PRELIMINARY ASSESSMENT OF HISTORIC CONDITIONS OF THE SKAGIT RIVER IN THE FIR ISLAND AREA: IMPLICATIONS FOR SALMONID HABITAT RESTORATION

Report to:

Skagit System Cooperative

Post Office Box 368

La Conner, Washington 98257

Report prepared by:

Brian Collins
6822 20th Avenue NE
Seattle, Washington 98115

August 31, 1998

SUMMARY

This investigation describes current and historic conditions of distributary and blind-tidal channels of the lower Skagit River, downstream from where it branches into the North and South forks and forms Fir Island before entering Skagit Bay. The study is pan of a larger effort by the Skagit System Coop to document salmonid habitat use and estimate historic habitat loss and its potential for future restoration.

Fir Island is a relatively small portion of the river's historic delta. Prior to late-19th century river diking, floodwaters and associated suspended sediment commonly exited to Samish Bay and Padilla Bay as well as to Skagit Bay. According to several map sources, historically at least one-half of the delta was perennially wet, consisting of tidal marsh, fresh-water marsh, or open channels. A persistent logjam nearly a mile long at the town of Mount Vernon presented an obstruction to floodwaters, and contributed to the routing of floodwaters onto the Skagit Flats and to Padilla and Samish bays. Removal of the jam in the late 1870s and the later completion of an effective diking system together increased the efficiency with which floodwater was routed to the Fir Island area. This enhanced routing of floodwater to Fir Island was later counterbalanced beginning in the 1930s by headwaters dams which substantially reduced flood peaks.

The river historically stored and transported vast amounts of large woody debris. Records of the federal "snagging" program provide an indication of the amounts of debris that accumulated in the river. For example, 35,000 snags were removed from the lower Skagit River in the two decades prior to 1910. Snags included very large pieces: the snag-boat captain's records include the largest-diameter snag removed each year from Puget Sound rivers. The maximum diameter ranged between 3.7 m and 5.2 m in the 1898-1909 period. It is likely that such large snags had significant geomorphic effects such as retaining and sorting sediment and scouring pools. The very large number of pieces would also have significantly affected stream productivity and the organic matter budget. Debris transported in floods also tended to plug distributary channels, especially in the South Fork. By the turn of the century, streamside forests were logged

along the two forks and along the mainstem as far upstream as the Sauk River, and snagging continued into the last few decades of this century, together effecting a century-long reduction in the supply of woodv debris from streamside forests and the amount of in-channel debris.

Diking of the sloughs on Fir Island is responsible for the greatest loss of distributary channel area. Dikes have closed the upstream and downstream ends of Hall, Brown, and Dry Sloughs—the sloughs which cross Fir Island—and eliminated flow through them. Dikes also closed off a smaller area of sloughs in the South Fork, including Wiley Slough. On the other hand, delta progradation and marsh development have increased the area of the North Fork and South Fork and smaller distributary channels associated with both. While the spatial distribution shifted, the overall area of distributary channels remained roughly constant from 1889 (the date of the earliest reliable mapping, by the U.S. Coast & Geodetic Survey) to 1991. There was an overall loss within the landward estuarine-emergent-forest transition zone ("transition zone") and a gain in the bayward estuarine emergent zone. Distributary channel area is not presumed to have changed in the first few decades of settlement prior to 1889, because no sloughs had yet been closed to dikes.

Between about 1860 and 1889, roughly two-thirds of blind-tidal channel area was cut off from tidal influence as much of the estuarine emergent zone and the transition zone were diked and converted to agricultural use. The pre-diking extent of the estuarine emergent zone and the transition zone were estimated from several sources, predominantly information on vegetation found in field notes of surveyors under contract to the General Land Office in the late 1860s and early 1870s, and from U.S. Coast & Geodetic Survey mapping. Blind tidal channels continued to be cut off from tidal flow as diking continued after 1889 and as tidal marsh has eroded between the North and South forks, presumably because of the loss of sediment from Brown, Dry and Hall slough systems. On the other hand, there has been significant accretion—and gains in area of blind tidal channels—in both forks since 1889. In the South Fork, most accretion occurred earlier (prior to 1937, when the first aerial photos are available) in the South Fork, and later (since 1937) in the North Fork. This may reflect an increase in flow from the South to the North forks at about the turn of the century. The total area of blind tidal channels is roughly half of the estimated area before diking. There were also substantial losses in the north-adjoining Sullivan Slough area and to the south of Fir Island; these were not quantified for this report. Most losses have been from the transition zone, and most gains in the estuarine emergent zone, which is important to the extent to which blind channels serve different, potentially limiting, habitat functions in the two zones.

Because of the large loss to the area of blind tidal channels, there is a great potential to restore the quantity of physical salmonid habitat by restoring these tidal channels, which are predominantly in the transition zone. Restoration opportunities include allowing tidal channels to redevelop in diked-off areas by reopening these areas to tidal influence. It is also possible that restoring the supply of sediment to the marsh on the delta front (i.e. between the two forks) would allow now-eroding saltmarsh in the estuarine emergent zone to rebuild. There is also a large potential to restore habitat quantity by restoring flow to those distributary sloughs that were blocked by dikes—the interior sloughs on Fir Islands, and sloughs in the deltas of the North and South forks. Opportunities to restore the quality of habitat include increasing the supply of large woodv debris.

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CHAPTER 1: INTRODUCTION

Objectives of the Study

The Skagit River drains 8.270 km^2 of mountainous terrain in British Columbia and Washington's northwest Cascade Range as it descends to its delta in the Puget Lowland. Downstream of the town of Mount Vernon, about 15 river kilometers from the river's mouth, the river splits into two major distributary channels, the North Fork and South Fork, which delineate Fir Island. This investigation concentrates on the North and South forks, smaller distributary channels that bisect Fir Island, and the blind channels that exist in tidallv influenced wetlands. The objective is to describe historic channel conditions and processes (prior to European settlement in the mid-19th century) and to describe how land uses and river engineering in the succeeding ~140 years have changed conditions. The report also quantifies changes in certain vegetation zones on the delta. The Skagit System Coop plans to use this information to characterize and quantify historic and existing salmonid habitat in these estuarine channels, and to assess the feasibility and relative value of restoring habitat that has been lost historically to land uses and channel modifications.

Geomorphic and Hydrologic Context

The Skagit River has built an extensive delta in the Holocene (post-glacial) period (Figure 1). Immediately following glaciation, it is likely that glacial-era sediments in the drainage basin eroded rapidly (Church and Slaymaker, 1989; Benda et al., 1991) and deltaic sedimentation and progradation were also rapid. Deposits from the Glacier Peak volcano probably also account for a portion of the deltaic sediments. Volcanic events have occurred at Glacier Peak at least nine times within the past 5,500 years (Beget, 1982). Ten kilometers east of Sedro Woolley an alluvial terrace contains volcanic sands and charcoal related to laharic deposits from Glacier Peak, dating to 4,800 YBP (Pessi et al., 1989) and an alluvial terrace 5-10 m above the floodplain near Sterling (immediately upstream of Burlington; see Figure 1) has been aged at 1,800 YBP.

Fir Island is a relatively small portion of the river's geomorphic delta. In this report, "Skagit River delta" refers to the entire geomorphic delta shown in Figure 1. It is likely that the lower Skagit River formerly flowed through the Olympia Marsh area into the Samish River valley and Samish Bay and more recently westward from Avon and into Padilla Bay (Figure 1). This latter speculation is supported by the observations of early river surveys, which indicated the presence in 1874 of what appeared to be a series of linked beaver ponds in a former course of the Skagit River, westward from Avon (Annual Report of the Chief of Engineers (herein abbreviated ARCE), 1874]. During the largest recorded floods, when the river overtops or breaks through its dikes, Skagit River water floods over its entire delta.

Floods occur in response to heavy winter rains, especially in combination with melting snow. High flows also occur during spring snowmelt runoff; the highest average monthly discharge is in June and the second highest is in November (see Appendix 3). The Skagit River in 1980-1991 transported 1.7x lO^6 t/yr of suspended sediment (see Appendix 3). This represents a specific yield of 200 t/km^2, or roughly twice that of the adjacent Fraser River. The river formerly transported vast amounts of large woody debris (see the following section of this report).

Terminology

In this report "blind" channels refer to channels that are formed by, and drain, tidally-introduced water rather than runoff from associated wetlands and uplands (Simenstad, 1983). These channels have also been called branching dead-end channel networks (Ashley and Zeff, 1988) and tidal creeks (e.g., Pethick, 1992). We subdivide tidal marshes into the seaward "estuarine emergent zone" and the landward "emergent-forest transition zone," which is in turn seaward of the "forested wetland" and "upland forest" zones (Hayman et al., 1996). The estuarine emergent zone is dominantly saltmarsh. The estuarine emergent-forest transition zone (abbreviated in this report as the "transition zone") is a mosaic of tidally influenced emergent marsh and scrub shrub habitats. It encompasses the transition from forest-dominated freshwater wetlands and uplands to saltwater-dominated estuarine emergent marsh. Forested wetland is dominated by palustrine and riverine forests. The mudflat zone is seaward of the estuarine emergent zone; the zone also includes estuarine open water, eelgrass, and low saltmarsh patches.

CHAPTER 2: MID-19th-CENTURY FLOODPLAIN AND CHANNEL CONDITIONS

Hydrographic Context of the Skagit Delta

In the early 1870s, prior to widespread influences by settlers, the federal government's General Land Office accomplished the earliest detailed mapping of the Skagit River delta. The mapping does not necessarily show all hydrographic features, because the purpose of the mapping was to define legal boundaries rather than to accomplish detailed land mapping.[1] However, the maps are useful for showing the majority of channels and wetlands. These maps and other information are compiled in Figure 1. The river emerges from its valley bottom at a constriction roughly one kilometer wide at the town of Sedro Woollev, and then diverges during floods, sending floodwaters to Samish Bay, Padilla Bay, and Skagit Bay (Figure 1).

Floodwaters exit through the Olympia Marsh into Samish and Padilla bays (Figure 1). The marsh is shown by land survey maps to encompass about 28 km^2 (2800 ha) in area, although another estimate of the area made in the early 1880s (by Morse, in Nesbit, 1885) is considerably larger (61 km^2). (Historic vegetation notes, which could help to refine boundaries of Olympia Marsh and other features, were not examined for this study, except for Fir Island.) The marsh in turn drained to Samish Bay by the Samish River and Padilla Bay by the Joe Leary Slough. Morse (in Nesbit, 1885) speculated that the Skagit River at an earlier time had a main distributary in the drainage of the Samish River.

Early maps suggest that at the time of first European settlement, perhaps an even greater amount of flood-water flowed to Padilla Bay, exiting from the right-bank side of the Skagit River between Avon Bend and Skagit City (near the junction of the North and South forks; Figure 1). Land survey mapping indicates that the Skagit River flowed to Padilla Bay via an extensive system of wetlands (Figure 1). These wetlands were probably created by beaver dams in channels formerly used by the Skagit River. This inference is supported by the observations of a federal engineer in an 1872 examination of the river; the engineer described the flow course from Avon Bend to Padilla Bay as an old channel which was then a series of linked beaver ponds. He also speculated that the main flow of the Skagit had recently been into Padilla Bav (ARCE. 1881).[2] This interpretation is also supported by relict channels having a comparable width to the mainstem Skagit River, in the area between Avon and the tidal marshes that drain to the Swinomish Slough and Padilla Bay, as visible on aerial photos from 1937 and on l:24,000-scale topographic maps.

There was a large (nearly a mile in length) and persistent complex of logjams in the Skagit River near the town of Mount Vernon (ARCE, 1898;[3] Figure 1). The backwater effect of these jams forced floodwaters to the Olympia Marsh and Beaver Marsh areas, and thus to Samish and Padilla bays. Contemporary accounts indicate that later removal of these jams rerouted floodwaters. After the jams were removed, there was more flooding in the downstream Fir Island area, and less in the upstream Olympia Marsh area.[4]

Sullivan Slough was the functional equivalent of a major distributary of the Skagit River. While in the mid-19th century it no longer existed as a defined perennial channel connected to the river, it was still a primary outlet for the floodwaters that traveled along relict Skagit River channels and linked beaver dams of the marshes on the present-day Skagit Flats. Originally called the "Swoolamish River", according to Eldridge

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[1]This assumption is confirmed by contemporary reports: "The Skagit River delta...is divided by numerous sloughs and channels, only a portion of which are laid down on the plots of the United States government land surveys" (Morse, in Nesbit, 1885, p. 109).

[2] "...I saw indications that the former at one time flowed into Padilla Bay... the old channel being easily traced, traversed by numerous beaver dams, doubtless the principal cause of the diversion into its present course" (ARCE, 1880). Morse (in Nesbit, 1885) also indicated in the early 1880s that the Skagit overflowed into this area frequently enough to limit successful cultivation.

[3] "Prior to 1879 a log jam, which was nearly a mile in length and almost completely covered the river, existed near where the present town of Mount Vernon is located....The obstruction caused by this jam to the free flow of the flood waters prevented the low lands farther down the river from being flooded, but it caused the flooding of the entire country known as the Olympia and Beaver Marsh country, to the west of the Skagit River, between the present location of the town of Avon and Padilla Bay" (ARCE, 1897).

[4] "Before the jams of drift wood were cut through, the snow floods generally escaped through the sloughs and low places on the river banks, overflowing the flats to a depth of 1 or two feet. This has not occurred since their removal, although the snow flood of 1880 rose higher than any within the memory of the settlers" (ARCE, 1880).

Morse (p. 69 in Nesbit, 1885), at high tide Sullivan Slough "appeared to be larger than any river on the sound."

The Skagit River's distributary flow was apportioned differently in the early 1870s compared to the 1990s. The South Fork was the greater channel and the North Fork the lesser one, opposite to now. Mapping shows that Brown's Slough and especially Dry Slough, which bisect Fir Island, were major distributaries (Figure 1). Both are now cut off to flow at both ends.

More than half of the freshwater wetland in the Skagit delta may have lacked a dense tree cover. According to Morse, 25,000 of an estimated 40,000 acres of freshwater marsh (see footnote 6) were "free from timber." He also indicated that the freshwater marsh did not differ in character from saltmarsh as much as one area of saltmarsh differed from another, except for freshwater marsh having a greater percentage of peat. Parts of the delta that were not perennially wet, according to a description in 1880, were covered "with dense forests, principally of fir, cedar, cottonwood and spruce, alder and ash abounding in the river bottoms, and cottonwood along its banks.[5]

In summary. the majority of the Skagit River delta was perennially wet in pre-settlement times. Keeping in mind that the available mapping underestimates freshwater wetlands, and that the extent of salt water marsh is approximate and may be underestimated, freshwater wetlands account for 22% (64 km^2) and saltmarsh for 27% (78 km^2) of the total area of 289 km^2. Freshwater channels and saltwater sloughs account for 2.6% and 1.4% of area, respectively. Areas not mapped as water account for 47% (136 km^2).[6] This contrasts with contemporary conditions (Figure 2), where freshwater wetlands, saltmarsh, and distributary channels account for a small portion of the Skagit River's delta.

[5] The description also indicated that "about one-fourth of the level land consists of grass meadows and beaver marsh, easily drained and cleared for cultivation" (ARCE, 1881).

[6] Contemporary estimates by Eldridge Morse differ considerably. For example, he estimates there are "over 40,000 acres" (162 km^2) of fresh water marsh on the Skagit delta, about 2.5 times more than the 64 km^2 measured from the GLO maps. He also estimates 32,000 acres (130 km^2) salt water marsh in Skagit County, also about 1.7 times more than measured.

Figure 1 (facing page). Preliminary sketch map of streams and wetlands on the Skagit River delta in the early 1870s, prior to widespread European settlement. Channels are drawn from land survey maps by the federal General Land Office (GLO). Date of survey for individual townships ranged from 1866 to 1874. The location of the Mt. Vernon log jam is from GLO mapping. Fresh-water wetlands are as shown on the GLO maps; note that some boundaries are incomplete, and significant amount of marsh area may not have been shown on the maps. The inner boundary of the combined estuarine emergent zone and transition zone (identified as "saltmarsh" in the map legend) is largely estimated. In the Samish River area the boundary is taken from vegetation boundary lines indicated on GLO maps, which coincide with the limit of non-forested area shown on 1887 mapping by the U.S. Coast and Geodetic Survey (USC&GS). The limit of cultivated area shown on 1889 USC&GS mapping was also used to estimate the landward boundary of the transition zone on Fir Island. The boundary on the Swinomish Flats was estimated from a combination of partial vegetation boundary lines indicated on GLO maps, and the extent of tidal sloughs. Based on analysis of field notes from the GLO surveys, it is likely that the boundaries drawn on the basis of areas that were cultivated at the time of the USC&GS mapping underestimates the area of the estuarine emergent and transition zones.

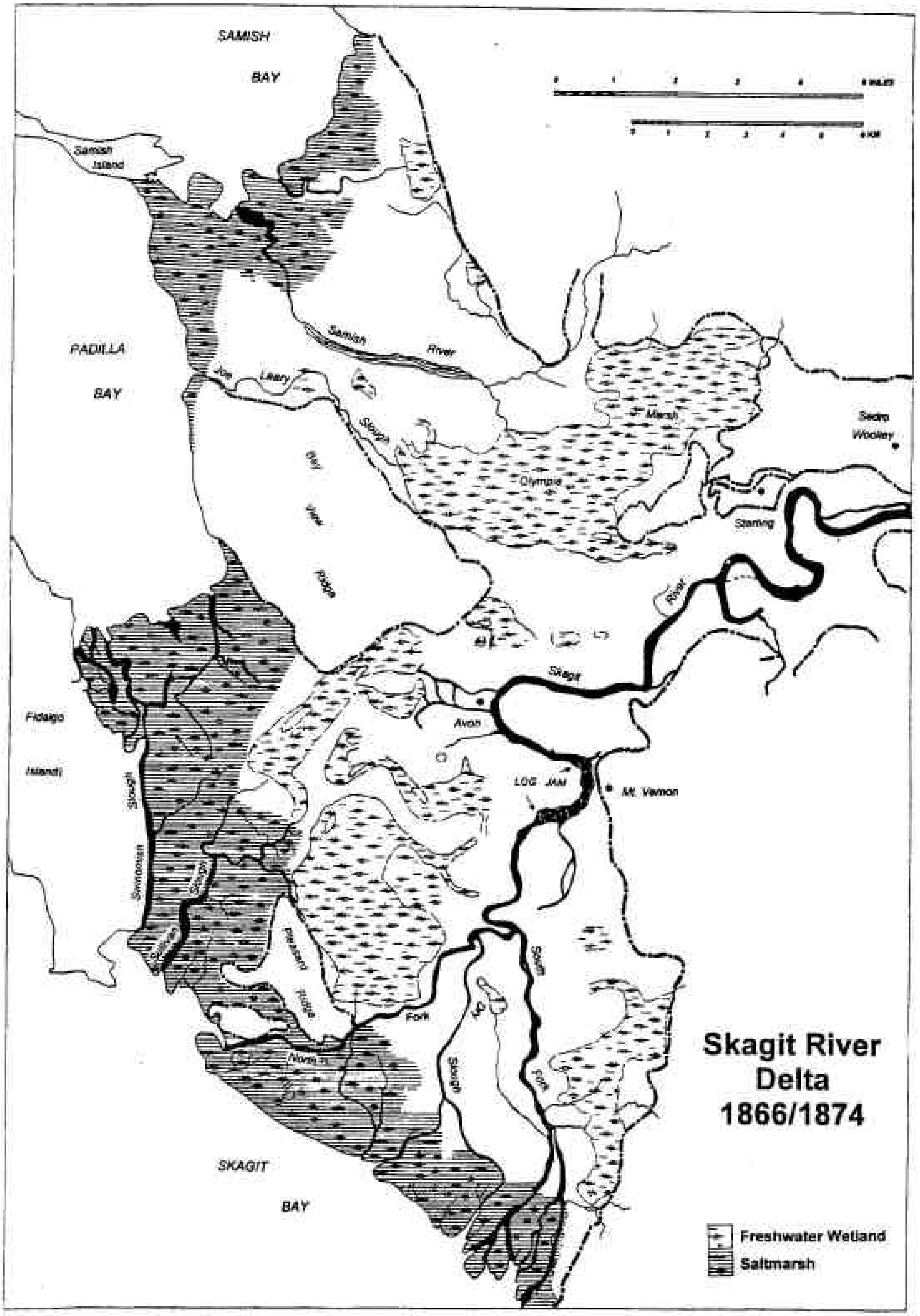
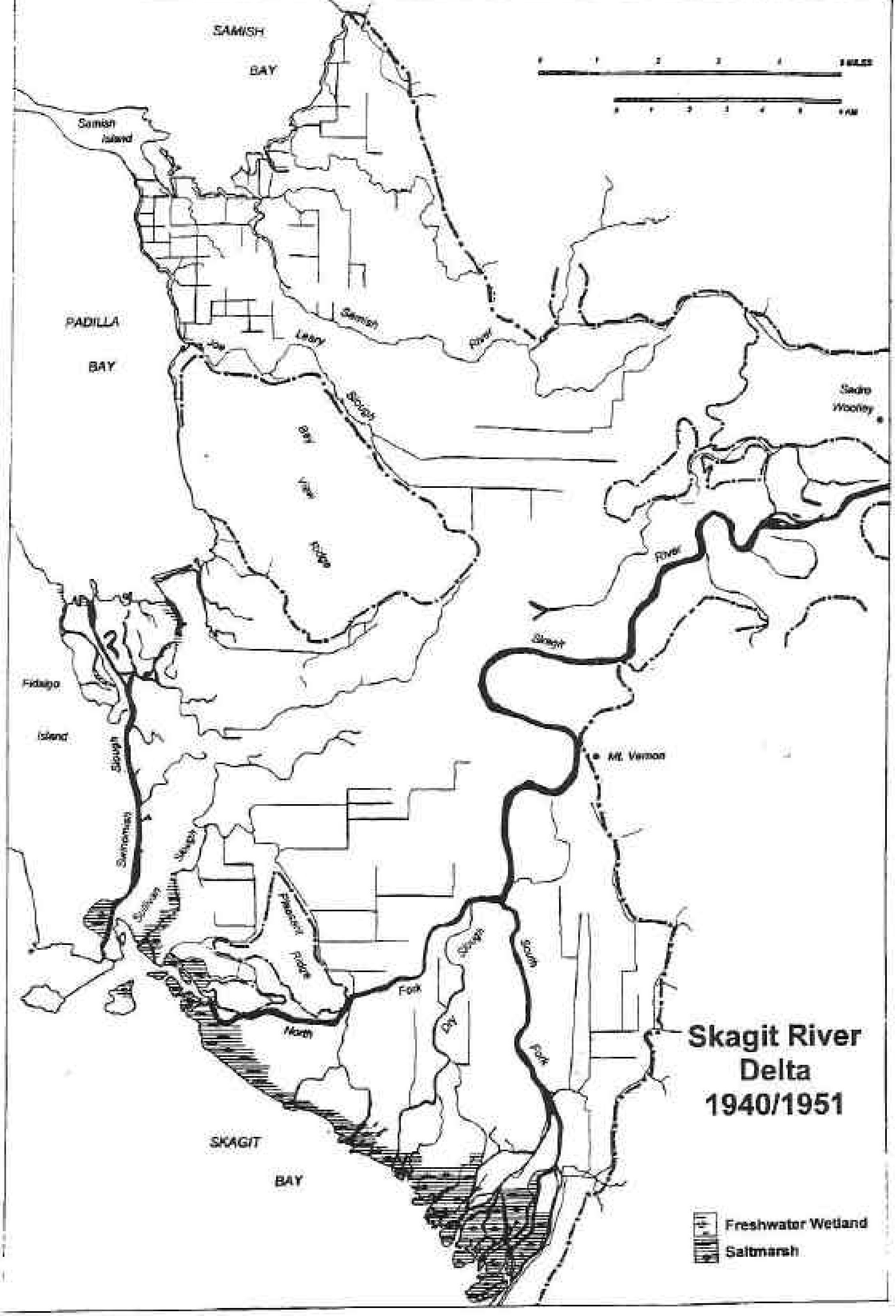

SAMISH
BAY
Samish Island
PADILLA
BAY
Joe Leary Slough
Samish River
Marsh
Olympia
Sedro Woolley
Sterling
River
Skagit
Avon
LOG JAM
Mt. Vernon
Fidalgo
Island
Swinomish Slough
Pleasant Ridge
Fork
North
Slough
Fork
SKAGIT
BAY
Skagit River Delta 1866/1874
Freshwater Wetland
Saltmarsh

Figure 2 (facing page). Stream channels and marshes on the Skagit River delta in the mid 20th century. Information is from U.S. Geological Survey 15' topographic maps from 1940 (Mt. Vernon Quadrangle, south of 48° 30', or roughly south of Sedro Woolley) or 1951 (Samish Lake Quadrangle, north of 48° 30').



Skagit River Delta 1940/1951

Historic Vegetation Zones of Fir Island

This report delineates broad historic vegetation zones, because such vegetation zones are useful for estimating the historic areas of different channel types. For example, delineating the areas of emergent marsh vegetation, and the areas of emergent-forest transition provide an index of the amount of blind tidal channels in each zone.

Wetlands included areas typically described as "prairie" by federal land surveyors and by other contemporary visitors (Morse, in Nesbit, 1885). We take these areas to correspond to areas we classify in this study as estuarine emergent marsh. As evidence for this, field notes from the land surveys in the late 1860s and early 1870s indicate extensive areas lacking any trees suitable for marking land boundaries (Figure 3). We draw the landward boundary of the estuarine emergent marsh zone primarily on this evidence.

A different line of evidence was used to delineate the landward limit of the emergent forest zone transition (i.e., the boundary between the transition zone, and the forested wetland or upland forest zones). Mapping by the USC&GS indicates a boundary between cultivated fields and forest in 1889 (see Figure 3). It is reasonable to assume that the first areas cleared for cultivation (i.e., prior to 1889) are probably within the transition zone areas, because these sparsely-vegetated areas would be easiest to clear of trees. Analysis of the trees noted by government surveyors does indicate a marked difference in the density of trees above and below this boundary. Table 1 shows the average distance a surveyor measured to a tree used in marking a legal boundary, which we take as an index of the tree spacing.[7] Landward of the vegetation boundary on the USC&GS mapping, the average distance to a noted tree (prior to any land clearing) was 20.1 ft, while seaward of this boundary the distance was 81.7 ft.

[7]This index is different than the actual tree spacing, which could be determined by use of bearings given in the notes. However, this would be misleading, because the criteria used by surveyors to choose trees is not known, but it was probably not systematic in a way that would allow an estimate of forest density.

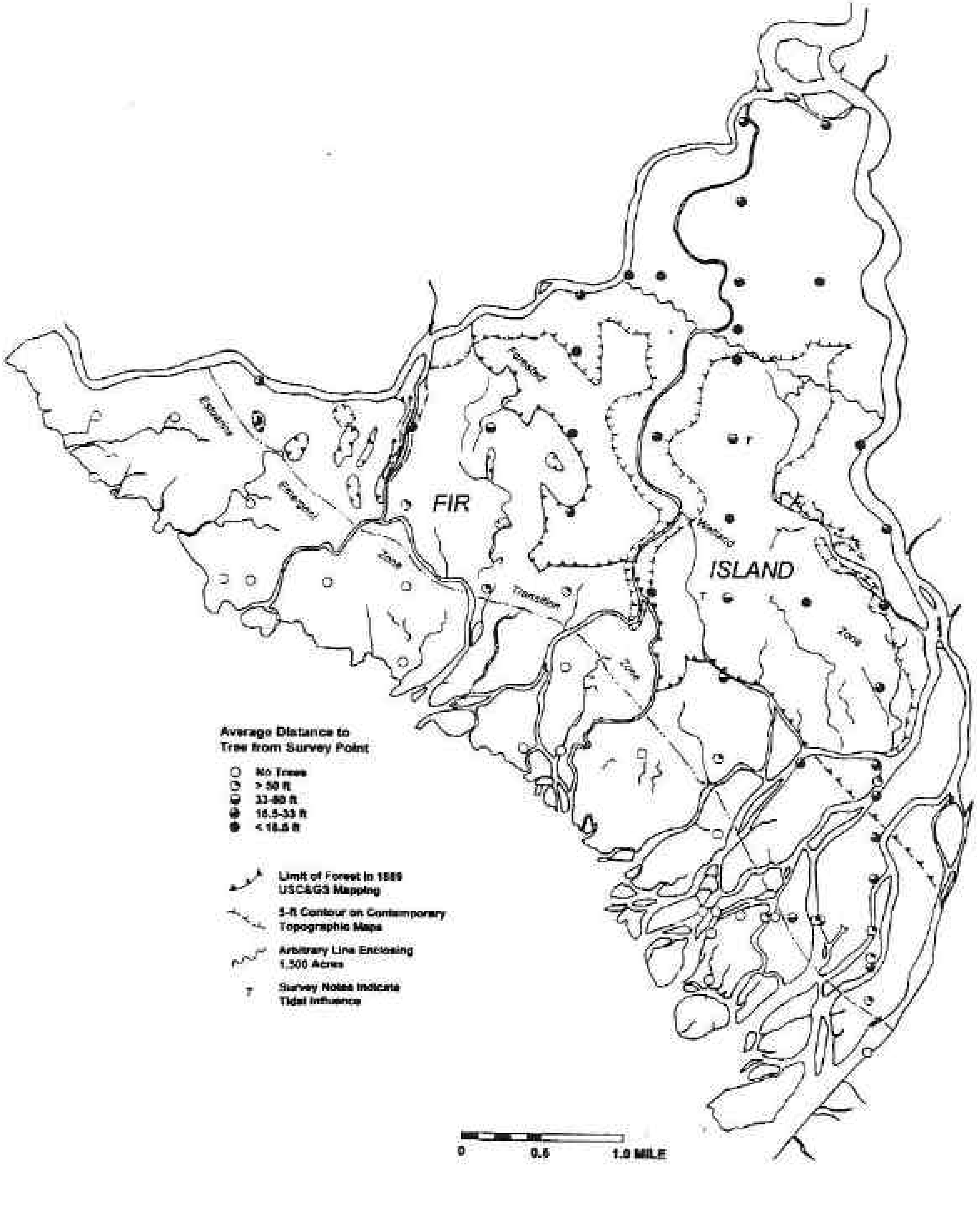


Figure 3. Evidence used to estimate boundaries of pre-settlement estuarine emergent zone and transition zone vegetation on Fir Island.

Table 1. Trees described by land surveyors in the 1850s to early 1870s, prior to widespread diking or land clearing on Fir Island. The table shows the average distance a surveyor measured to a given tree; this is assumed in this report to give a rough index of the general spacing of trees. Also shown is the average diameter of trees; the height at which tree diameter was measured is not known.

Area	Average Distance to Tree (ft)	Average Tree Diameter (inches)	Percent Spruce	Number of Trees in Sample
Landward of Arbitrary 1,500 Acre Line	17.9	17.2	43.5	23
Landward of USC&GS Map Forest Limit	20.1	15.9	32.9	73
Seaward of USC&GS Map Forest Limit	81.7	9.0	31.3	48
Landward of 5 ft Contour	19.1	17.2	30.0	50
Seaward of 5 ft Contour	62.4	10.3	33.8	71
Fir Island Total	**44.9**	**13.1**	**32.2**	**121**

Spruces were the largest trees (Figure 5), and they were also the second most common tree identified in surveyor's notes (Figure 4) on Fir Island. Spruce accounted for 32% of trees identified in land survey notes, second only to alder, which accounted for 38%. However, given that spruce trees were much larger than other species, it seems likely that the number of spruces singled out by surveyors is disproportionate to their actual occurrence, so that their actual frequency would have been smaller than 32%. Crabapple and willow together account for an additional 21%. Interestingly, surveyors notes do not include reference to firs on Fir Island.

Elevation might also be useful as an indicator of the upper limit of the emergent forested transition zone. A study of three tidal marshes on coastal Oregon found the upper limit of transition zone at 1.9 ft above MHW, or 5.1 ft elevation NGVD (Frenkel et al., 1981). This agrees well with the upper limit of marsh on Ebey Slough in the Snohomish River delta (in Puget Sound to the south of the Skagit River) of 1.7 ft above MHW (U.S. Department of Commerce NOAA-NOS, 1975, in Frenkel et al., 1981). If the Ebey Slough marsh data is assumed to approximate marsh conditions in the Skagit delta, then the upper limit of the

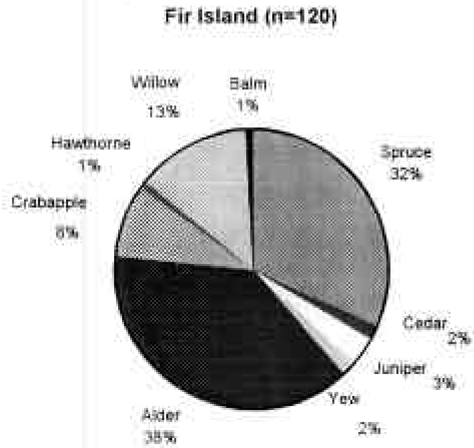


Figure 4. Abundance of tree species in surveyors notes from Fir Island. Sample represents the trees chosen by surveyors for use in locating property boundary markers, and is not a random sample.

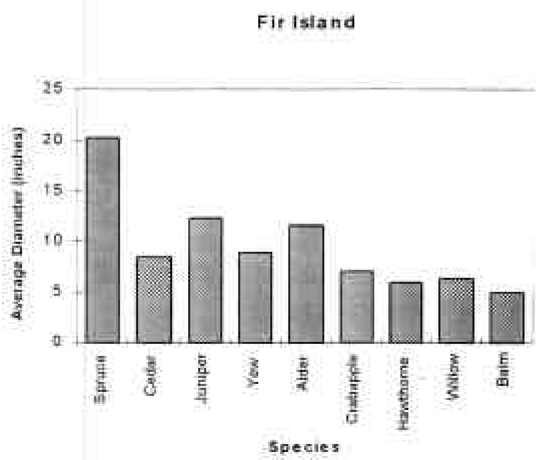


Figure 5. Average diameter of tree species in surveyors notes from Fir Island. The height at which trees were measured is not known.

transition zone would be about 6.3 ft elevation NGVD (using MHW of 4.6 ft NGVD from Ponnell Point). Modern topographic maps indicate a 5 ft contour, which is close to the 6.3 ft elevation, which could make it an approximate indicator of the historic upper limit of the transition zone. However, the modern 5-ft-contour on Fir Island does not accurately represent conditions more than 100 years ago, because there has likely been significant subsidence in the intervening time resulting from diking and draining of the delta. For example, in the Salmon River estuary of coastal Oregon, marshland had subsided by 14 inches in over 17 years after having been diked (Frenkel and Morlan, 1991). Assuming that Fir Island has subsided at least this much in the past century, use of the modern 5-ft contour would overestimate the historic area of the transition zone. However, while unsatisfactory as an indicator of the historic upper limit of marshland, the modern 5-ft contour is informative because it indicates the presence of natural levees along the two forks and Drv Slough. It is likely that these levees significantly influenced the upper limit of the transition zone, as a secondary effect to the generalized landward limit indicated by the forest edge on the USC&GS mapping.

Relict blind tidal channels evident on the earliest known aerial photos from 1937 (or ~50 yr after the original diking) represent a third line of evidence useful in estimating the upper limit of the transition zone. As indicated on Figure 3, these channels penetrate into the forested area indicated on the USC&GS map. Based on observations of contemporary tidal marshes in western Washington, it seems likely that this indicates that narrow bands of tidal marsh vegetation extended landward of the generalized forest boundary along some blind tidal channels, an effect that is not reflected by the generalized boundary on Figure 3.

A final piece of information relevant to delineating the historic upper limit of saltmarsh is the contemporary description by Eldridge Morse that Fir Island had 4,500 acres (18 km^2) of "brush and spruce tide marsh," 4,500 acres "open tide marsh prairie," and 1,500 acres of "ordinary bottom land." It is reasonable to assume that these descriptions correspond roughly to the estuarine emergent, emergent-forest transition, and upland forest vegetation zones used in this study. Drawing an arbitrary line to delineate 1,500 acres at the upper end of Fir Island (Figure 3) indicates the possible extent of tidal marsh according to Morse's estimate. The line is significantly landward of the line suggested by the forest edge on the USC&GS survey map. Evidence supporting this larger limit to the transition zone is that it includes the upper limit of what appears to be an extensive relict tidal slough near the South Fork (Figure 3). However, there is not independent evidence to confirm the accuracy of Morse,s estimates, and his other estimates do not necessarily square with independent observations (e.g., see footnote 6).

Taking all of this evidence into account, the edge of forest on the 1889 USC&GS map is the most objective evidence for delineating the upper limit of the transition zone. It probably represents a conservative estimate of the landward extent of the transition zone (ie., it underestimates its extent) on Fir Island. It is generalized: the line probably followed somewhat more than as shown the contours of the natural levees of distributary channels, and also probably extended landward in narrow fingers along major blind tidal channels. Landward of this line it appears likely that vegetation was predominantly a forested wetland in which fresh-water levels were influenced by tides, and also mixed with salt water during the highest tides. Blomberg et al. (1988) interpret similarly-situated areas (e.g., landward of areas shown as marsh by USC&GS mapping) on an 1854 map of the Duwamish River estuary as "tidal swamps.[8]"

If the Morse estimates are accurate, it is possible that he included such tidal swamps (e.g. forested wetlands influenced bv but not dominated by tidal action) in his estimate of the "brush and spruce tide marsh" as distinct from the landward "ordinary river bottom," but this is speculative. However, land survey notes indicate the presence of a tidal influence in this area between the USC&GS forest boundary and the arbitrarilv-drawn limit from Eldridge Morse's estimates (Figure 3). This supports the assumption that this area mav have consisted of tidally-influenced forest wetlands, possibly equivalent to the "tidal swamps" of Blomberg et al. (1988). As previously indicated, it is also likely that this area of tidally-influenced forest wetlands included fingers of tidally-dominated marsh along large blind tidal channels.

[8] Blomberg et al. (1988) define tidal swamps as "wetlands comprised by shrub and forest vegetation and extending landward to the line of non-aquatic vegetation. Tidal swamps are generally inundated by spnng tides, yet may extend waterward in some areas to MHHW."

Log Jams and Large Woody Debris

Woody debris and jams were integral aspects of the hydrologic and geomorphic function of the lower Skagit River. There were large channel-blocking logjams on many North American rivers (e.g., Sedell and Luchessa, 1981; Triska, 1984; Sedell et al. 1982), and such floating "raft" jams, as they were termed, appear to have been a significant influence on the lower Skagit. Federal engineers described these raft jams on the Skagit River mainstem in October 1874 (ARCE, 1874). A lower jam at the forks, near Skagit City. was three-quarters of a mile long, and filled the channel from the bed to the banks. The second jam was about a mile upstream at the town of Mount Vernon (Figure 1), was divided into a lower and upper portion, and was "about 4,000 feet long and 1,000 feet wide" (ARCE, 1874).[9] According to early accounts, these jams caused the river to overflow its banks annually, "flooding 150 square miles" (ARCE, 1881).

The Mount Vernon Jam appears to have existed for at least a century: its surface supported live trees two to three feet in diameter.[10] The jam was described as 30 feet deep, consisting of "from five to eight tiers of logs, which generally ranged from three to eight feet in diameter" (Interstate Publishing Company, 1906). There appear to be numerous jams elsewhere on the North and South forks and the distributary sloughs of the South Fork, although it is unclear whether they were as persistent as the Mount Vernon jams. According to Morse, "the Skagit has suffered more from jams than any or all other Puget Sound streams" (p. 76, Morse, in Nesbit, 1885). He indicated that all of the South Fork's distributary sloughs were filled with jams: "only one small channel can now be navigated by steamers, the others being stopped with drift...the

[9] "The lower jam, at the time of this examination, was found to be about 1,700 feet long and 460 feet wide. Its dimensions vary, however, from year to year, by portions being detached during freshets from its lower end, while at the same time receiving additions from above. It rises and falls with the tide, being apparently held only by the banks, and causes, during high-water, an overflow of a considerable part of the adjoining valley." (ARCE, 1874). Another account indicates the lower part of the Mount Vernon jam was "perhaps half a mile" in length and of "comparatively recent formation." By this account, the upper jam in the Mount Vernon complex began about a half mile above the lower jam, and extended "about a mile," and was "believed to be at least a century old" (p. 113, Interstate Publishing Company, 1906).

[10] A pioneer had "learned from the Indians that the big jam had been in existence from time immemorial. So solidly was this jam packed that it could be crossed at almost any point, and upon it had grown a... forest, in some instances of trees of even two or three feet in diameter." Underneath the jam was in some places "furious cataracts," and in others "deep black pools filled with fish." (p. 106, Interstate Publishing Company, 1906). The river was as deep as 24 feet below the jam at the lowest water stage (p. 113).

largest is filled from bank to bank for 3 miles." He also indicated that a jam extended across the head of the North Fork. One function of these jams was to route water and sediment to the Skagit River floodplain. Removing the jams increased the routing of water and sediment downstream to Fir Island and the Skagit Bay mudflats (see later in this section of the report).

There was a tremendous number of fallen trees in the lower Skagit River and transported into the estuary. There are no quantitative estimates available of the quantity or characteristics of woody debris prior to any land use modifications. However, the following section of the report provides quantitative estimates based on conditions described in the first few decades following the onset of land clearing and logging.

CHAPTER 3: MODIFICATIONS TO FLOODPLAINS AND CHANNELS

Early Modifications: ~I860 to ~1910

The following discussion considers how land uses following the arrival of settlers on Fir Island have affected various aspects of the function or structure of the channel network. The chapter concludes with a summary of how these changes may have affected salmonid habitat.

Removal of Raft Jams and Snagging Operations

Settlers in northern Puget Sound requested government assistance in removing major river-blocking jams which were significant barriers to upriver settlement and navigation. The federal government removed a blocking jam on the Nooksack River near Lynden,[11] but settlers removed the principal blocking jams on the Skagit and Stillaguamish rivers without government assistance. In 1877-1879, settlers removed the Mount Vernon raft jam (Figure 1) by removing "'key-logs" during low water (ARCE, 1881).[12] Clearing the jam reportedly increased the height of downstream floods on Fir Island (ARCE, 1898) but on the other hand, it reduced flooding in the vicinity of the jam, and facilitated settlers' efforts to drain valley bottom areas to the west of the jam.[13] Private individuals also cut through a raft that closed the North Fork, and removed other snags (ARCE, 1881).

[11]H. J. Swim, as Secretary of a citizen's meeting, spoke in 1884 of the need to remove the Nooksack River jam for commerce (ARCE, 1884). In 1888, the snag boat "Skagit" removed the jam.

[12] "In 1874 an examination of the river was made by Major Michler, Corps of Engineers, who recommended an appropriation for the removal of the raft. In 1877, nothing further having been done by the government, two men who had settled on the river lands above the rafts undertook to cut a steamboat channel through them with saws and axes, cutting loose the "key-logs" during low-water, leaving them to float off during floods. Assisted by occasional volunteers...the two originators of the project persevered in their work of hardship and danger for two years, until a passage wide enough for steamboats had been cut through; since which time those portions of the raft which were fast to the banks have floated off, leaving the channel clear." (ARCE, 1880)

[13] "Since the breaking up of the log jam and the construction of dikes in the river, confining the waters of the river and preventing them to a very great extent from spreading over the adjacent country, the floods in the lower river have naturally increased in height. The country to the west of Avon, however, has been to a very great extent reclaimed, and now contains many of the richest and most valuable farms in the State of Washington" (ARCE, 1897).

Early investigations in 1873 and 1880 by Army Engineers led to a recommendation that a snag boat be built to open the river for navigation (ARCE, 1880). On the basis of these initial examinations, the River and Harbor Act of August 2, 1882 authorized the Army Corps of Engineers to remove obstructions to navigation, which consisted in early decades primarily of pulling trees from the river bed ("snagging") and cutting streamside trees from the Skagit and several other Puget Sound rivers (the Nooksack, Stillaguamish, and Snohomish). The project's scope was expanded by the July 13, 1892 Rivers and Harbor Act, to include Puget Sound and its tributary waters (e.g., the Puyallup and Duwamish rivers). Puget Sound rivers have been snagged continuously since then until at least the 1970s under the 1892 authority.

The federal government began removing snags on the Skagit River in 1881 (ARCE, 1882). Because Congress had yet to appropriate funds for a snag boat, one was improvised. However, a larger boat designed for the purpose was necessary because snags were "...generally so large and so deeply embedded in the bottom as to require great power to remove them, while the current was so swift that small boats could be used only with great danger to life and to little purpose." Workers cut a channel 50 feet wide through a raft at the head of the North Fork and removed numerous snags and leaning trees. Several blocking accumulations of drift were not removed; Freshwater Slough and the Main River remained blocked (ARCE, 1881). Congress appropriated money for a snag boat in 1882 (ARCE, 1882), and the *Skagit* was built and outfitted in time to begin removing snags in 1886 (ARCE, 1885). It was later rebuilt in 1896 (ARCE, 1897).

Until the 1896-1897 fiscal year (ending June 30, 1897; subsequent references are to fiscal years), there were not sufficient appropriations for the boat to operate more than a small part of the year. This meant the boat could only remove "the worst obstructions which were in the actual steamboat channels and rendered navigation hazardous" (ARCE, 1898). An appropriation of June 3, 1896 was sufficient for the boat to operate throughout the year, and to rebuild the *Skagit*, whose hull had become rotten. Thus it is not likely that the rivers were thoroughly cleared of snags on an annual basis until the 1896-1897 operating year.

The steamboat *Skagit* was a 112-ft-long sternwheeler (ARCE, 1884). Leverage for pulling snags was provided by a large A-frame overhanging the bow. In March 1915, the snag boat *Swinomish* replaced the *Skagit*. In 1929 the *W. T. Preston* replaced the *Swinomish*; the work of the *Preston* was supplemented by the *Puget* beginning in 1972. On a few occasions in the first years of the program, a party in a small boat used dynamite to remove snags before the snag boat was available (ARCE, 1881; 1884) or when the boat was in need of repair (ARCE, 1896; 1897), or when the boat's lifting power was inadequate for lifting large snags (ARCE, 1895). In the first two decades of the program, snagging was generally in the fall months (ARCE, 1881-1896), and thereafter generally continuous throughout the year. In years with a protracted low-water season, snagging could be more thorough. For example, very low water during the fall of 1895 and the winter of 1896-1897 allowed for "unusually thorough" cleanings of the Skagit River in 1896 and 1897 (ARCE, 1896; 1897). During higher water, upper portions of the river only navigable under higher water could be snagged (e.g., ARCE, 1897).

The Skagit River was the most heavily and regularly snagged river. The Skagit was navigated through its south fork as far as Hamilton, and upriver to Lyman to tow log rafts, although it was possible for steamboats to ascend as far upriver as the Sauk River during high water (ARCE, 1899). Figure 6 shows the total number of snags removed from the Skagit River from 1881 to 1969. As indicated previously, limited snagging was done by improvised boat from 1881 to 1886; the snag boat was not used until 1886, and then only on a limited basis to 1896. The largest number of snags was removed in (fiscal year) 1898. This was the second year the boat operated full-time, and a very large flood on the Skagit occurred in November 1897.

After 1898, the rate of snagging declined. For three decades between 1910 and 1940, snagging totals were not reported for individual rivers and harbors. However, the trend for all Puget Sound rivers between 1910 and 1940 is a gradual decline (Collins, unpublished data), and it is reasonable to assume the Skagit followed this trend because it accounted for the largest number of snags removed from Puget Sound rivers: 63% of all snags removed between 1881 and 1909 were from the Skagit River. A total of more than 150,000 snags were removed from Puget Sound rivers between 1881 and 1969. Of this total, 35,000 were from the Skagit River between 1881 and 1910. In addition to the snags removed from river beds, nearly 10,000 trees were cut from banks from the same rivers between 1891 and 1969. Most of these (77%) were removed by 1910, with the Skagit River accounting for more than half (52%) of these.

Between 1889 and 1909, the captain of the snag boat kept records on the total length of debris, and also the largest and smallest snags and riparian trees, aggregated for all rivers. Figure 7 shows the maximum and minimum diameters of snags and streamside trees in this period. The maximum diameter was approximately constant from about 1898 to 1909, and ranged from 3.6 m to 5.3 m. The smallest snags removed were tvpicallv 6 inches (15 cm). Average snag length during this time period gradually declined from about 10 m to 5 m (Collins, unpublished data). This decline in length may reflect a depletion, with continued snagging, of younger pieces of large woody debris, and the increasingly importance proportionately of older pieces in the debris that was snagged; this interpretation is based on the observation that younger pieces of debris are longer than older pieces measured in summer 1998 in the Snohomish River (Collins and Haas, unpublished data). Some of the snags were stumps eroded from streambanks,[14] which may also account for some of the change in length. The size of trees available from the banks probably also decreased. The maximum diameter of the trees that were cut down annually increased from 0.8 m in 1891 to 4.2 m in 1900, after which it declined to about 1.2 m in 1909 (Figure 7). Tree length followed a similar pattern, increasing from about 10 m to about 30 m, and decreasing again to about 20 m. Presumably the decline in tree size reflects a depletion of large trees in the riparian area with continued cutting by the Army Corps and commercial logging.

[14] For example, the 1895 engineers report commented on the number of large stumps that tended to wedge into the riverbed of the Skagit River: "These giant [spruce and fir] stumps are often as much as 8 and 9 feet across the tops, with trunks of 10 to 12 feet, and a spread of large roots from 20 to 30 feet. They are constantly being washed from the banks by the currents at the times of freshets and deposited in the channel, where they at times set up as straight as they did in their native soil. In time their roots become embedded in the gravel and sand of the river's bottom, thus causing very dangerous obstructions." (ARCE, 1895)

These records of snag removal and tree cutting can provide some indication of the probable annual recruitment of large woody debris in the first few decades following the arrival of settlers. Snagging records from 1898-1909 provide the best estimate, from available data, of the average annual replenishment of snags by bank erosion and by transport from upstream. This is because this is the first decade when snagging can be assumed to have removed nearly all major snags in any given year, but prior to substantial reductions in recruitment. This assumption may underestimate the annual recruitment to the extent to which annual stream-cleaning was not complete, or overestimate it to the extent to which snags removed included older snags that lodged in the stream prior to the 1898-1909 period. It would also underestimate recruitment under pre-settlement conditions because recruitment was already substantially reduced by streamside logging. The riparian forest had been largely cleared by 1902 (Plummer, 1902), although it is unclear how thoroughly the riparian forest had been cleared.

The snagging records also must be spatially averaged over the entire navigable reach, even though this is not a good assumption, because snags were more concentrated in some reaches of the river than in others. In addition, a single decade is an inadequate and approximate characterization of a long-term average, as is made obvious by the inter-annual variation in snagging shown in Figure 6. However, keeping these caveats in mind, the rate of annual snagging can provide a minimum and approximate estimate of annual recruitment. The estimate is a minimum because it ignores pieces of debris that would be transported out of the river to Skagit Bay. The amount of debris that was transported out of the river during floods in a typical year was apparently great.[15] With these caveats in mind, the estimated recruitment is 49 pieces/river mile/year, and an additional 6 pieces/river mile/year when leaning trees are considered as individual pieces that would recruit, for a total of 55 pieces/river mile/year.

[15] "The amount of drift which floats down one of these rivers in a freshet is astonishing. It is not unusual, when a river is bank full and the current running 6 miles an hour, to see the channel covered with drift, and the flow kept up twenty-four hours with scarcely a break. Such a flow of drift may be repeated several times in a year on a stream like the Skagit or Snohomish" (Morse, in Nesbit, p. 76).

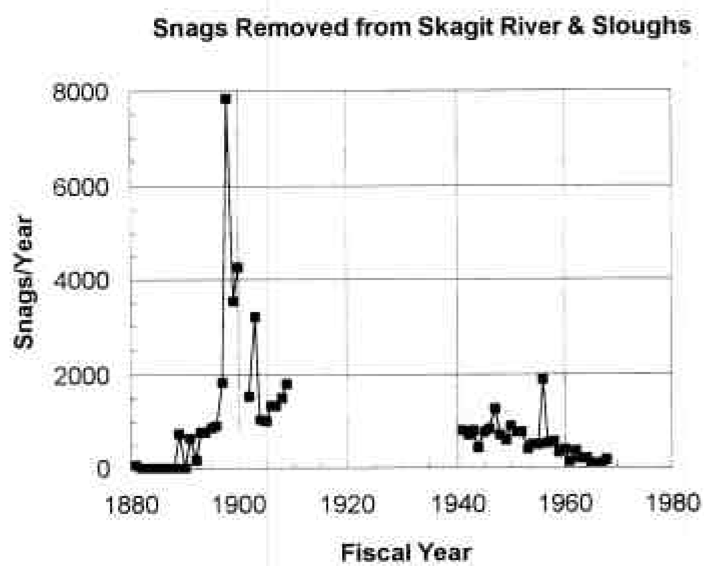


Figure 6. Snags removed from the Skagit River and sloughs. Records were not kept separately for individual rivers in the period between 1911 and 1939.

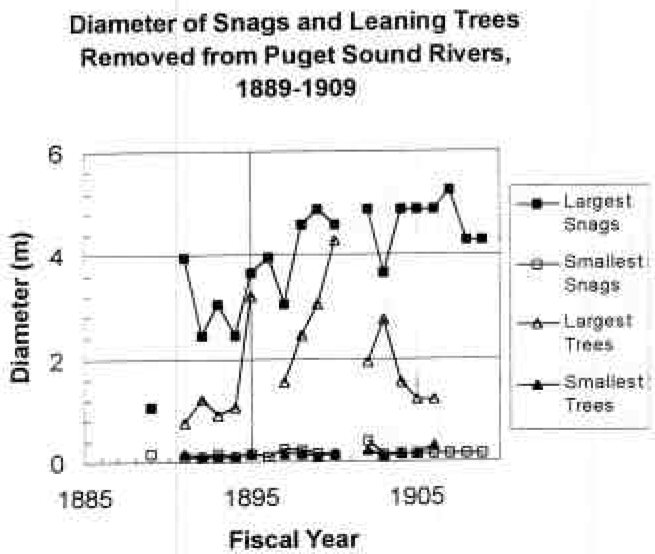


Figure 7. Diameter of snags removed from riverbeds, and leaning trees cut from streambanks, from Puget Lowland rivers, 1889-1909.

Diking, Ditching. Draining and Logging of Tide Lands

The first dikes to protect reclaimed farmland were built in 1863 in the Sullivan Slough area (Interstate Publishing Company, 1906). Early dikes on Fir Island were relatively low, because "the floods did not attain a great height in the lower river" (ARCE, 1898), presumably in part because of the effects of the Mount Vernon log jam and in part because of the vast amount of floodwater storage available on the Skagit River’s delta before the river was effectively diked.

By the end of the 1880s, most of the land currently under cultivation had been reclaimed and protected by sea dikes, according to the 1889 U.S. Coast & Geodetic Survey mapping. The dike system was improved and extended; the first county-sponsored diking districts were formed in 1888, and by 1895 the first state diking districts were created. However, a federal engineer writing in 1897 found that the system of dikes remained ineffective. Behind the dikes, saltmarsh and freshwater wetlands were ditched and drained, and plans were made for a big ditch from Mount Vernon to Skagit Bay to drain the flats to the east of the Skagit River, and to facilitate the transport of logs (Morse, in Nesbit, 1885).

Logging reportedly began on the lower river "as early as 1871" (Interstate Publishing Company, 1906). Widespread forest fires were common in western Washington in the time of early settlement, but there were reportedly no forest fires on Fir Island until after logging had proceeded for a number of years. The forest was resistant to fires because the timber was so dense that the forest did not become dry enough to burn until after logging created clearings and built up dead limbs on the ground.

River Engineering to Maintain Distributary Flows

Beginning around 1896, the South Fork began to shallow, and freight boats began to use the North Fork instead. Contemporary accounts dated the shoaling to a series of floods (ARCE, 1928). A federal engineer determined that while the booms may have aggravated the situation, shoaling would have occurred as a result of natural floods (ARCE, 1898). The engineer went on to indicate that an early settler had informed him that when he first arrived. Steamboat Slough was so small that only a rowboat could have been rowed through it. It did not appear that under natural conditions that more than any one slough was navigable at any one time. He was of the opinion that if all of the sloughs were opened up, "it would be but a short time before they would be closed up so that none of them would be navigable" (ARCE. 1898).

There was also contemporary speculation that log booms in the South Fork may have played a role in the shoaling. A boom company was organized and began commercial operations in 1882. Booms were moved from slough to slough in the South Fork, and in each case the sloughs became gradually obstructed to navigation. Booms were placed in Tom Moore Slough for two years, after which time the slough filled up. The boom was then moved to Freshwater Slough, and then to Log Slough. As each slough filled with drift, it became closed to navigation. By 1897, Steamboat Slough was the only slough open to navigation (ARCE. 1898).

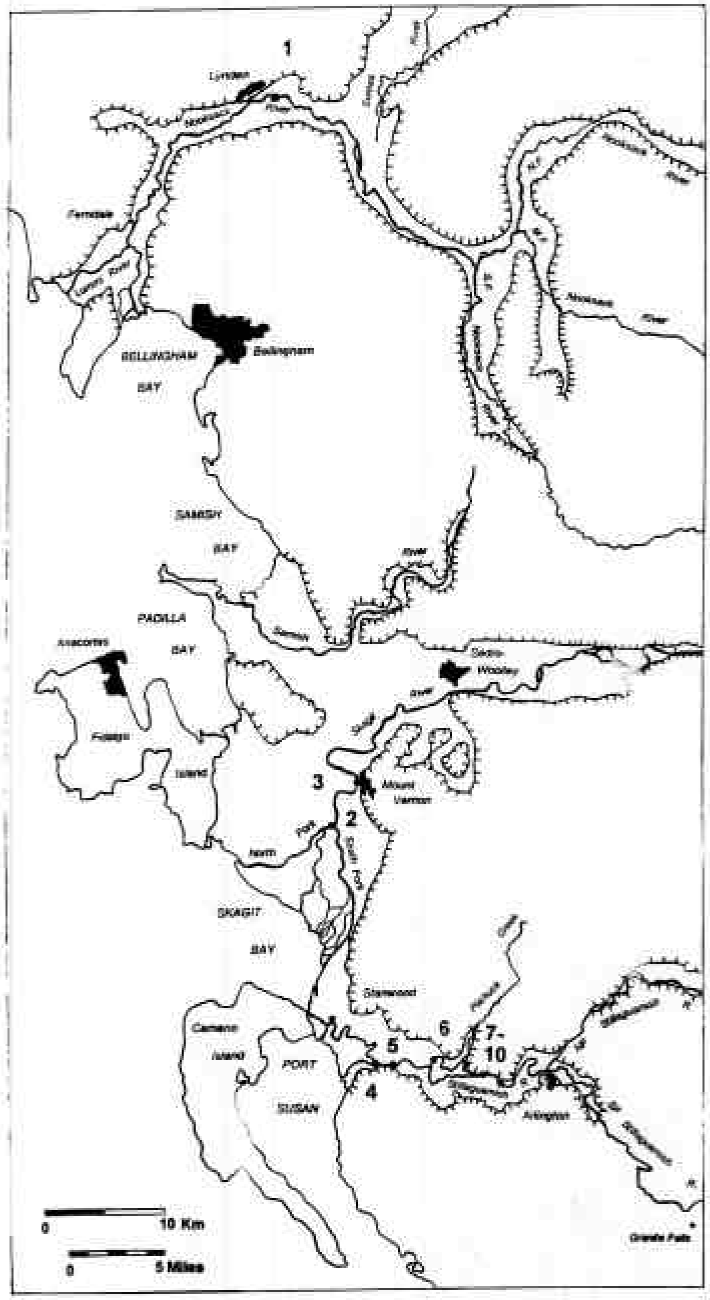
Whatever its cause, federal engineers attempted to remedy the situation by placing a sill at the head of the North Fork in 1910-1911 to divert more water into the South Fork. In addition, a training dike was constructed at the mouth of the South Fork, and dikes closed off "subsidiary sloughs" (ARCE. 1928). The project was expanded in 1919 to include dredging at the Skagit City Bar and construction of training dikes. However, the effort was not judged to be successful, and was instead considered to have possibly caused problems by decreasing the channel gradient. For these reasons and to improve navigation in the North Fork, the sill was later partially removed (ARCE. 1928).

Change in dominance between one distributary channel and another also occurred on the adjacent Stillaguamish and Nooksack rivers in the same time period (Figure 8). Review of this history provides some insight into the dynamics of the Skagit River. The shifting of the Stillaguamish met with similar, and similarly ineffectual, engineering measures. In the 1890s and 1900s, the main flow of the Stillaguamish River switched to Halt's Slough, which was formerly a secondary distributary channel. The "Old Mainstem" which the river began to abandon flowed adjacent to Stanwood and through East Pass and South Pass to Skagit Bay and Port Susan, respectively. Earliest maps show that Hatt's Slough in 1886 was considerably narrower than the Old Mainstem, although according to Morse (p. 94, in Nesbit, 1885), during floods the river carried as much water as the Old Mainstem. It seems likely that the river would eventually have switched the predominance of its flow to Halt's Slough without human action, because it has a shorter path to Puget Sound than the Old Mainstem.

Settlers engaged in various actions which may have influenced this natural process. In 1879 and 1880, settlers first attempted, unsuccessfully, to dam Halt's Slough, in order to limit high flows through it and to reduce the effects of flooding on newly-reclaimed tidelands downstream (Morse, p. 94, in Nesbit, 1885). On the other hand, settlers also wanted to remove a jam at the head of the slough in order to improve navigation: two settlers removed the jam in 1892-1893 in hopes of establishing a town on the slough that could rival Stanwood (Eide, 1996). Removing the logjam at the head of Halt's Slough in 1892-1893 may or may not have encouraged more flow into the slough. However, over a decade later, in 1906 the slough remained "so choked by debris ...as to carry little water except at flood stages" (ARCE, 1930).

But flooding in November of 1906 removed the debris, with the flood's erosive effects possibly accentuated by the effects of the earlier jam removal. This renewed the efforts of those who wished to reduce flow in the slough; a second dam was installed at the head of the slough in 1909 (USACOE Drawing E-2-9-4. 1909; ARCE, 1930). This second attempt to build a weir was abandoned as rapidly as the first attempt, when the river breached it later the same year. The River and Harbor Act of 1910 provided for renewing this sill, which was done later that year, with the sill being constructed "...to a height as to divert nearlv all of the low-water flow down the main river..." (ARCE, 1930). This third structure remained intact until 1915, when the river destroyed it. No subsequent structures appear to have been built. As a result of the shifting of flow from the Old Mainstem to Hatt's Slough, the Old Mainstem has narrowed substantially, and Hatt's Slough widened correspondingly (Collins, 1996).

Figure 8. Locations of deltaic distributary channels and large, persistent log jams encountered by settlers in the late 19th century on the lower valleys of the Stillaguamish, Skagit, and Nooksack rivers. Hatchured lines indicate limit of alluvial valley fill, as indicated on geologic maps (Dethier and Whetten, 1981; Wunder, 1976; Artim and Wonder, 1976; Huntting et al., 1961; Minard, 1985a, 1985b, 1985c). Detail on jams is in Collins (unpubl.).



The Nooksack River reportedly changed its course from Lummi Bay to Bellingham Bay in the mid 19th century, because of the effects of a log jam, according to a government engineer writing in 1893 (Figure 8).[16] The consequent filling of Bellingham Bay with fine sediment[17] caused settlers and the government engineer to call for a dam to switch the river back to its former path to Lummi Bay. Similar to the Nooksack, the Stillaguamish River has also accreted significant amounts of saltmarsh and tide flats into Port Susan as a result of the shifting from the Old Mainstem to Hatt's Slough. It is possible that post-settlement land use patterns have accentuated the rate of accretion in both cases, but this has not been systematically evaluated.

Review of these three rivers' history suggests several conclusions relevant to understanding channel and habitat conditions in the Skagit River. First, natural sedimentation through time would cause dominant distributary channels to lengthen and consequently for their gradient to lessen. These physical changes would be expected to induce the deposition of sediment and woody debris, including jams. All of these physical changes would then favor flow to shift to a shorter, steeper distributary, which would also be more clear of woody debris. With time, this process would repeat. Second, the presence of log jams near the divergence of distributary channels appears to have had the capacity to preserve the status quo, by maintaining flow dominance even after the main channel began to lengthen, decrease in slope, shallow, and fill with debris. By removing jams at points of distributary channel branching, settlers probably facilitated the natural channel shifting. Third, a significant consequence of channel shifting was on the spatial patterns and rates of tidal marsh accretion. This is true (and will be true) of the Skagit as it has been on the Nooksack and Stillaguamish. Shifting of dominant flow from the Skagit River South Fork to its North Fork is influencing spatial patterns and rates of tidal marsh accretion (see below).

[16]"Until about fifty years ago the Nooksack flowed out into Lummi Bay...the present outlet did not exist or was insignificant. A big jam of timber was formed in the river just below the junction, and forced the river to open its present channel... The former outlet is now entirely closed." (ARCE, 1893).

Later Changes: ~1910 to ~1990

Diking of Distributary Channels

Dikes built in this century have blocked off distributary sloughs on Fir Island. By 1991, many had been disconnected from inflow at the upstream or downstream ends, or both (Figure 9). By 1900, one distributary of Dry Slough had been blocked off from saltwater, and two more had been closed by 1937 (Figure 9). Between 1940 and 1956, all of the major sloughs between the North and South Forks were blocked off at the upstream and downstream ends excepting Wiley Slough, which was not disconnected until between 1958 and 1991. Several distributary sloughs in the South Fork system were also disconnected (e.g.. Deepwater and Brandstedt sloughs).

Accretion, Erosion, and Continued Diking of Tidal Marsh

Significant amounts of marsh have accreted, and patterns of marsh accretion have changed during the study period. Figure 10 shows the extent of marsh and tidal networks in 1889 (from USC&GS mapping), 1937 (from 1:12,000 aerial photographs) and 1991 (from enlargements made from 1:12,000 aerial photographs). There was a significant gain in marsh area in the mouth of the South Fork between 1889 and 1937 (Figure 10A), while there was little change in marsh in the North Fork (Figure 10C). On the other hand, from 1937 to 1991, the situation is reversed, with significant marsh accreting in the North Fork, and relatively little change in the South Fork. This presumably reflects at least in part the change in dominant flow of water and sediment from the South Fork to the North Fork. In contrast to marshes in the North and South forks, tidal marsh on the delta front has diminished over time (Figure 10B). This marsh loss has occurred by some combination of subsidence and erosion, which in turn is presumably the result of loss of sediment replenishment from diked-off distributary sloughs. Continued diking has diminished the area of tidal marsh.

[17] "Reliable parties state that the sand flats at the mouth of the Nooksack have extended out more than a mile within the past thirty years." (ARCE, 1893).

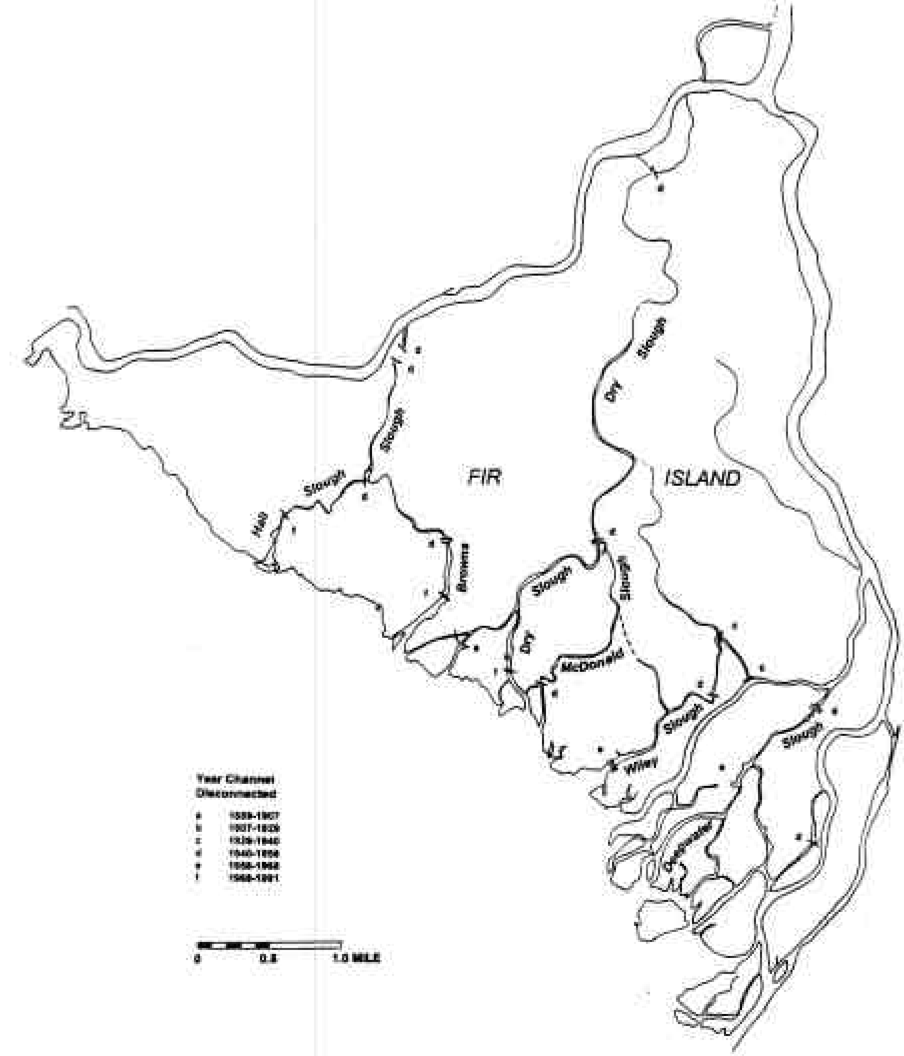
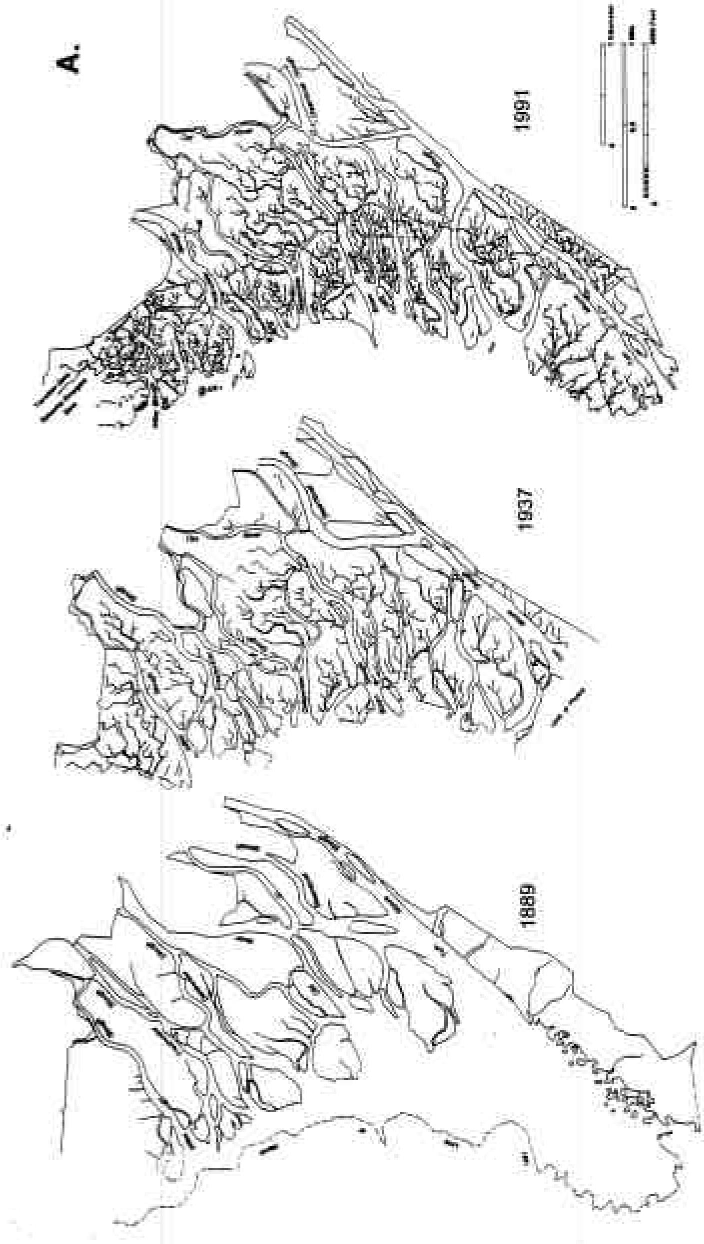
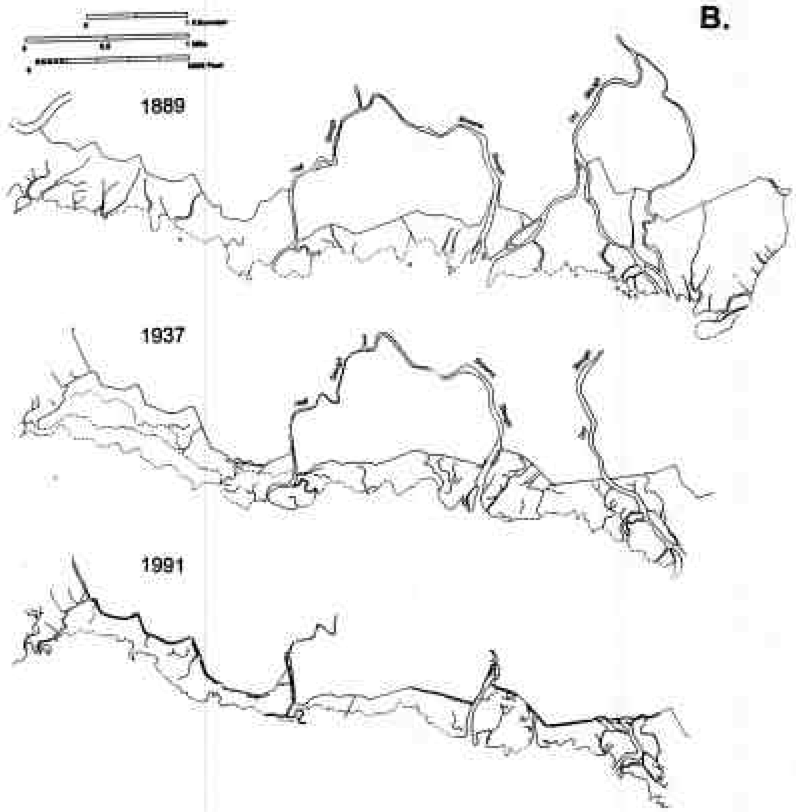


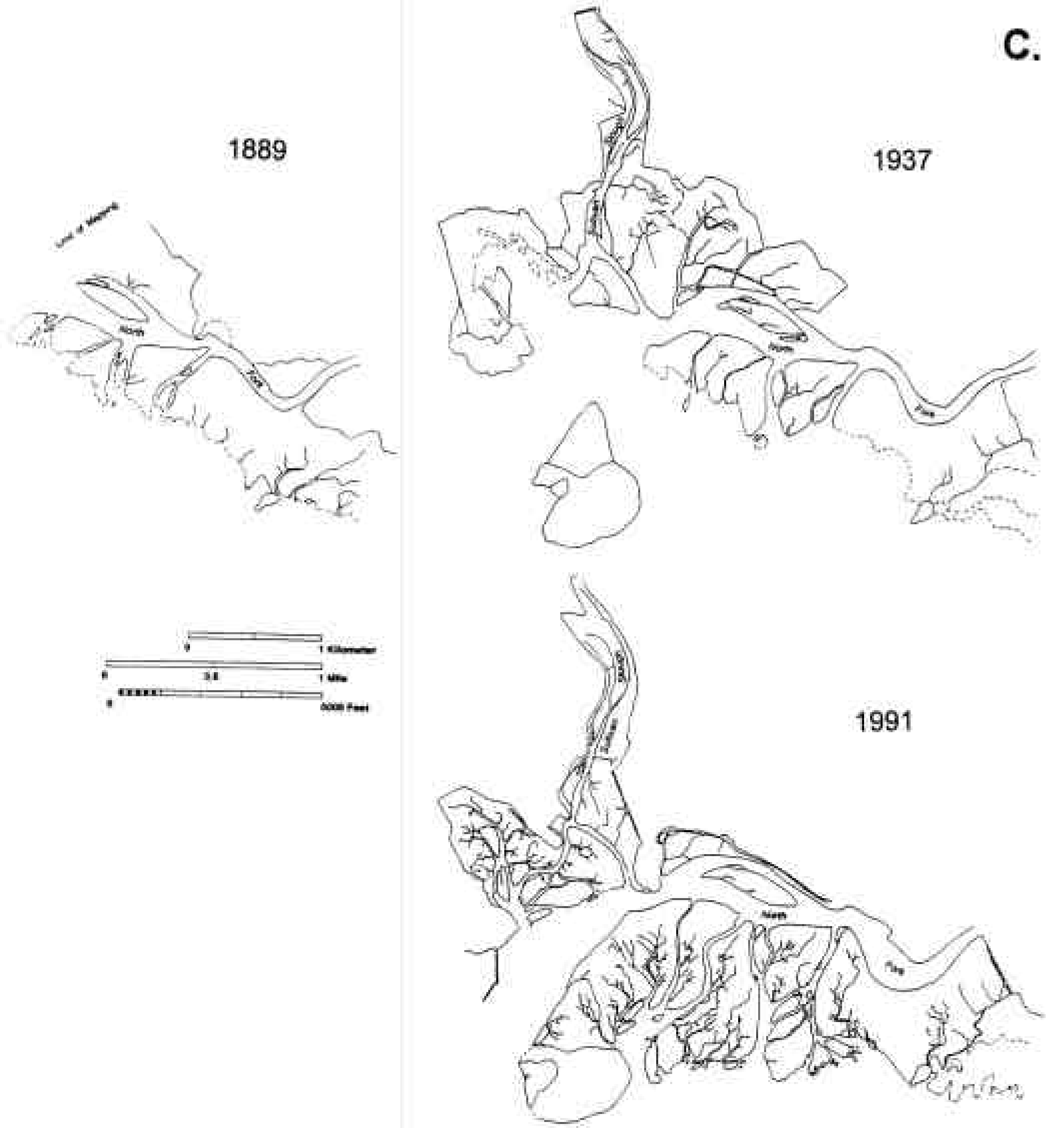
Figure 9. Distributary sloughs disconnected from the channel network. Years are bracketed from maps and aerial photographs.

Figure 10. Blind tidal channel networks of the Fir Island area in 1889 (from USC&GS mapping), 1937 (from l:12,000-scale aerial photos; see Table Al-1), and 1991 (from photo enlargements of 1991 black-and-white aerial photographs, (a) South Fork delta channels. Southern boundary is Douglas Slough. Photo enlargements did not include the lower portion of the marshes east of Tom Moore Slough and north of Douglas Slough, and 1:24,000 scale photographs were used for this area. Marsh channel area for this portion was extrapolated from that part having photo enlargement coverage. (b) Front of the Fir Island delta. Marsh boundary was indistinct on aerial photos from 1991 and 1937. Inner dashed lines in both cases is the best estimate of marsh boundary. Indistinct boundary is presumed to a result of marsh eroding or settling in the absence of sediment replenishment from up-stream sloughs, (c) North Fork delta, including Sullivan Slough area.


A.
1991
1937
1889



B.
1889
1937
1991


C.
1889
1937
1991
0
1 Kilometer
0
0.5
1 Mile
0
5000 Feet

Effects on Water and Sediment Discharge

The river has a history of very large floods (Steward and Bodhaine, 1961), but flood sizes have been reduced since the development of a series of reservoirs on the upper river. A dam on Baker River was constructed in 1926. Diablo Dam on the Skagit mainstem was constructed in 1930. and practically all peaks have been reduced by storage in Diablo Reservoir (Stewart and Bodhaine 1961). Ross Dam was completed in 1940. and all peaks since that date have been affected by storage in Ross Reservoir. Storage was increased when Ross Dam was raised in 1949. Stewart and Bodhaine (1961) reconstructed flood peaks prior to river gaging. The first and largest flood peak they documented was 400,000 cfs in 1815. By comparison, the 1991 flood, the largest in recent decades, had a discharge of 152,000 cfs. Peak annual floods early in this century commonly exceeded the 1991 flood (Figure 11).

There is no existing data on historic sediment loads, or in what ways land uses may have affected the Skagit River's sediment load. Appendix 3 summarizes recent suspended sediment loads, as computed from published U.S. Geological Survey data. Based on suspended sediment data from similar basins, it is likely that logging and related forest roads have significantly increased sediment influx to the river. On the other hand, the series of dams in the upper river would also have decreased the river's sediment load. It is beyond the scope of this study to attempt to quantify these two opposing effects.

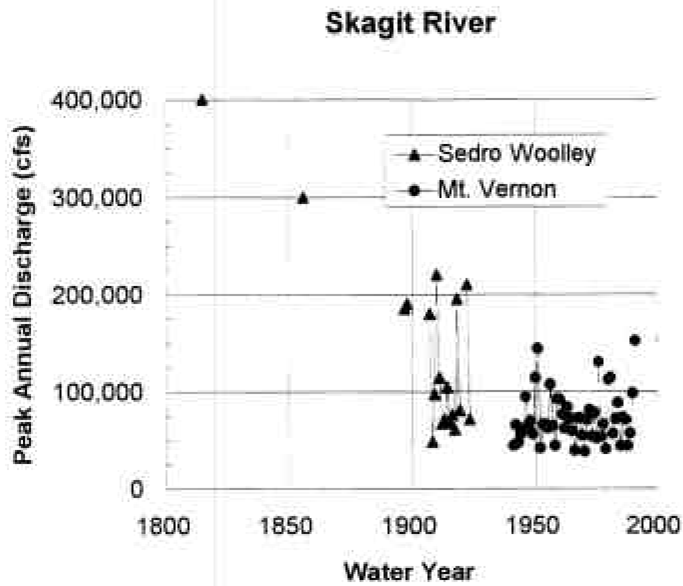


Figure 11. Peak annual discharge of the Skagit River at Sedro Woolley and, since 1941, near Mount Vernon.

Summary of Historic Changes to Channel Conditions with Implications for Aquatic Habitat

The following discussion summarizes some of the ways in which historic changes to channels are likely to have affected the quantity and quality of salmonid habitat.

(1) Clearing of the Mount Vernon log raft jam and other woody debris appears to have increased flooding on Fir Island. This in turn would have increased the amount of sediment fated for deposition in Skagit Bav, by reducing the amount of sediment-laden floodwater that would previously have been routed onto the greater Skagit River delta. Removing the jam may also have released to the estuary a significant amount of previously stored sediment. Investigations elsewhere (e.g., Harvey and Biedenham, 1988; Triska, 1984) suggest such raft jams may have stored significant amounts of sediment and buffered estuarine sediment accumulation from variation in watershed supply. Clearing the Mount Vernon Jam would presumably also have changed the routing of large woody debris from the upper watershed, but the nature of this effect is not known.

(2) Removing tremendous numbers of snags from the forks beginning last century would have reduced the standing crop of woody debris. This in turn reduces the productivity of invertebrates and other organisms, dissolved and particulate organic matter, habitat complexity, and probably reduced sediment and organic detritus retention in the forks.

(3) Logging of streamside forests on Fir Island began in the 1870s. Streamside forests had been removed from the Skagit River as far upstream as the Sauk River by as early as 1902 (Plummer et al., 1902). This early streamside logging would have substantially reduced the supply of large woody debris to all channels in the study area by the turn of the century. This effect has remained essentially unchanged since then, because most streamside areas of Fir Island now consist of bank revetment. The implication for habitat is that there will be a continued loss of productivity, habitat complexity, and sediment and organic detritus retention.

(4) Log booms were present in the late 19th century on many distributary sloughs. The potential effects of log storage and handling on salmonids in the nearby Fraser River delta is discussed by Levy et al. (1982)

and summarized for the region by Sedell et al. (1991). Without more information it is not possible to determine whether effects in the Skagit River estuary were positive, negative, or insignificant (see Table 9.7 in Sedell et al., 1991 for summary and pp. 360-364 for discussion).

(5) Shifting of flow dominance from the South to North forks (and, presumably at some time in the future, back again) is a natural process that results from the deposition of sediment, which lengthens the channel, decreasing its slope, which induces deposition of sediment and woody debris. Removing logjams near the flow divergence, and the presence of log booms in the South Fork may or may not have hastened this change. One result of this shifting is that while there was significant accretion of saltmarsh in the South Fork in the late 19th and early 20th century, accretion shifted to the North Fork later in this century.

(6) Dikes have blocked both ends of numerous distributary channels. Tills has eliminated access bv salmonids to a substantial amount of habitat. Since the time when they were blocked off, most of these former sloughs have been substantially degraded by pollutants, fill, and loss of riparian plant communities.

(7) Freshwater off-channel habitat has probably been lost from diking and ditching. Loss of freshwater channels and wetlands were not accounted for in detail. However, several mapped wetlands and channels were prominent on maps, and it is likely there was a significant amount of freshwater habitat lost in forested wetland vegetation zone. Beechie et al. (1994) document losses in the lower valley and upper Fir Island.

(8) A large amount of blind tidal channel habitat has been lost. While there has also been a gain of marsh area and blind tidal networks have established in these newly accreted areas, there has been a net loss because of diking. (This is quantified in Chapter 4 of this report.) Most of this loss has occurred in the estuarine emergent-forest transition zone.

(9) Dams have reduced flood peaks. In the absence of any other channel modifications, this would have the effect of reducing the amount of bed scour and overbank flooding. However, channel diking bv concentrating flow would have increased flow depths for floods that do not overtop the dikes. Removal of the Mount Vernon Jam would also have increased downstream flow depths. Quantifying how these factors interact with the effect of upstream dams is beyond the scope of this report.

(10) Land use changes to sediment supply probably include an increase in supply due to widespread erosion from forestry activities and a decrease in supply due to the impounding effect of upstream dams. It is beyond the scope of this project to quantify these effects.

CHAPTER 4: QUANTITATIVE CHANGES TO CHANNEL AREA, ~1860-1991

Approach

To facilitate a quantitative analysis of channel area change, the channel network was broken into segments. Channels are classified as either distributary river channels, or blind tidal channels. Because the purpose is to support an analysis of habitat use by salmonids, the segments take into account habitat variables. Habitat variables in turn are closely tied to hydrologic and biotic gradients: vegetation zones were taken as the best index of these gradients. The segment-based analysis is being conducted by the Skagit System Coop using GIS and is incomplete at this time. The following reports on preliminary, generalized results from by-hand measurements. The GIS-generated marsh and channel areas will differ from preliminary measurements, and will be broken down by vegetation zone.

Blind Tidal Channels

To quantify the area of blind tidal channels, three blind-channel networks were examined in the field. The mouth of each network was in the estuarine emergent zone. Networks visited were located along Tom Moore Slough, between Wiley and Freshwater Sloughs, and within the delta of the North Fork (see Appendix 2 for sketch maps of the networks). Channels were first mapped on aerial photo enlargements at a scale of 1:2400. This map was enlarged to a scale of 1:1200 (1 inch equal to 100 ft). In the field, the length, width and depth of all larger channels (third order and higher) were measured. All smaller channels (first and second order) were mapped or identified in the field, and for a sample of these, the bankfull width, depth, and length were measured. To be included, a channel had to be integrated in the network, incised below the rooting zone of marsh plants and into the underlying mud, and at least 30 cm in width near its confluence with a larger channel. The channel was taken as terminating at the point where its width became much greater than its depth (i.e.. had the appearance of a swale).

These measurements were used to relate the channel top width at the network's mouth to the total channel area (see Appendix 2). A power-law regression was fit to the pooled data (R^2 = 0.940; R^2 = 0.970 when the Tom Moore data was excluded). The channel top width was chosen as the dependent variable because it is readily measured from aerial photographs and maps. In addition, the channel top width is expected to correlate with the total channel area; Leopold and others (e.g. Leopold et al., 1964) showed in the 1950s that channel dimensions can be related to the bankfull discharge, which can in turn be related to the drainage basin area. In the case of blind tidal channels, the tidal prism is analogous to discharge, which is related to the total marsh area (e.g. Haltiner and Williams, 1988). To estimate channel area in the study area, the channel top width of all channel networks visible on photographic enlargements was measured, and used as a surrogate for channel area using the correlation between the two. Outlet channels with top widths less than ~2 m, which were too small to measure from the photos, were given an average width based on field observations.

More than half of the total area in 1991 is in the delta of the South Fork Skagit River (Table 2). The largest loss of combined estuarine emergent and transition zone areas, and of blind tidal channels, was prior to anv map documentation (Table 2). The largest amount lost was on the delta front. On the South Fork delta, a significant amount of area has been lost in each of the time intervals. On the other hand, since 1889, a significant amount of saltmarsh accreted in the South Fork. Nearly all of this was between 1889 and 1937 (see Figure 10). As a result the total area is slightly greater in 1991 than in ~1889. A significant amount of marsh also accreted in the North Fork. Most of this was between 1937 and 1991. (The difference in timing is probably related in part to the gradual shifting of dominant flow from the South Fork to the North Fork.) There is significantly more area in the North Fork delta in 1991 compared to ~1860. However, it is important to note that the table does not separately consider changes to area of the estuarine emergent zone and of transition zone. Most of the lost area has been from the transition zone.

Table 2. Areas of combined estuarine emergent zone and transition zone on Fir Island, estimated for ~1860 (see Figure 1 caption and text for explanation), 1889 (USC&GS mapping), 1937 (aerial photos), and 1991 (aerial photos).

TIME PERIOD	South Fork Delta (km^2)	Fir Island Delta Front (km^2)	North Fork Delta (south side of NF, and island) (km^2)	TOTAL (km^2)
~1860[1]	**~8**	**~15**[3]	**~1**[7]	**~24**
Diked ~1860-1889	loss ~1	loss ~12	~0	loss ~13
1889	**6.86**	**3.33**	**0.94**	**11.13**
Diked 1889-1937	loss 1.48	loss 0.60	-	-
Accreted 1889-1937	---[2]	---[4]	gain 0.27	-
Eroded 1889-1937	---[2]	---[5]	0	-
1937	**---**[2]	---[5]	**1.21**	**-**
Diked 1937-1991	loss 1.08	0	0	loss 1.08
Accreted 1937-1991	---[2]	gain 0.04[6]	gain 3.11	-
Eroded 1937-1991	---[2]	loss 0.89[6]	0	-
1991	**7.90**	**2.03**	**4.32**	**14.25**

[1] Estimates for pre-settlement (~1860) conditions are using vegetation information on USC&GS mapping. Note that Bortleson et al. (Table 2, 1980) estimated the pre-settlement area based on vegetation and landforms as 29 km^2; this compares to the estimated 24 km^2 in this study; the areas included in this estimate and that in Bortleson et al. differ. [2] Incomplete coverage by 1937 aerial photos. [3] Morse (in Nesbit, 1885) estimated Fir Island to have 4,500 acres (18.2 km^2) of "brush and spruce tide marsh" and 4,500 acres "open tide marsh prairie." [4] 0.16 km^2 gained by removing dikes. [5] Vegetation limit indistinct on 1937 photos. [6] Represents period 1889-1991. [7] Assumed equal to 1889 (0.94 km^2).

The ratio of channel area to marsh and wetland area varies throughout the study area. For example, in the South Fork delta, channels account for 11% of the area in the estuarine emergent zone, and 4% in the emergent-forest transition zone (Table 3). On the North Fork delta (on the south side of the North Fork), where most of the marsh has recently accreted (ie., since 1937), the portion of marsh area occupied by channels is only 4%. The front of the Fir Island delta has the lowest amount of channel area as a proportion of saltmarsh; it includes 3% channel by area. However, this figure is misleadingly large as an indication of the channel density, in that most of the channel area is accounted for by the relict channels of truncated Brown, Hall, and Dry sloughs (see Figure 10) and few branching networks exist of smaller channels.

Overall, the amount of channel area in 1991 (0.7 km²) is roughly equal to the amount of channel area that was present in 1889. However, roughly twice as much channel area is estimated to have been present in pre-settlement (~1860) times. As indicated above, significant habitat loss occurred in the 1860s-1880s, but continued loss of area to diking and erosion in the subsequent century was compensated for by channels developing on newly-accreted marsh. However, most of the loss was from the transition zone, and the gain in the estuarine emergent zone. There was also a propoportionately more substantial loss to area in both zones to the south of Fir Island and to the north (the Sullivan Slough area); these areas were not quantified in this report.

Table 3. Estimated area of blind tidal channels. All measurements are in square kilometers. Assumptions are given in table notes.

TIME PERIOD	SF Delta	Fir Island Delta Front	NF Delta (south side of NF)	TOTAL
~1860[1]	0.56	0.6-1.2	0.04-0.08	**1.2-1.8**
1889[2]	0.48	0.13-0.27	0.04-0.08	**0.6-0.8**
1991[3]	0.55	0.07	0.09	**0.7**

[1] Assumes same ratio of channel area to marsh area as for 1889 estimates. Area estimates are from Table 1. [2] Assumed 7% for South Fork delta; assumed range of 4%-8% for Fir Island delta front and for North Fork delta. [3] South Fork delta channel density measured as 7% (11% in emergent zone, and 4% in transition zone); North Fork delta channel density measured as 4%; Fir Island delta front measured as 3%, with cut-off distributary slough mouths accounting for most of this; East of South Fork measured as 4%.

Distributary Channels

Table 4 shows preliminary distributary channel area measurements. No estimates were made for conditions prior to 1889. Because no sloughs appear to have been disconnected from the network prior to that time, the 1889 estimates are assumed to approximate ~1860 conditions. The total channel area is the same in 1889 as in 1991 (5.8 km² in 1889 and 5.9 km² in 1991, a difference well within the measurement error), but the spatial distribution of channel area changed. The greatest loss was in Hall, Brown, and Dry Sloughs—

the sloughs which cross Fir Island, and which were blocked off from flow at various times since 1889 (see Figure 9). A smaller amount of area was lost from the South Fork sloughs, primarily due to diking. The largest gain was in the North Fork, which widened and also lengthened (as tidal marsh prograded) and in the North Fork's distributary sloughs, which lengthened as tidal marsh accreted.

Table 4. Areas of mainstem and distributary slough channels measured for 1889 (from USC&GS mapping) and 1991 (from orthophotos). All measurements are in square kilometers.

TIME PERIOD	North Fork	North Fork Sloughs [1]	Hall, Brown, and Dry Sloughs	South Fork	South Fork Sloughs	TOTAL
1889	0.9	0.1	0.8	1.1	2.9	**5.8**
1991	1.8	0.3	0.2 [2]	1.0	2.6 [2]	**5.9**

[1] South side only of North Fork delta. [2] Excludes sloughs blocked off at upstream and downstream ends.

Change in Total Channel Area

Table 5 summarizes changes to channel areas in the Fir Island area. As indicated previously, the estimate does not include areas adjacent to Fir Island or any other parts of the Skagit River delta. The measurements should be considered as preliminary estimates.

Table 5. Areas (in square kilometers) of blind tidal channels, and distributary sloughs, estimated for ~1860, measured for 1889 (from USC&GS mapping), and 1991 (aerial photos and orthophotos).

TIME PERIOD	Blind Tidal Channels	Distributary Channels	TOTAL
~1860	1.2-1.8	~5.8	**7.0-7.6**
1889	0.6-0.8	5.8	**6.4-6.6**
1991	0.7	5.9	**6.6**

CHAPTER 5: RESTORATION IMPLICATIONS

A summary of considerations in restoration planning includes:

(1) Suspended Sediment. Forestry in steep headwaters has caused significant erosion, although the effects of this on sediment loads or on the timing of sediment transport in the Skagit River, and in turn the effects on salmonids, is not known. It is likely that diking and channel clearing have enhanced delivery of suspended sediment to Skagit Bay and enhanced its shallowing, the effects of which are beyond the scope of this report. Effective restoration measures to reduce erosion include landslide hazard zoning, such as used in Washington's Watershed Analysis, to minimize landsliding basin-wide, and other erosion control planning.

(2) Tidal Channels. By restoring diked lands to tidal influence, it is possible to restore tidal channels lost to previous diking (see Zedler, 1996 for summary with emphasis on California efforts; Frenkel and Morlan, 1991 for a coastal Oregon example). Restoration efforts elsewhere have indicated that areas more recently diked are more readily restored than areas diked at an earlier time (e.g., Frenkel and Morlan, 1991); mapping of the history of diking can aid in determining this one variable that is relevant to prioritizing the feasibility of restoration.

A large amount of marsh has accreted in the last century. A network of channels is well established on the marsh accreted in the first half of the study period in the South Fork. The area of tidal channels should also increase in the more recently-accreted North Fork. In both cases, as continued sedimentation builds up the low saltmarsh that fringes both areas, channel networks will develop. The rate of saltmarsh development has been rapid in the study period. It is beyond the scope of this study to evaluate the factors influencing this, but it is possible that upland land uses have increased the rate of erosion; it is also possible that because river dikes direct the Skagit River's floodwaters to the Fir Island area, that a disproportionate amount of sediment is depositing, compared to historic (pre-diking) period, when floodwaters fanned out over the entire delta, and suspended sediment deposited delta-wide.

On the other hand, marsh along the front of Fir Island (ie., between the two forks) appears to have eroded in the last century. The reasons for this are not known, but it is possible that the disconnection of numerous sloughs that formerly crossed Fir Island has starved these marshes of sediment. If this is the case, then restoring flow and sediment transport to these sloughs (see below) could rebuild these marsh areas as well.

The relative constancy through time in total blind channel area obscures the fact that there has been a significant loss in the channel area in the transition zone. This is important to the extent that channels in the transition zone functions as a limiting habitat for salmonids.

(3) Distributary Channels. A significant quantity of channel area has been lost to diking. The sloughs that cut across Fir Island account for the largest amount. The obvious restoration effort is to reconnect these sloughs to freshwater and saltwater influx.

(4) Hydrology. As indicated previously, there are several historic effects on flood hydrology. For example, channel clearing and channel diking have increased flooding in the Fir Island area. On the other hand, dams have significantly decreased flood peaks. It is beyond the scope of this report to quantify these effects, or to speculate on how future changes could change flood hydrology.

(5) Large Woody Debris. Most of the mainstem, North Fork, and South Fork have lacked large conifer recruitment for a century. This and the removal of woody debris may have had several consequences, including loss of habitat quantity, quality, and diversity. Further work is needed to better understand the effects of a reduced load of large woody debris.

ACKNOWLEDGMENTS

Eric Beamer of the Skagit System Coop initiated and supervised this investigation. Eric Beamer and John Klochak, also of the Skagit Coop, and Andy Haas of the Tulalip Tribes Departement of Fisheries provided assistance and helpful input and comments. The approaches, data, and interpretations in this report are preliminary and will be refined, and extended to include the entire Skagit River delta, in an ongoing study.

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VII. APPENDICES

Appendix 1: Supporting Data for Historic Interpretations

Table A1-1. Maps and aerial photographs of the lower Skagit River used in this study.

Year of Publ.	Data	Type	Title	Scale	Source
1867	1866 survey	plan	Township 33 N, Range 3 E	1:31,680	GLO (BLM)
1872	1872 survey	plan	Township 33 N, Range 3 E Township 34 N, Range 4 E Township 34 N, Range 3E	1:31,680	GLO (BLM)
1873	1872 survey	plan	Township 33 N, Range 4 E	1:31,680	GLO (BLM)
1889		plan	Skagit Bay, Delta, and River, Washington. Field Sheet T-2156	1:20,000	USC&GS
1907	1897 survey	plan	Skagit River, Washington, from Sedro-Woolley to its Mouth	1:24,000	USACOE
1907	1897 survey	plan	Survey of Skagit River 1907. Sheet 1: Skagit City; Sheet 2: Sterling Bend; Sheet 3: Mount Vernon; Sheet 5: Mouth of Steamboat Slough	1:4,800	USACOE
1932		plan	Sedro Woolley to Mouths, Skagit River, Washington (5 sheets) (K-2-112 through 116)	1:4,800	USACOE
1937	1937 photos	stereo photos		1:12,000	
1943	1940 survey	topo	Mt. Vernon, WA 15' Quadrangle	1:62,500	USGS
1944	1941 photos	photo mosaic		1:20,000	USACOE
1956	1954 photos	topo	Mt. Vernon, WA 7.5' Quadrangle Conway, WA 7.5' Quadrangle La Conner, WA 7.5' Quadrangle Utsalady, WA 7.5' Quadrangle	1:24,000	USGS
1963		plan	Existing Levee System, Skagit River, Washington (E-6-6-197)	1:24,000	USACOE
1968	1968 photos	topo	Utsalady, WA 7.5' Quadrangle	1:24,000	USGS
1974	1974 photos	stereo photos	SKAGIT	1:24,000	
1981	1968 and 1978 photos	topo	La Conner, WA 7.5' Quadrangle	1:24,000	USGS
1981	1978 photos	topo	Mt. Vernon, WA 7.5' Quadrangle Conway, WA 7.5' Quadrangle	1:24,000	USGS
1991		stereo photos	S91003		
1992		stereo photos	SWS-92	1:24,000	Walker & Associates

APPENDIX 2: Supporting Data for Analysis of Blind Tidal Channel Networks

Hydraulic Geometry of Field Sites

The "Tom Moore" network is fifth order. The channel was mapped on 1:4,000-scale aerial photos as third order. The network has 178 channel links, 126 (or 70%) of which are first-order (Table A2-1). The area of channel, as measured by the average channel top width and length, by order, for the 33 links that were measured, totals 5,120.6 m^2 (0.51 km^2). Most of this area (60%) is accounted for by the main channel, which is the only fifth-order link. The site was measured during a spring minus tide. The fifth-order link had several decimeters of water at all times, the fourth-order links had from zero to a few decimeters of water, and the remaining third-through-third order links were either dewatered or had a few centimeters of water at the time of the field visit.

Tidal channels differ from terrestrial channels in that discharge at any section varies depending on how the flow shapes the entire length of the channel between the point in question and the main body of tidal water. The result is that a tidal channel changes more rapidly in width and less rapidly in depth as discharge changes downstream than does a terrestrial channel (Myrick and Leopold, 1963). Channel depth tends to change with distance less than in terrestrial rivers, so that the width-depth ratio varies rapidly downstream. At the mouth, a tidal estuary is wide and relatively shallow, and at its head, it is narrow and relatively deep (Langbein, 1963).

The width-to-depth ratio of tidal channels typically decreases with cumulative distance up the channel network. In a study of a marsh in the San Francisco Bay area, the ratio of channel width to depth was found to be greater than one (i.e., channel is wider than deep) where the full tidal range is exhibited (Collins et al., 1987). Where the thalweg elevation exceeds mean low tide level, the ratio was found to be less than one (i.e., channel is deeper than wide). The channel width changes exponentially with the distance up the estuary (e.g. Langbein, 1963).

While the tidal datum was not determined for the field sites in this study, the literature suggests that changes in width-to-depth ratio could be used as a surrogate for tidal levels, and thus for different types of habitat use. For example, in the Tom Moore #1 site, the width-to-depth ratio decreased with cumulative channel distance from the network mouth. A linear regression of width-to-depth ratio to cumulative channel distance showed the ratio decreased from 2.9 at the mouth, to 2.1 at 100 m, and 1.0 at 350 m. There was no significant difference of width-to-depth ratio between first, second, and third order streams, which averaged 1.2; the width-to-depth ratio of fourth order streams was 1.6 and 10.5 for the one fifth-order segment.

Tidal channels can form tight meander bends because of the cohesiveness of fine-grained estuarine sediments and the high resistance of channel banks due to salt marsh vegetation (Ashley and Zeff, 1988). The radius of curvature to width ratio of tidal channels is less than is considered optimal in alluvial channels (Ashley and Zeff, 1988). This information is useful for delineating historic vegetation zones, because relict tidal channels in diked areas can be differentiated from terrestrial river channels.

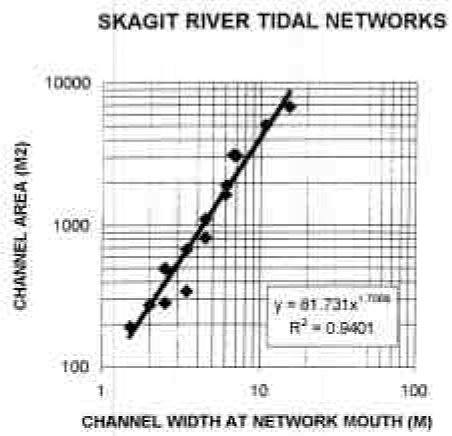

Figure A2-1. Regression of channel top width at the mouth of third-order and higher networks, and cumulative area of the channel network above the cross section. Data is from three networks in the Estuarine Emergent Zone

Table A2-1. Channel area in the "Tom Moore #1" field site, a fifth-order channel network.

Stream Order	Number Sampled	Average Length (m)	Average Width (m)	Average Depth (m)	Number of Links	Total Channel Area (m^2)
1	11	12.6	0.33	0.27	126	523.9
2	7	15.1	0.73	0.63	37	405.4
3	8	45.5	1.11	0.92	10	505.4
4	4	66.1	2.14	1.31	4	565.6
5	1	175.3	5.43	1.69	1	1,077.4
-	**33**	-	-	-	**178**	**3,077.7**

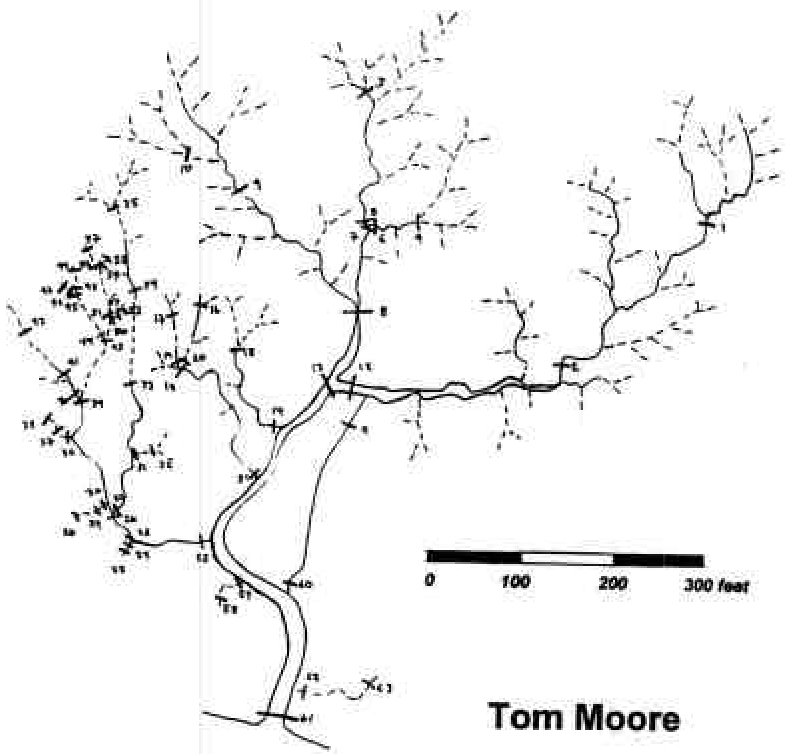

Figure A2-2. Sketch map of the "Tom Moore" channel network. Solid lines show channel links that were mapped from aerial photos. Dashed lines are schematic and indicate order and general location of channel links.

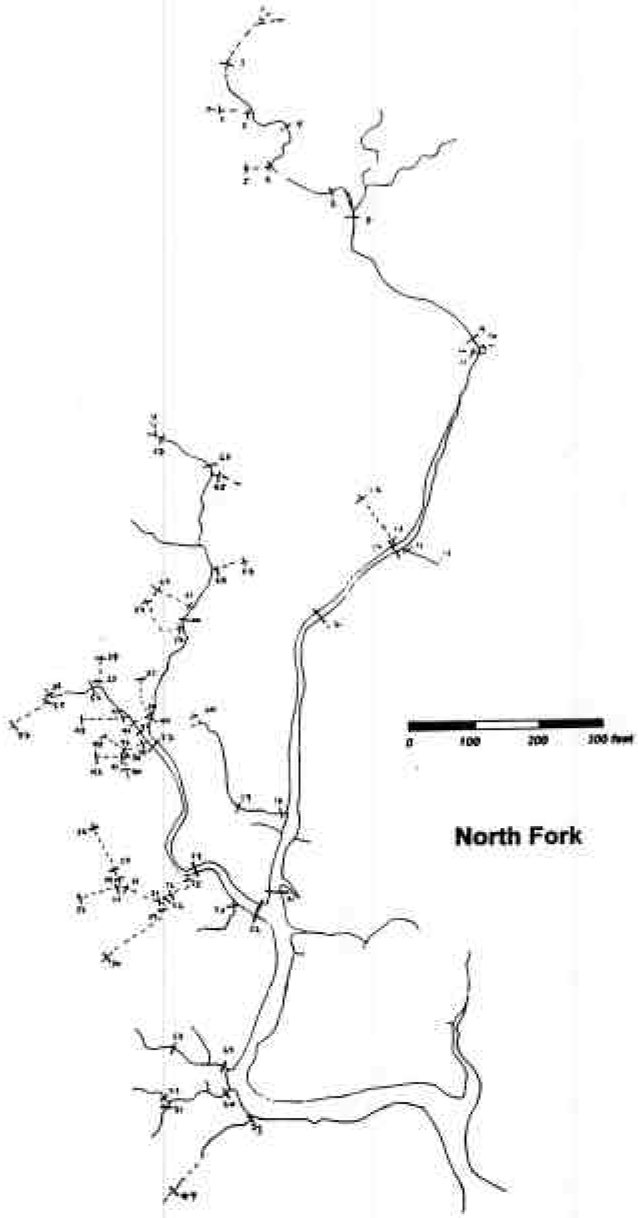

Figure A2-3. Sketch map of the "Wiley-Freshwater" channel network. Solid lines show channel links that were mapped from aerial photos. Dashed lines are schematic and indicate order and general location of channel links.

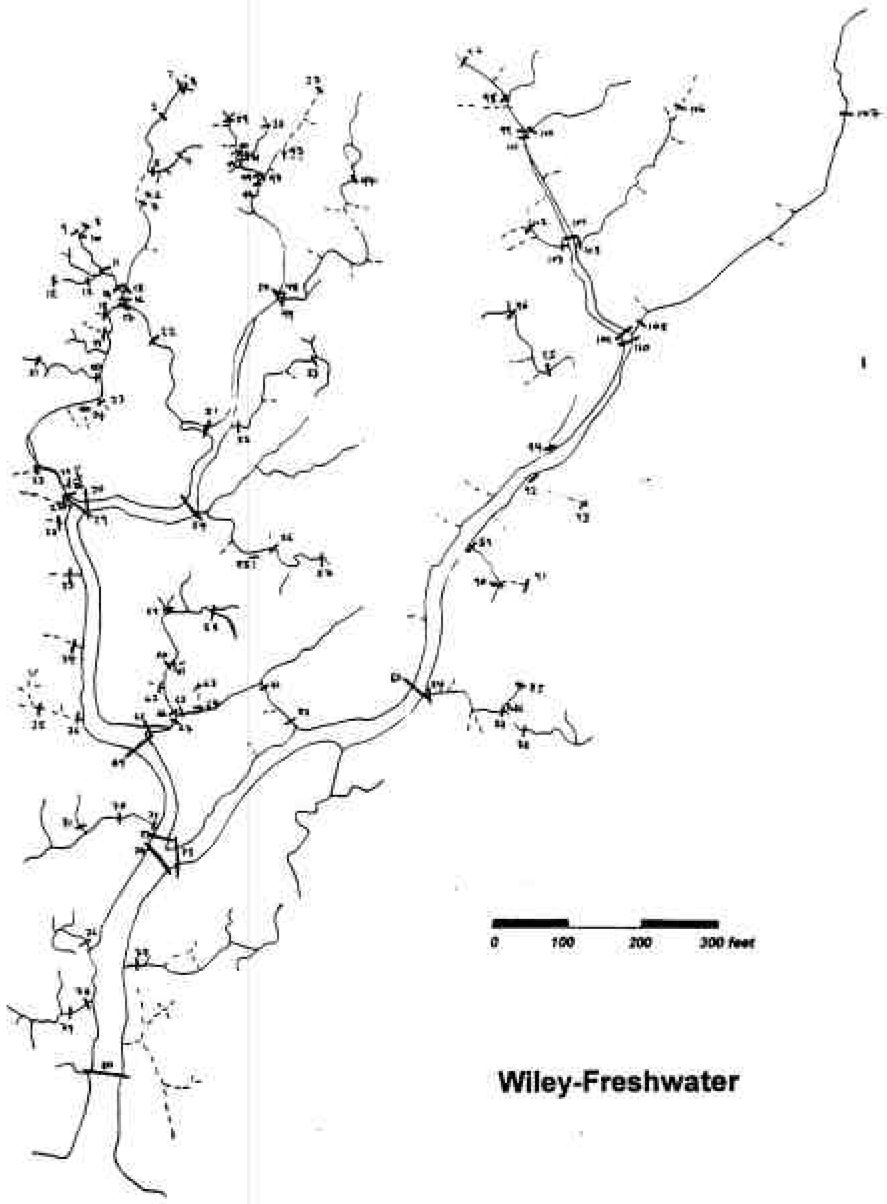

Figure A2-4. Sketch map of the "North Fork" channel network. Solid lines show channel links that were mapped from aerial photos. Dashed lines are schematic and indicate order and general location of channel links.

APPENDIX 3: Suspended Sediment Data and Calculations

Suspended Sediment and Water Flux, WY 1980 - WY 1991

Suspended sediment data collected by the U. S. Geological Survey is useful for characterizing interannual and monthly variations in recent suspended sediment flux in the lower Skagit River. The U. S. Geological Survey collected suspended sediment data at the Mount Vernon station (12200500) from WY 1974 through WY 1993. This was applied to the record of water discharge in the 1980-1991 period by developing a sediment rating for the 1980-1991 suspended sediment data (Figure A3-1). It is important to note that no suspended sediment samples are available from the highest discharges, and that there is a large scatter in the few points at the moderately high discharges. As a result, any estimates of sediment flux will have a very large error, because of this scatter and the necessity to extrapolate beyond the data. Because of this error, the data is best suited for showing general patterns of relative sediment discharge between years and months. It is not well suited for computing accurate estimates of sediment flux.

The highest monthly average water discharge is in the month of June, and the second highest is in November (Table A3-1 and Figure A3-2). The average discharge begins increasing in April to the June peak, and then gradually declines to the lowest average monthly flow in August. Flows increase more rapidly in the fall leading up to the November peak, which is substantially higher than the October average. Flows gradually decline from November and through the winter and spring to April. Average monthly sediment discharge follows the same overall pattern as the average monthly water discharge, except that there is more sediment transported in the late-fall and early-winter peak than in the summer peak; average suspended sediment transport is greater in November and December than in June.

The annual water discharge averaged 12.1 x 10^6 ac-ft, and ranged from 10.2 x 10^6 ac-ft (in WY 1985) to 16.7 x 10^6 ac-ft (in WY 1991) (Table A3-1 and Figure A3-3). The annual suspended sediment discharge averaged 1.7 x 10^6 tonnes, and ranged from 0.9 to 4.4 x 10^6 t. The greatest water and sediment discharge was in WY 1991.

Table A3-1. Total annual water and sediment discharge for the period WY 1980 to WY 1991, and mean monthly water and sediment discharge for the same period.

YEAR	Q (10^6 AC-FT)	Qs (10^6 T)	MONTH	Q (10^3 CFS)	Qs (10^3 T/DAY)
1980	11.064	1.4	OCT	350.3	61
1981	12.276	3.2	NOV	640.7	287
1982	13.090	1.6	DEC	595.7	309
1983	11.841	1.3	JAN	563.5	150
1984	12.288	1.5	FEB	535.8	151
1985	10.170	0.9	MAR	490.9	92
1986	11.320	1.4	APR	484.4	96
1987	10.657	1.1	MAY	579.1	133
1988	10.578	1.1	JUN	664.5	185
1989	11.654	1.2	JUL	589.1	142
1990	13.561	1.9	AUG	349.3	45
1991	16.678	3.4	SEPT	271.8	28

The annual water discharge averaged 12.1 x 10^6 ac-ft, and ranged from 10.2 x 10^6 ac-ft (in WY 1985) to 16.7 x 10^6 ac-ft (in WY 1991) (Table A3-1 and Figure A3-3). The annual suspended sediment discharge averaged 1.7 x 10^6 tonnes, and ranged from 0.9 to 4.4 x 10^6 t. The greatest water and sediment discharge was in WY 1991.

It is useful to compare rates and patterns of sediment transport in the Skagit to Canada's Fraser River, because a large amount of fisheries data that is useful for understanding the Skagit fishery has been collected in the Fraser. The Fraser River basin is considerably larger, totaling 228,000 km^2 at the lowest stream gage near Mission; the Skagit near Mount Vernon drains only 8,000 km^2. For the period 1965-1987, the Fraser transported 18.1 x 10^6 t/yr as suspended load (wash load and suspended sand bed material in Table 11-1, Church and McLean, 1994). This represents a specific yield of 79 t/km^2. The Skagit River in 1980-1991 transported 1.7 x 10^6 t/yr, which represents a specific yield of 200 t/km^2, or more than twice that of the Fraser River. The seasonal pattern of water and sediment transport in the Fraser River also differs from that in the Skagit. Sediment and water transport in the Fraser River each have a single peak. Sediment transport peaks in April and May, and declines steadily to a low in October through February (e.g., see Figure 11-2 in Church and McLean, 1994). Water discharge peaks in May-July, and declines to a low flow in January through March.

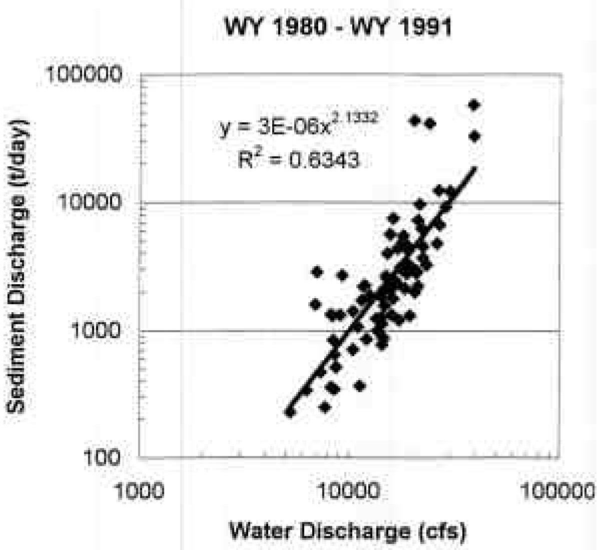

Figure A3-1. Suspended sediment rating curve for the Skagit River near Mount Vernon, for Water Years 1980-1991.

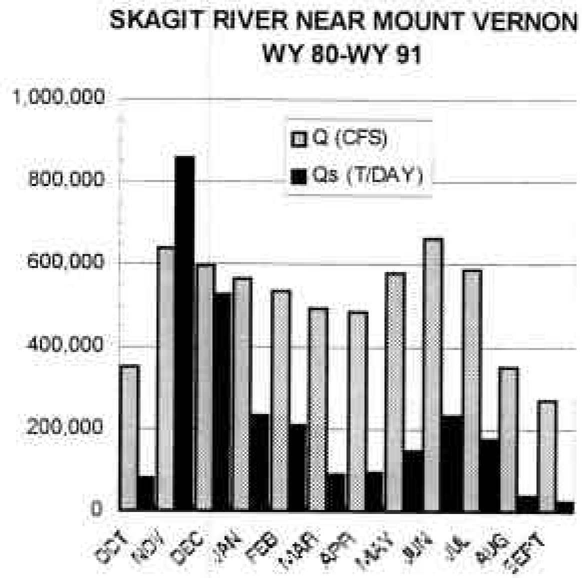

Figure A3-2. Average monthly transport of water and suspended sediment in the Skagit River near Mount Vernon, for WY 1980-1991. Sediment discharge calculated as $Q_s = 0.000003x^{2.1332}$ ($R^2 = 0.6343$).

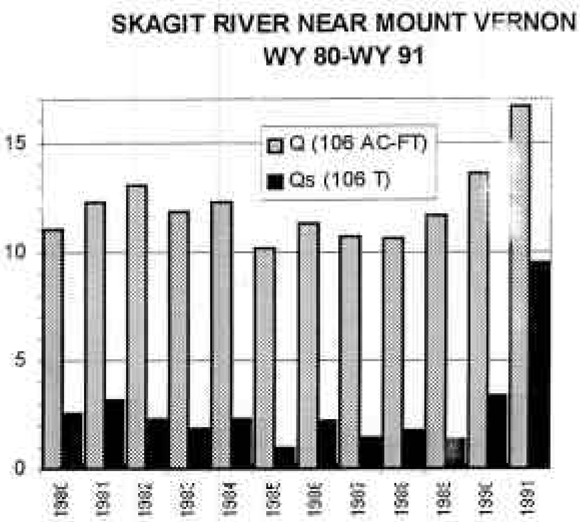

Figure A3-3. Annual transport of water and suspended sediment in the Skagit River near Mount Vernon, for Water Years 1980-1991. Sediment discharge calculated as Q_s = $0.000003x^{2.1332}$ ($R^2 = 0.6343$).