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AN ASSESSMENT OF POTENTIAL HABITAT RESTORATION PATHWAYS FOR FIR ISLAND, WA

Prepared for

The Skagit Watershed Council

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1. INTRODUCTION

The Skagit River, the largest river system draining to Puget Sound, supports major runs of chinook (*Oncorhynchus tshawytscha*), chum (*O. keta*), coho (*O. kisutch*), pink (*O. gorbuscha*), and sockeye (*O. nerka*) salmon and other salmonids and native char such as cutthroat (*O. Clarkii*), steelhead (*O. mykiss*), and bull trout. The Skagit River delta and estuary provide critical habitat functions for salmon, primarily for rearing, migration and refuge. Historically, Fir Island in the delta provided hundreds of acres of prime estuarine and tidal freshwater habitat for salmon and many other fish and wildlife. Human development in the Skagit delta over the past 150 years brought increasing demands for land suitable for agriculture, residential and urban development, and subsequent needs for drainage and flood control, all of which significantly helped build the economy of Skagit County and this region. The dikes and infrastructure necessary for this economic development, however, also resulted in considerable habitat losses, particularly in the Skagit estuary and delta through isolation of estuarine and tidal freshwater channels and wetlands. The loss of natal estuarine habitat has been identified as a limiting factor to chinook population recovery in the region (Beamer et al., 2000).

In an effort to address the significant decline of salmonid populations in the Skagit River basin, the Skagit Watershed Council was formed in 1997 as a coalition of diverse interests who share a common goal to develop community-based, voluntary solutions to this problem. As part of this effort, the Council developed a series of documents to guide their actions including a "Habitat Restoration and Protection Strategy" (SWC 1998), the "Application of the Skagit Watershed Council Strategy" (SWC, 2000), and an annual "Strategic Approach" which identify the need to address the isolation, fragmentation, and sustainability of habitat in the delta and estuary as a high priority. Through a partnership with Seattle City Light, the Skagit System Cooperative, and the Washington Department of Fish and Wildlife, the SWC commissioned this study to evaluate the feasibility and potential of alternative pathways for salmon habitat restoration that focus on the Fir Island portion of the Skagit Delta.

The purpose of this document is to present a logical scientific methodology that can be applied in the development of feasible restoration alternatives and to illustrate how this methodology is applied in developing and assessing five potential restoration "pathways." This methodology is based on an understanding of the dynamic evolution of the morphology and physical processes inherent in all river and tidal systems that support and sustain key habitats and ecological functions. The study draws on scientific research conducted in the Skagit River delta and on the broader literature related to river delta morphology, and examines a range of potential habitat restoration pathways and the anticipated evolution of Fir Island conditions, both for salmon habitat and land use, over the next 30 years.

The methodology proceeds in the following six steps:

1. Establish explicit restoration objectives
2. Identify simple quantitative measurable indicators of achievement of objectives
3. Identify opportunities and constraints
4. Formulate alternative pathways, including the no action alternative
5. Analyze future physical and habitat evolution of alternatives over selected planning horizon
6. Estimate and compare ecological indicators for each alternative

For purposes of this study selected pathways are evaluated at a level of detail appropriate to an analysis of restoration potential at a landscape scale. Specific pathways having merit, from both a technical and community development perspective, are likely to be advanced for further analysis and consideration by one or more of the members of the SWC.

This report describes the project setting in Section 2, relevant physical processes affecting evolution of habitat in Section 3, and restoration objectives in Section 4. Section 5 describes the formulation of alternatives pathways, and Sections 6 and 7 evaluates and then compares the different pathways.

2. PROJECT SETTING

2.1 THE SKAGIT RIVER DELTA AND FIR ISLAND NATURAL LANDSCAPE

The glacial trough known as Puget Sound was carved by continental glaciers that covered the area several times over the past 100,000 years. The glaciers created valleys, basins, and the north-south bays that are characteristic of the region. The Cordilleran ice sheet retreated approximately 16,000 years ago, leaving behind features of Puget Sound evident today. Since this time, three long-term processes have driven landscape evolution in the Skagit basin: isostatic uplift, erosion of glacial sediments from the valleys, and changes in sea level. At the time of ice retreat, land elevations and sea level were both much lower than today and both began rising as the ice moved northward from Puget Sound (Beechie et al. 2001). Sea level at ice retreat was about 295 feet (90 m) lower than today. Voluminous lahars from Glacier Peak, approximately 5,500 years before present, created an extensive low-gradient delta on the Skagit River.

As the Skagit River flowed toward Puget Sound and lower elevations it deposited coarser sediments and tended to split and form smaller channels progressively decreasing in size towards the delta front. These distributary channels conveyed fine sediments to the delta front where they were deposited in the form of mudflats. Coarser sediments were transported through the distributary channel network during larger flood events and contributed to the growth of the delta front. This delta provided extensive abundant contiguous estuarine habitats for salmonids and other species in wetlands, blind channels, and distributary channels through a continual process of alluvial sediment deposition, estuarine sedimentation and erosion through wind and wave action (see Figure 2.1).

The finer estuarine sediments were constantly reworked by wind and wave action and redistributed by tidal action. Some of these estuarine sediments built large expanses of near-shore emergent marsh habitat at elevations suitable for vegetation colonization. Part of the coarse sediment load passing through the distributary channel network during large flow events was deposited on the over-bank emergent marsh plain, building natural levees and raising the elevations to heights suitable for less salt tolerant scrub-shrub and forested wetland vegetation.

Blind tidal channels were formed in the estuarine mudflats and inter-tidal emergent marsh plains by the action of tidal water flooding and draining these areas on a twice-daily basis. The channels adopted a morphology (depth, width, sinuosity) that is directly related to the volume of tidal flow that they drain.

These physical landscapes and processes within the estuary served many important functions for salmonids, providing habitat for smoltification, migration, rearing and refuge, as well as contributing to habitat complexity and ecological processes, such as detritus cycling that supports the food web (Williams and Thom 2000; Aitkin 1998). Distributary and tidal marsh blind channels provided juvenile salmon places where they have access to abundant prey species as they acclimatize to the transition between fresh and salt water. Distributary channels provided migration corridors for juvenile salmon leaving the river system and adult salmon returning to spawn.

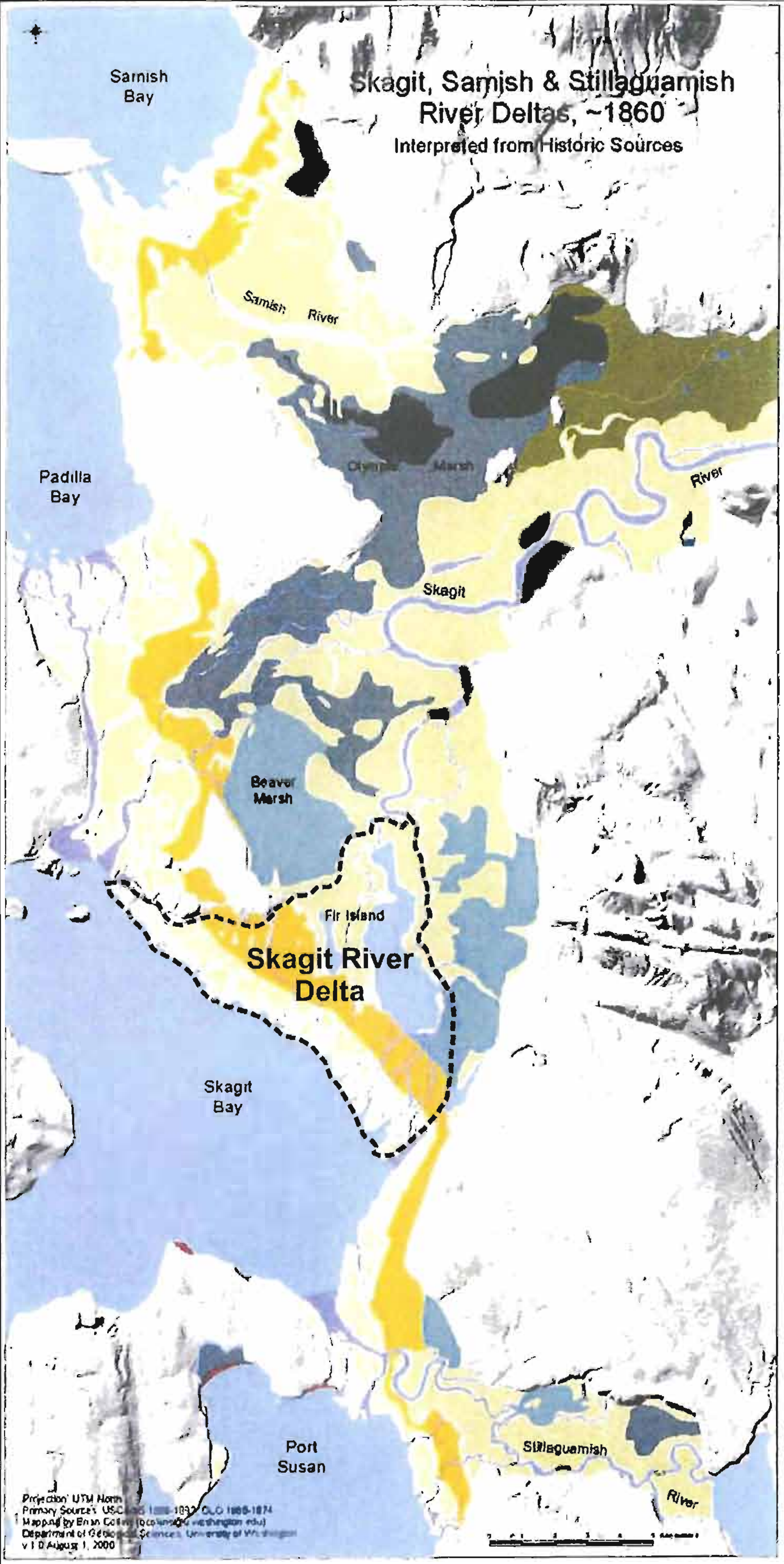

figure 2.1

Fir Island Restoration Pathways Assessment

Historic Extent of Skagit and Samish Deltas

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Source: Collins, 2000

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Of the five species of Pacific salmon, chinook, chum and pink salmon used the estuary most extensively with chinook salmon being the most dependent on estuarine habitat (Groot and Margolis, 1991). Chinook salmon exhibit two basic variations in life history within the Skagit River System. These variations are centered primarily on upstream migration patterns and timing, and the choice of spawning areas. Out-migrating juvenile chinook salmon also exhibit two generalized variations in timing, individual residency period, and habitat utilization (Beamer, 2003 unpublished data).

Juvenile chinook that migrate to the marine environment within a few days to a few months after emerging as fry from their freshwater incubation areas are considered the 0+ age class and are generally identified by fork-length measurement. Healey (1991) referred to this 0+ age class as an *"ocean-type"* life history. Residency of individual 0+ chinook within the lower riverine and estuarine environments ranges from 6 to 189 days (Simenstad et al., 1982). Levy and Northcote (1982) estimated the residency of individual 0+ chinook within the Fraser River Estuary as 30 days. 0+ chinook utilize the salt marsh habitats of the lower Skagit River as rearing habitat. Individual 0+ chinook were present within the lower Skagit River System between February and June.

Juvenile chinook that spend at least a full year rearing in freshwater prior to migrating to marine habitats are considered the 1 + age class. Healey (1991) referred to this age class as exhibiting a *"stream-type"* life history. Juvenile 1+ chinook typically migrate to the lower riverine and estuarine environments as yearling smolts and move directly into neritic habitats (shallow marine surface water zones) without extended utilization of salt marsh or other near shore habitats (Simenstad et al., 1982). Additionally, some fish may spend two winters in freshwater rearing areas prior to out-migration. Beamer and Henderson (1994) documented single catch observations of this chinook life history type within the lower Skagit River System in January, April, May, September, and October.

In the Skagit, juvenile chinook grow fastest in emergent tidal marsh habitat as compared to in the transitional and forested wetland habitat further upstream (Beamer et al., 2002b).

2.2 HISTORY OF DISTURBANCE AND CHANGE AT FIR ISLAND

Land development since 1860 has removed a large proportion of historical habitats from the landscape, and fundamentally altered some of the geomorphic processes that form and sustain remaining salmonid habitats (Beechie et al., 2001). These changes have resulted in extensive losses of habitat in the Skagit delta and Fir Island, which is the portion of the Skagit delta downstream of the North and South Fork divergence.

Diking of distributary channels on Fir Island over the past 150 years has had a significant impact on wetland and channel habitat in the delta (Collins, 1998). While the total area of all distributary channels has remained reasonably constant through time (as the North and South Fork deltas continue to prograde and create smaller emergent marsh zone channels) the loss of large distributary channels in the estuarine-fluvial transition zone has been significant. These lost channels provided a critical transition zone for juvenile salmonids as they migrated downstream from their freshwater rearing grounds to Puget Sound Diking eliminated these pathways, and drained or isolated large areas of emergent marsh that had sustained the estuarine food web. Blocking of distributary channels separated, and made more inaccessible, the remnant bayfront marshes from use by juvenile salmon outmigrating down the remaining main river channels.

Diking of emergent marshes eliminated blind tidal channels behind the levees and reduced the size and complexity of remnant channels on the outboard side. Collins (1998) estimates that between 1860 and 1889 approximately 67% of all blind-tidal channels were lost due to diking of the Skagit Delta to facilitate agriculture. In the same time period, approximately 3,200 acres (13 km^2) of emergent and transition zone marsh were lost. Since 1889, approximately 17% of these blind channels have been regained due to delta growth in the North and South Forks, in addition to approximately 740 acres (3 km^2) of marsh. Today, there is approximately 50% of the historic extent of blind channels (Collins, 1998). The Skagit River delta has lost approximately 72% of historic tidal marsh habitat, including a loss of 68% of estuarine emergent habitat, 66% of transitional estuarine forested habitat, 94% of tidal scrub shrub habitat and 84% of riverine tidal habitat (Collins and Montgomery, 2001; Beamer et al., 2002b; Hood 2003, unpublished data).

It is likely that in the time since the last glacial period, the Skagit River has changed course across the landscape, flowing at times to the Samish, Padilla and Skagit bays. The active delta front is now 'frozen' in its present location due to extensive diking and development in the delta as the Skagit River currently empties only into Skagit Bay limiting any significant delta growth to the nine-mile (15 km) interface of the Fir Island bayfront. Much of the gain in the South Fork delta occurred early in the 20^{th} century, with the North Fork expansion occurring later (post 1937). This has been connected to a gradual shifting of river flow distribution from the South to the North Fork (Collins, 1998).

Early records indicated the presence of a persistent logjam, nearly a mile in length, on the Skagit River at the town of Mount Vernon. This likely contributed to the routing of flood flows and sediment to Padilla and Samish bays. The removal of the logjam and construction of levees along the Skagit River probably increased the delivery of fine sediments and flood flows to Fir Island. Headwater dams, constructed from the 1930s onwards have likely had a subsequent effect of reducing fine sediment supply to Fir Island. The exact effects of these changes on the Fir Island sediment budget are unknown.

Large wood debris played an important role in the function and morphology of Fir Island. It is estimated that 35,000 snags (large woody debris) were removed from the lower Skagit River between 1890 and 1910 (ACOE, 1911-1939; Collins 1998). These snags would have acted to store coarser sediment, provide organic matter storage and recycling, scour pools and redistribute flow and sediment between the various distributary channels. Snagging (the practice of removing large woody debris) continued throughout most of the 20^{th} century. Combined with large scale logging of upstream floodplains and headwaters, this significantly reduced the supply of large wood to the delta.

Recent studies on habitat conditions and juvenile chinook life history types of the Skagit River Delta have shown both a large loss of Skagit River delta estuarine habitat and a high percentage of juvenile chinook utilizing this habitat for extended rearing (Beamer et al., 2002). These studies have concluded that current levels of estuarine habitat may be constraining the production of wild Skagit chinook. This is shown by recent studies that have examined juvenile chinook abundance, fish size, and otolith data, collected from 1995 through 2001 in river delta blind channel habitat and Skagit Bay nearshore habitat. As smolt population increases the proportion of juveniles migrating quickly through the estuary increases, and those that do rear in the estuary are smaller (Beamer et al., 2002). This indicates that the loss of Skagit estuarine habitat is having a significant impact on the total abundance of Skagit chinook salmon.

2.3 EXISTING SITE CONDITIONS

The following sections describe current physical habitat conditions in the Fir Island area in order to provide background for this study's analysis of expected future site conditions and the analysis of habitat restoration potential pathways, which is dependent on these site conditions and their expected evolution over time.

2.3.1 Hydrology

The Skagit is the largest river system discharging to Puget Sound. It contributes approximately 39% of the total sediment load of all rivers draining to the Sound (Downing, 1983) and more than 20% of the freshwater flowing into Puget Sound. The Skagit River drains a watershed of approximately 3,100 square miles (8,030 square kilometers) with elevations ranging from sea level to 10,770 feet (3,285 m) on Mount Baker. The Skagit has a snowmelt driven hydrology in three out of five hydrologic regions, with peak flows typically occurring April through June (Beechie, 1995). However, rain on snow events can cause flooding earlier in the year.

The Skagit Basin has a marine climate with mild winters and drier summers. In the mountains, precipitation can exceed 140 inches (356 cm) per year, while the lowlands average less than 80 inches (203 cm) annual rainfall. Most (75%) of the precipitation falls from October through March.

2.3.2 Topography and Soils

Where the river meets the influence of the highest tides, flood flow velocities slacken and the Skagit River bifurcates into the North and South arms that define Fir Island, a major part of the Skagit Delta.

Detailed topographic data using LIDAR technology were collected for Fir Island in April 2002. LIDAR acquisition occurred at 7,500 feet (2286 m) AMT using an AeroScan System at 15,000 pulses per second with an average post spacing of 13.1 ft (4 m), +/- 7.8 in (20 cm) vertical accuracy and +/- 11.9 in (30 cm) horizontal accuracy during low tide conditions.

LIDAR Processing involved using ground control points within the project area for LIDAR pre-processing validation and accuracy assessment. Data were processed by Spenser B. Gross for all positional corrections and removal of noise. A Surface Elevation Model (SEM) was produced from the data and then post processed to create a Digital Elevation Model (DEM).

In total data was collected for an area of approximately 50 square miles (129 sq. km) extending from over a mile off shore to the opposite banks of the adjacent mainland. The topography within the study area ranges from negative (-) 7.43 feet (2.26 m) NGVD to 442.0 feet (135 m) NGVD. The higher elevations being primarily located around the region of Pleasant Ridge and the lower elevations being the mud flat extending throughout the bay front. The lowest elevations in side of the levee system on Fir Island are in the 0.5-1.0 ft. (0.15-0.31 m) range. Areas adjacent, but immediately outside the levee system on the boundary with the emergent marsh zone generally range in the 4-5 ft. (1.22-1.5 m) NGVD range.

Figure 2.2 shows the resultant LIDAR data mapped in a 32.8 ft. (10 m) grid with 1-foot (0.3 m) contour intervals.

These data represent a significant advance in our understanding of the morphology of Fir Island and comparison with earlier less detailed photogrametric mapping in 1954 allows interpretation of likely subsidence rates and evolution in the future. The LIDAR data will form the basis for developing the physical models of each restoration pathway over the 30-year planning horizon, on which the pathway evaluation will be based.

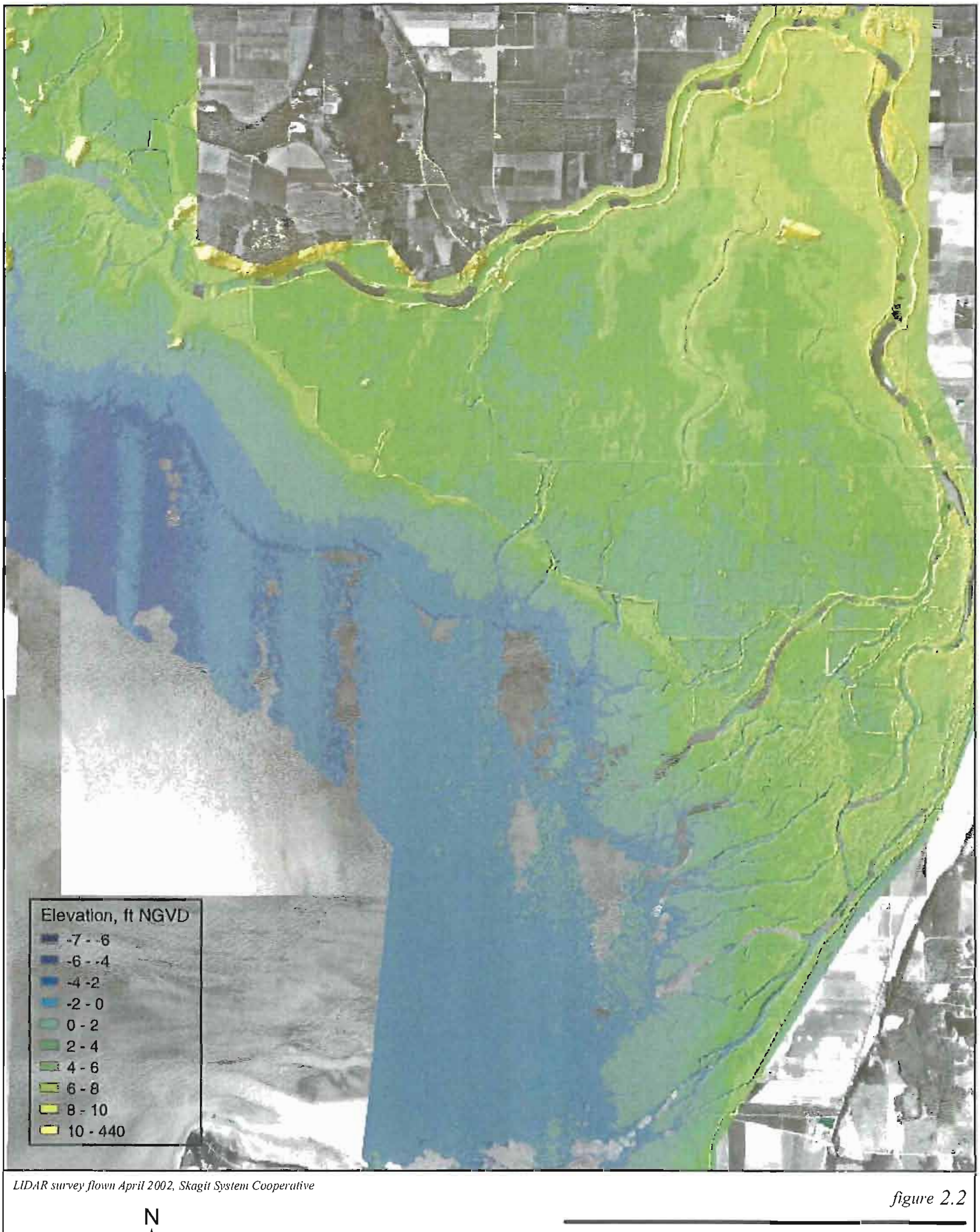
The soils of Fir Island are characterized by two sub-groups:

- Alluvium – gravel, sand, silt and clay deposits with minor organic content, and
- Estuarine deposits – organic rich silt, silty clay, and fine sand.

The alluvium deposits are located in the upstream portion of the delta at elevations higher than the normal tidal inundation (MHHW). Historically these areas were subject to periodic inundation during flood events, which deposited large volumes of coarser alluvium on the land surface. In the inter-tidal zone the soils are formed of finer estuarine deposits (Dragovich et al., 2000). NRCS Soil classifications indicate that within the levee system agricultural lands are dominated by three silt loam variants; Sumas silt loam, Tacoma silt loam and Skagit silt loam. These three variants differ primarily in their salt content. Tacoma silt loams being most closely associated with a higher potential for residual salts and Skagit silt loams being the lowest. Figure 2.3 shows the orientations of the predominant soils types within the levee system.

2.3.3 Tides

Tidal data for Fir Island is available from a tide gauge at Crescent Harbor, Washington, which is located approximately 8 miles (12.8 km) west of Fir Island. Table 2.1 shows estimates of tide ranges based on this data. The tide data is used to guide our understanding of Fir Island drainage, estuarine sedimentation processes and tidal channel development.



LIDAR survey flown April 2002, Skagit System Cooperative

figure 2.2

Fir Island Restoration Pathways Assessment

LIDAR Topographic Data

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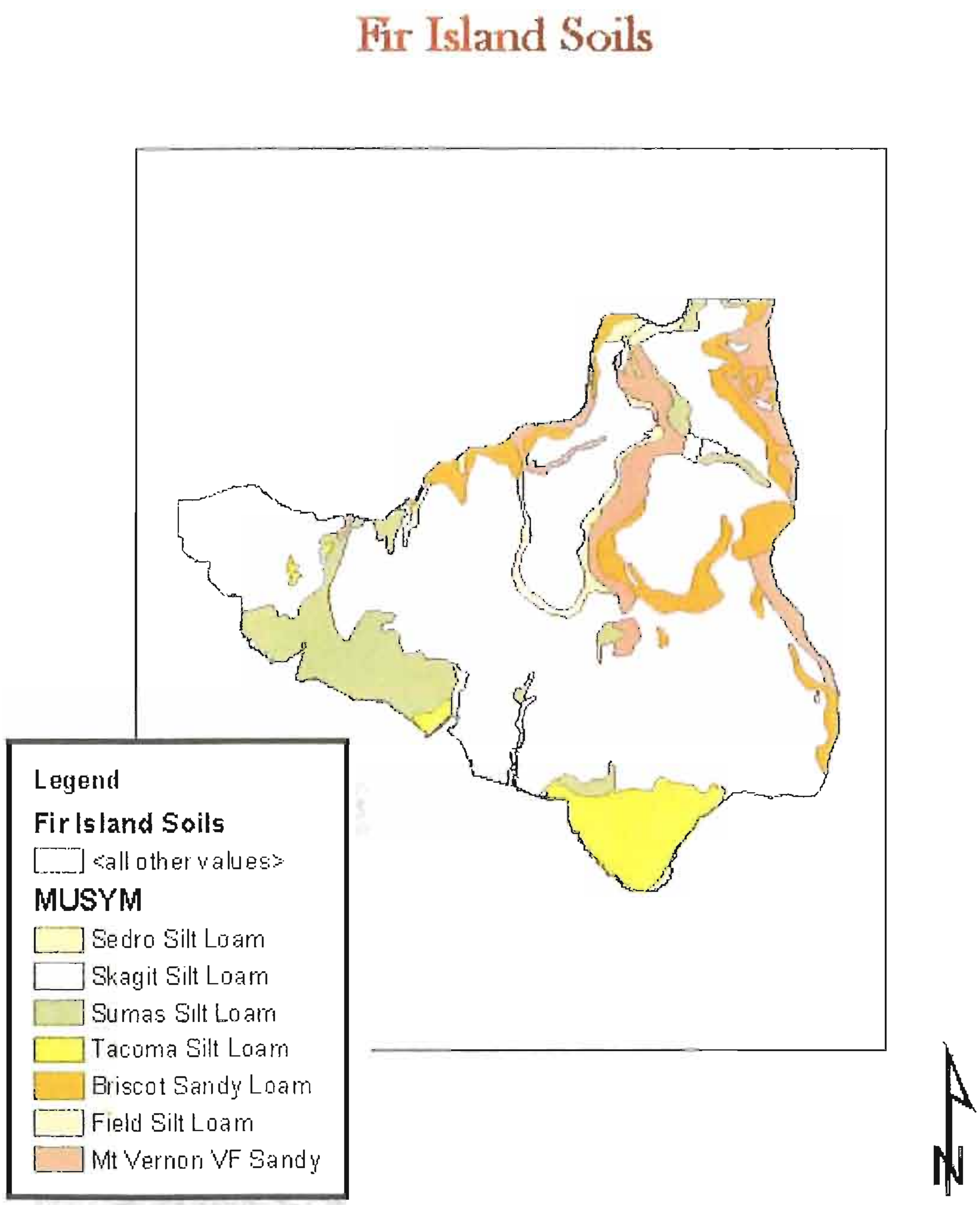
Figure 2.3 – Fir Island Soils



Source: Skagit Systems Coopertive

Table 2.1 – Fir Island Tide Elevations

Tide Elevation	Tide Datum	
	MLLW (ft)	NGVD29 (ft)
Highest Estimated Tide	15.0	8.9
Highest Observed Tide	13.4	7.3
Mean Higher High Water (MHHW)	11.7	5.5
Mean High Water (MHW)	10.8	4.6
Mean Tide Level (MTL)	6.8	0.7
NGVD Zero Datum	6.1	0
Mean Low Water (MLW)	2.8	-3.3
Mean Lower Low Water (MLLW)	0	-6.1
Lowest Observed Tide	-2.0	-8.2

Source: U.S. Navy Pier, Crescent Harbor, Washington, Tide Gauge 9447952

2.3.5 Vegetation Elevation Relationships

An empirical relationship between saltwater influenced estuarine vegetation–and surface elevation was developed for the Fir Island Delta (Hood 2003, unpublished). The vegetation-elevation relationship for Fir Island was devised from field measurements using 0.78 inch (2 cm) resolution (horizontal and vertical) GPS. Table 2.2 and Figure 2.4 outline a vegetation/elevation relationship for Fir Island based on this work and the studies of Ewing (1982) and Collins (1998). The relationship between surface elevation and vegetation type is an essential tool for estimating how sedimentation, associated with restoration, relates to the change in spatial extent of various habitats.

Table 2.2 – Vegetation/Elevation Relationship

Elevation Range (ft, NGVD29)	Vegetation/Habitat Type
< -6.1[a]	Sub-tidal
-6.1 to +1.0	Inter-Tidal Mudflat
+1.0 to +5.2	Inter-Tidal Emergent Marsh
+5.2 to +7.5	Scrub-Shrub Marsh
>7.5	Forested Upland

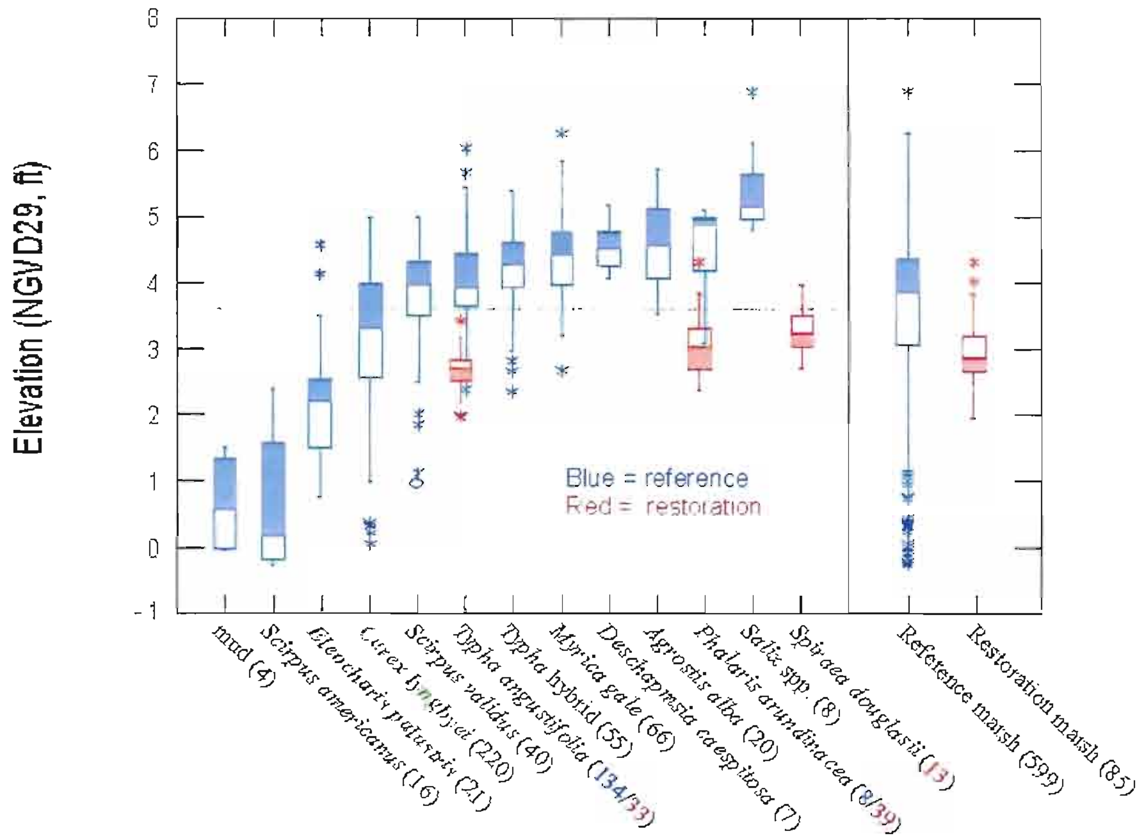
Notes: based on SSC empirical data

a. Lower extent of sub-tidal vegetation is MLLW

2.3.6 Blind-Tidal Channel Morphology

The surface area of tidal channel (slough) draining a marsh is dependent on marsh size as is illustrated in Figure 2.4 and qualified in Figure 2.5. North and South Fork islands belong to two different populations.

center line = median
box edges at 1st and 3rd quartiles
whiskers extend to 1.5 * the range of the 1st-3rd quartiles (box range)



Source: Skagit System Cooperative (SSC)

figure 2.4

Fir Island Restoration Pathways Assessment

Vegetation-Elevation Relationship

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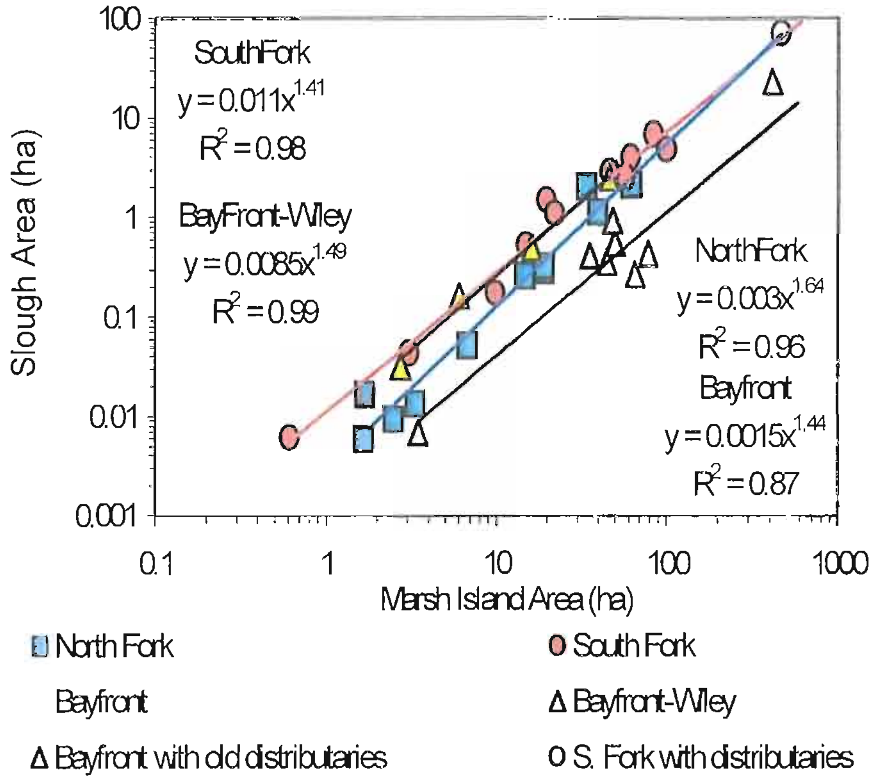
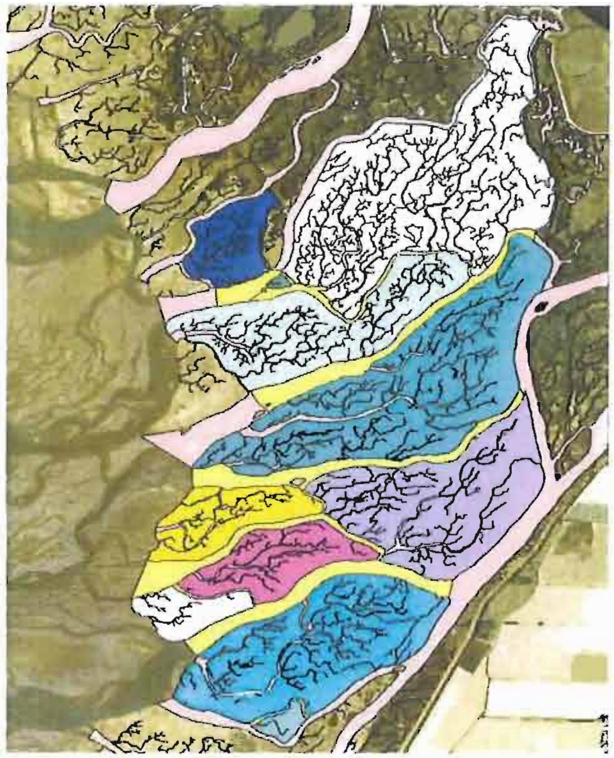
Figure 2.5 – Relationships between Marsh Area and Blind Channel Habitat Area



Source: Skagit Systems Cooperative

In general, North Fork islands are drained by less channel area than are South Fork islands. South Fork islands have approximately twice the percentage of channel area as North Fork islands. Additionally, as marsh islands increase in size, the total area of tidal channels that drain an island increases even more rapidly, i.e., one large island supports more channel area than two or more smaller islands of equal total size (see Figure 2.6). Therefore, it is more efficient and effective to restore one large area than several smaller areas of equivalent total area. Marsh area size also influences channel complexity — the larger the area, the greater the number of channel junctions (Hood 2003, unpublished).

Figure 2.6 – Marsh Islands for the South Fork Skagit Delta



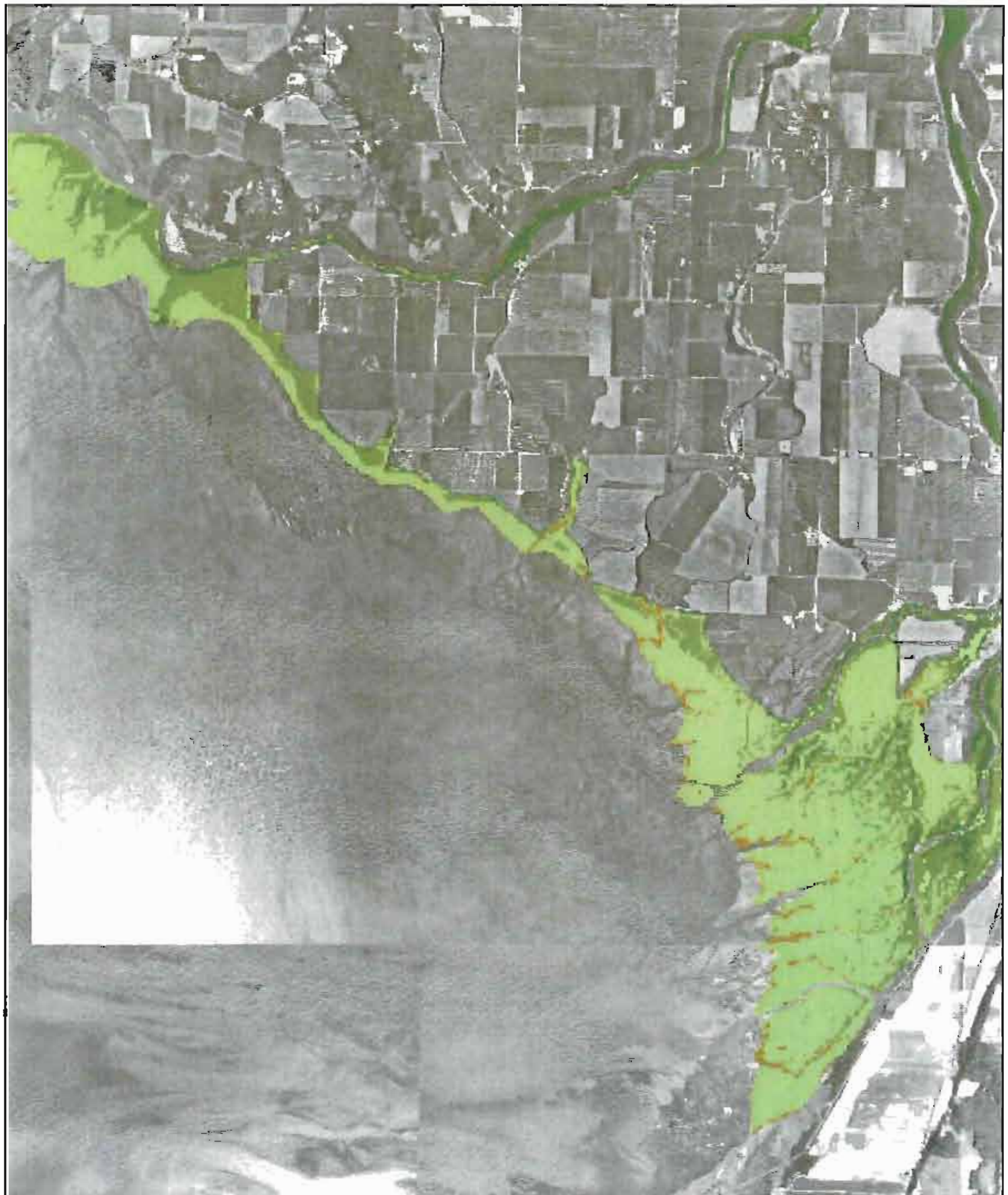
Source: Skagit Systems Cooperative

2.3.7 River Flow & Distributary Channel Morphology

Historic and modern distributary channel measurements were taken by Collins (1998) for analysis of delta habitat evolution. Collins (1998) measured the surface areas of the distributary slough channels for 1889 (from USC&GS map) and 1991 (from orthophotos). Collins (1998) reported that the total area of distributary channels had remained static over the 102-year period (approximately 1458 acres or 5.9 km^2), yet the spatial distribution of channel area had changed. The greatest amount of loss was reported in Hall, Brown, and Dry Sloughs (a decrease of approximately 148 acres or 0.6 km^2), which are sloughs that have been blocked off from flow since the mid-1950s (Collins, 1998). The largest gain in distributary channel area was in the North Fork delta, where the area increased by a factor of 2 over the 102-year period.

2.3.8 Existing Potential Habitat Conditions

The data collected from vegetation/elevation relationship outlined in Section 2.3.5 was overlain on the LIDAR data (Figure 2.2) to represent potential habitat based on elevation zones for existing topographic conditions. Figure 2.7 illustrates these data.



Aerial photos sources: 1990, 1998 DOQQs (University of Washington) and Skagit System Cooperative

Legend
- Inter-tidal Mudflat
- Inter-tidal Emergent Marsh
- Srub-Shrub Marsh
- Forested Upland

N

1 inch equals 5,681 feet

figure 2.7

Fir Island Restoration Pathways Assessment

Potential Habitat with Existing Conditions

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3. PREDICTING HABITAT EVOLUTION

3.1 SEDIMENTARY PROCESSES AND HABITAT EVOLUTION

The Fir Island Delta and its physical habitat is a dynamic landscape adjusting to multiple driving forces. The most important of these are floods, tides, and wind waves. Wetland habitat zones are largely dependent on their elevation relative to tide and river flood levels. Consequently, predicting their extent at any given time depends on the rate of net sedimentation, which is driven by sediment accumulation, sediment erosion, subsidence, and sea-level rise.

River deltas form where alluvial sedimentary processes (influenced by the average flood level) interact with estuarine processes (influenced by the high tide level) Figure 3.1 illustrates where these two processes tend to dominate on Fir Island.

In Section 5 we describe how alternative restoration 'pathways' have been developed. The following sections outline the tools and assumptions used to guide our understanding of Fir Island's net sedimentation for each restoration pathway. ArcView GIS was used to estimate surface models of each restoration pathway over a 30-year planning horizon. This was based on the existing condition LIDAR data updated to reflect changes due to each of the processes described below.

3.2 ESTUARINE SEDIMENTATION

The MARSH 98 sedimentation model was applied and calibrated using limited coring data to determine future estuarine sediment accumulation rates in sheltered restored areas on Fir Island under project conditions. Technical details of MARSH 98 are provided in Appendix A. The calibration of the model included determining an 'effective' average annual suspended sediment concentration responsible for observed estuarine sediment deposition at the Fir Island Delta front over the past 50 years. The 'effective' suspended sediment concentration was determined through an iterative process of estimating the concentration and modeling past sediment accumulation until the suspended sediment concentration was appropriate for the observed sediment accumulation. The 'effective' suspended sediment concentration was then used to predict sediment accumulation on Fir Island (30-year time frame) under the various project conditions. The following sections detail the inputs used for model calibration and subsequent future sediment accumulation prediction.

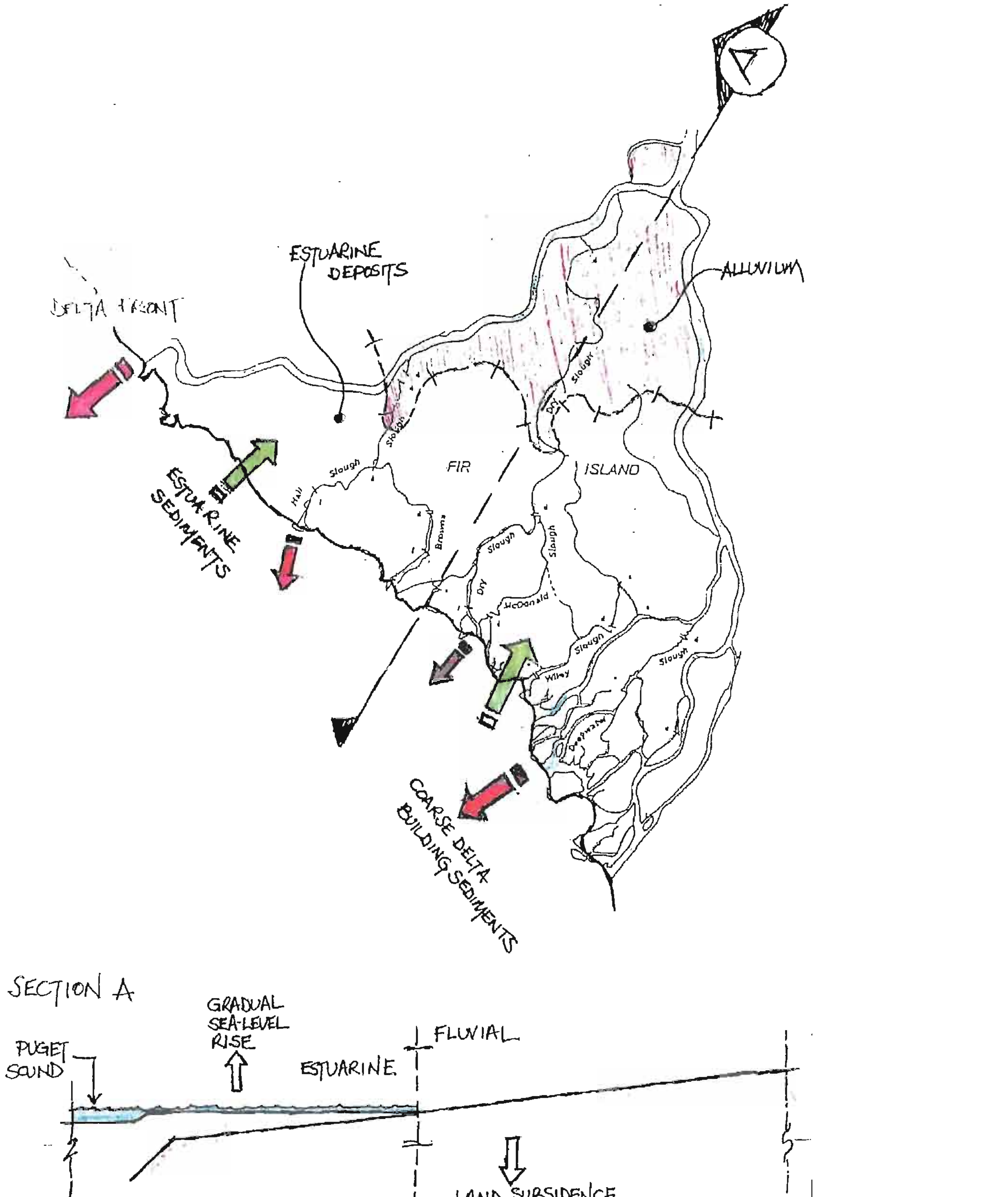

figure 3.1

Fir Island Restoration Pathways Assessment

Fir Island Sedimentary Processes

Source: PWA

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3.2.1 Initial Bed Elevation

The initial bed elevation used for model calibration was derived from an estimate of accumulated estuarine sediment within cut-off distributary channels on the Fir Island Delta. PWA took sediment cores in May 2002 at the mouths of Hall Slough, Browns Slough, and Dry Slough. The sediment cores were taken to a depth where the estuarine mud ceased and coarse fluvial sand began, thereby indicating the amount of estuarine sediment accumulation since the distributaries were diked. Collins (1998) reports that the major sloughs that historically drained Fir Island were cut-off between 1940 and 1956, giving a time frame by which to estimate estuarine sediment accumulation. Coring results indicate that approximately 7 ft (2.13 m) of estuarine sediment accumulation has occurred over the past 50 years. Initial bed elevations were then taken as current bed elevation for the core locations less the depth of accumulated sediment. The initial bed elevation (assumed 1950 elevation) for Hall Slough was taken as –6 ft (1.83 m) NGVD, initial bed elevation for Browns Slough was taken as –6.3 ft (1.92 m) NGVD, and initial bed elevation for Dry Slough was taken as –7.5 ft (2.29 m) NGVD.

3.2.2 Tidal Elevation

To model long-term sediment accumulation rates with MARSH-98, it is necessary to use a representative tidal time series that does not have infrequent storm-induced peaks tidal elevations. Therefore, the input tidal elevation time series contains a spring-neap tide cycle with key tidal elevation values similar to long-term averages. To model the historical estuarine sediment accumulation rates at the bay front of the island, a synthetic time series of tidal elevations based on the tidal time series for Puget Sound from an arbitrary monthly tidal time series for the sound. The values for mean higher high water (MHHW), mean high water (MHW), mean low water (MLW), and mean lower low water (MLLW) were adjusted to equal the values reported for U.S. Navy Pier tide gauge in Crescent Harbor (see Table 2.1). Relative sea-level (RSL) rise in the Puget Sound region was accounted for in the model from a combination of mean sea-level rise (0.08 in./yr) (2.0 mm/yr) and delta subsidence estimates (0.02 in./yr) (0.6 mm/yr) (USGS, 2001).

3.2.3 'Effective' Suspended Sediment Concentration

The sedimentation model uses "average annual suspended sediment concentration" as a key parameter to estimate long term sediment accretion rates. In reality, actual suspended sediment concentration varies spatially and temporally in Skagit Bay, daily, seasonally and inter-annually. The best definition of this parameter is therefore dated field corings of sediment accumulation in tidal areas not influenced by wave action or tidal currents.

Sediment accumulation was analyzed for the past 50 years for only three locations where sediment cores were taken (Hall Slough, Browns Slough, and Dry Slough). Based on this very limited calibration data, the average annual suspended sediment concentration responsible for estuarine sediment accumulation at the delta bay front ranged from approximately 100 mg/L (Dry Slough) to 110 mg/L (Hall and Browns Slough).

3.2.4 Projected Estuarine Sedimentation Rates

The results for determining the effective suspended sediment concentration responsible for historic estuarine sediment accumulation on the Fir Island Delta are given in Figure 3.2a. Future estuarine sediment accumulation for a 30-year time period was estimated from the synthetic tidal elevation (including estimated RSL) and the 'effective' suspended sediment concentration for historic estuarine sediment deposition on the Fir Island Delta front (taken as 110 mg/L). Relative sea-level rise (RSL) for the projected 30-year restoration horizon was assumed to be the same as the RSL prediction within the Puget Sound for the previous 50 years, 0.1 in./yr (2.6 mm/yr) (USGS, 2001). Elevation increase for Fir Island over the next 30 years due to estuarine sedimentation was then modeled for initial surface elevations ranging from -6 ft (1.83 m) NGVD (MLLW) to approximately +5.5 ft (1.68 m) NGVD (the elevation on Fir Island above tidal influence).

The results from modeling estuarine sediment accumulation are given in Figure 3.2b. A linear relationship between current and future surface elevations under estuarine sedimentation exists for elevations below +6.6 ft (2.01 m) NGVD. Modeling predicts that an elevation of –6 ft (1.83 m) NGVD will silt in to approximately –1.3 ft (0.39 m) NGVD under estuarine sedimentation over the next 30 years, with the modeled increase in elevation decreasing linearly with an increase in initial surface elevation. The extent of modeled estuarine sedimentation was +6.6 ft (2.01 m) NGVD, which is highest synthetic tidal elevation in 30 years under the assumed RSL rate of 0.1 in./yr (2.6 mm/yr).

This linear relationship between current and future delta elevation due to estuarine sedimentation was then used in conjunction with LIDAR data of the Fir Island region to illustrate estuarine sedimentation effects on future elevation (and associated vegetation zonation) throughout the delta for the various restoration pathways. Figure 3.3 shows a plot of this relationship applied to the entire Fir Island LIDAR data. The figure illustrates the amount of vertical accretion of estuarine sediments that would be expected across the entire project area over the 30-year planning horizon.

It should be noted that these predictions are 'best estimates' based on very limited calibration data and assumption of typical bulk density of sediment. These estimates will have to be refined and verified at later stages in the planning process.

Restoration of distributary channel pathways will allow for the restoration of fluvial sedimentary processes. The intent is to take advantage of these processes and use them to reestablish a natural and sustainable distributary channel morphology that over time develops natural levees and a transition in elevation from supratidal to intertidal.

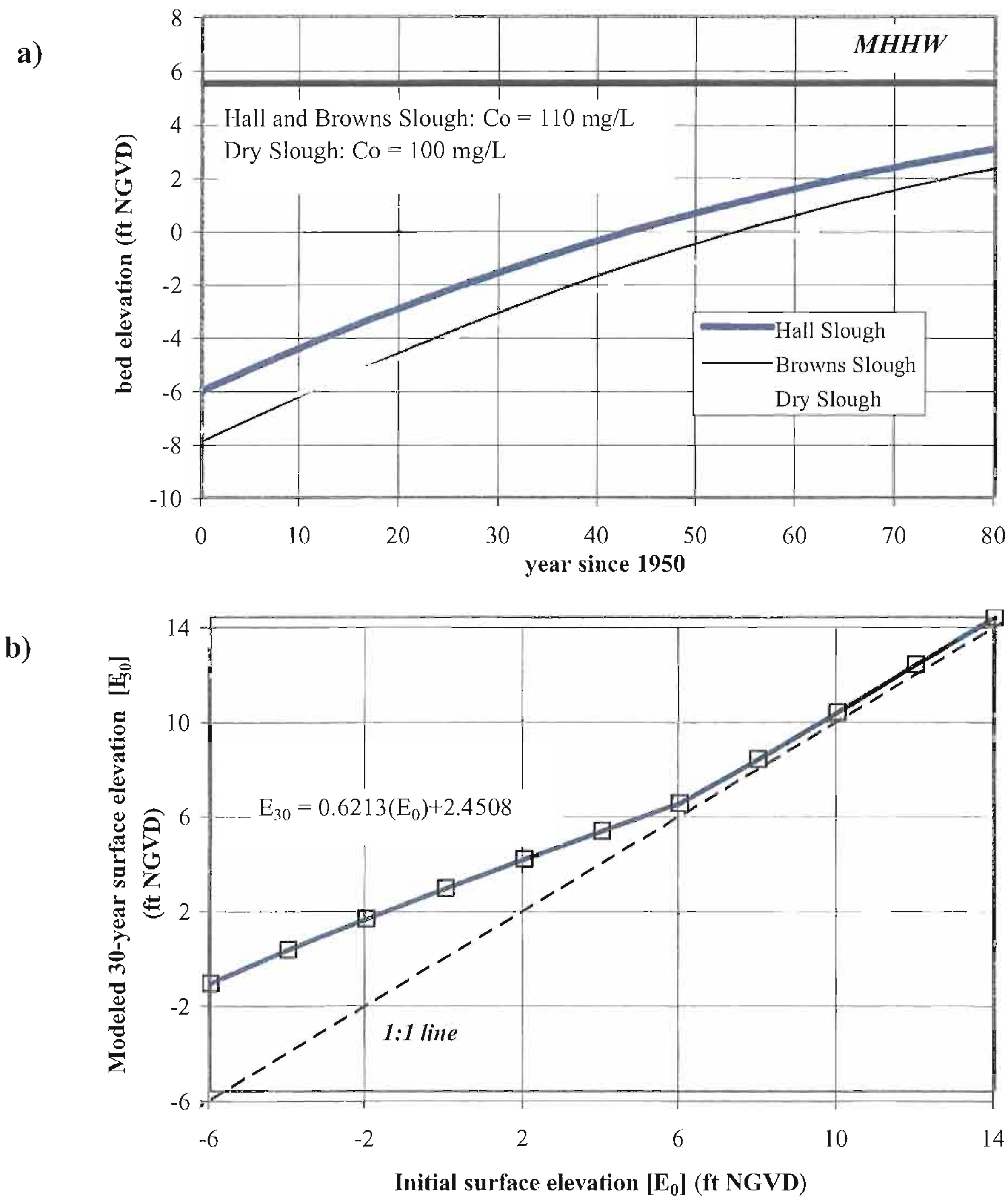

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figure **3.2**

Fir Island Restoration Pathways Assessment

Estuarine Sediment Accumulation Modeling Results

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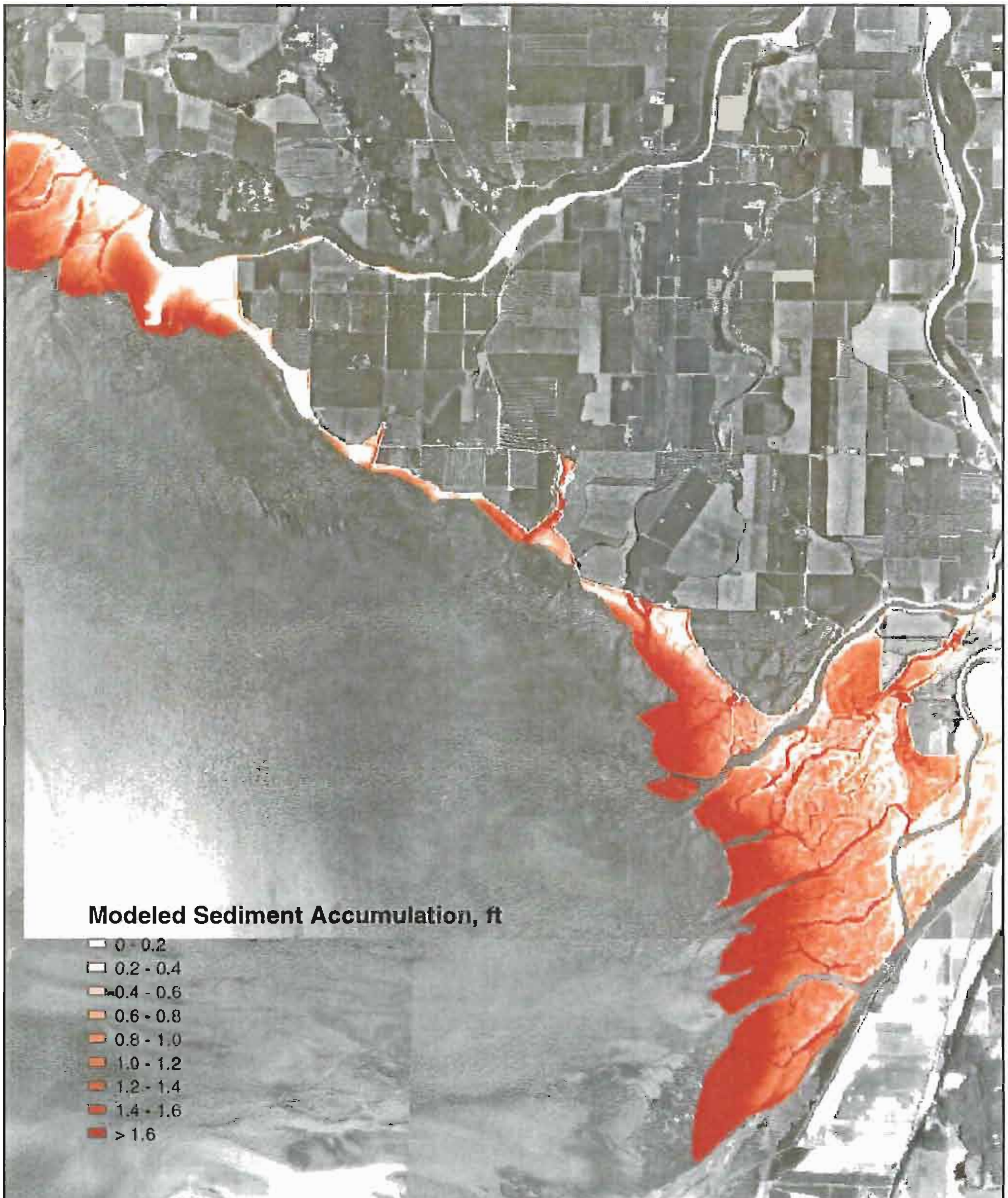

Aerial photos sources: 1990, 1998 DOQQs (University of Washington) and Skagit System Cooperative

figure 3.3

N

1 inch equals 5,000 feet

Fir Island Restoration Pathways Assessment

Predicted Fir Island Sediment Accumulation Over 30 Years

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3.3 FLUVIAL SEDIMENTATION

3.3.1 Distributary Channel Morphology and Evolution

The distributary channel network in each restoration pathway will determine the distribution of alluvial sediments across the Fir Island Delta over time. Alluvial sediments are currently supplied to the delta front via the North and South Forks. The majority of Fir Island (on the interior of the levee system) is cut-off from alluvial sedimentation, except during flooding as witnessed in January 1997, when new sediments were deposited over much of the Island. This lack of alluvial sedimentation contributes to subsidence of the island. The conceptual model for distributary channel development used in the assessment of each pathway is based on two morphological zones for each constructed channel; the fluvial zone (Bankfull elevation >MHHW) and the estuarine zone (Bankfull elevation = MHHW). In the fluvial zone, floodplain deposition consists of alluvium, whereas in the estuarine zone floodplain deposition consists predominantly of estuarine sediments. Due to historic subsidence, areas open to new distributary channels will likely be lower than their equilibrium floodplain elevations. In the fluvial zone the equilibrium elevation for the floodplain is determined by the bankfull water surface profile for each distributary, whereas in the estuarine zone the equilibrium elevation is determined by mature marsh elevation (approximately MHHW). Over time the process of alluvial sedimentation in the fluvial zone and estuarine sedimentation in the estuarine zone will build up subsided floodplains to equilibrium elevations.

The distributary channel parameters for each restoration pathway are outlined in Table 3.1. The potential pathways are described in Section 5. For pathways 4 and 5, the bankfull width for the distributary channels was assumed to be 175 ft (53.3 m). The 175 ft calculation is based upon initial evaluations of distributary channels and mouth widths associated with those identified as 3rd order in magnitude (Beamer, unpublished). Bankfull depth for the channels associated with pathways 4 and 5 was determined by the bankfull width to depth ratio for the North Fork of the Skagit River (w/d ratio of approximately 20; bankfull depth = 8.75 ft or 2.7 m). Bankfull discharge was determined for each distributary channel by: 1) use of an estimate of bankfull stage at the junction of the North Fork and the distributary channel, and 2) cross-sectional area data (assumed 5:1 side slopes for the cut channels). The depth of the channel below bankfull water surface elevation determined thalweg elevation at the mouth of distributary channels. Sinuosity of each distributary channel was determined by average historical sinuosity of Hall, Browns, Dry, McDonald, Freshwater and Steamboat sloughs measured from the 1897 Corps map (USCOE, 1897). Total stream length was then determined using the sinuosity and valley length. Equilibrium slope for the fluvial portion was taken as the ratio of difference between thalweg elevation at distributary channel head and MLLW (-6.1 ft or -1.9m MLLW) and total stream length. The transition point between the fluvial and estuarine zones was determined by the intersection between the equilibrium channel slope in the fluvial zone with MHHW.

The goal of pathway 2 is to capture approximately half of the North Fork Discharge during bankfull flow conditions, and to allow estuarine sedimentation to build up the North Fork Marsh using the levee of the distributary channel as a breakwater. The 4th order channel associated with pathway 2 was sized to handle approximately 21,000 cfs (see Section 3.3.2 for discharge determination). To insure that the channel has the required capacity, the bankfull width was set at 350 ft (106.7 m) and bankfull depth was set at 10 ft (3.05 m) below bankfull stage in the North Fork, which results in a channel thalweg elevation of –3.1 ft (0.94 m) NGVD. As with pathways 4 and 5, channel side slopes were set at 5:1 and the sinuosity of the channel was assumed to be 1.2. Table 3.1 outlines the channel morphology parameters.

Figure 3.4 shows an existing ground surface elevation cut along the distributary channel alignment for Pathway 4. Increased elevation at the 30-year restoration horizon due to both estuarine and fluvial sedimentation is shown, as well as equilibrium ground surface and thalweg elevation. It should be noted that for Pathways 4 and 5, there are numerous potential geomorphic pathways for the restored channel (as shown in Figure 5.2). The profile shown in Figure 3.4 represents restored conditions for one possible channel layout.

Table 3.1 – Assumed Distributary Channel Morphology

Parameter	**Pathway 2**	**Pathway 4**	**Pathway 5**
Bankfull Width (ft)	350	175	175
Bankfull Depth (ft)	10	8.5	8.5
Bankfull Discharge [a] (cfs)	21,000	6,400	6,400
Bankfull Water Surface Elevation (ft, NGVD)	6.9	+7.8	+7.8
Thalweg Elevation at North Fork (ft, NGVD)	-3.1	-0.7	-0.7
Sinuosity	1.2	1.2	1.2
Stream Length (ft)	14,000	15,000	17,500[b]
Equilibrium Slope for Fluvial Portion	N/A	0.00036	0.00027[c]
Fluvial Portion Length (ft)	N/A	6,600	8,500

a. Bankfull discharge determined by the formula $Q=CLH^{3/2}$, where C is a coefficient (2.63), L is crest channel width (90 ft), and H is head (8.5 ft).
b. Stream length from the head at the North Fork to the mouth west of the bifurcation.
c. Average of equilibrium slope from the head to the west mouth and the head to the east mouth.
d. Stream length from the head at the North Fork to the mouth west of the bifurcation.
e. Average of equilibrium slope from head to the west mouth and the head to the east mouth.

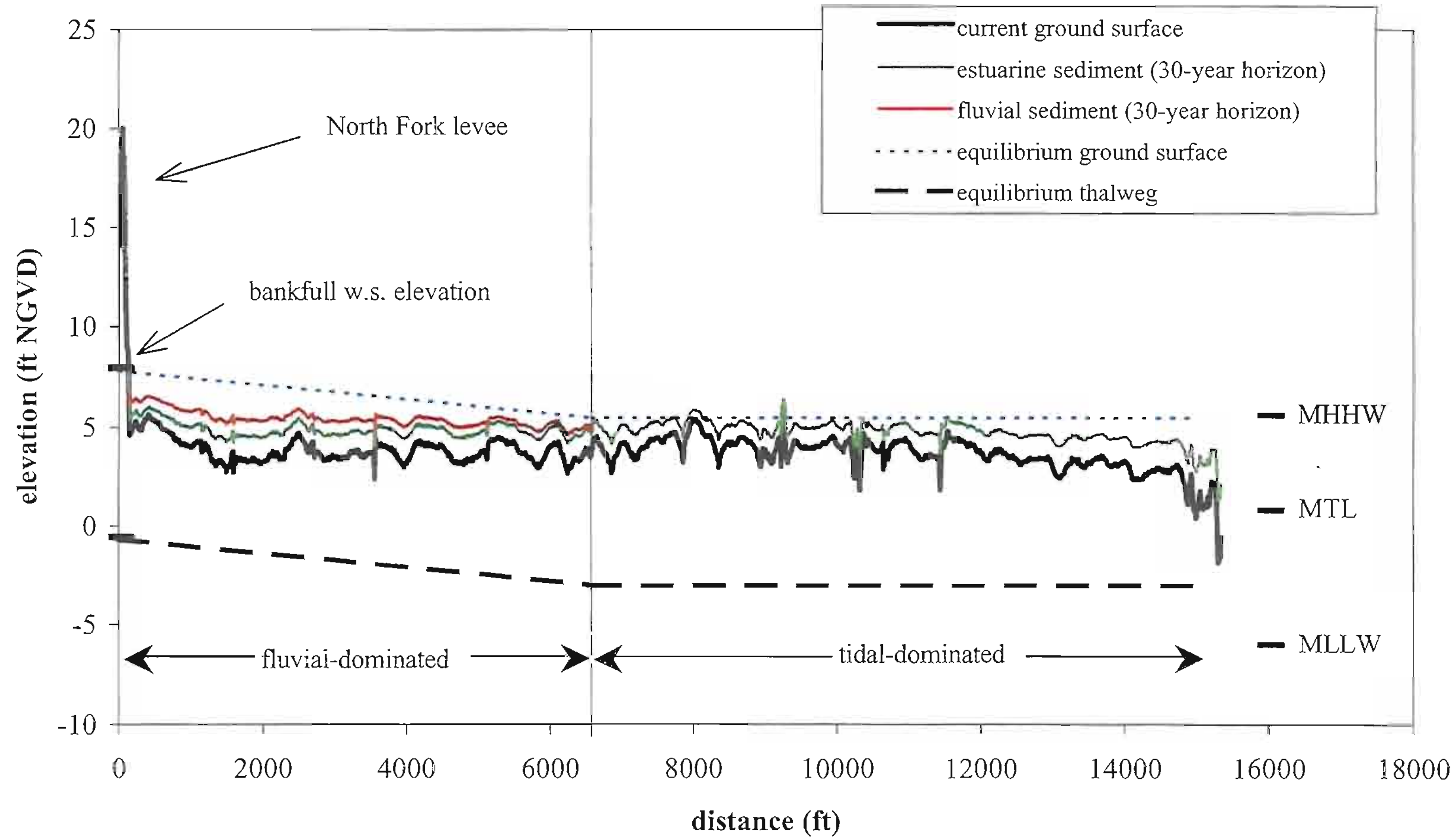

figure 3.4

Fir Island Restoration Pathways Assessment

Distributary Channel Design for Pathway 4

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3.3.2 Suspended Sediment Discharge for Constructed Distributary Channels

The annual suspended sediment load for the constructed distributary channels was determined by the sediment rating curve developed for the Skagit River by Collins (1998), which relates sediment discharge (tonnes/day) to an annual average river discharge estimate (cfs). Collins (1998) estimated the sediment rating curve for the Skagit River from USGS data collected at the Mount Vernon gaging station from 1980-1991. The average annual discharge for the constructed distributary channels was calculated by weighting the North Fork annual average discharge (10,000 cfs) by the ratio of distributary bankfull discharge to North Fork bankfull discharge (42,000 cfs). The North Fork bankfull discharge was calculated from a rating curve for the North Fork given in PWA (2000) and an estimate of bankfull stage (10 ft or 3.05 m NGVD) The North Fork annual average discharge was determined by weighting the Skagit River at Mount Vernon annual average discharge (16,721 from 1940-2000 [USGS]) by the amount of the Skagit River that flows to the North Fork (60%). Annual average discharge for the distributary channel associated with Pathway 2 is on the order of 5,000 cfs. Annual average discharge for the constructed distributary channels associated with pathways 4 and 5 is on the order of 1,500 cfs. Applying the distributary channel annual average discharge to the sediment rating curve developed by Collins (1998) gives a suspended sediment discharge of approximately 235 tonnes/day 19 tonnes/day, or approximately 86,000 tonnes/year, of sediment for pathway 2. Pathways 4 and 5 have suspended sediment discharge of approximately 20 tonnes/day, or approximately 7,000 tonnes/year, for each distributary channel.

3.3.3 Sediment Deposition on Constructed Distributary Channel Floodplains

Floodplain deposition of sediment from the constructed distributary channels for Pathways 4 and 5 was estimated from the annual sediment loading estimates. The sediment load was converted to a volume of sediment (sediment bulk density = 1,500 kg/m^3), and sediment delivery to the floodplain was determined by assuming floodplain trap efficiency. For this analysis, in the absence of detailed sediment transport modeling, an assumption was made that approximately 60% of the available alluvial suspended sediment was deposited on the floodplain. For simplicity the deposited sediment was distributed evenly throughout the floodplain (entire area within levees in fluvial portion of the reach), with the equilibrium ground surface marking the upper elevation available for sediment deposition. In reality the depositional pattern is likely to develop in a wedge form, with the depth of sediment accumulation decreasing in the downstream and cross-floodplain directions.

In general, with this approximate assumption of sediment trapping on the floodplain, an average of approximately 0.5 ft fluvial sedimentation is expected within the fluvial portion of pathways with distributary channels over the next 30 years. The amount of fluvial sediment deposited within each pathway was added to the modeled estuarine sediment accumulation to obtain net sediment accumulation and increase in the total surface elevation, and associated vegetation zonation, within a 30-year time frame.

It should be noted that these sedimentation estimates represent the best available information based on limited existing data and analysis. There is a considerable level of uncertainty that can be narrowed with more extensive data collection and modeling analysis.

3.4 DELTA-FRONT MARSH EXPANSION/EROSION

3.4.1 Marsh Area Increase from Historical Estimates

Historical estimates of net gain/loss of marsh area for the North Fork delta, South Fork delta, and the Fir Island Delta (bay front dike region) are given in the Collins (1998) study of Fir Island. Between 1889 and 1991, Collins (1998) suggests that the South Fork delta increased in area by 257 acres (1.04 km^2), the mid Fir Island Delta decreased by 321 acres (1.29 km^2), and the North Fork delta increased in area by 835 acres (3.38 km^2). Fluvial sediment delivery to the North and South Fork deltas maintains the rate of marsh expansion while the removal of the fluvial sediment source to the mid Fir Island Delta front causes tidal marsh areas to continue to erode due to wind wave action.

For this study, a refinement of the Collins (1998) estimate for Fir Island marsh front expansion was done using USGS topography of the region (which was taken from a 1954 aerial photograph) and the estimate of current marsh front along the delta from the vegetation-elevation relationship (see Section 2.3.5) and current year 2000 orthophotos of Fir Island (provided by the SSC). The USGS topographic data, LIDAR data, and recent orthophotos of the Fir Island Delta were imported into GIS (ArcView 3.2), put into a common projection, and the marsh fronts for 1954 and 2002 were delineated. Comparing the location of the current marsh front along Fir Island with the mapped marsh front from the USGS topographic map shows that the North Fork delta marsh front has expanded by approximately 229 acres (0.93 km^2) over the past 48 years, the mid Fir Island Delta marsh front has eroded by approximately 160 acres, and the South Fork delta marsh front has expanded by approximately 518 acres (2.09 km^2)(see Table 3.2). Therefore, under current sedimentation conditions (conditions that have existed since 1954), the North Fork delta marsh is projected to increase by approximately 144 acres (0.58 km^2) over the next 30 years, the South Fork delta marsh is projected to increase by approximately 324 acres (1.31 km^2) over the next 30 years, and the mid Fir Island Delta marsh is projected to decrease by approximately 99 acres (0.40 km^2).

Table 3.2 – Projected Marsh Front Gain Rate for Current Conditions

	North Fork Delta	Mid Fir Island Delta	South Fork Delta
Marsh front gain/loss from 1954 to 2002 (acres)	+229	-160	+518
Marsh front gain/loss rate (acres/yr)	+4.8	-3.3	+10.8
Marsh Gained/Lost at 30-year Restoration Horizon (acres)	+144	-99	+324

3.4.2 Effects of Constructed Distributary Channels on Future Marsh Expansion

Introducing distributary channels that provide additional connections from the North Fork of the Skagit River to Skagit Bay has implications for changing the rate of erosion of the delta front marsh, as well as altering the rate of expansion for the North Fork delta marsh. To determine the effects of the distributary channels on marsh expansion throughout the entire Fir Island bay front region (North Fork delta, mid Fir Island Delta, and South Fork delta) for the 30-year restoration horizon, the redistribution of fluvial sediment for the restoration pathways was examined. Marsh expansion for the North Fork under current conditions was first related to current North Fork bankfull discharge (42,000 cfs) to get an estimate of the relationship of marsh expansion to a bankfull discharge assumed responsible for sediment delivery to the marsh (acres/cfs). For each pathway, bay front marsh expansion associated with each distributary channel mouth was determined by multiplying the North Fork expansion rate/bankfull discharge by the bankfull discharge at the distributary channel mouth. Essentially, for constructed distributary channels without bifurcations (i.e., pathway 4), predicted marsh expansion at the mouth is 22 acres (0.09 km^2) for the 30-year restoration horizon. For distributary channels that include bifurcation (Pathway 5), predicted marsh expansion at the mouth is 11 acres (0.04 km^2) for the 30-year restoration horizon. Because the distributary channel levee associated with Pathway 2 is designed to trap estuarine and fluvial sediment, the marsh expansion rate associated with Pathways 4 and 5 does not apply. Section 7.4 explains the expected marsh area increase for the 30-year restoration horizon.

The constructed distributary channels may cause net deposition at the mid Fir Island Delta marsh as well as net erosion, or net decrease in deposition, at the North Fork delta marsh. The North Fork delta marsh expansion rate for each pathway was determined by first subtracting the bankfull discharge for each distributary channel associated with the pathway from the bankfull discharge for current conditions. The new bankfull discharge for the North Fork for Pathways 4 and 5 were then multiplied by the marsh expansion/bankfull discharge relationship for the North Fork under current conditions.

On a time scale of marsh evolution, the North Fork delta marsh can be considered a relatively young marsh, while the South Fork delta marsh can be considered a relatively mature marsh system. The North Fork delta marsh front is expanding at a relatively fast rate (with respect to delta marsh size), which is indicative of a dynamic, youthful marsh environment. The switch in Skagit River flow dominance from the South Fork to the North Fork (see Collins, 1998) has caused the relatively rapid marsh expansion rate for the North Fork delta marsh front observed in the recent past. The relatively slow rate of marsh front expansion at the South Fork delta marsh front (with respect to delta marsh size) indicates a marsh system that is closer to equilibrium with respect to sedimentary and erosion processes, therefore the South Fork delta marsh is a relatively stable, mature system.

3.5 SUBSIDENCE AND RELATIVE SEA-LEVEL RISE

Passive drainage of low lying agricultural land on Fir Island is influenced over the long term by the cumulative effects of land subsidence and sea level rise – referred to as relative sea level rise (RSL).

Subsidence on Fir Island occurs on two scales; the local scale and the regional scale.

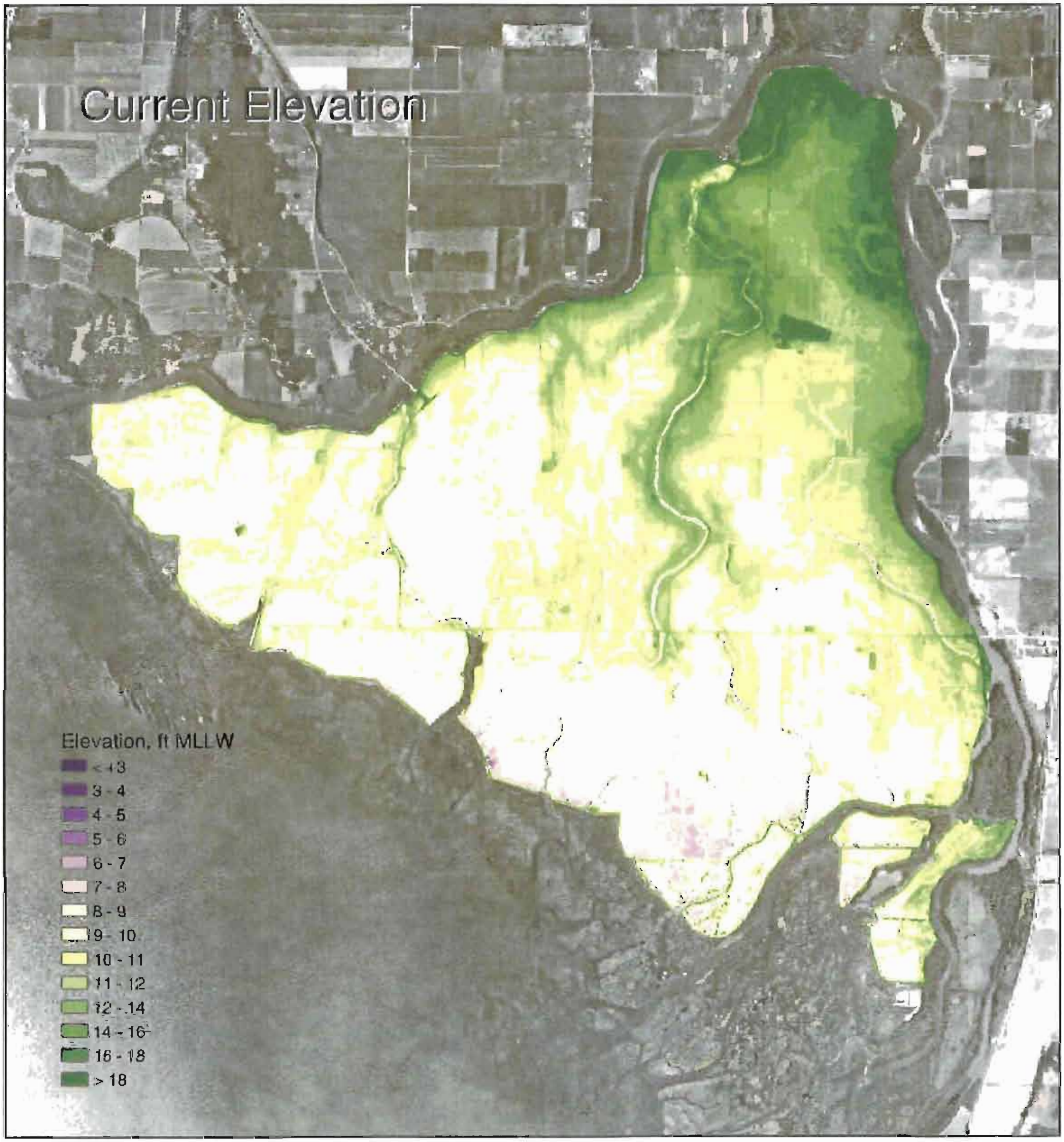
On the local scale, the low lying land within the diked portion of Fir Island has subsided up to 4 ft. over the last century (1.22 m) due to soil compaction and oxidation resulting from land drainage (DES, 1999). Soil compaction is expected to be much greater in the lower lying former tidal marsh areas than in the higher elevation sandier alluvial deposits. This process is likely continuing although at a slower rate than occurred in the period immediately after initial diking. On the regional scale the entire delta is subsiding as sedimentary deposits consolidate, as well as by displacement by regional faulting within the Puget Sound.

Comparing current surface elevations from the 2002 LIDAR data with the 5-ft. (1.52 m) contour of the 1956 USGS topographic map of the region suggests an average subsidence of 9.6 in (244 mm) over the 46-year period, or approximately 0.21 in. (5.3 mm) of total subsidence per year. This includes regional subsidence, which are estimated for this region is on the order of 0.024 in./yr (0.6 mm/year) (USGS, 2001).

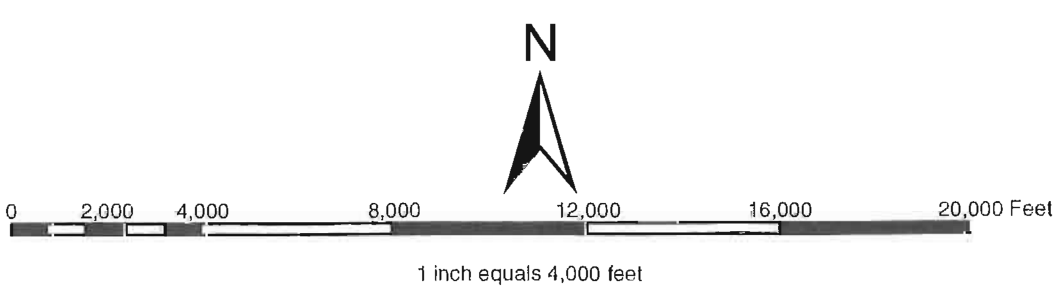
For this analysis, subsidence rates on diked and drained low lying land below the potential tidal influence of (lower than +6.6 ft or 2.01 m NGVD) was assumed to continue at the recent historic rate of about 0.21 in./yr (5.3 mm/yr), while subsidence rates for higher areas above potential tidal influence was assumed to be only the regional estimated rate of 0.024 in./yr (0.6 mm/yr.)

Over 30 years 0.21 in./yr (5.3 mm/yr) amounts to about 0.5 ft (0.15 m) of total subsidence. Figure 3.5 shows shows how a lowering of 0.5 ft (0.15 m) would affect the lower lying portions of Fir Island. The lowest lying areas, below 8.6 ft (2.6 m) MLLW, equivalent to 2.5ft NGVD, would expand from 700 acres (2.8 km^2) to 1,400 acres (5.7 km^2). Historical eustatic, sea-level rise due to long term climate changes, as estimated by the Intergovernmental Panel on Climate Change (IPCC, 1995), for the previous century ranged from 0.04-0.09 in./yr (1.0 – 2.5 mm/yr). Projections for eustatic sea level rise for the next century range from 0.08-0.34 in./yr (2.0 – 8.6 mm/yr).

For the purposes of the sedimentation analysis used in predicting habitat changes for alternative pathways, sea-level rise for both high and low tide elevations was assumed to be the 0.08 in./yr (2.0 mm/yr) observed for the previous 50 years continued for the next 30 years. It was also assumed that land drainage induced subsidence would cease once tidal action was reintroduced to restored regions. Therefore, adding eustatic sea-level rise and the regional subsidence rate translates to a relative sea-level rise of 0.10 in./yr (2.6 mm/yr) or a relative rise of the high and low tide elevations of 0.25 ft (0.07 m) over 30 years at the Fir Island Delta. This estimate does not include the impact of global warming over the next 30 years.



2002 based on LIDAR survey flown April 2002, Skagit System Cooperative



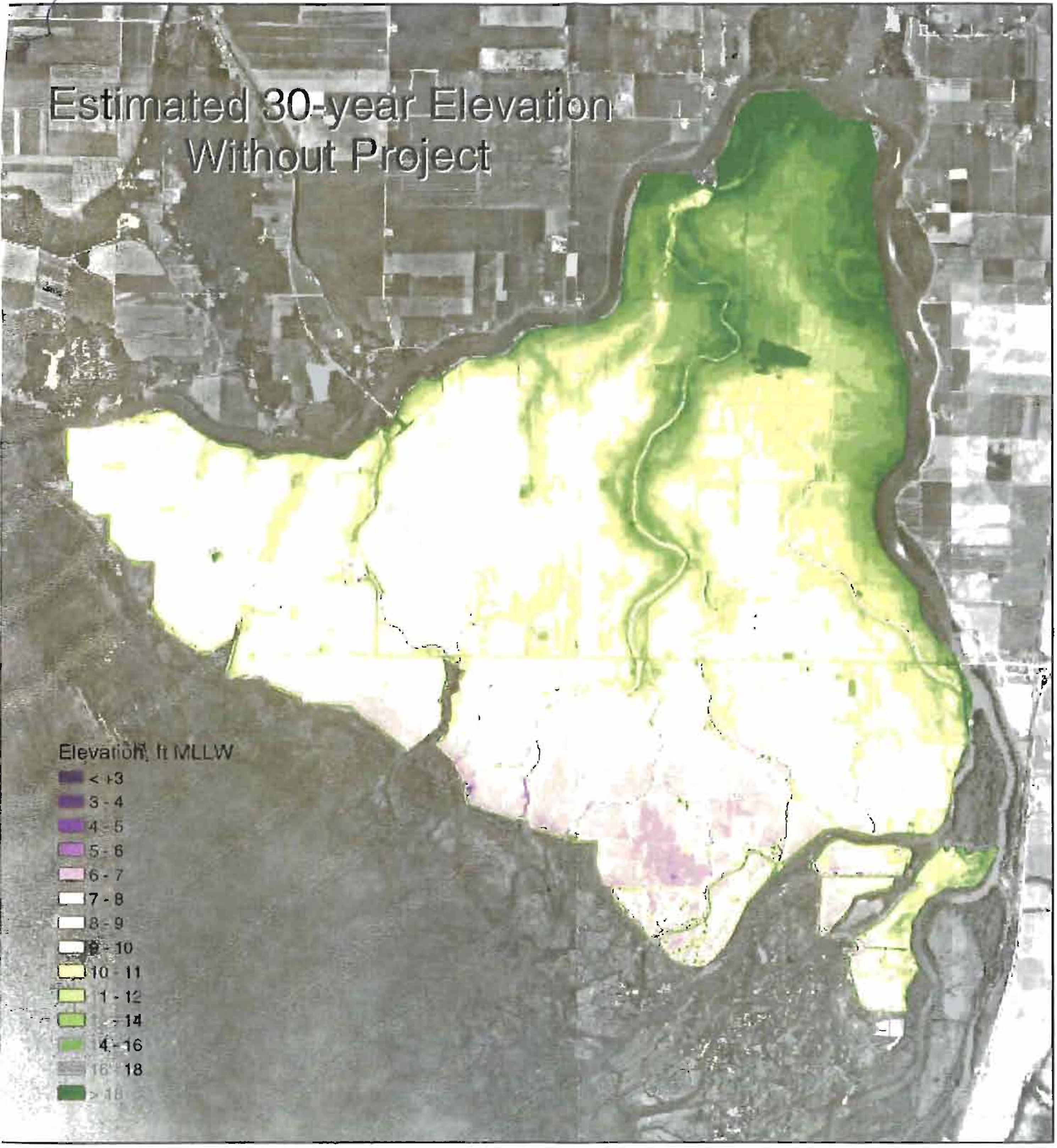


figure 3.5

Fir Island Restoration Pathways Assessment

Fir Island Subsidence Estimate

PWA

4. RESTORATION OBJECTIVES

4.1 GOAL STATEMENT

The starting point of any ecologic restoration plan is a clear concise goal statement. The following has been selected for this assessment of potential habitat restoration pathways on the Fir Island Delta:

> "To *develop and evaluate a range of alternative pathways that aim to restore the productivity and sustainability of estuarine habitats that support native fish and wildlife populations in the greater Fir Island Delta within three decades. Alternative pathways will be evaluated for potential land-use impacts and opportunities for (land-use) improvements.*"

It should be noted that the focus of this statement is restoring habitat – acknowledging its relationship to land use. There are many other factors influencing land use such as agricultural economies or social issues that are not included in this goal statement.

4.2 FIR ISLAND DELTA RESTORATION OBJECTIVES

Four restoration objectives were identified for purposes of this study. These objectives are used in this feasibility study to evaluate the site potential for native habitat restoration work on Fir Island based on the analytic tools described in Section 3 and 6. Evaluation is accomplished through the use of performance indicators directly tied to achievement of each project objective that can either be directly measured or estimated for each pathway. These performance indicators used in conjunction with each objective are described in detail in Section 7 of this report.

The objectives used to define the site potential of each restoration pathway include:

1. Increase productivity of chinook salmon rearing habitat (define productivity)
2. Expand channel migratory opportunity between the Skagit River and existing or restored near-shore marsh habitats.
3. Restore landscape scale ecological processes on Fir Island
4. Minimize the impact on current land-uses

Objectives 1 through 3 articulate intent to restore key ecosystem functions to Fir Island. Objective 4 recognizes the need to minimize impacts to existing land uses and infrastructure. The objectives are further defined in the following sections.

4.2.1 Objective 1: Increase Productivity of Chinook Rearing Habitat

Fir Island forms a critical landscape link in the life cycle of Skagit River chinook salmon. It provides a transitional zone between the freshwater rearing and spawning grounds on the Skagit River and the salt-water environment of Puget Sound. Chinook rearing is dependent on the range of habitats provided in this transitional zone, including emergent tidal marsh, scrub-shrub marsh and forested wetland. The performance indicators for these habitats are based on estimates of each habitat area based upon comparative analysis of time series GIS remote sensing and evidence from historic reconstruction based upon Government Land Office (GLO) surveys (Collins, 2000). Analysis was conducted by SSC primarily through data collected through aerial orthographic techniques, including multi-spectral imaging, LIDAR, and orthographic photography from the time periods of 1937, 1947, 1954, 1965, 1972, 1991 an 1998 (Beamer, in press; Hood, unpublished).

4.2.2 Objective 2: Expand Migratory Opportunity between the Skagit River and Near-shore Marsh Habitats

Distributary channels play several key roles in the life cycle of Skagit River salmonids and other native biota. One key function is to provide connection between the main forks of the Skagit River and near-shore emergent marsh habitat, particularly along the mid-delta front, where emergent marsh habitat is currently under-utilized by salmonids (Hood, personal communication, 2003). Without these channels out-migrating fish have a limited amount of rearing habitat available throughout their transition to salt water. A large portion of the important emergent marsh and scrub-shrub vegetation zones is unavailable to juvenile fish until after they have made their transition to salt water or progressed significantly through the osmo-regulatory adjustment (Beamer et al., 2002). By providing additional migratory pathways to under-utilized existing and/or restored emergent marsh habitats, significant increases in salmonid production potential can be realized. In addition to providing physical connectivity to these areas, by redirecting suspended sediment supply, distributary channels will help reverse the trend of channel aggradation in the North Fork and the potential for major channel avulsion in the near future. Moreover, emergent marsh development could be accelerated by spreading sediment deposition throughout a wider area of the delta forefront.

4.2.3 Objective 3: Restore Landscape Scale Ecological Processes on Fir Island

Landscape processes such as the delivery and routing of wood, water, sediment, nutrients, heat and contaminants are driving mechanisms behind the formation of habitat features in the aquatic ecosystem.. Large-scale human modifications to the landscape have altered the frequency, magnitude and duration of habitat forming events in some areas and increased them in others. Restoration of landscape processes to Fir Island would attempt to increase the diversity and spatial distribution of habitat features for aquatic dependent species.

4.2.4 Objective 4: Minimize the Impact on Current Land-Use

Fir Island provides for approximately 7,600 acres (30.8 km^2) of highly productive agricultural land, in addition to being home for several hundred residential and business properties. The conversion of Fir Island from delta to productive agricultural land was a significant contribution to the overall development of the regional economy. Objective 4 is intended to help guide future decisions about where restoration resources can be best applied to minimize impacts to the local community. Inherent in this objective is the understanding that certain restoration actions may be mutually beneficial, in terms of improving drainage infrastructure and minimizing maintenance to these facilities in exchange for restoring some of the lost physical process to the island.

4.3 OPPORTUNITIES AND CONSTRAINTS

The purpose of evaluating opportunities and constraints is to establish, at an early stage in project planning, the rationale on which key project decisions can be based. In addition to the project goals and objectives, the opportunities and constraints will help shape the range of project pathways developed and evaluated as part of this study. The following contains bullet point lists of opportunities and constraints presented by the physical, biological and cultural environment of Fir Island.

OPPORTUNITIES

- Restore distributary channels along their historic alignments.
- Allow more fish to distribute themselves to a wider array of feeding and rearing opportunities.
- Recreate high quality rearing habitat by restoring naturally vegetated corridors and channel complexity along distributary channels.
- Restore emergent tidal marshes adjacent to distributary channels.
- Restore complex high order tidal channel systems by restoring large areas to tidal marsh.
- Create scrub-shrub and forested wetland habitat by encouraging natural alluvial sedimentation in distributary channel corridors.
- Reduce flood hazards through levee reconstruction.
- Redistribute sediment delivery to help spread delta growth over a wider area and reduce temporal horizon for avulsion of North Fork.
- Improve land drainage through drainage system improvements.
- Understand more about subsidence rates on the Skagit Delta.
- Investigate variables regulating salt-water intrusion.
- Connect remnant patch habitats so that functional linkages exist with higher quality habitats.

CONSTRAINTS

- Potential for river capture by a distributary channel.
- Development proximate to historic distributary channels that may increase the cost of levee setbacks.

- Number of landowners along the historic distributary channel alignments.
- Potential amount of subsidence of former tidal marsh areas.
- Need to protect infrastructure with new setback levees.
- Potential for wind and wave action to limit the evolution of emergent marsh.
- Potential for restoration actions to cause saltwater intrusion to neighboring agricultural lands.

5. RESTORATION PATHWAYS

The key to restoring functioning sustainable ecologic processes in Fir Island is restoring the functioning of fluvial and tidal pathways that have been blocked by levees. Restoring pathways not only reestablishes migratory corridors for fish and other organisms, they allow for the flow of water and sediment that build and sustain estuarine and deltaic habitats.

Two criteria were used to underpin the development of potential restoration pathways:

1. Pathways considered for evaluation were those that had significant likelihood of improving access to emergent marsh rearing habitat for chinook salmon, and

2. Pathways are developed with the principle of sustainability in mind. Sustainability is defined as having equal or better quality habitat as time progresses. Pathways requiring on going maintenance will not be developed beyond the conceptual phase. Our evaluation will be based upon a minimum standard of long-term (~100yr) sustainability. Sustainability is defined as having equal or better quality habitat as time progresses.

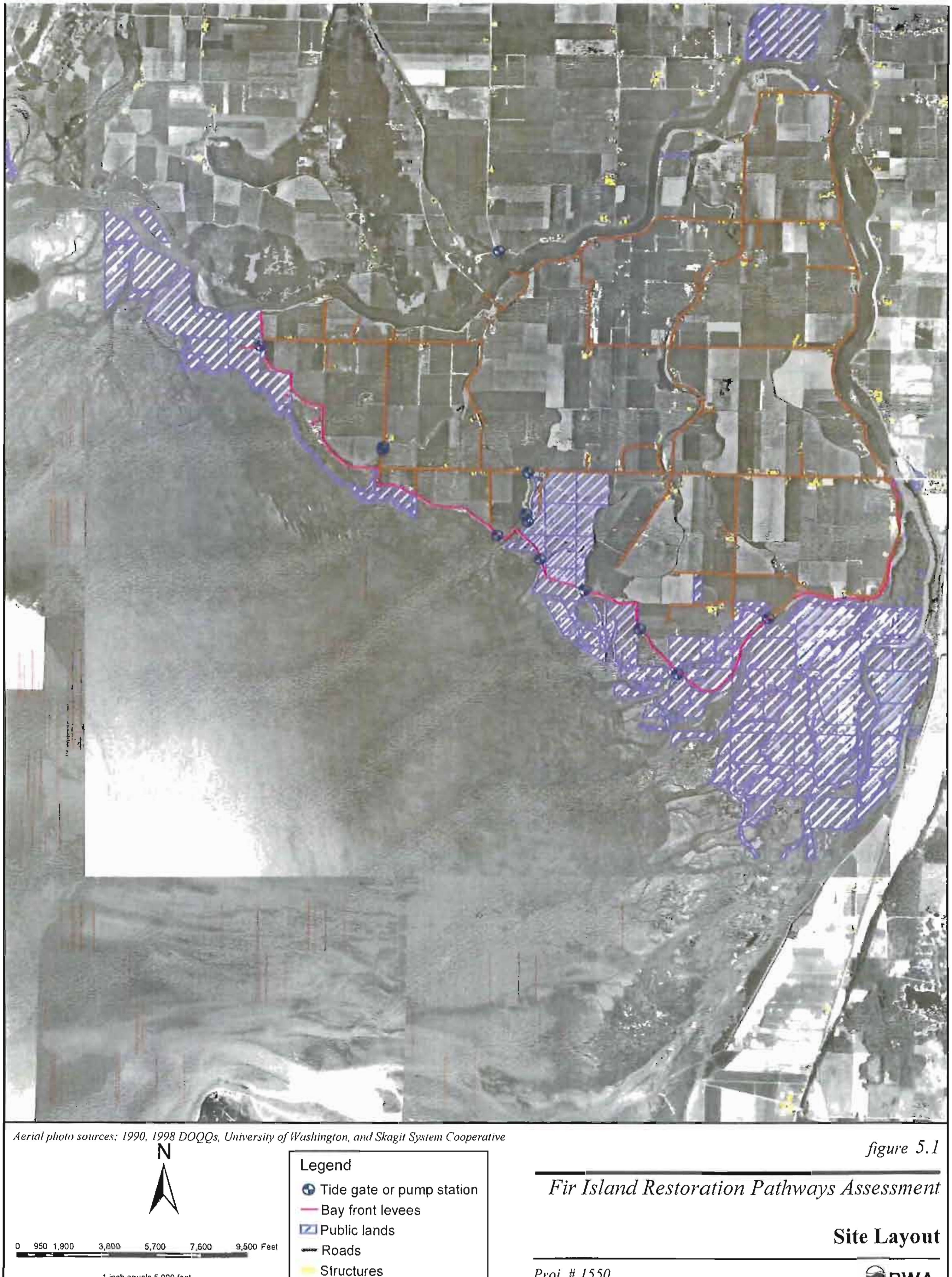
For this stage of alternative development pathways will be evaluated on a planning horizon of 30 years post-restoration. Therefore the expected habitat 30 years from now will take into account large-scale geomorphic processes such as land subsidence, sea-level rise, and delta growth.

Five restoration pathways have been developed for the purposes of this study including a no=-action pathway. A theoretical full restoration scenario, that assumes all levees are removed, is also described for the purpose of establishing a maximum ecological benefit benchmark against which the remaining pathways can be assessed..

The following descriptions summarize the basis of the pathways. Figure 5.1 provides a layout of the project area, including locations of structures, roads, tide gates and existing levees. Figure 5.2 illustrates potential locations of new distributary channels, determined by local topography, associated with Pathways 2, 4, and 5.

5.1 PATHWAY 1 – NO-ACTION

Pathway 1 assumes current maintenance of existing levees, drainage network and tide-gates over the next 30 years. Based on field investigations of current condition, this pathway predicts net expansion of the North and South Fork deltas and net erosion of the mid delta front marsh. Drainage issues related to land subsidence and sea-level rise will be discussed but not evaluated.



Aerial photo sources: 1990, 1998 DOQQs, University of Washington, and Skagit System Cooperative

figure 5.1

Fir Island Restoration Pathways Assessment

Site Layout

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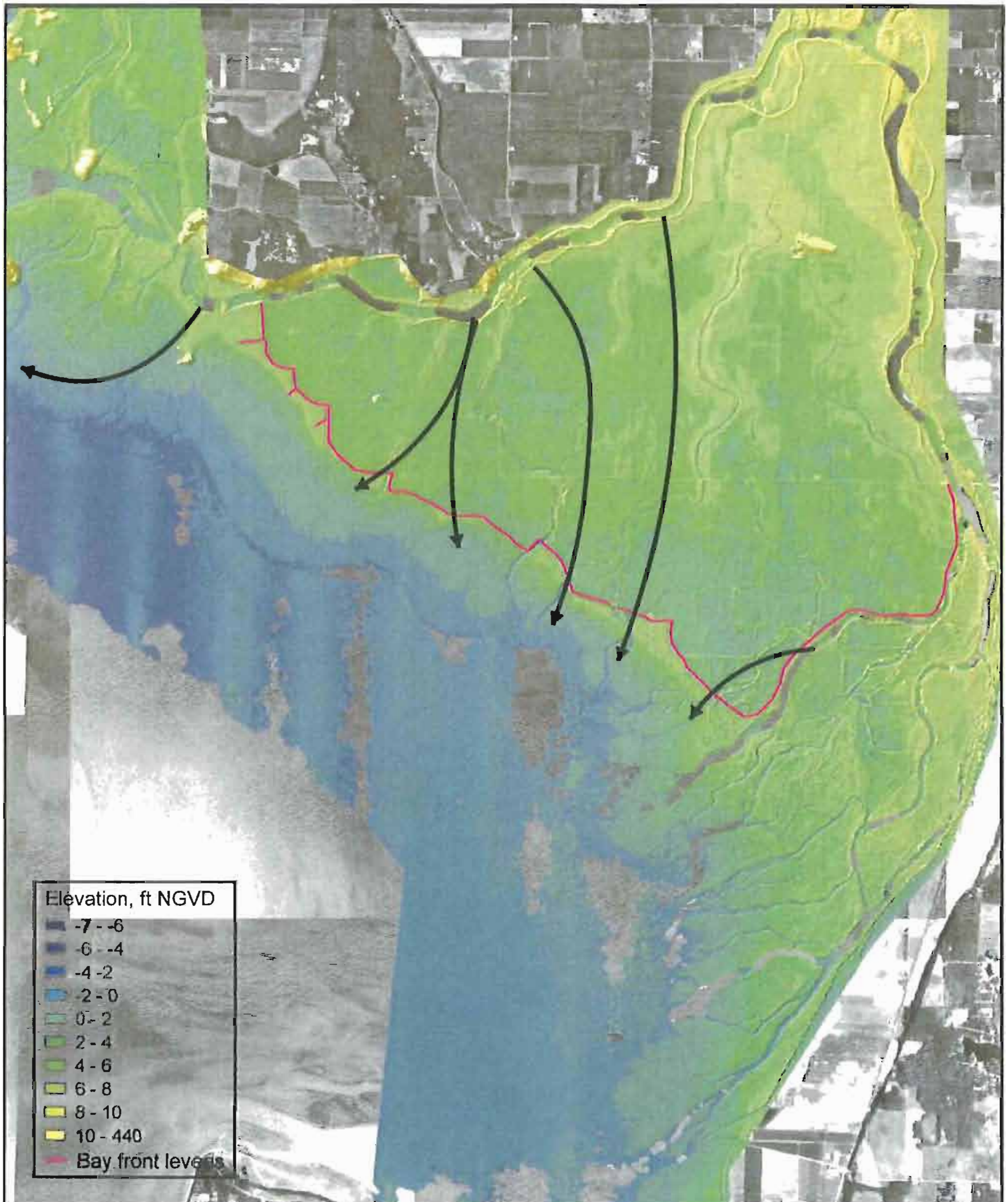
PWA



LIDAR survey flown April 2002, Skagit System Cooperative

N

1 Inch equals 5,667 feet

figure 5.2

Fir Island Restoration Pathways Assessment

Potential Location of New Distributary Channels

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PWA

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5.2 PATHWAY 2 – RESTORATION ON PUBLIC LANDS OUTSIDE THE BAYFRONT LEVEE

The areas considered for restoration in Pathway 2 are tidelands outside the bay-front levee and are mainly intertidal mudflats. In most areas, natural processes are constrained by the levee system, thereby limiting the ecological potential of the system. At present, intertidal marsh and distributary channels are slowly evolving at the mouth of the North Fork and the South Fork of the Skagit River. However, on the North Fork, the main channel discharges most of its sediment beyond Ika Island, where it is subject to wave action and periodic dredging. Consequently, this sediment is not readily available for widespread marsh formation. Therefore, Pathway 2 examines the potential for reconfiguring the North Fork distributary channel system to facilitate marsh habitat creation.

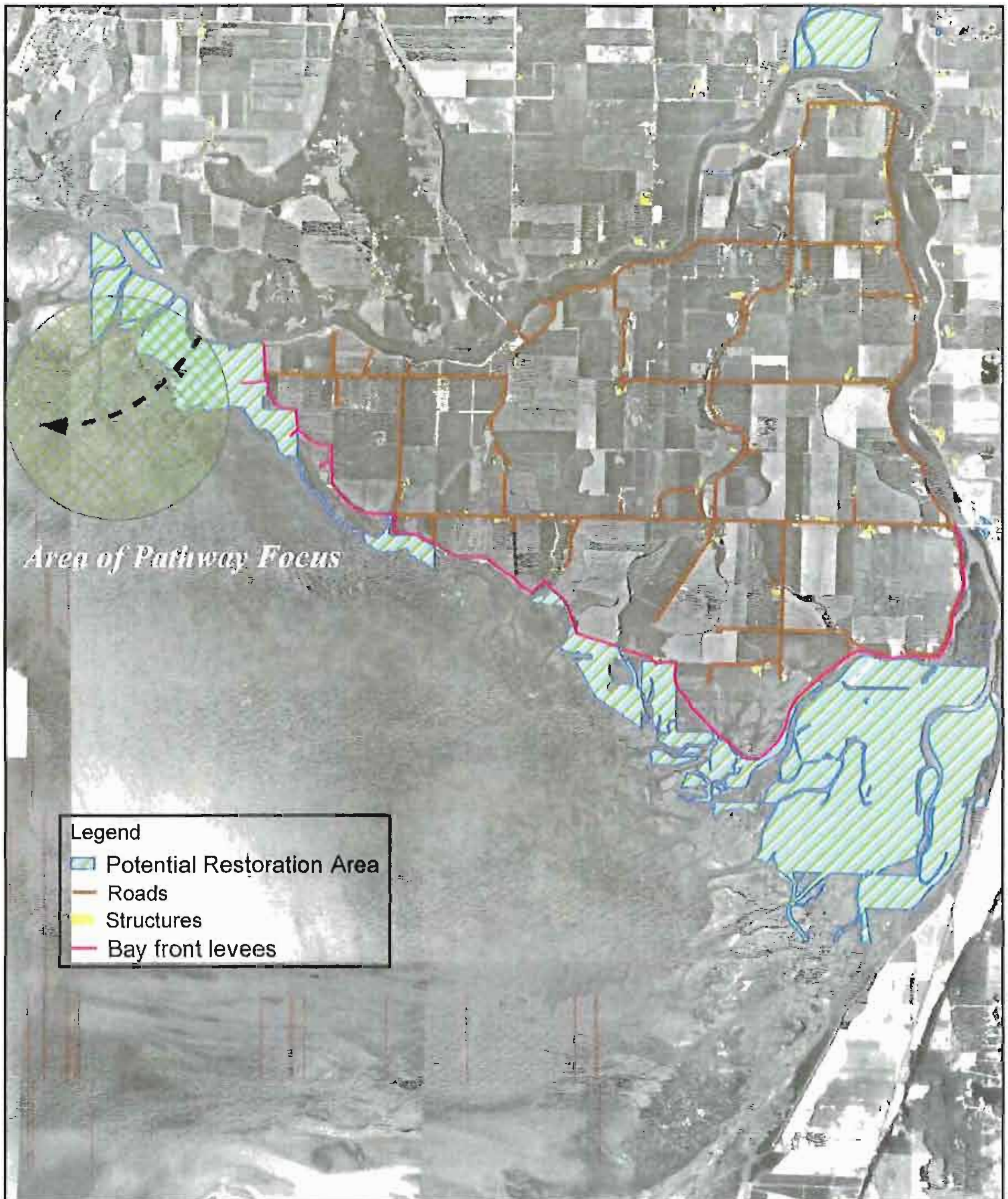
Figure 5.3 highlights the restored region of the North Fork delta under Pathway 2. Sediment from the North Fork would be diverted to the delta marsh front by a constructed large 3rd order distributary channel. This channel will be designed to be large enough to be self sustaining, diverting a significant portion of the North Fork's flow and sediment. This would probably be accomplished by constructing a training dike. The new distributary channel will elongate over time and bifurcate, creating more channel habitat. It also would help facilitate accelerated marsh expansion by: 1) causing estuarine sediment to deposit due to the 'breakwater effect' of the natural levees formed as the channel network system evolves, and 2) diverting fluvial sediment to supply the eroding mid-delta marsh front.

5.3 PATHWAY 3 - RESTORATION OF PUBLIC LANDS CURRENTLY MANAGED FOR WATERFOWL

Pathway 3 was developed to evaluate the restoration potential for publicly owned agricultural areas that are currently managed for waterfowl habitat. The areas considered for restoration under Pathway 3 are shown in Figure 5.4. The design of Pathway 3 includes restoring tidal action to the mouths of Dry Slough and Wiley Slough, thereby restoring the function of mouths of the two distributary channels and creating blind tidal channel networks, and restoring tidal action to the Deepwater Slough regions that are currently still diked. No new distributary channels are included in this alternative. Overall, this pathway is believed to have a low level of impact on private operations and infrastructure.

5.4 PATHWAY 4 – RESTORATION OF ECOLOGICAL FUNCTION TO PERFORMANCE BENCHMARK

Pathway 4 is based on areas and connections of key habitats required to function at a minimum standard of ecological function. This standard was established through technical team discussions and empirical analysis of existing habitat conditions and associated fish use (Beamer et al., 2000, 2002).



Aerial photo sources: 1990, 1998 DOQQs (University of Washington) and Skagit System Cooperative

N

1 inch equals 6,250 feet

figure 5.3

Fir Island Restoration Pathways Assessment

Pathway 2 Layout

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PWA

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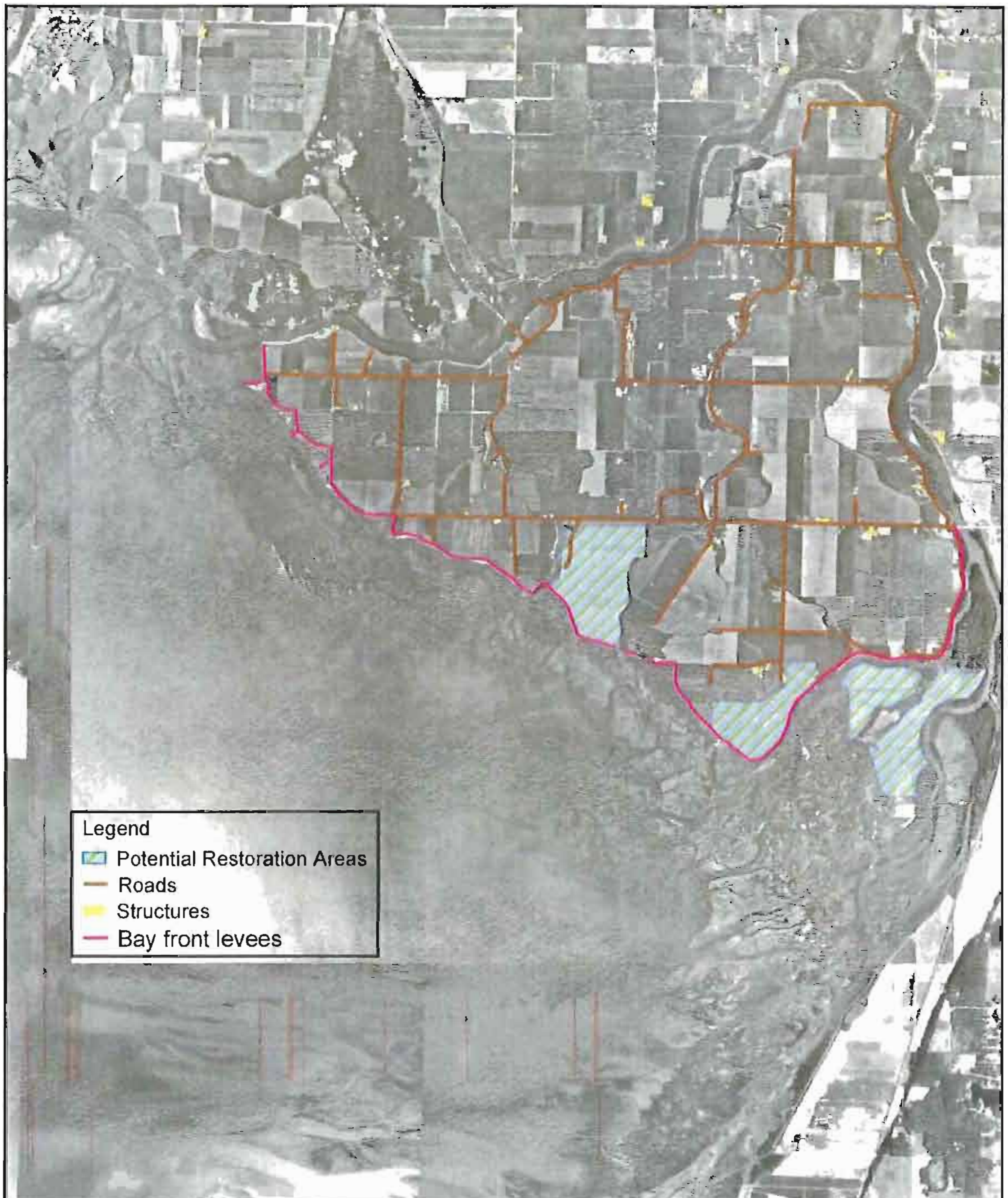

Aerial photo sources: 1990, 1998 DOQQs (University of Washington) and Skagit System Cooperative

N

1 inch equals 6,250 feet

figure 5.4

Fir Island Restoration Pathways Assessment

Pathway 3 Layout

Proj. # 1550

PWA

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The minimum standard was defined as a contiguous landscape unit with site potential consisting of the following criteria:

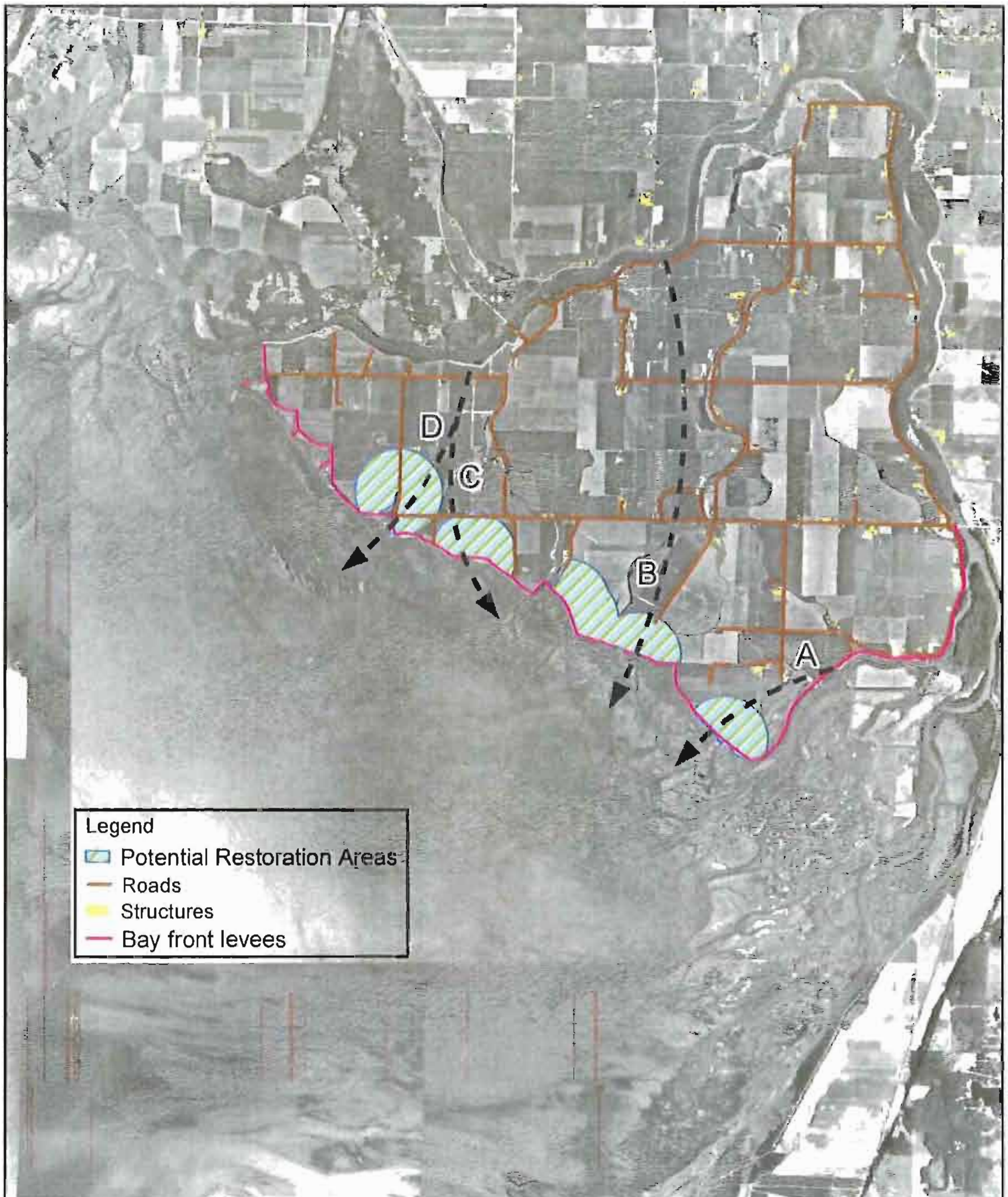
- A distributary channel corridor, of 3rd order magnitude or greater, that provides a pathway for out-migrating smolts to emergent marsh habitat that is currently isolated from such transitional habitats;
- A geomorphically sustainable flow route for potential distributary channel connections to emergent marsh habitats;
- Associated emergent marsh plain of sufficient size to sustain a blind channel network of a magnitude that is likely to be wetted at Mean Low Water (MLW).

It was determined, based on preliminary analysis, that these requirements would not be met by the predicted evolution of habitat with pathway 1,2 or 3 in either the North or South Fork deltas. However, new distributary channels flowing into one of four marsh restoration locations as shown in Figure 5.5 would have the potential for meeting these requirements. These locations are:

A: The vicinity of Wiley Slough
B: The vicinity of Dry Slough
C: The vicinity of Brown Slough
D: The vicinity of Hall Slough

Therefore the landscape units described above were located on the retreating delta front to the southeast of the remnant Browns Slough channel outlet. This location has the benefit of opening up areas that are currently underutilized by salmon, and supplying sediment to rejuvenate tidal marshes in this eroding zone (See Figure 5.5).

Except in the Wiley Slough location, the distributary channel associated with Pathway 4 would be of 3rd order complexity, would be approximately 175 ft (53 m) in width, and would discharge adjacent to an area of emergent marsh of approximately 100 acres (0.4 km^2). Tidal flows in 1,100 acres (4.45 km^2) of emergent marsh would sustain a 3rd order blind channel tidal drainage network. A 3rd order channel would be deep enough such that at low tide, water depths would be sufficient for fish using the marsh to remain within the marsh. A target of 3rd order blind channel complexity was chosen as the desired condition because field data indicate these channels are likely to be wetted at MLW.



Aerial photo sources: 1990, 1998 DOQQs (University of Washington) and Skagit System Cooperative

N

1 Inch equals 6,250 feet

figure 5.5

Fir Island Restoration Pathways Assessment

Alternative Pathway 4 Layout

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PWA

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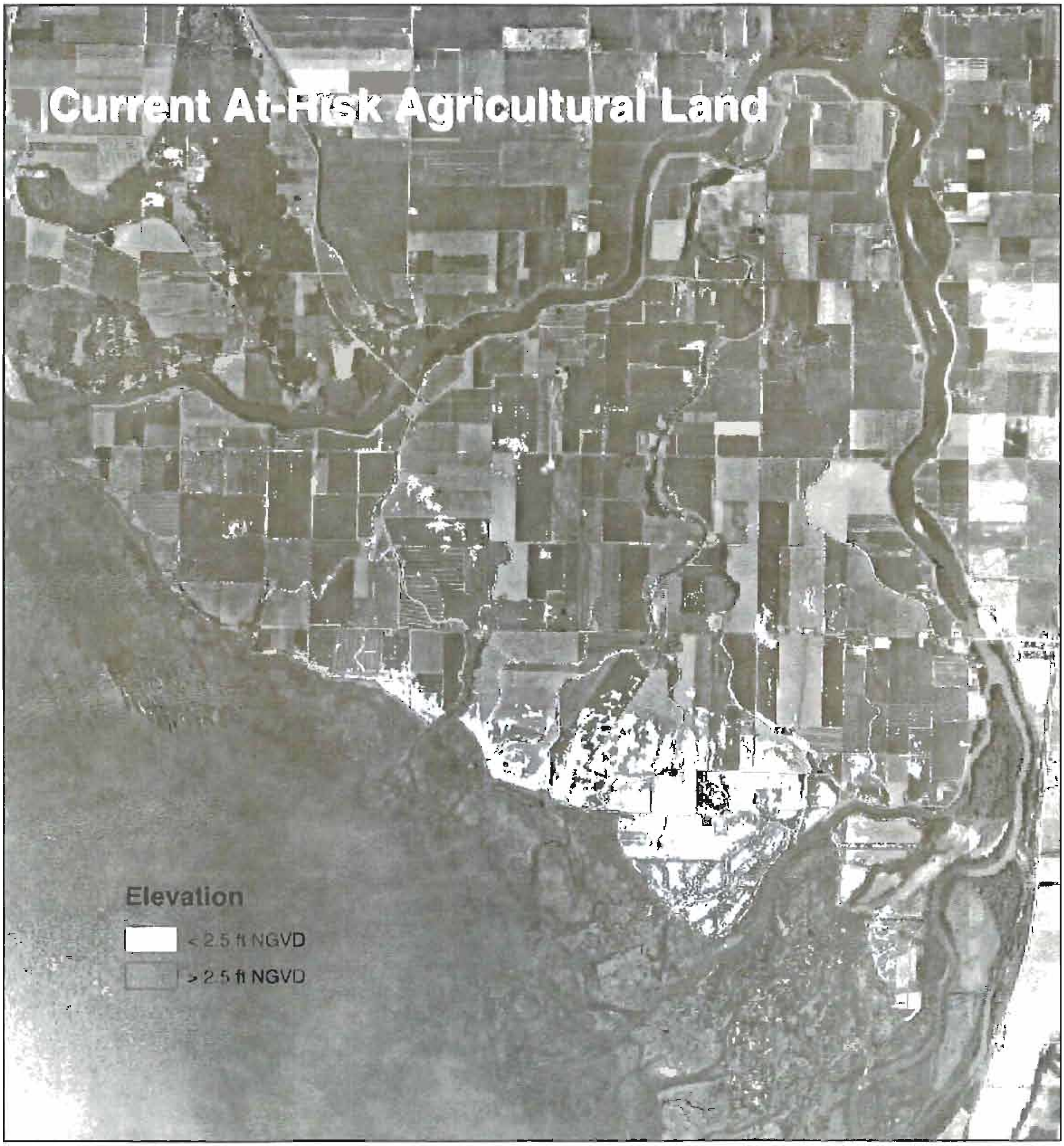
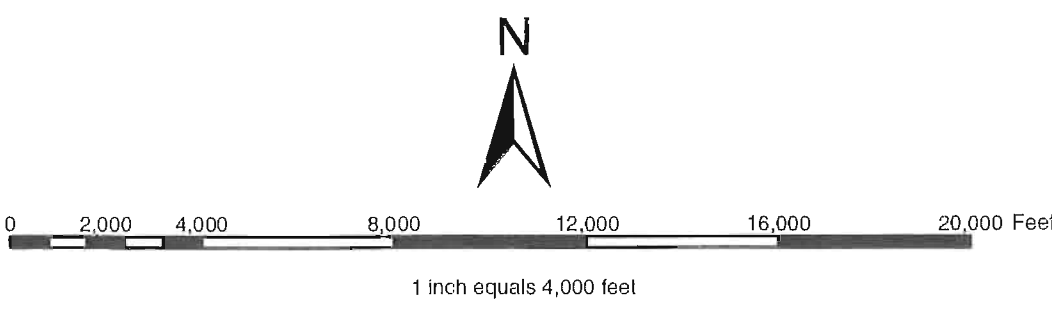


2002 based on LIDAR survey flown April 2002. Skagit System Cooperative



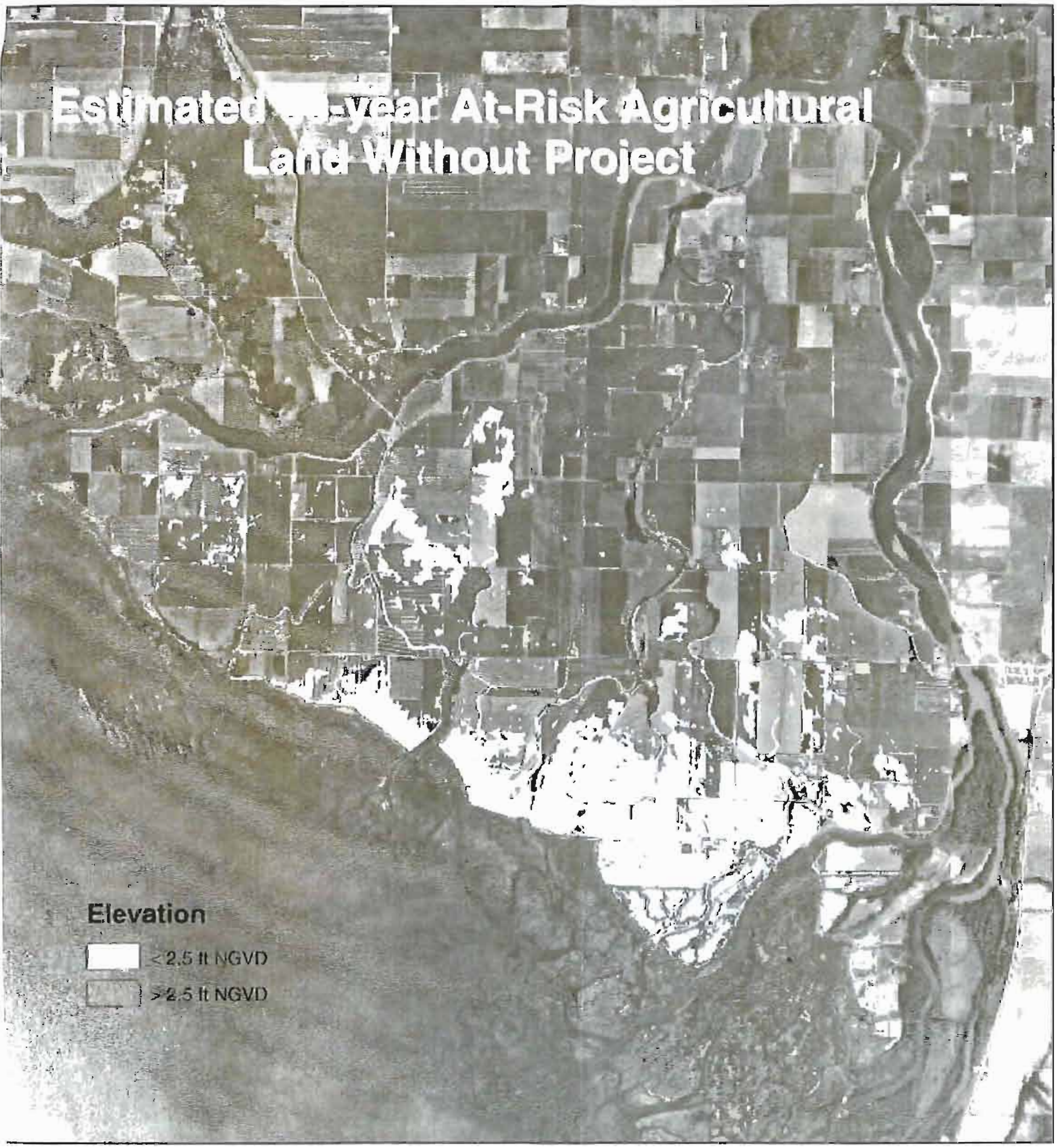


figure 5.6

Fir Island Restoration Pathways Assessment

Predicted Increase in Area below 2.5' NGVD

PWA

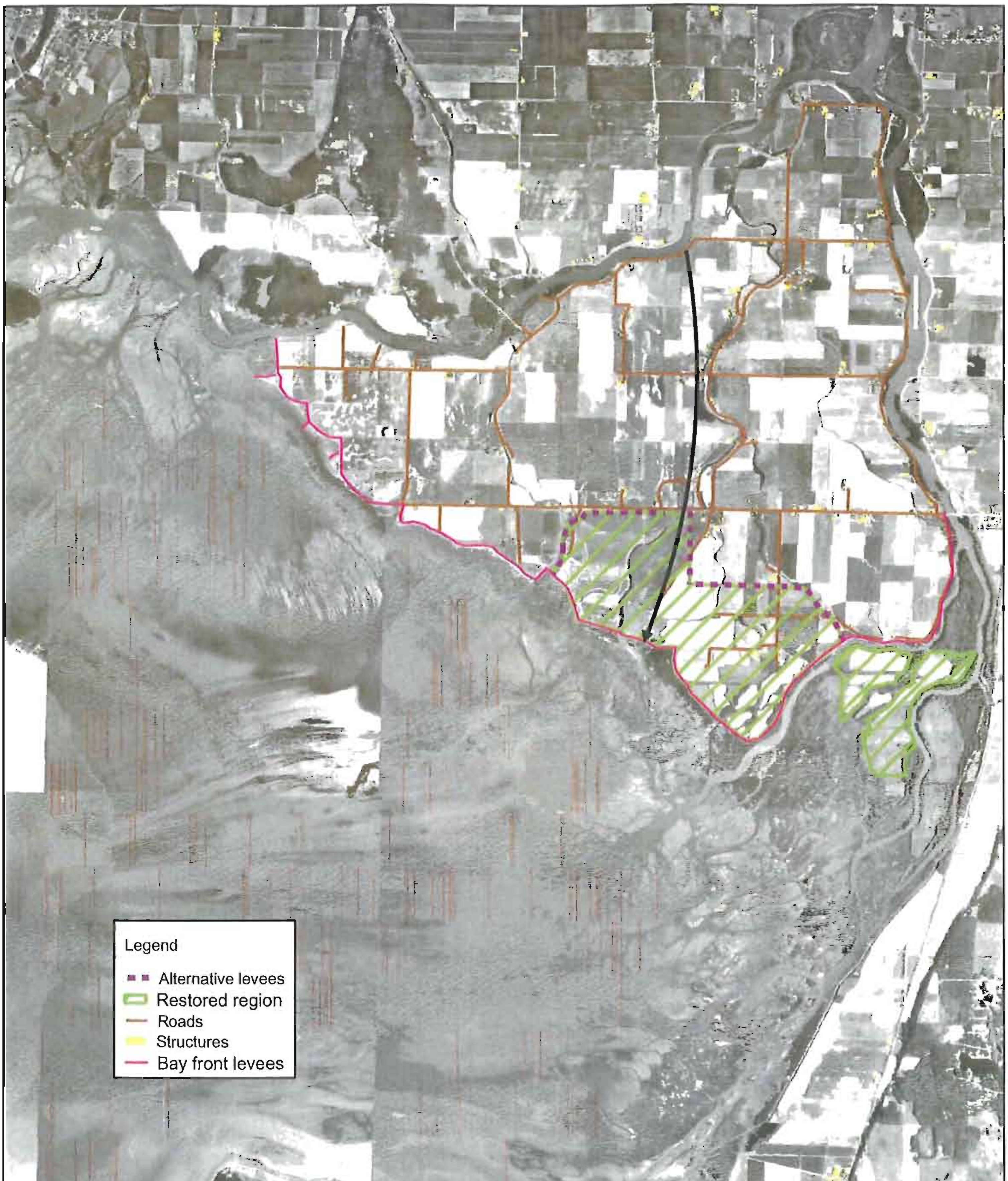
5.5 PATHWAY 5 – RESTORATION TARGETED TO AGRICULTURAL LANDS AT RISK OF IMPARED DRAINAGE

This pathway was developed to maximize ecologic benefits while minimizing impacts to agricultural land that is likely to continue to be adequately drained after predicted land subsidence over the next 30 years. Figure 5.6 shows those areas of Fir Island that are expected to be below an elevation of 2.5 feet (0.76 m) NGVD or less and therefore believed to be at risk of lower productivity over the next 30 years with anticipated subsidence of 0.5 ft (0.15 m) . The 2.5 ft NGVD elevation was selected because it appeared to coincide with existing areas that experience impaired drainage. This area actually underestimates the area at risk of impaired drainage, because in addition approximately 0.2 ft (0.06 m) of sea level rise is anticipated in the next 30 years.

In addition to maximizing ecological benefit for at-risk agricultural land this pathway minimizes loss of structures and roads (Figure 5.7). Net subsidence was estimated based on historic land subsidence and estimated values of sea-level rise. Section 3.5 discusses the processes of land subsidence and sea-level rise. Pathway 5 incorporates one major distributary channel that connects the North Fork to Skagit Bay. The distributary channel will be constrained by levees within a 1,000 ft (305 m) wide corridor located in a low-elevation route between Brown's Slough and Dry Slough and would pass underneath Fir Island Road. This width of corridor would allow for 300 ft to 400 ft (91 m to 122 m) of floodplain wetland on either bank, sufficient room to allow a native woodland to develop. South of Fir Island Road the new distributary channel would branch to form two higher order channels. These will provide better connectivity between newly created emergent marsh habitat and the North Fork Skagit River. A new bay front levee would be constructed around the low-lying agricultural land to be converted to emergent marsh habitat. The new distributary channels would likely decrease flood stage along the North Fork, thereby decreasing flood risk within the delta. Such an analysis of distributary channel effects on water surface was not part of the scope of this project, and therefore not considered in the performance indicator evaluation.

5.6 LEVEE REMOVAL SCENARIO

This scenario assumes that all artificial structures and management on Fir Island will be removed and is included only to illustrate the maximum restoration potential if Fir Island was abandoned. Figure 5.8 shows the expected habitats that would emerge under this hypothetical scenario based on elevations and expected sedimentation rates described in Section 3 (together with the no-action pathway) on the restoration potential available for Fir Island.



Aerial photos sources: 1990, 1998 DOQQs (University of Washington) and Skagit System Cooperative

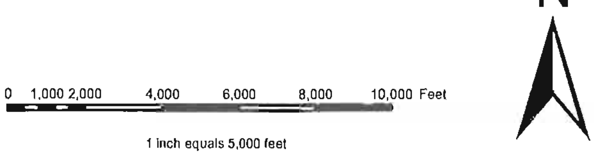


figure 5.7

Fir Island Restoration Pathways Assessment

Pathway 5 Layout

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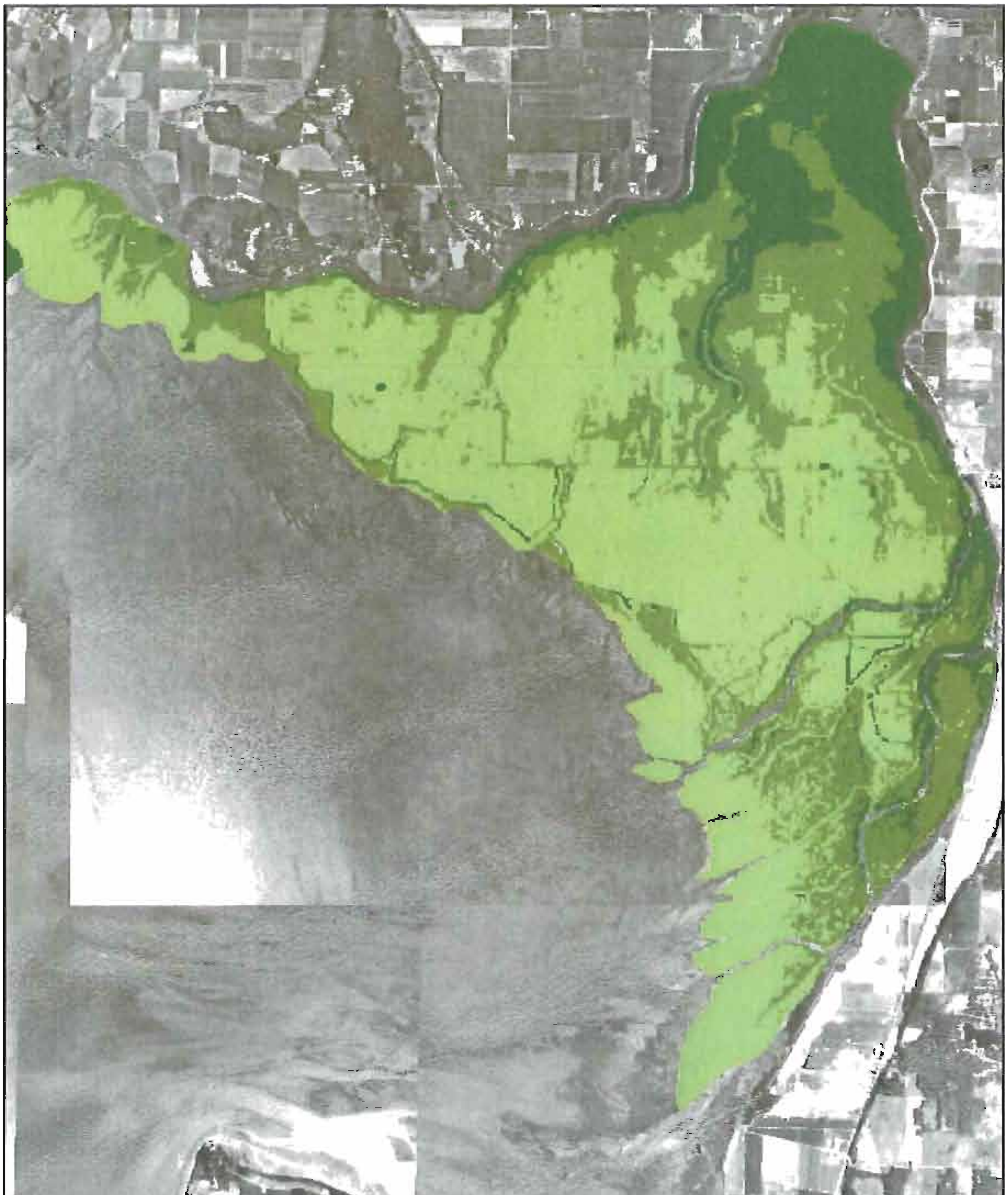

Aerial photos sources: 1990, 1998 DOQQs (University of Washington) and Skagit System Cooperative

N

1 inch equals 6,250 feet

Legend
- Inter-tidal Mudflat
- Inter-tidal Emergent Marsh
- Scrub-Shrub Marsh
- Forested Upland

figure 5.8

Fir Island Restoration Pathways Assessment

Potential Habitat with Levee Removal Scenario

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PWA

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6. EVALUATION OF RESTORATION PATHWAYS

6.1 EVALUATION METHODOLOGY

Each restoration pathway will be evaluated against a series of performance indicators that relate directly to the project objectives discussed in Section 4. The boundary of Fir Island used in estimating values of habitat indicators is the main channel of the North and South Fork Skagit River, and Skagit Bay. The performance indicators are discussed in more detail in this section and are summarized in Table 6.1. The evaluation of each pathway is based on the prediction of physical evolution of each pathway over the 30-year planning horizon. Relationships between vegetation, physical habitat and elevation and between marsh area and area of blind tidal channel networks (see Section 2) are used as the basis for each evaluation. Data on road layouts and structure locations were obtained from the U.S. Army Corp of Engineers (ACOE) and the State of Washington.

Table 6.1 – Project Objectives and Performance Indicators

Project Objective	Performance Indicator(s)
1. Increase the Productivity of Chinook Rearing Habitat	1.1 Relative change in chinook smolt rearing potential
	1.2 Estimated cChange in blind channel area
	1.3 Change in total tidal wetland
	1.4 Area of emergent tidal marsh
	1.5 Area of scrub-shrub marsh
	1.6 Area of forested wetland
	1.7 Total length of 3rd and 4th order distributary channels
	1.8 Total area of distributary channels
2. Expand migratory opportunity between the Skagit River and existing or restored near-shore marsh habitats.	2.1 Number of 3rd and 4th order distributary channels
	2.2 Area of emergent tidal marsh within .5 kilometer of a 3rd or 4th order distributary channel outlet.
3. Restore Landscape Scale Ecological Processes for Fir Island	3.1 Area available to annual floods.
	3.2 Increase in area of each historic habitat type – Inter-tidal mudflats, emergent tidal marsh, scrub-shrub marsh, forested wetland, upland
4. Minimize the Impact on Current Land Use	4.1 Area converted from agricultural land-use
	4.2 Number of structures removedlost
	4.3 Linear feet of roads removed and not rebuilt
	4.4 Linear feet of bay front dikes removed
	4.5 Linear feet of new dikes constructed

The purpose of the performance indicators is to provide a framework within which each pathway may be assessed. This study is a large-scale feasibility level assessment of a wide range of potential restoration action. As restoration pathways become more defined and site specific, the level of detail associated with the evaluation of each pathway can be increased appropriately.

The evaluation of project pathways is summarized in a matrix where each pathway, including the no-action pathway, is evaluated against each performance indicator. In addition, implementation cost of each pathway is estimated at a feasibility level. The matrix is given in Table 7.1.

In addition to being used to evaluate pathways, the performance indicators outlined in Table 6.1 should form the basis for any post-project monitoring program.

6.2 PERFORMANCE INDICATORS

6.2.1 Chinook Rearing Habitat

Chinook rearing habitat will be assessed using 6 indicators. The first of these, the rearing potential , is based on empirical research developed by SSC (Beamer et al., 2001 described in PWA, 2000). Total areas of each habitat type, including lengths and areas of blind and distributary channels are also used to evaluate each pathway in terms of increasing the productivity of chinook rearing habitat.

6.2.2 Migratory Corridors

Two performance indicators are used to evaluate how each pathway provides for additional migratory corridors between the Skagit River and existing or restored near-shore marsh habitats; the numbers and orders of 4th and 3rd order distributary channels in the delta, and the total area of near-shore emergent marsh habitat within 1640 feet (0.5 km) of a 4th order or higher distributary channel mouth. Proximity of tidal marsh to a distributary channel enhances growth potential for juvenile salmonids.

6.2.3 Landscape Scale Ecological Processes

A total of five performance measures will be used to evaluate the impact each pathway has on landscape scale ecological processes in the project area. The disturbance to existing natural habitats, total area of each habitat type, length of natural boundary/transition, average patch size and connectivity of habitat patches will all be assessed to guide pathways evaluation.

6.2.4 Land Use Impact

Given the important role Fir Island plays in the local economy and its place within the community for residential and business use, five performance measures are used to evaluate the impact each Pathway will have on current land-use. The performance measures range from the number of structures that will be lost, to the change in linear feet of dikes required to maintain existing levels of flood protection.

7. EVALUATION SUMMARY

Each of the key indicators for each pathway was evaluated at the 30-year planning horizon, and is described below and summarized in Table 7.1. This table allows for comparison between each pathway and with current conditions.

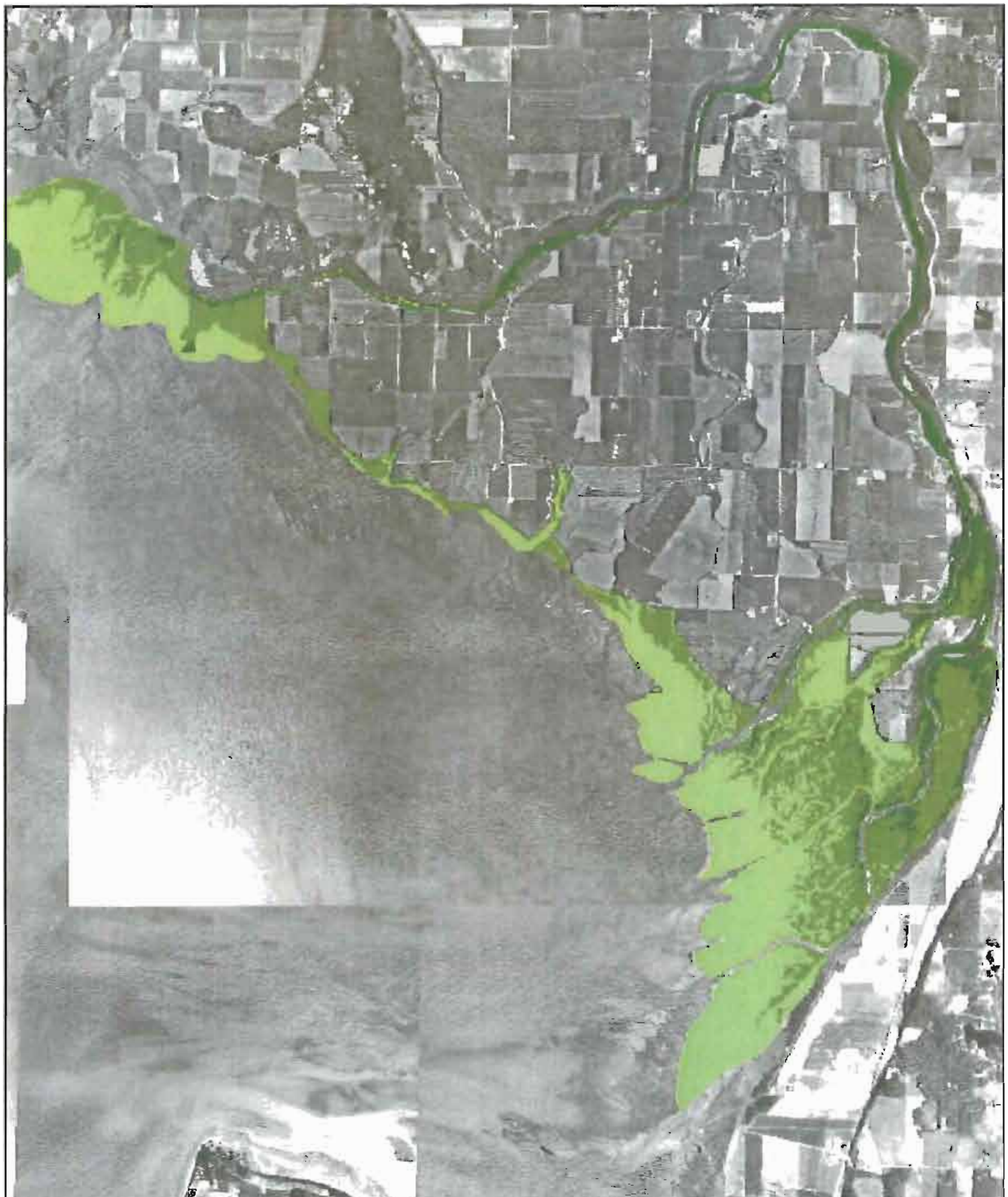
7.1 PATHWAY 1 – NO-ACTION

While the North and South Fork deltas would continue to develop and restore lost emergent zone marsh habitat, continued erosion of the mid-delta front would likely isolate the two deltas from one another (Figure 7.1). A portion of emergent marsh would convert to transitional scrub-shrub habitat due to alluvial sedimentation. Because most of new habitat is close to the river mouth forested wetland habitat is not expected to develop in these areas. Over the next 30 years, the diked portion of Fir Island would continue to subside in relation to sea-level in Skagit Bay. As a result, drainage on the island would gradually worsen so that gravity driven drainage systems become less viable. Suspended sediment supply from the watershed would probably continue at relatively high levels in response to upstream land-use. Sedimentation and elongation of the North Fork would likely raise the bed elevation and flood levels in relation to constraining levees. This would lead to an increased risk of a major channel avulsion and decreased flood protection.

The extent of the distributary channel network would remain fairly constant with all 3rd and 4th order channels concentrated in the South Fork Delta. It is not anticipated that additional 3rd or 4th order distributary channels would develop over the planning horizon.

7.2 PATHWAY 2 – UNDEVELOPED PUBLIC LANDS

The restoration of currently undeveloped public land by creating a new distributary channel at the mouth of the North Fork would potentially increase emergent tidal wetland habitat by approximately 400 acres in 30 years when compared to the no-action alternative (Figure 7.2). It should be noted that there are significant uncertainities concerning the amount of sediment delivered by the new channel. Ensuring adequate sediment delivery. would require appropriate design to ensure the channel was sustainable in the long run. Increases in transitional and upland habitat over the 30-year restoration horizon are similar to the no-action alternative (see Table 7.1). The increase in total 3rd and 4th order distributary channel length from approximately 54,000 ft (16.5 km) to 68,000 ft (20.7 km) results in an increase of emergent marsh habitat within 1640 ft (0.5 km) of distributary channel mouths to increase by 270 acres (1.09 km^2), when compared to current conditions. Pathway 2 requires no removal of the bay-front dike, and no net loss of agricultural land, roads, or structures.



Aerial photos sources: 1990, 1998 DOQQs (University of Washington) and Skagit System Cooperative

N

1 inch equals 6,250 feet

Legend
- Inter-tidal Mudflat
- Inter-tidal Emergent Marsh
- Scrub-Shrub Marsh
- Forested Upland

figure 7.1

Fir Island Restoration Pathway Assessment

Pathway 1 Habitat Evolution

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PWA

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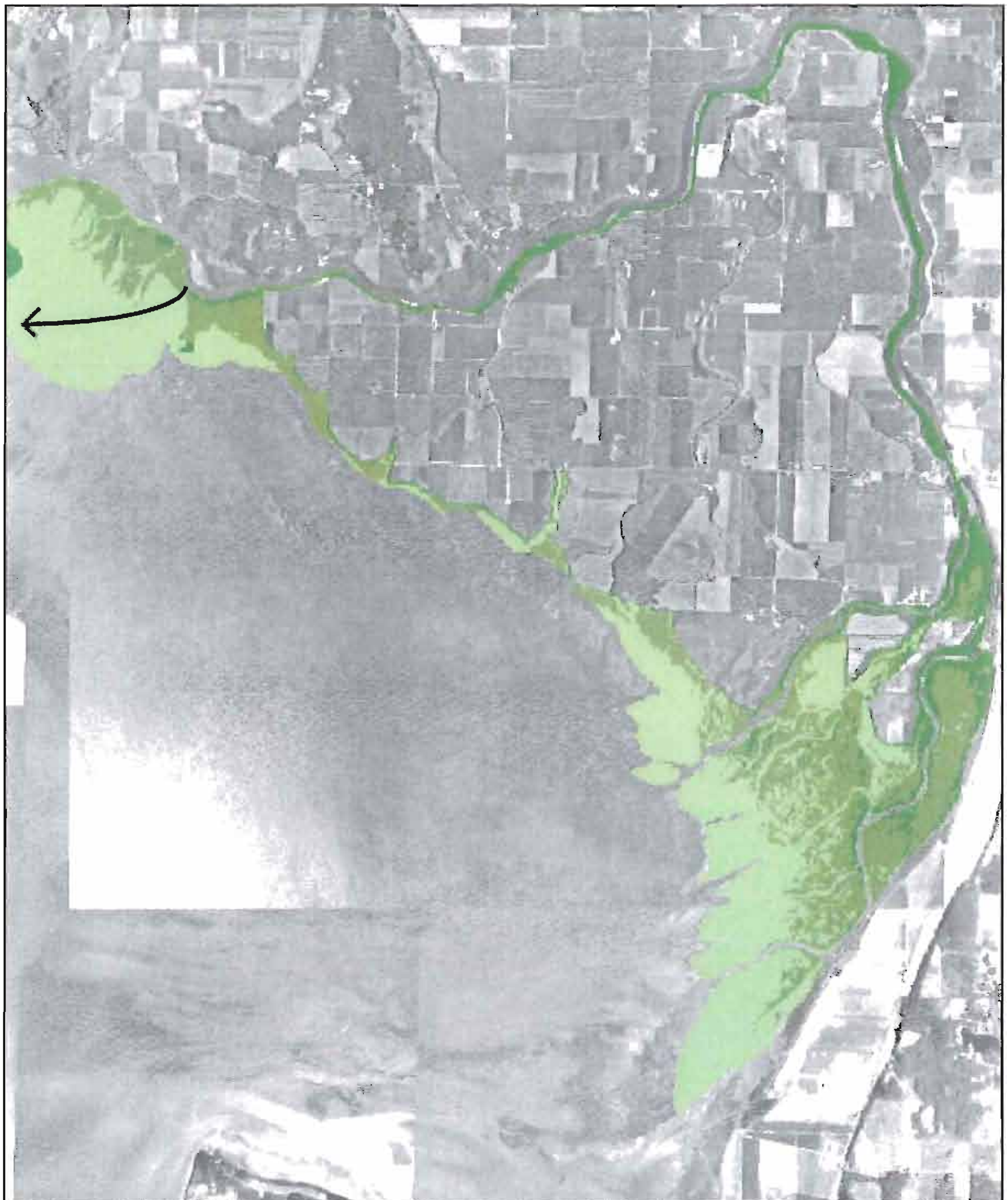

Aerial photos sources: 1990, 1998 DOQQs (University of Washington) and Skagit System Cooperative

N

1 inch equals 6,250 feet

Legend
- Inter-tidal Mudflat
- Inter-tidal Emergent Marsh
- Scrub-Shrub Marsh
- Forested Upland

figure 7.2

Fir Island Restoration Pathway Assessment

Pathway 2 Habitat Evolution

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PWA

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Table 7.1 Pathways Performance Evaluation

Objective	Performance Indicator	units	Current
1. Increase productivity of Chinook Rearing Habitat	1.1 Relative change in Chinook smolt rearing potential	smolts	N
	Change expressed as a %	%	N
	1.2 Estimated change in blind channel area	acres	[illegible]
	1.3 Change in total tidal wetland	acres	[illegible]
	1.4 Area of emergent tidal marsh	acres	2,
	1.5 Area of scrub-shrub marsh	acres	9
	1.6 Area of forested wetland/upland	acres	5
	1.7 Total length of 3rd and 4th order distributary channels	feet	54
	1.8 Total area of distributary channels	acres	[illegible]
2. Provide Additional Migratory Corridors between Shore Marsh Habitats	2.1 Number of 3rd and 4th order distributary channels	--	
	2.2 Area of emergent tidal marsh within .5km of a 3rd or 4th order distributary channel outlet	acres	[illegible]
3. Restore Landscape Scale Ecological Processes for Fir Island	3.1 Area available to annual flooding	acres	3,
	3.2a Total area of intertidal mudflats	acres	[illegible]
	3.2b Total area of emergent tidal marsh	acres	2,
	3.2c Total area of scrub shrub marsh	acres	9
	3.2d Total area of forested wetland/upland	acres	5
4. Minimize the Imapct of Current Land Use	4.1 Area converted from agricultural land-use	acres	
	4.2 Number of structures lost	--	
	4.3 Linear feet of roads removed and not relocated/rebuilt	feet	
	4.4 Linear feet of bay front dikes removed	feet	
	4.5 Linear feet of new dikes constructed	feet	
Feasibility Level Cost Estimate			

[1] Excavated new channel = 5000 ft.

	Restoration Pathways				
	1	2	3	4	5
'onditions					
A	135,000	270,000	380,000	27,000 - 1,085,000	1,085,000 - 1,6256,000
A	10%	21%	30%	21% - 85%	85% - 127%
0	30	60	90	60 - 250	250 - 370
.0	+400	+800	+1,000	+800 - +1,900	+1,900 - +3,100
.00	2,000	2,400	2,500	2,300 - 3,100	3,300 - 4,000
)0	1,400	1,400	1,500	1,500 - 1,800	1,600 - 2,000
70	570	570	620	570 - 600	620 - 640
000	54,000	68,000[1]	54,000	67,000 - 98,000	67,000 - 98,000
30	280	400	280	340 - 450	340 - 450
3	3	4	3	4 - 6	4 - 6
80	280	450	280	450 - 750	450 - 750
500	4,000	4,000	4,700	4,400 - 5,500	5,500 - 6,600
40	140	140	140	140	200
.00	2,000	2,400	2,500	2,300 - 3,100	3300 - 4,000
)0	1,400	1,400	1,500	1,500 - 1,800	1,600 - 2,000
70	570	570	620	570 - 600	620 - 640
-	0	0	650	200 - 600	1,500 - 3,000
-	0	0	0	0 - 6	35 - 40
-	0	0	1,550	2,000 - 18,000	10,000 - 18,000
-	0	0	12,000	3,000 - 17,000	16,000 - 27,000
-	0	0	19,000	25,000 - 50,000	35,000 - 85,000
-	--	$5,000,000	$1,500,000	$17,000,000 - $50,000,000	$30,000,000 - $80,000,000

7.3 PATHWAY 3 – PUBLIC LANDS

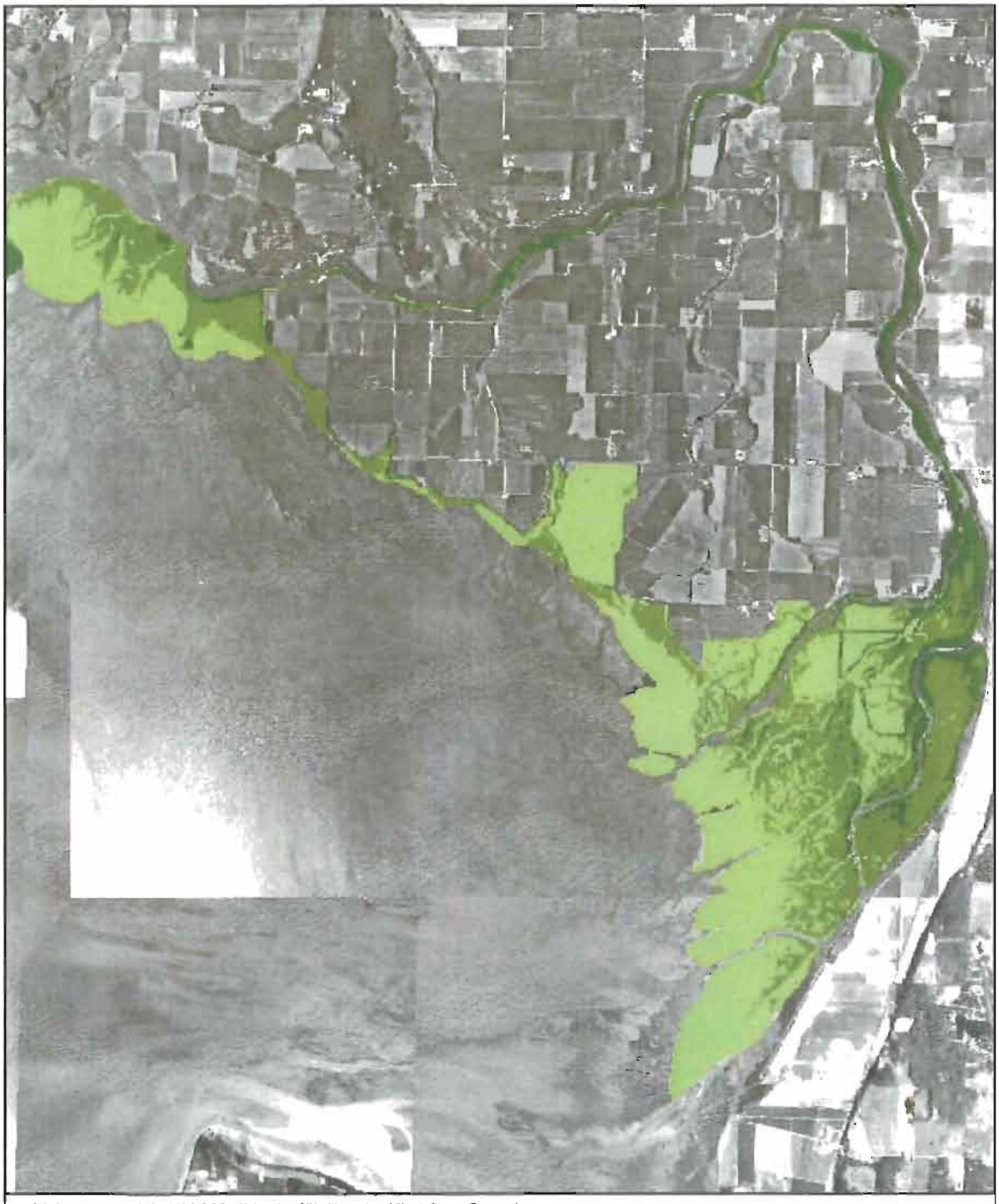
The public lands pathway creates more habitat than the no-action pathway. An additional 500 acres (2.02 km^2) of emergent marsh habitat would likely form in breached areas (Figure 7.3). Compared to the no-action pathway a total of approximately 100 acres (0.4 km^2) of transitional habitat and approximately 50 acres of forested wetland/upland habitat would be created in Pathway 3 in the South Skagit Delta (see Table 7.1). Pathway 3 would also require approximately 3.6 miles (5.8 km) of new dikes to be constructed. The emergent marsh habitat restored under Pathway 3 is somewhat fragmented, with an average marsh area of approximately 100 acres (0.4 km^2).

7.4 PATHWAY 4 – ECOLOGICAL PROCESS BENCHMARK

Pathway 4 has four alternative footprints that are defined by the overall objective of restoring key habitat that is required to function at a minimum ecological process. The low-end values given in Table 7.1 for Pathway 4 represent restoration of the smallest landscape unit, and the high-end value represent restoration of all the landscape units defined.

The Minimum Ecological pathway would restore between 200 (0.81 km^2) and 1,100 acres (4.15 km^2) of emergent marsh habitat above what would be created under the no-action pathway, depending on the total number of parcels restored. Approximately 100 acres (0.4 km^2) to 400 acres (1.62 km^2) of transitional marsh will be created with Pathway 4 in comparison to the no-action alternative, with the freshwater/upland habitat increasing due to fluvial deposition in the distributary channel floodplain (see Table 7.1). The emergent marsh habitat restored under Pathway 4 will have the benefit of being concentrated in discrete parcels. All of the restored area in Pathway 4 would be well connected with 3rd and 4th order distributary channels, opening up under utilized portions of the delta front to fish use. These distributary channels (including channel bifurcations) linking the North Fork with the delta front are also considered necessary to support the restored parcels in Pathway 4. Sedimentation within the corridors that support the restored parcels would contribute to the increase in marsh and upland vegetation.

Except in the Wiley Slough location, Pathway 4 will result in the conversion of between 200 acres (0.81 km^2) and 600 acres (2.43 km^2) of agricultural land and require between zero and 6 structures to be demolished. A total of approximately 1 mile (1.6 km) to 5 miles (8.05 km) of new levees would be required to maintain the existing level of flood protection.



Aerial photos sources: 1990, 1998 DOQQs (University of Washington) and Skagit System Cooperative

N

1 inch equals 6,250 feet

Legend
- Inter-tidal Mudflat
- Inter-tidal Emergent Marsh
- Scrub-Shrub Marsh
- Forested Upland

figure 7.3

Fir Island Restoration Pathway Assessment

Pathway 3 Habitat Evolution

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PWA

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7.5 PATHWAY 5 – AT-RISK AGRICULTURAL LANDS

Pathway 5 represents a range of restoration possibilities to restore the at-risk agricultural land on Fir Island. The values given in Table 7.1 for Pathway 5 represent the range of creating one distributary channel to three distributary channels to facilitate sedimentation and habitat restoration within the at-risk land. Figure 7.4 depicts the predicted 30-year habitat evolution for the regions that are currently at or below 2.5 ft (0.76 m) NGVD.

Pathway 5 will restore approximately 1,300 acres (5.3 km^2) to 2,000 acres (8.1 km^2) of emergent tidal marsh over the no-action alternative, bringing the extent of this habitat type back to historic levels (Figure 7.5). An additional 200 acres (0.81 km^2) to 600 acres (2.43 km^2) of transitional marsh and 50 acres (0.2 km^2) to 70 acres (0.28 km^2) of forested wetland/upland habitat more than what is expected from the no-action alternative will also be created. In addition to creating new emergent marsh habitat, the distributary channels associated with Pathway 5 increase the amount of emergent marsh adjacent to distributary channel mouths by approximately 270 acres (1.09 km^2) to 570 acres (2.31 km^2) over current conditions (see Table 7.2). Habitat areas given in Table 7.2 for Pathway 5 represent maximum values that include the restored at-risk agricultural lands as well as the riparian corridor for the necessary distributary channel.

Pathway 5 will result in approximately 1,500 acres (6.07 km^2) to 3,000 acres (12.14 km^2) of agricultural land conversion, of which approximately 600 acres (2.43 km^2) is currently public land. The remainder is largely classified as poorly drained over the 30 year planning horizon. Pathway 5 has the greatest impact to the number of structures, 38 in total, and the amount of roadway removed, approximately 2 miles (3.2 km) to 3 miles (4.8 km). Pathway 5 will require approximately 7 miles (11.3 km) to 16 miles (25.7 km) of new levee to maintain flood protection.

7.6 FEASIBILITY LEVEL COST ESTIMATES

Feasibility level cost estimates are provided in Table 7.1. These costs do not include any acquisition costs. The assumptions regarding unit costs are given below and include the following items:

- Existing Levee Removal/Breach – \$3 per cubic yard
- New Levee Construction – \$5 per cubic yard
- Distributary Channel Excavation – \$25 per cubic yard
- New Road Bridges – \$4,000 per linear foot
- Road Removal – \$50 per linear foot
- Tide Gate Removal – \$5,000 EA
- Tide Gate Installation – \$45,000 EA
- Structure (Building) Demolition – \$50,000 EA

Aerial photos sources: 1990, 1998 DOQQs (University of Washington) and Skagit System Cooperative

N

1 inch equals 5,000 feet

Legend
- Inter-tidal Mudflat
- Inter-tidal Emergent Marsh
- Scrub-Shrub Marsh
- Forested Upland

figure 7.4

Fir Island Restoration Pathways Assessment

Pathway 5 Habitat Evolution

Proj. # 1550

PWA

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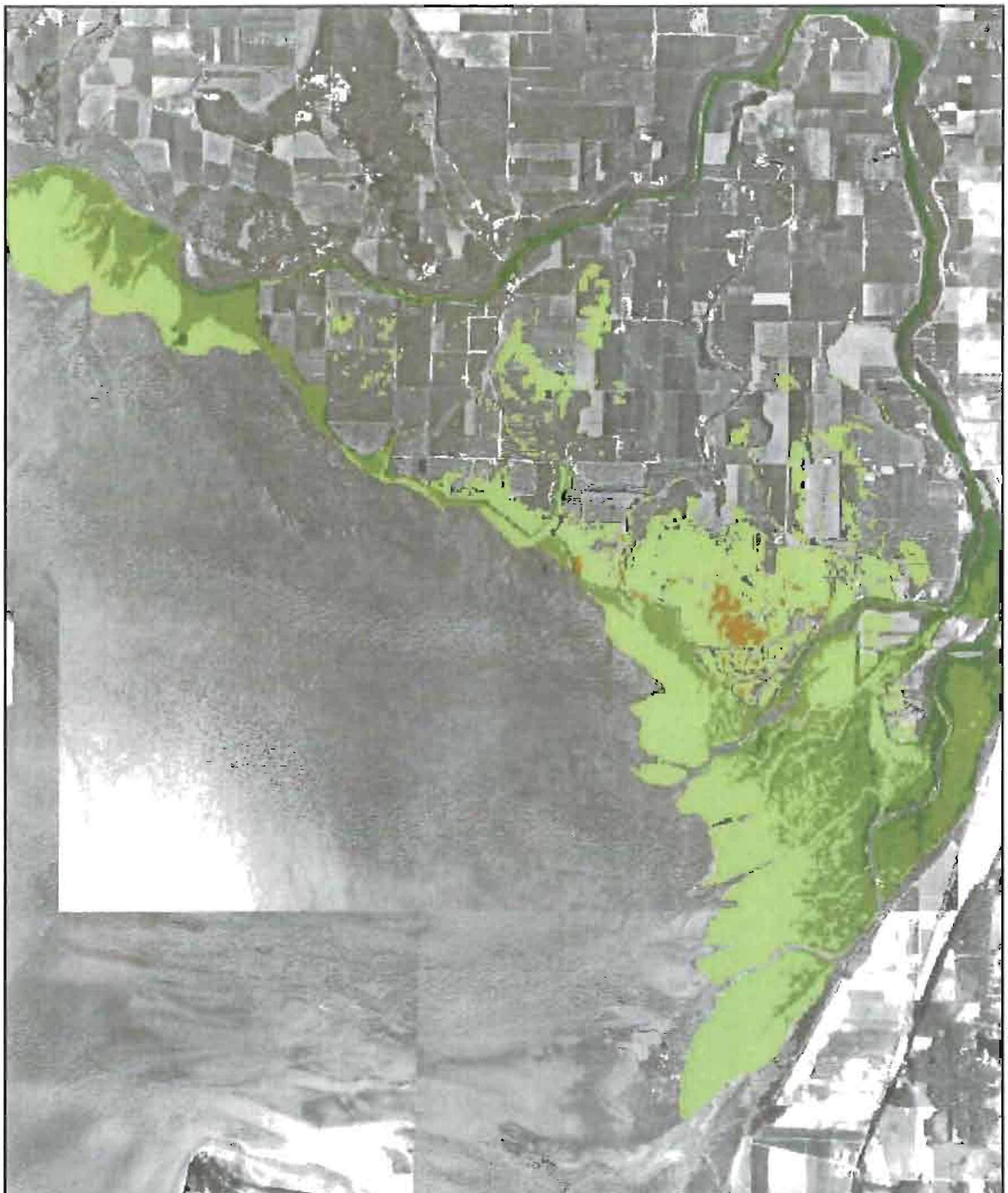

Aerial photos sources, 1990, 1998 DOQQs (University of Washington) and Skagit System Cooperative

N

1 inch equals 6,250 feet

Legend

- Inter-tidal Mudflat
- Inter-tidal Emergent Marsh
- Scrub-Shrub Marsh
- Forested Upland

figure 7.5

Fir Island Restoration Pathway Assessment

Pathway 5 Habitat Potential

Proj. # 1550

PWA

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These costs are intended for use in the feasibility level assessment and should not be used to prepare budget estimates for potential projects. Final cost of any given project will depend on actual labor and material costs, competitive market conditions, final project scope and layout, implementation schedule and other variables. In addition, final design and construction mobilization costs are typically in the range of 30% to 40% of construction cost.

The costs range from approximately $1.5 million for Pathway 3 to a maximum of approximately $80 million for the Pathway 5. Earthwork is the most significant cost item, particularly the construction of new distributary channels, whose costs range from approximately $5 million for Pathway 2 to a maximum of approximately $40 million for Pathway 4. However, given the feasibility and high cost if residents had to be relocated along the existing distributary channel network, it is likely that these costs are comparatively low . In addition, the excavated material from the new distributary channel network could be used to reduce the cost of importing materials for new levee construction.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

1. Habitat for salmonids in the Skagit River Delta evolves and changes in response to the dynamic nature of the fluvial, tidal, and sedimentary processes acting on the Delta. Depending on management and restoration actions undertaken in the Delta these habitat changes can be significant within a 30-year planning period.
2. With continuation of existing management practices –the no action pathway -we expect continued expansion of wetlands at the Delta front amounting to 400 to 500 acres of intertidal and scrub-shrub wetland habitat over the next 30 years, primarily in the North Skagit Delta. (very important to verify model's output that is driving this assessment)
3. Over the 30 year planning horizon no new major distributary channels are likely to emerge.
4. Over the next 30 years the area of farmland on Fir Island most likely to be adversely affected by drainage problems is expected to increase from about 700 to 1,400 acres due to continued land subsidence and sea-level rise.
5. There are restoration pathways that can result in significant increases in habitats preferred by juvenile salmon. These pathways include those that would restore the functioning of large distributary channels, nearly doubling the length of large distributary channels that now exist.

8.2 RECOMMENDATIONS

1. There may be additional benefits and opportunities in the design of restoration pathways that restore major distributary channels. Detailed evaluations of additional benefits or impacts were outside the scope of work for this study and were therefore not investigated. These benefits could be analyzed and integrated into the next stage of restoration planning. They include, but are not limited to: potential reduction in flood elevations upstream; potential reduction in sedimentation and dredging at the mouth of the North Fork Skagit; reduction in bay front levee maintenance costs, drainage improvements to adjoining agricultural lands and benefits to wildlife populations such as migratory birds and waterfowl.
2. There are important data and analysis whose refinement could have a significant affect on future stages of restoration planning and on potential cost effectiveness of restoration design. These include:
    - Definition of long term subsidence rates across Fir Island;

- Analysis of water levels, water quality and salinity within agricultural drainage ditches on Fir Island;
- Analysis of groundwater/surface water connections;
- Coring of sediments to better define long term average annual fluvial and estuarine sedimentation rates;
- Definition of rates of change to habitat types by repeat of LIDAR survey in 2007;
- Hydrodynamic and sedimentation modelling to predict and confirm patterns of sedimentation;
- Additional geomorphic analysis to define self-sustaining distributary channel design parameters;
- Develop a long-term sediment budget of the Skagit River (Skagit Bay system to determine linkages between alluvial sediment delivery and estuarine sedimentation rates as well as trends in average suspended sediment concentrations).

3. Future restoration planning should also take into account other potential major long-term changes in the Skagit River system affecting water and sediment delivery to the Delta, for example the Avon flood bypass or dike setback Pathways being considered by the Army Corps of Engineers under the Skagit River Flood Damage Reduction Feasibility Study.

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APPENDIX A
MARSH-98

Numerical Modeling (MARSH-98)

MARSH-98 is a numerical model (FORTRAN code) used to estimate long-term sediment deposition on mudflats and marsh plains. The program, proprietary to PWA, is based on an approach to marsh plain modeling developed by Krone (1987) and has been used successfully in several PWA projects over the past decade. According to Krone (1987), marsh plain elevations rise at rates dependant on: (1) availability of suspended sediment; and (2) water depth and inundation periods. As an example, if an evolving marsh surface is low in respect to tidal range, sedimentation rates could be high (assuming ample sediment supply) due to a larger relative accommodation space. However, as the marsh surface aggrades through the tidal range, the frequency and duration of tidal flooding is diminished so that the rate of sediment accumulation declines. Following the approach of Krone (1987), MARSH-98 calculates suspended sediment deposition during each tidal inundation period and sums this accumulation over the period of record.

The algorithm used in MARSH-98 is based on a mass balance of suspended sediment throughout the water column. The equation for the mass balance used in the model is:

During the flood tide when $\frac{d\eta}{dt} \geq 0$,

$$(\eta - z)\frac{dC}{dt} = -V_s C + (C_o - C)\frac{d\eta}{dt}$$

During the ebb tide when $\frac{d\eta}{dt} < 0$,

$$(\eta - z)\frac{dC}{dt} = -V_s C$$

Where:

η = water surface elevation (m above MLLW),
z = marsh plain elevation (m above MLLW),
C = suspended sediment concentration (kg/m^3),
t = time (seconds),
V_s = settling velocity (m/s)
C_o = ambient suspended sediment concentration of flood laden waters (kg/m^3).

A key underlying assumption of the mass balance equation is that material settling to the bed is not scoured by ebb currents, large waves, or storm conditions and becomes part of the accumulating deposit. Settling velocity for suspended particles is related to sediment concentration by:

$$V_s = KC^{4/3}$$

Where:

K = 0.00011.

Accumulation of material on the bed is determined by the following equation:

$$\Delta z = \frac{\int V_s C dt}{C_d}$$

Where:

Δz = change in bed elevation (m)
C_d = dry density of inorganic material in the deposit (kg/m^3).

The dry density C_d value used for modeling was 600 kg/m^3, which can be considered to be a value representative of estuarine mud.

During flood tide, suspended sediment storage in the water column is affected by: (1) re-supply from sediment-laden floodwaters (inflow); and (2) deposition to the marsh surface (outflow). Suspended sediment concentration during flood tide is affected by both of these processes. In contrast, during ebb tide, the storage of suspended sediment in the water column is affected by: (1) ebb waters that remove sediment (outflow), and (2) deposition on the marsh surface (outflow). As such, depositional processes as modeled by MARSH-98 only affect non-ambient (C) suspended sediment concentrations during the ebb tide. Ambient suspended sediment concentrations (C_o) remain constant. MARSH-98 performs the mass balance when the marsh surface is subtidal (always submerged) or intertidal (submerged only part of the time) and can transition between the two states.

To initialize the model, input parameters that must be defined are:

- initial bed elevation
- a time series of tidal elevation
- estimated relative sea-level rise (RSL)
- suspended sediment concentration
- dry density of inorganic material in the sediment (given above)
- time step (600 sec)
- total run time

Using a series of successively approximating and correcting half- and full-step advances, the algorithm moves the solution forward through time to the total run time. The technique is very similar to how a second order Runge-Kutta ODE integrator would integrate the equations and advance the solution in time.

The tidal data that is entered into the model (monthly time series) is repeated within the model for the duration of the simulation. In the end, the model sums the change in bed elevation for each time step over the entire model run to give a final output of increased bed elevation with time.