta Pre-Development Historical Landscape Reconstruction (Collins, 2002)
Figure 4 – Skagit River Delta 1889 T-Sheet
Figure 5 – Skagit River Delta 1937 Aerial Photograph
Figure 6 – Skagit River Delta 2006/2009 Aerial Photograph Composite
Figure 7 – Tidal Channel Geomorphic Regression Equations
Figure 8 – Tidal Marsh Regression Analysis Comparison for Channel Cross Section Area
Figure 9 – Skagit Delta Vegetation and Mudline Data

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TABLE 1
SCALAR DESCRIPTIONS OF SKAGIT RIVER PRIMARY GEOMORPHOLOGIC PROCESSES
(also shown in Figure 1 for existing conditions)

Scalar	Process	Description
	Tidal Flow	Tidal flow includes both the daily tidal prism "volume of water exchanged between low and high tide that floods and ebbs from the marsh area" as well as larger storm surges, waves, and tsunamis that can influence tidal marsh morphology.
	River Flow	River flows include typical average flow conditions and as larger flood related channel and floodplain forming events.
	Coastal Longshore Sediment Transport	Coastal sediment transported due to long shore transport, littoral drift, and shoaling processes.
	River Sediment Transport	River sediment transported, eroded, and deposited in the delta of the river. Alluvial sediment includes large sediment transport events such as lahars and debris flows.
	Coastal Large Wood Debris	Coastal wood debris transported along the nearshore area from tidal, coastal, wave, wind, and storm surge events.
	River Large Wood Debris	River large wood debris is supplied from and transported by river flood flows.
	Coastal Biological Inputs	Coastal biological inputs refer to biota, but are primarily salt-water coastal systems. Biological inputs can affect morphologic composition of marsh plains and tidal channels (such as establishment of vegetation forming tidal channels and/or mass consumption of vegetation from bird species causing marsh erosion).
	River Biological Inputs	River biological inputs include nutrients, invertebrates, fish, mammals, vegetation, and seed sources that are transported primarily by the river, and can affect the morphologic composition of the channel (such as establishment of vegetation forming tidal channels and/or mass consumption of vegetation from bird species causing marsh erosion).

TABLE 2
SCALAR DESCRIPTIONS OF SKAGIT RIVER PRIMARY GEOMORPHOLOGIC PROCESSES

Process	Historical Scalar	Existing Interior Dikes Scalar	Existing Exterior Dikes Scalar	Proposed Setback Interior Dikes Scalar	Proposed Setback Exterior Dikes Scalar	Description
Tidal Flow						Restoration involving dike setback provides benefits and likely improves both interior and exterior dike tidal prism exchange.
River Distributary Flow						Restoration alternatives do not include river distributary flow processes. Recommend considering flow through options to restore this process. Would likely need to be considered as linkage to separate set of projects. Current distributary flow scalars are associated with farmland interior drainage, which is a fraction of historic distributary flow and poorer water quality conditions.
Coastal Longshore Sediment Transport						Restoration involving dike setback provides benefits and likely improves both interior and exterior dike tidal prism exchange. It does not likely create full restoration of coastal sediment processes, as current external areas are experiencing vegetation losses. Likely need river sediment linkage restored in order to maximize coastal sediment dynamics of Bay Front.
River Distributary Sediment Transport						Restoration alternatives do not include river distributary flow processes. River distributary sediment is linked to coastal sediment processes. Recommend considering flow through options, as well as sediment management and dredge spoil options to emulate natural processes. Current distributary sediment scalars are associated with farmland interior drainage which is a fraction of historic distributary sediment loads and poorer sediment quality. Likely not of adequate scale to develop significant complex tidal marsh channels in short term without major distributary linkage.
Coastal Large Wood Debris						Restoration involving dike setback provides benefits and likely has near full restores coastal transport of large wood into the marsh area. Current Bay Front conditions indicate that large amounts of wood debris will be transported into the restored marsh, which is a consideration in designing and protecting the dike setback structures. Design of anchored large wood debris structures could be included to offset and emulate this process. This could be done in such a fashion as to actually protect setback dike from wave run-up, erosion, and wood debris transport damages.
River Large Wood Debris						Restoration alternatives do not include river large wood debris inputs. Historical scale of wood input is not known. Upstream linkages would not likely be designed in such a fashion to allow large wood debris transport through distributary systems.
Coastal Biological Inputs						Restoration involving dike setback provides benefits and likely improves both interior and exterior dike tidal prism exchange. Full restoration will need to address Snow Geese and farm drainage water quality inputs.

TABLE 2
SCALAR DESCRIPTIONS OF SKAGIT RIVER PRIMARY GEOMORPHOLOGIC PROCESSES

Process	Historical Scalar	Existing Interior Dikes Scalar	Existing Exterior Dikes Scalar	Proposed Setback Interior Dikes Scalar	Proposed Setback Exterior Dikes Scalar	Description
River Biological Inputs	⬅	⬅	⬅	⬅	⬅	Restoration alternatives do not include river distributary flow processes and resulting biological inputs. Recommend considering flow through options, as well as farm drainage water quality treatment measures for upstream drainages. Additional biological consideration is the loss of marsh vegetation due to snow goose consumption. Reduction in Snow Goose forage areas could have effect on marsh vegetation consumption. This applies for both distributary and coastal biological inputs.

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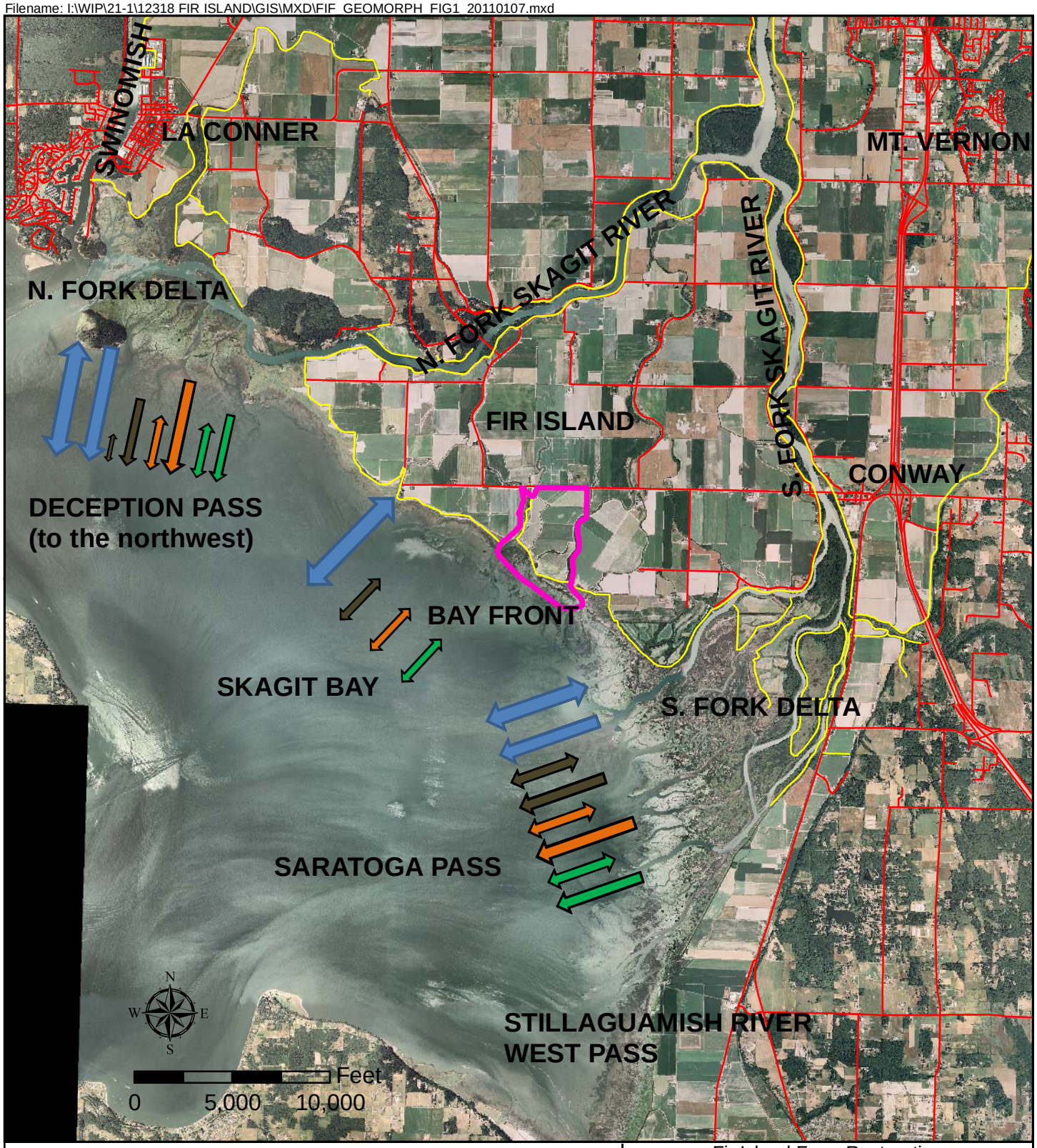

PROJECT FOOTPRINT
LEVEE
ROADS
TIDAL FLOW
RIVER FLOW

COASTAL WOOD DEBRIS
RIVER WOOD DEBRIS
COASTAL SEDIMENT
RIVER SEDIMENT
COASTAL BIOLOGICAL
RIVER BIOLOGICAL

State Plane Washington
North 4601 NAD83/NAVD88

Fir Island Farm Restoration
Skagit Snow Goose Preserve
Skagit County, Washington

DRAFT

SKAGIT RIVER DELTA GEOMORPHOLOGIC PROCESSES

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FIG. 1

Filename: I:\WIP\21-1\12318 FIR ISLAND\GIS\MXD\FIF_GEOMORPH_FIG2_20110107.mxd

LEVEE

ROADS

N
W E
S

Note: Aerial source NAIP 2006.

State Plane Washington North 4601 NAD83/NAVD88

Fir Island Farm Restoration
Skagit Snow Goose Preserve
Skagit County, Washington

DRAFT

SKAGIT RIVER DELTA DISTRIBUTARY & TIDAL CHANNEL MORPHOLOGY

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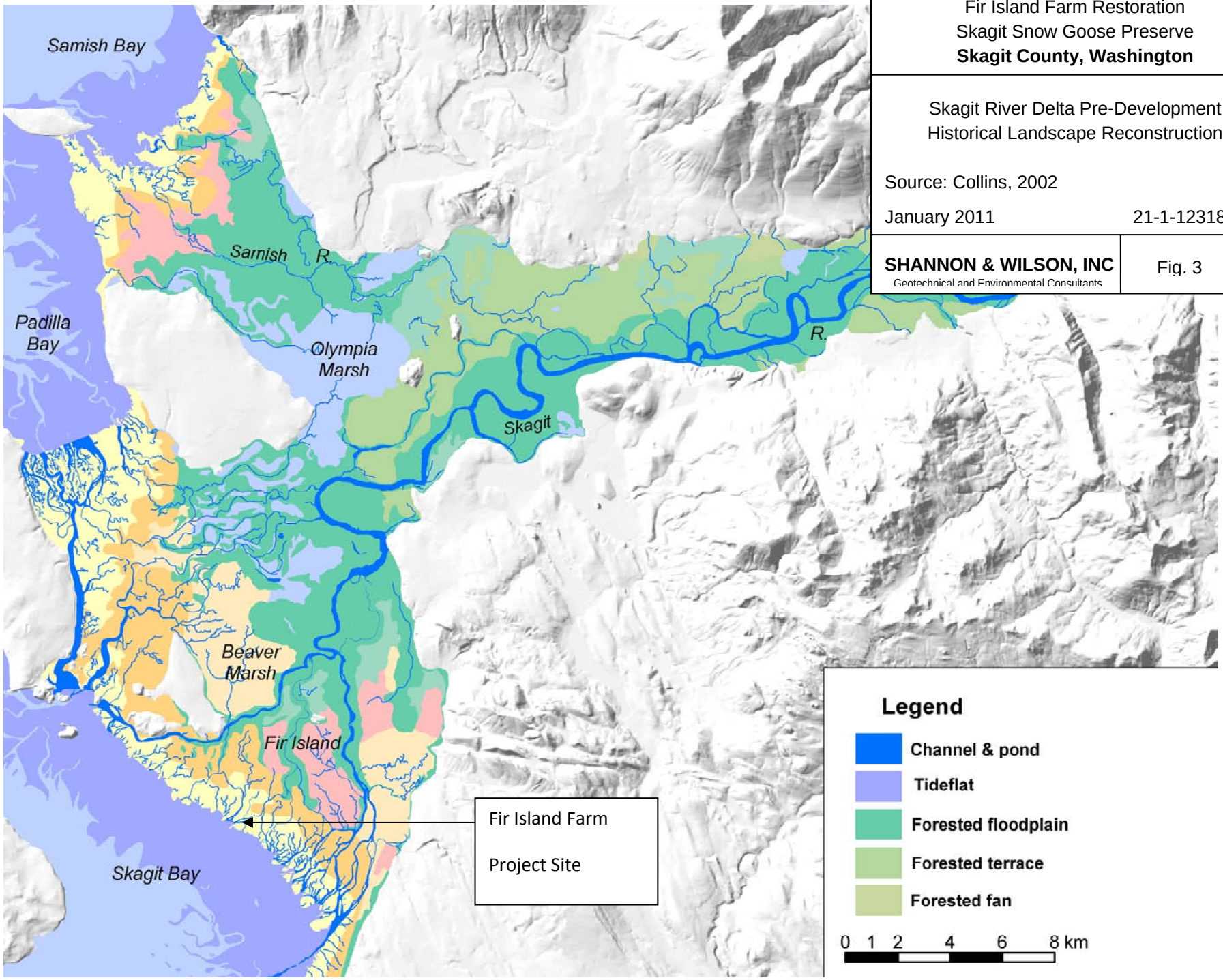
FIG. 2



Fir Island Farm Restoration
Skagit Snow Goose Preserve
Skagit County, Washington

Skagit River Delta Pre-Development
Historical Landscape Reconstruction

Source: Collins, 2002

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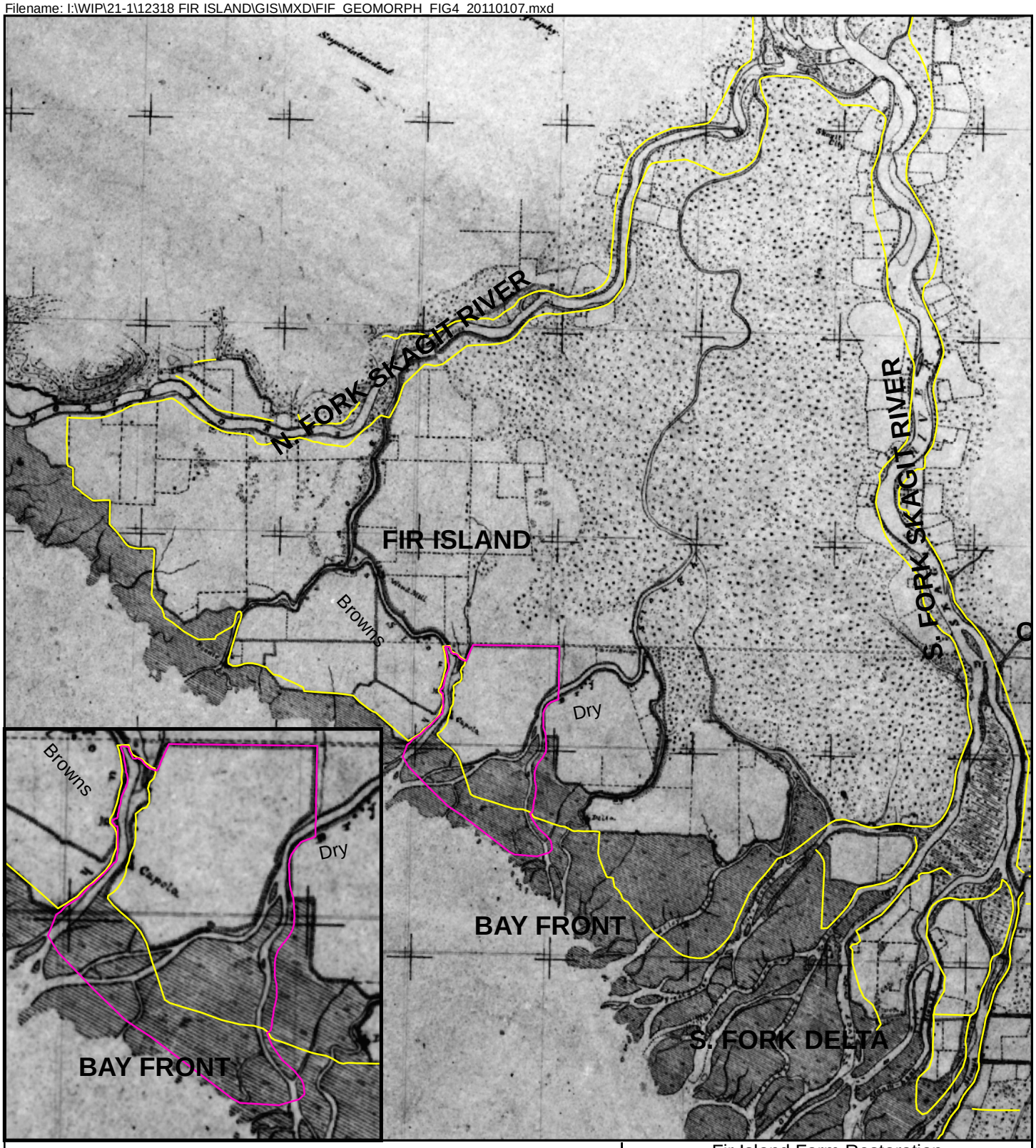
Fig. 3

Filename: I:\WIP\21-1\12318 FIR ISLAND\GIS\MXD\FIF_GEOMORPH_FIG4_20110107.mxd



PROJECT FOOTPRINT

2010_LEVEES

State Plane Washington
North 4601 NAD83/NAVD88

N W E S

Feet

0 2,500 5,000

Fir Island Farm Restoration
Skagit Snow Goose Preserve
Skagit County, Washington

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SKAGIT RIVER DELTA
1889 T-SHEET

SOURCE: PUGET SOUND RIVER HISTORY PROJECT
UNIVERSITY OF WASHINGTON

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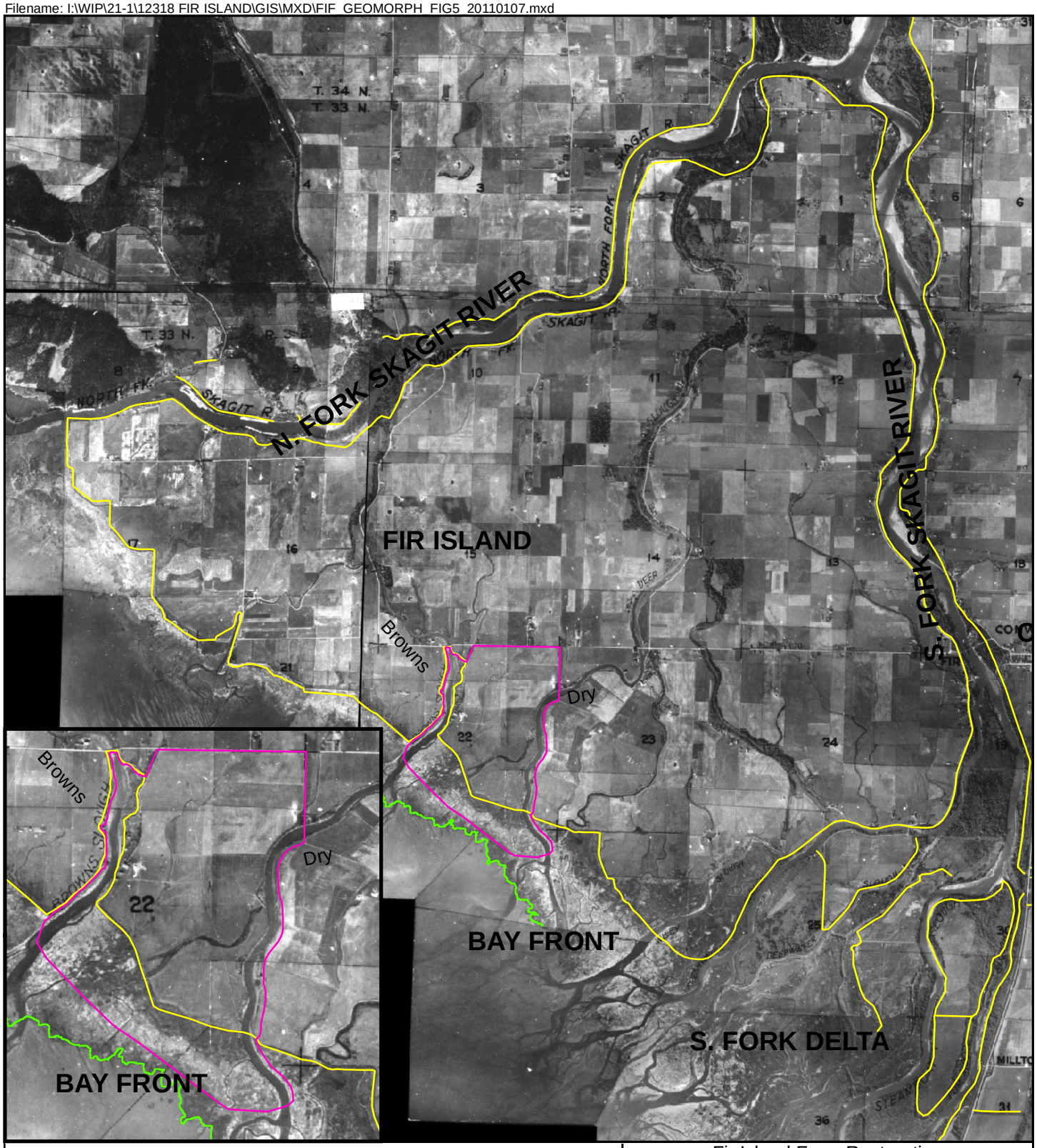
FIG. 4

Filename: I:\WIP\21-1\12318 FIR ISLAND\GIS\MXD\FIF_GEOMORPH_FIG5_20110107.mxd



PROJECT FOOTPRINT
2010_LEVEES
1937_VEG_LINE

State Plane Washington
North 4601 NAD83/NAVD88

N W E S

0 2,500 5,000 Feet

Fir Island Farm Restoration
Skagit Snow Goose Preserve
Skagit County, Washington

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SKAGIT RIVER DELTA
1937 AERIAL PHOTOGRAPH

SOURCE: SKAGIT COUNTY

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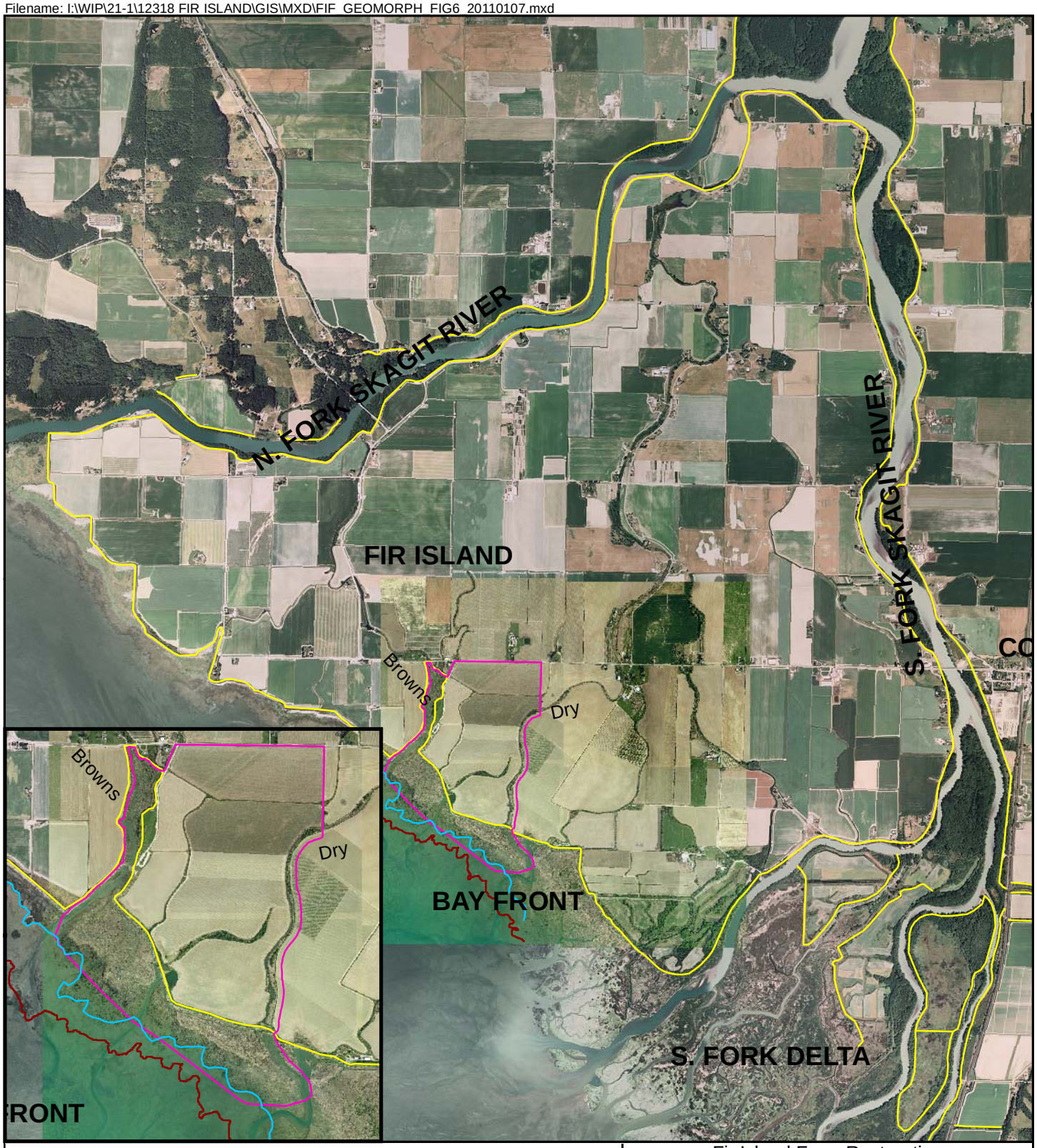
FIG. 5

Filename: I:\WIP\21-1\12318 FIR ISLAND\GIS\MXD\FIF_GEOMORPH_FIG6_20110107.mxd



PROJECT FOOTPRINT
2010_LEVEES
2009_VEG_LINE
1937_VEG_LINE

State Plane Washington
North 4601 NAD83/NAVD88

N W E S

0 2,500 5,000 Feet

Fir Island Farm Restoration
Skagit Snow Goose Preserve
Skagit County, Washington

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SKAGIT RIVER DELTA
2006/2009
AERIAL PHOTOGRAPH COMPOSITE
SOURCE: SKAGIT COUNTY

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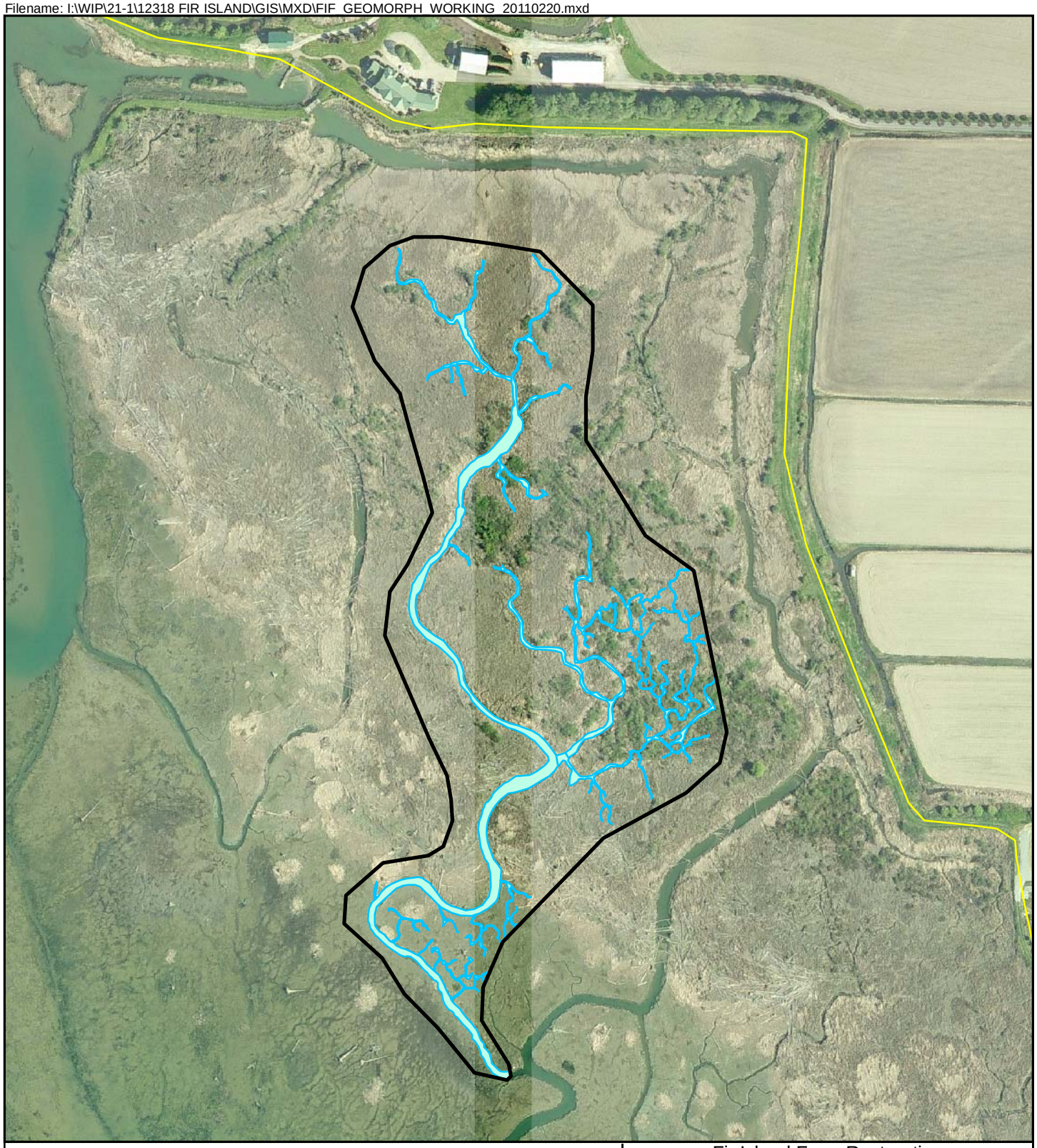
FIG. 6

Filename: I:\WIP\21-1\12318 FIR ISLAND\GIS\MXD\FIF_GEOMORPH_WORKING_20110220.mxd



TIDAL_DRAINAGE_AREA

TIDAL_CHAN_AREA

N W E S

250 125 0 250 Feet

Fir Island Farm Restoration
Skagit Snow Goose Preserve
Skagit County, Washington

SKAGIT RIVER DELTA - BAY FRONT TIDAL MARSH DRAINAGE AREA TO TIDAL CHANNEL SURFACE AREA COMPARISON

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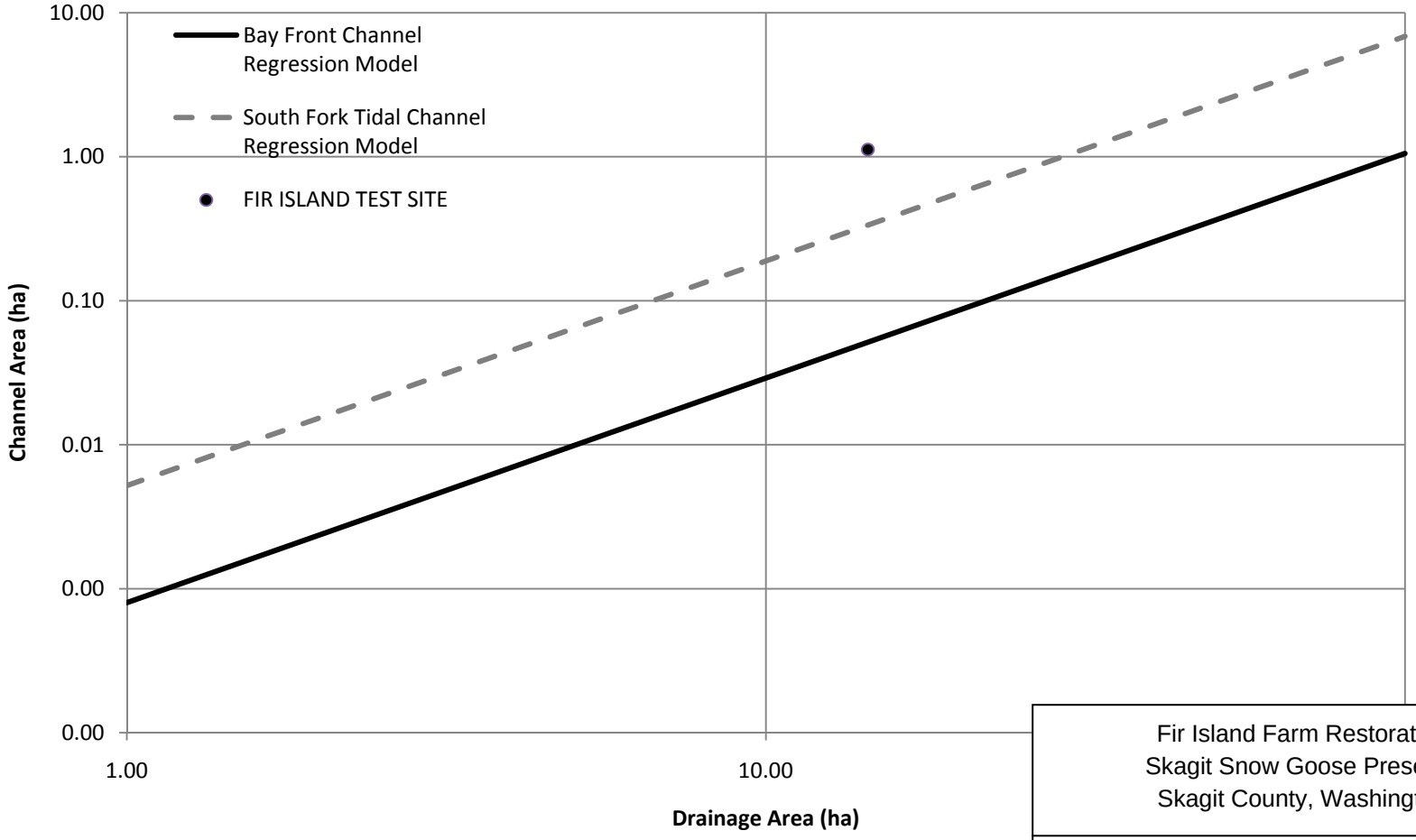
FIG. 7



Fir Island Farm Restoration
Skagit Snow Goose Preserve
Skagit County, Washington

Tidal Channel Geomorphic Regression Equations & Test Site Comparison

Source: Hood, 2007

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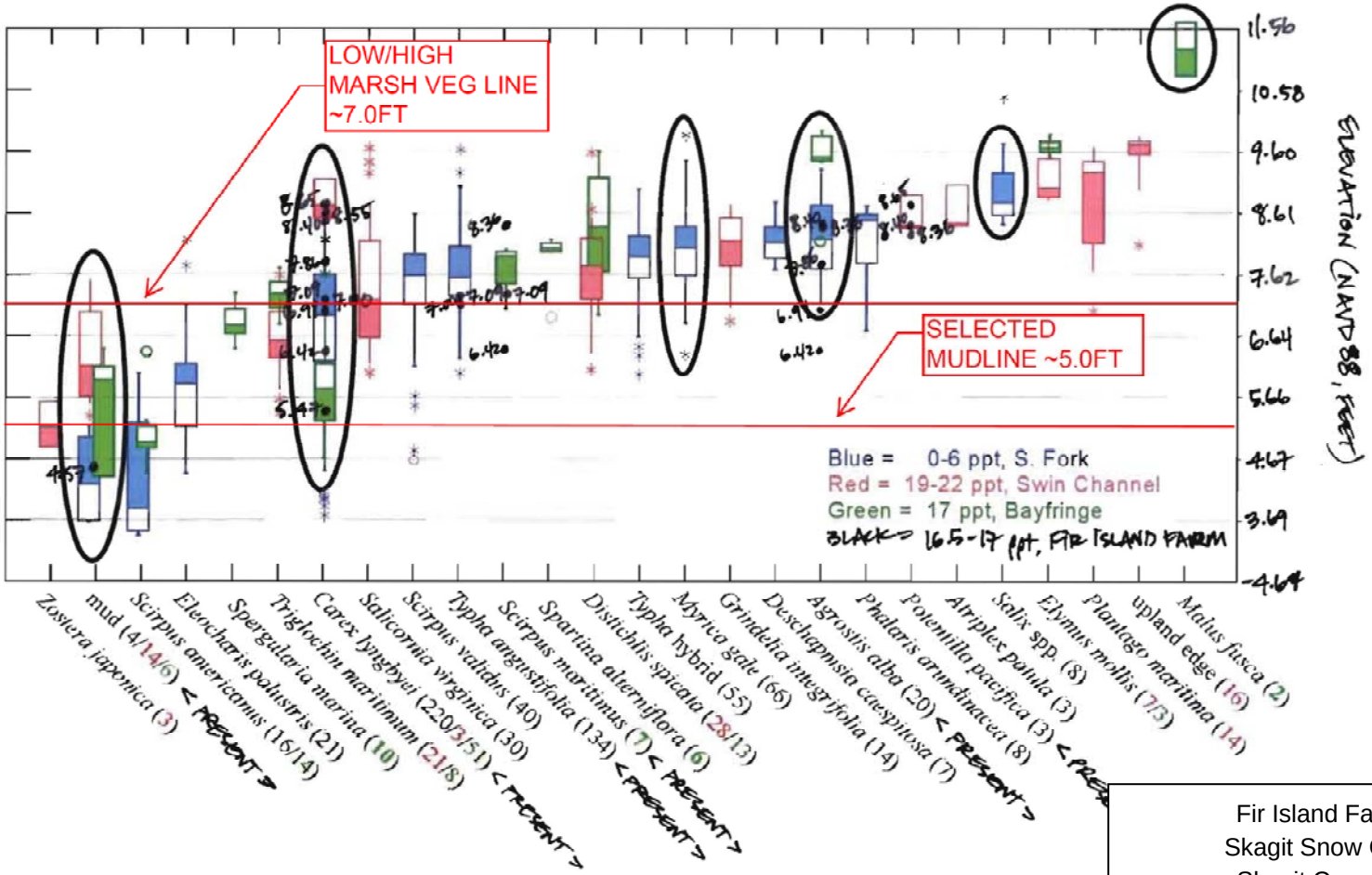
Fig. 8

SKAGIT DELTA VEGETATION MONITORING DATA



SOURCE: HOOD, GREG. SKAGIT RIVER SYSTEM COOPERATIVE. ESTUARINE HABITAT RESTORATION WITH GLOBAL CLIMATE AND RISING SEA-LEVELS PRESENTATION, SLIDE 18 OF 20. LA CONNER, WASHINGTON

NOTES: CONVERTED FROM ELEVATION DATUM NGVD 29 TO DATUM NAVD 88 AND FROM METERS TO FEET.

Fir Island Farm Restoration
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Skagit County, Washington

Skagit Delta Vegetation and Mudline Data

Source: Hood, 2009

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Fig. 9