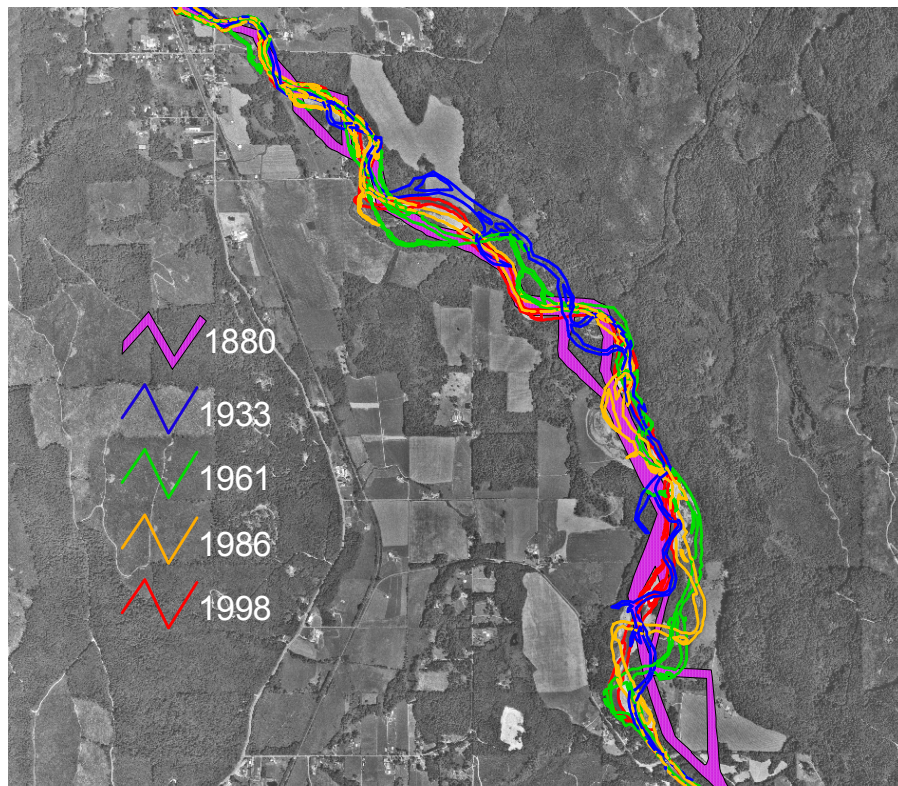


South Fork Nooksack River

Acme-Saxon Reach

Restoration Planning:

Analysis of Existing Information and Preliminary Recommendations



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Introduction

The Acme-Saxon Restoration Planning Group was convened in spring 2000 to restore salmonid habitat in the South Fork Nooksack River and its floodplain between the Saxon Road Bridge (River Mile 13) and the Highway 9 Bridge at Acme (River Mile 8.5; Figure 1). The planning group is comprised of representatives from the Lummi Nation, Nooksack Tribe, Nooksack Salmon Enhancement Association, Washington Department of Fish and Wildlife, Whatcom Land Trust, Whatcom County Parks, Whatcom County Water Resources, Whatcom County River and Flood Engineering and the Acme-Van Zandt Flood Control Sub-zone. The Acme-Saxon Reach was selected because it comprises an important portion of the anadromous salmonid use area of the South Fork and has been the focus of land acquisition and conservation efforts that have resulted in approximately 726 acres of parks, conservation easements and acquisitions (Table 1; Figure 1).

It is also a reach where the forestry land use of the upper watershed transitions into the agricultural and residential land use of the lower watershed. In the watershed above the Acme-Saxon Reach, habitat-forming processes are essentially on a trajectory of recovery, with newer forestry rules for road and timber management. However, the lower watershed will require active intervention to effectively restore the habitat-forming processes required to create and maintain salmon habitat. Comprehensive restoration planning at the reach or sub-basin scale constitutes an important step in the move towards more strategic watershed restoration, as explicitly described in the Salmon Habitat Recovery Project Prioritization Strategy for WRIA 1 (NNR et al. 2001). This comprehensive approach to reach-scale restoration planning ensures that projects will be sequenced appropriately and interact positively to successfully restore the habitat conditions thought to be most limiting salmon production. Further, involvement of multiple stakeholders in the Planning Group ensures feasibility of, and community support for, recommended projects.

The Acme-Saxon Reach Restoration Planning Effort consists of the following six sequential steps, identified in the Saxon-Acme Reach Restoration Planning document (Maudlin and Coe 2001):

- Desired future conditions and goal setting: agreed-upon statement of purpose;
- Collection of baseline physical and biological data;
- Analysis of existing information and development of recommendations;
- Restoration planning, project prioritization, and project development;
- Project implementation;
- Monitoring and evaluation of reach and restoration projects.

Acme-Saxon Restoration Planning: Analysis and Recommendations

Figure 1: Acme-Saxon Reach of the South Fork Nooksack River, indicating properties in Whatcom County Parks and Whatcom Land Trust ownership.

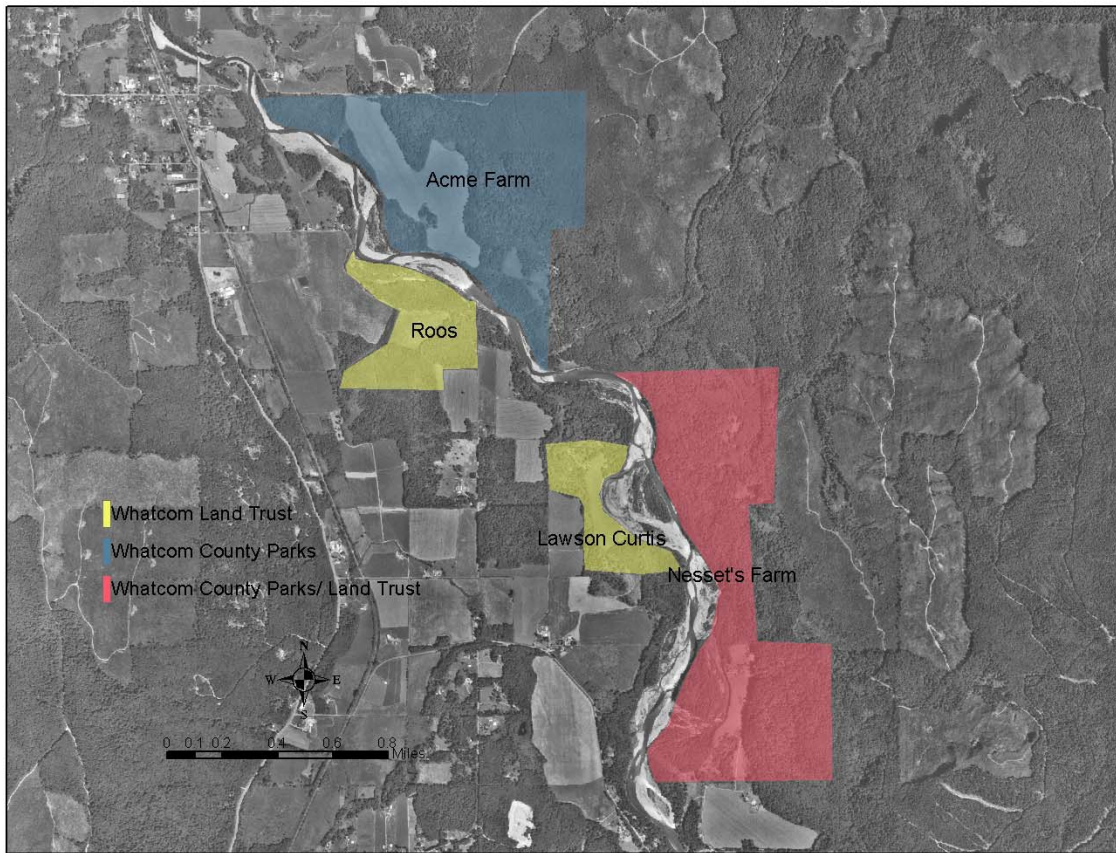


Table 1: Whatcom County Parks and Whatcom Land Trust Properties in the Acme-Saxon study area.

Property	Size (ac.)	Features:
Nessel Farm/ Overby Homestead	312	Spawning and rearing side channel with habitat structures, two small tributaries, 5000 feet of river banks
Roos	78	Side channel complex, riparian wetlands
Lawson Curtis	74	Side channel complex, past restoration efforts in secondary channel
Acme Farm	262	7000 feet of river banks

While the level of floodplain development of the Acme Valley between Acme and Saxon creates constraints for restoration, the goal of this report is not to assess restoration alternatives and identify constraints. Rather, the purposes of this document are to: (1) analyze existing information to characterize habitat-forming processes and salmonid habitat concerns in the reach; and (2) present recommendations for each of four generalized types of restoration envisioned for the reach — riparian restoration, mainstem South Fork habitat restoration, floodplain habitat restoration, and restoration of channel/ floodplain interaction. Constraints to restoration, restoration alternatives, and impacts will be identified in the Preliminary Restoration Plan, which will follow from this report.

Acme-Saxon Restoration Planning: Analysis and Recommendations

The goal of restoration activities in the reach is to restore historically representative habitat-forming processes when possible through active, voluntary restoration activities. Since funding is limited, it will be necessary to focus and direct restoration efforts towards recovering priority species (NNR et al. 2001). Habitat restoration in the reach will focus on Endangered chinook salmon and bull trout with a secondary focus on wild-spawning coho, chum, sockeye salmon, steelhead and sea-run cutthroat trout. By combining a process-oriented approach with an understanding of species and life stage needs, the assessment will ensure benefits to multiple species, while maximizing benefits to priority species.

Physical Characterization

Reach Description

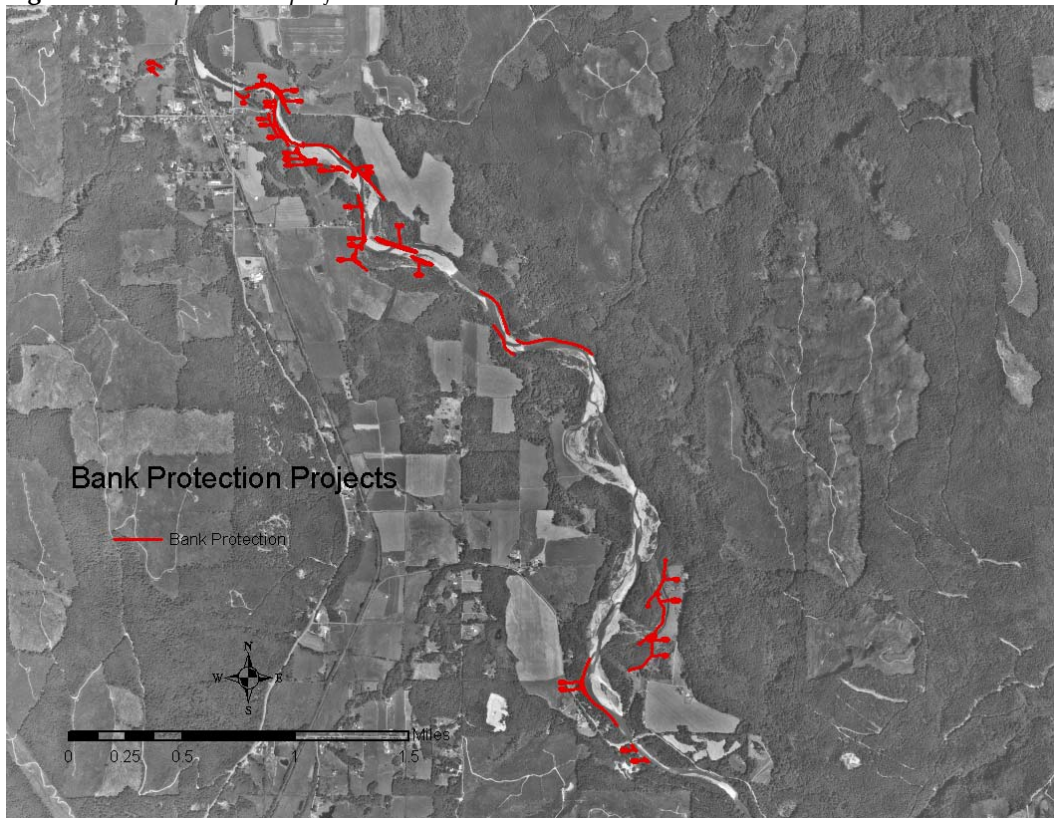
The South Fork Nooksack River passes under the Saxon Bridge, the upstream extent of the assessment reach, at River Mile (RM) 13 and winds northwest to the community of Acme (RM 8.5), which marks the downstream end of the assessment reach. The elevation of the valley floor is approximately 300 feet, with steep flanking ridges approaching 3000 feet. Alluvial fans are present along the valley walls where steep tributaries deposit sediment onto the flat plain of the South Fork. The Jones Creek alluvial fan, which lies at the downstream end of the assessment reach, has been historically active and at times has had a profound influence on the South Fork and its floodplain. At the upstream end of the reach, the South Fork Nooksack River exhibits a dramatic shift from a moderately confined channel to an unconfined channel, where the 100-year floodplain abruptly increases from .1 miles to between 1 and 1.3 miles (FEMA 1990). This unconfined portion of the South Fork Valley, from the Saxon Bridge downstream to the confluence with the North Fork Nooksack, is comprised of thick sequences of glacial outwash and Vashon glacial drift deposits overlain with river and lake deposits (Dragovich et al. 1997). Drilling near the town of Acme found recent river deposits to be 20-30 feet deep, with a maximum depth of 90 feet documented further downstream (W.D. Purnell and Associates 1988; Dragovich et al. 1997). This would imply that the Acme valley has had a long history of sediment deposition and storage.

The change in physiography between the more confined valley above the Saxon Bridge and the Acme Valley is manifested in a change in channel morphology. The wide floodplain and low gradient make this reach an area of fine sediment deposition, channel migration and wood accumulation. The large amounts of wood described in early accounts (Morse 1883) would likely have caused frequent channel jumping, or avulsions, among a series of channel configurations. Channel movement through avulsion, coupled with logjams that functioned as hard-points across the floodplain, would likely have yielded a patchwork mosaic of mature forest and immature forest, as has been described in similar reaches that have not been as heavily impacted by land use activities (Fetherston et al. 1995). Evidence of such river dynamics is present in the pre-historic South Fork channels that dissect the valley floor, some now occupied by floodplain tributaries such as the Landingstrip Creek area and lower Hutchinson Creek.

The area where the processes of channel migration and avulsion can occur has changed from early historic conditions. Currently, bank protection begins midway through the assessment reach and is nearly constant to the confluence

with the Nooksack River (Figure 2). Through this lower section of the reach, bank armoring strictly controls channel migration and the gradient becomes a nearly constant .002 (Figure 3). Through this lower section of the reach the channel has little opportunity to change in response to upstream inputs of sediment, wood and floodwater. Upstream of the bank armoring, the channel migrates freely, creating a range of gradients as the channel lengthens and shortens in response to upstream conditions. These two areas likely have a different potential for biological productivity and channel response under a variety of flow, sediment and woody debris levels. Based on historic channel positions, degree of bank protection and gradient, three reaches were selected for analysis. Figure 4 shows the reaches chosen for assessment along with channel positions between 1938 and 2000 (Whatcom County Public Works 1999).

Figure 2: Bank protection projects in the Acme-Saxon Reach.

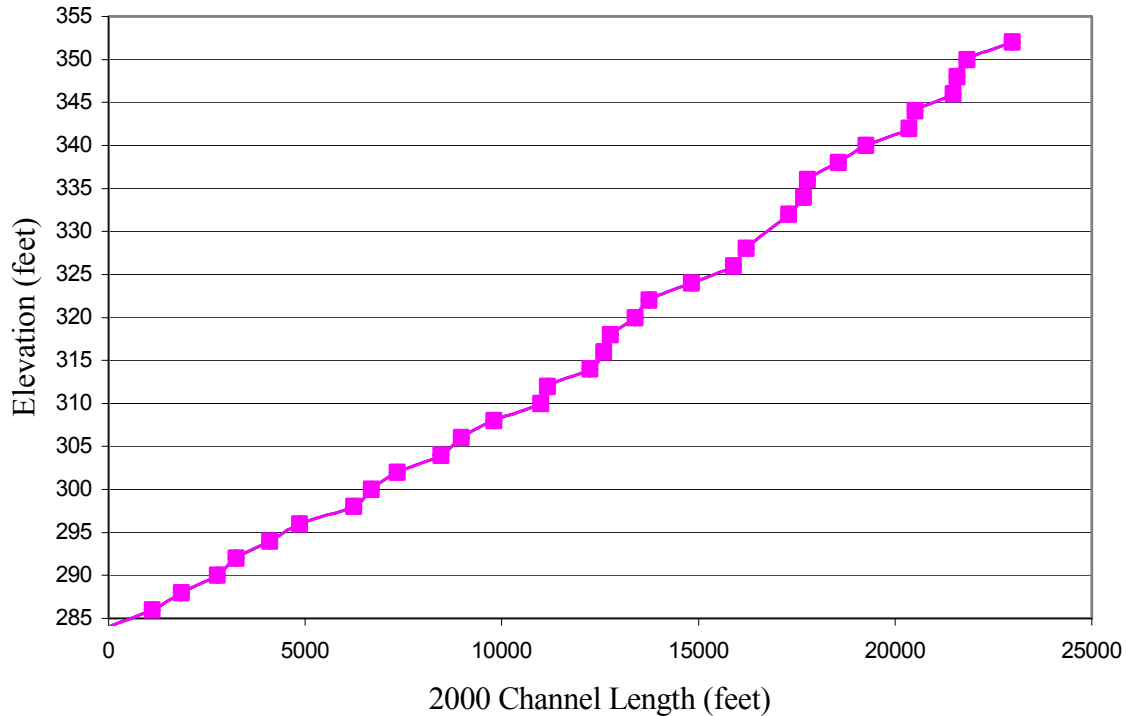


Reach Three is the furthest upstream, beginning at the Saxon Bridge and continuing downstream to immediately above Hutchinson Creek. This reach has little bank armoring within the historic channel migration area, although extensive bank protection work has been done along the boundary of the historical channel migration area. It has been a reach that has responded to disturbance through active channel migration, avulsion and widening. The channel through this reach is currently shorter than at any other time since the late-1930s because two major avulsions since 1990 have cut-off extensive portions

Acme-Saxon Restoration Planning: Analysis and Recommendations

of the channel length. These two avulsions have created the off-channel areas at Nessel's Farm and the Lawson Curtis property. Likely because of the freedom the channel has to move, the reach has the greatest variation in gradient, ranging from .002 to .011.

Figure 3: Acme-Saxon South Fork Nooksack Longitudinal Profile, 2000 Channel

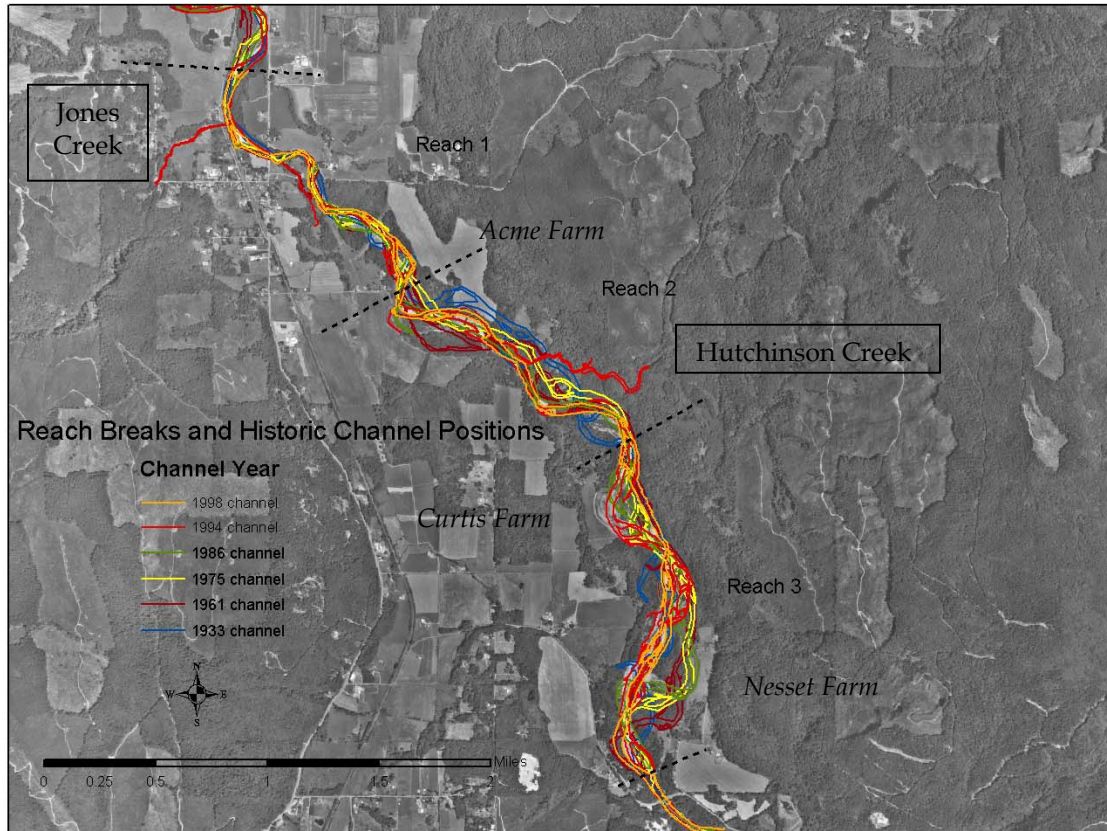


Reach Two begins above Hutchinson Creek and continues downstream to the Acme Farm. This reach has seen progressively more bank armoring between 1938 and 2000, with several installations narrowing the historic channel migration area. Likely associated with the bank armoring and channel cleaning operations, the active channel width of this reach has gotten progressively narrower since the 1966 aerial photos, despite several large flooding events in the 1980s and 1990s that caused channel widening in the unconfined reach upstream. The channel gradient through the reach varies less than the upstream reach, from .002 to .004. In spite of the extensive bank hardening, this reach has been gaining channel length since the mid-1980s when it reached a historic low. All of the gain in channel length has been due to channel migration at the one unconfined section of the reach, along Acme Farm.

Reach One begins at the Acme Farm and continues downstream to below the Jones Creek alluvial fan. This reach shows the smallest variation in channel position since the 1930s, possibly because it was the reach with the earliest bank protection focus. The reach is constrained by a railroad, the Williams natural gas

pipeline, the Valley Highway, Mosquito Lake Road and the town of Acme. The reach is now almost completely confined by bank hardening and has a nearly constant gradient of .002. This reach has seen the least variation in sinuosity since 1933 as well as the least variation in active channel width- showing only modest response to flooding events.

Figure 4: Reach breaks and historic channel positions in the Acme-Saxon Reach.



Hydrology

The characterization of channel response to flooding will rely on discharge recorded at the South Fork Nooksack gage at Wickersham (12209000), located upstream from the project reach. This gage is upstream from and, therefore does not include the influence of, either Skookum Creek (the South Fork's largest tributary) or Hutchinson Creek, which enters the South Fork midway through the reach. Flood recurrence estimates were calculated using the Log Pearson III method (Table 2). "Bankfull" discharge, or the discharge where a river tops its banks and accesses its floodplain, is considered to be an important channel-forming flow in lower gradient self-formed rivers (Wolman and Miller 1960); approximate recurrence interval of such flows is 1 to 2 years (Leopold et al. 1964). The annual or 1.5-year recurrence interval flow, an approximation of "bank-full" discharge, is approximately 8000 cubic feet per second (cfs) for the Wickersham gage.

Acme-Saxon Restoration Planning: Analysis and Recommendations

Table 2: Flood Recurrence Intervals for the South Fork at Wickersham gage (GeoEngineers, 2002).

Return Interval	Discharge (cubic feet per second)
Annual	8000
2-year	10000
5-year	14000
10-year	16000
20-year	19000
50-year	22000
100-year	25000

Evidence indicates that 5-year flows are important channel-forming events in steeper mountain channels, causing sufficient scour to alter the channel profile (Lisle 1981). The Watershed Analysis Methods Manual considers fish habitat significantly affected when the 5-year discharge (14000 cfs) occurs significantly more frequently (WFPB 1997). During several periods since the mid-1930s, a 5-year flood reoccurs with a high frequency (Figure 5). Between 1946 and 1951, the annual peak flow exceeded the 5-year flood in five of the six years. Conversely, between 1963 and 1976, a space of 14 years, there were no 5-year floods. In spite of the high annual peak flows observed in the reach, the 75% quartile (75% of all daily means are below this mark) of the daily mean discharge through the Acme-Saxon reach is well below 2000 cfs (Figure 6). From the late 1930s through 1998, the greatest variation in mean flow comes from October through April. This is the time of year when impacts to fish due to flooding and scour would be expected. Analysis is limited by the lack of flood season data from 1977 through 1994, when discharges were generally only recorded from June through October.

Because much of the watershed alteration occurred before the start of the hydrologic record, detecting a change in 5-year flow due to land use is difficult with data from the Wickersham gage, although gaining an understanding of channel response to flooding is possible. Review of aerial photos and channel plan-form changes indicates that the reach has likely changed the way it responds to flooding from historic times when the floodplain was unconfined and the channel choked with large pieces of wood. Accounts of the Acme valley from 1921 describe the response to floodwaters (Norgore and Anderson 1921):

“Following heavy rains during the winter months the river rises and causes complete inundation of vast areas on both sides. Every year the town of Acme is flooded.”

Acme-Saxon Restoration Planning: Analysis and Recommendations

Figure 5: Annual peak flow recorded at the Wickersham gage (12209000).

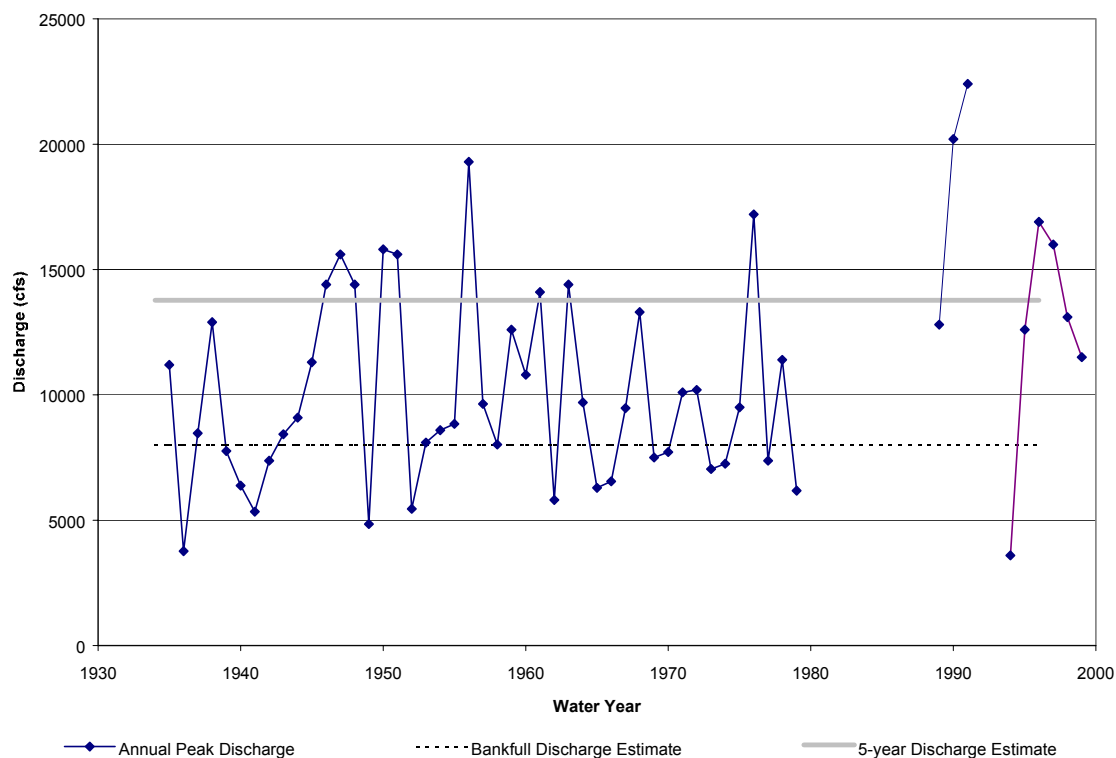
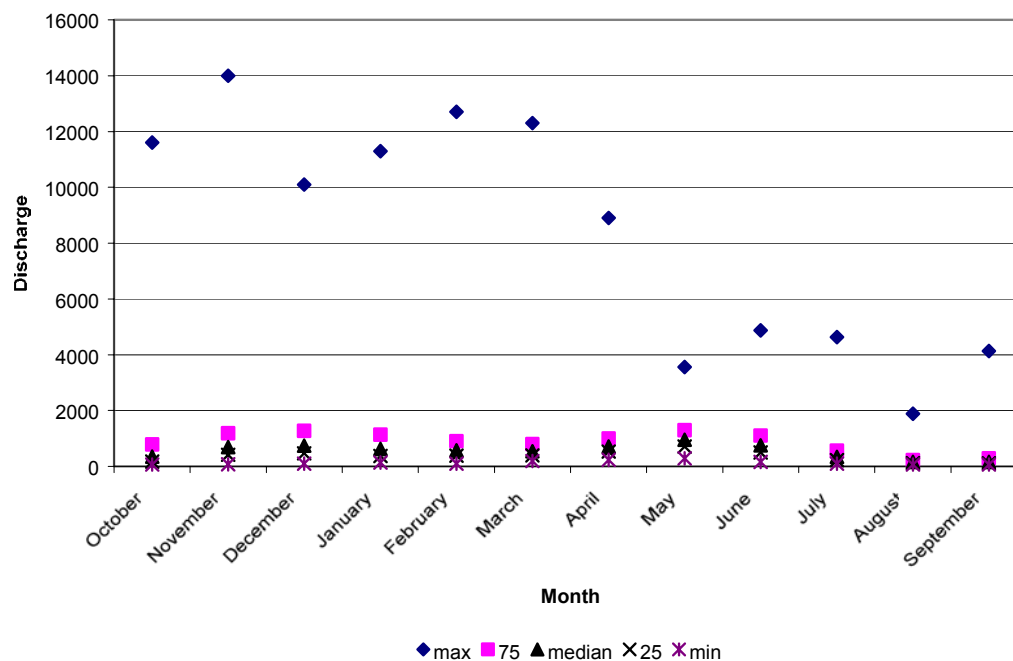


Figure 6: Monthly discharge (minimum, lower quartile, median, upper quartile, maximum).



Land use impacts, including removal of wood and installation of bank armoring, have led to the isolation of floodplain channels and wetlands that have potential to store flood water and moderate the impacts of flooding downstream. Since the installation of bank armoring in the lower half of the reach, the active channel no longer widens and creates secondary channels following flood events as the unconfined reaches do (see *Unvegetated Width* Section). Also, the channel length of the confined areas does not change due to channel avulsion and bank erosion as occurs in the unconfined reaches above (see *Channel Migration* Section). It is also likely that land use activities have lead to channel incision and isolation of the floodplain that was historically regularly flooded (GeoEngineers, 2002; see *Channel-Floodplain Interaction* Section). Currently, the annual flow is contained in a narrow corridor, in many places less than 200 feet wide, between armored terraces that once were part of the floodplain. These changes from wide floodplain to narrow floodplain would suggest that the confined portions of the channel have changed from areas where sediment and wood were historically deposited, to a transport reach where wood and sediment are moved more frequently through the channel.

Channel Classification

The South Fork Nooksack below Saxon Bridge lies in an unconfined alluvial valley, with slope of less than one percent. Due to the slope and floodplain width, the channel is predominantly transport-limited and an area where sediment and wood generated in the watershed is deposited and transported more slowly through the channel. The alluvial fill overlying the glacial deposits suggests that the current conditions are representative of a long history of sediment supply exceeding the transport capacity of the channel through this reach. In low gradient, unconfined valleys certain channel types tend to dominate because reach level morphologies are controlled by slope, discharge and sediment supply, along with wood loading, potential for debris-flow impacts and channel confinement (Montgomery and Buffington 1993). Currently, the channel through the Acme-Saxon Reach is characterized by pool-riffle morphology with pools formed by either semi-stable accumulations of large wood, bedrock or bank hardening.

Because pool-riffle channels are typically transport-limited areas, they can respond to changes in discharge, sediment and roughness elements in a variety of ways (Montgomery and Buffington 1993). In pool-riffle channels, increased discharge may cause bank cutting and meander development, potentially decreasing channel slope. Higher peak flow or more frequent sediment-transporting discharges can potentially increase depth of scour. Furthermore, increased discharge increases the degree to which basal shear stress exceeds the

critical shear stress for bed mobilization, which would increase bedload transport rates, decrease storage and potentially coarsen the bed. Lower frequencies of channel-forming flows leads to pool filling and increased sediment storage. Pool filling in response to increased sediment loading reduces bedform roughness and also increases sediment storage. Higher sediment loads increase the likelihood of bed fining, while decreased sediment loads can cause bed armoring. Increased supply can also expand the zone of active transport, causing bedload movement over a greater area of the channel.

Pool-riffle channels are extremely sensitive to the availability of flow obstructions (Montgomery and Buffington 1993). For example, removal of large woody debris (LWD) from channels (termed “forced pool-riffle” channels, Montgomery and Buffington 1998) in which abundant LWD maintains a pool-riffle morphology may result in either a change in the size and location of pools or conversions to plane-bed morphology. In one section of the Acme-Saxon Reach, the channel flows adjacent to the bedrock wall of the valley where it is straight and lacks any distinguishable channel bedforms. A change in the amount of LWD on large channels, where LWD acts basically as sediment, also has impacts on channel morphology. In some cases, debris jams control channel avulsions and side channel development across floodplains. Large, low gradient channels, such as this reach, are areas that generally have high wood loading levels. Historic accounts of the lower reaches South Fork Nooksack indicate that prior to land conversion and flood control, this area had large amounts of wood in the channel (Morse 1883, Sedell and Luchessa 1982). Wood mapping conducted in the summer of 2000, shows that unconfined portions of this reach are still areas with high wood loading, although artificial confinement has contributed to a reduction in wood per channel length from .226 pieces per foot of channel length to .064 pieces per foot in the confined portion of the reach.

The influence of riparian vegetation on channel bank stability is greatest in low-gradient, unconfined reaches where loss of bank reinforcement may result in dramatic channel widening, especially in non-cohesive alluvial deposits, such as those in the Acme Valley. This can be readily seen in aerial photos of the Acme-Saxon Reach, where the loss of streamside vegetation in the 1930s is associated with excessive widening of the active channel area and an increase in sinuosity. Because the channel began to rapidly move laterally, it became necessary to protect the infrastructure and the newly created farmland from erosion.

Currently, in areas where the channel migration is unconfined the dominant pool-forming feature is wood and in areas where the channel has been confined by bank protection, riprap is the dominant pool-forming mechanism. The wood that historically was in the channel would likely have led to an increase in pool frequency over that expected in a freely formed pool-riffle channel, creating

diverse in-stream habitat with an abundance of cover (Montgomery et al. 1995). Unfortunately, pool-riffle channels are both highly important for anadromous fish habitat and are most likely to experience significant, persistent impacts from changes in sediment, wood loading or flow regime (Montgomery and Buffington 1993).

Channel Planform

Sinuosity

Channel sinuosity, or the channel length divided by the valley length, in the Acme to Saxon Reach has changed throughout the historic period (Table 3). Changes in sinuosity represent the channel gaining and losing length through channel migration and channel avulsion, two important habitat-forming processes in the reach. Both channel migration and avulsion are natural processes as the river attempts to balance its channel configuration with the supply of sediment, wood and water. Changes in land use can influence this balance, causing the river to adapt to the changing conditions. Changes in sediment production, along with changes in run-off pattern from the upper watershed, have likely impacted channel conditions in a manner that will persist long after the initial disturbance has ended (GeoEngineers, 2002). Along with watershed-scale impacts, local changes can have impacts on the channel response by changing the rate of migration or the frequency of avulsion. Bank clearing for agriculture likely contributed to an increase in sinuosity due to rapid erosion into the unconsolidated alluvial banks. In other areas, bank hardening has reduced channel migration and the likelihood of channel avulsion, causing the channel length to remain constant for long periods of time. These changes can have important impacts to habitat creation and maintenance at the reach scale.

Table 3: Reach Sinuosity in the Acme-Saxon Area.

Reach	Aerial Photo Year												
	1933	1938	1943	1947	1956	1961	1966	1975	1986	1994	1998	2000	Mean (Range)
R1	1.25	1.22	1.19	1.27	-	1.21	1.25	1.19	1.22	1.20	1.22	1.26	1.23 (.08)
R2	1.19	1.29	1.14	1.22	-	1.18	1.44	1.12	1.08	1.12	1.17	1.21	1.20 (.36)
R3	1.22	1.34	1.30	1.46	1.37	1.32	1.12	1.27	1.34	1.19	1.11	1.13	1.26 (.35)
Entire Reach	1.22	1.29	1.22	1.33	-	1.24	1.26	1.20	1.22	1.17	1.16	1.19	1.23 (.17)

Since the 1938 aerial photographs, the channel has lost approximately 50% of its sharp angled meander bends (Crown Pacific Ltd. 1999), which are important because the increased scour on the outside of the bend can create the deep pools important to holding adult salmon. In many cases, these sharp angled bends were associated with bank clearing and increased lateral migration. In at least one instance, a tight bend appears to be the result of a logjam that has formed on

the outside of a meander, decreasing the radius of curvature of the bend. The latter bend formed in an area with mature second growth and larger deciduous trees in the riparian zone, where channel migration can undercut trees and form stable *in situ* logjams. These two different bank conditions (hardened and natural) represent different habitat quality for fish holding in the deeper water created by the bend. The logjam would have provided complex in-stream cover and formed a more persistent barrier to channel migration, increasing habitat stability, than the tight bend lacking the woody debris.

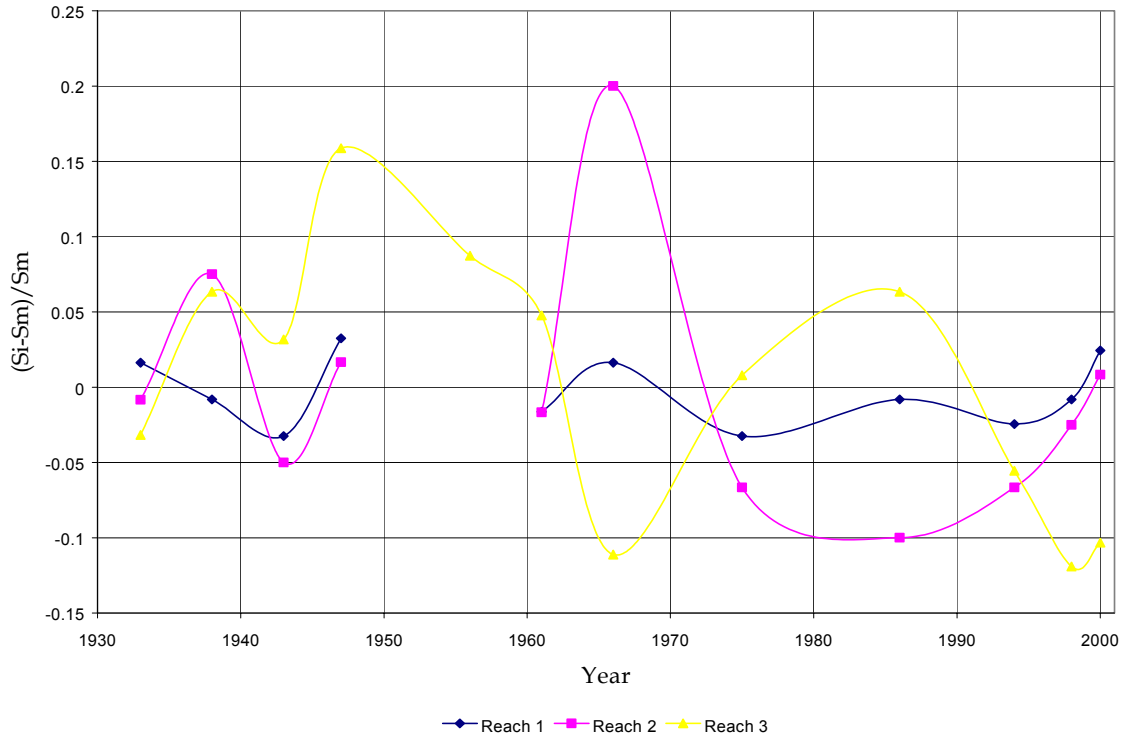
With the increase in bank protection, the riparian zone has been isolated from channel migration, halting the formation of stable *in situ* logjams. The reduced rate of recruitment means that wood accumulations in bank-hardened areas are formed from transported wood, rather than from local wood that is still connected to the stream banks, and thus more stable. Because logjams have an impact on channel migration and channel avulsion in the reach (GeoEngineers, 2002), the loss of more stable jams has likely had an impact on the variability of channel sinuosity, as well as channel length from secondary channels and ultimately habitat stability. Examining sinuosity of pre-historic South Fork channels indicates that the tight angled bends present in the 1930s were possibly more a result of local land use than a reflection of more pristine conditions, where sinuosity may have played a much less significant role in channel length than multiple channels. Sinuosity of the channel mapped on the 1885 General Land Office survey was 1.17, much less than the 1.29 calculated for the 1938 aerial photos. As the floodplain conditions changed following settlement, it is possible that the sinuosity became a more important mechanism for increasing channel length.

Following the 1938 photos, bank cohesion began to improve through the reach as riparian vegetation improved and bank protection projects became more widespread. The bank hardening projects began to have a considerable impact on habitat formation by reducing channel change due to channel migration and channel avulsion. The sinuosity in the three reaches reflects the impact of bank hardening and channel cleaning operations. From the sinuosity measurements, an index that relates the sinuosity of the aerial photo year to the average of all years was calculated ($[S_i - S_m]/S_m$, where S_i = individual measurement and S_m = mean sinuosity), where negative numbers show a loss in channel length and positive numbers show a gain (Figure 7). The variability in the channel length from year-to-year is reduced in Reach 1, which is impacted by bank hardening, while the variability is much higher in Reaches 2 and 3, which are less confined. Although the variability within the reaches differs, Table 3 shows the average values between the reaches are not markedly different (± 3 feet of channel length per 100 feet of valley length). This variability represents the channel's planform response to changes in discharge, sediment, roughness and local bank

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conditions and the creation and maintenance of aquatic habitat. As the variability decreases, the potential for habitat formation decreases.

Figure 7: Reach Sinuosity in the Acme-Saxon Reach (S_i = individual measurement, S_m =mean sinuosity).



Because sinuosity changes depending on the stage of the river, with alternating bars throughout the reach giving the low-flow channel added channel length, aerial photos can misrepresent the actual channel length and width depending on the channel shape. There are several intervals in the aerial photo record where drastic changes in sinuosity occur. As mentioned previously, the 1938 aerial photos probably reflect conditions heavily influenced by land use activities, where the channel was adjusting to rapid changes in local and watershed conditions. Also, the 1938 photos followed a fairly large peak flow, nearly a 5-year event, and may reflect that disturbance. Between 1938 and 1943, the channel loses considerable length, particularly in the second reach where the channel lost nearly 1000 feet of length. During this period, the river saw four successive years without a “bank-full” event. The channel through the Acme-Saxon Reach lengthened between 1943 and 1947 and reached its greatest sinuosity, as all three reaches were above their historic mean channel length. The 1947 photos reflected a steady increase in annual peak flow from 1941 to 1947, with consecutive annual peaks greater than a 5-year flood. The greatest increase in sinuosity in the 1947 aerials came in the area of the Nessel Farm, where two tight-angled bends developed and migrated into the adjacent agricultural lands.

Between the 1961, 1966 and 1975 aerial photos, sinuosity changed considerably. By 1961, Reach 3 had been steadily decreasing in channel length until channel avulsions and straightening in 1966 shortened the channel to a historic low. Also in this interval, Reach 2 increased in channel length, reaching its historic high. This increase in Reach 2 appears to be the result of channel migration into what is now the lower Hutchinson Creek area and the formation of a tight angled bend into a cleared field. By the mid-1970s, the channel began to increase channel length through migration in Reach 3 ultimately leading to the channel avulsion between 1986 and 1994, while the sharp angled bend in Reach 3 had been lost to a channel avulsion. Today, this same process is still active in areas that are not confined by bank hardening. The channel is creating a new tight angled bend adjacent to the Acme Farm where it is actively eroding a high, unforested terrace.

Based on the average floodplain gradient and the sinuosity of the channel, it is likely that the average gradient of the reach has not changed much from pre-historic conditions. This entire reach would have had a <1% (~0.003) gradient and been unconfined, based on a sinuosity of 1.26 (channel lengths per valley length). The sinuosity of 1.26 is the mean sinuosity of the portion of the reach without bank hardening, although changes in the wood and sediment have likely had an impact on the mean sinuosity before the 1933 aerial photos. A more significant change is the loss of variability in the channel length, which reflects the channel's inability to respond to changing watershed conditions, as well as a loss of habitat formation through channel migration and avulsion.

Unvegetated Channel Width

The Acme to Saxon Reach has experienced changes in bank cohesion since the conversion of much of the forested floodplain to agriculture. The changes in the active channel area (the unvegetated portion of the channel) through time are a result of channel response to discharge, sediment supply, local bank conditions and in-channel roughness. The two most important changes related to land use are vegetation clearing on the floodplain and subsequent bank protection to prevent erosion. Reduction in the riparian vegetation and the bank cohesion its roots provided has likely allowed the active channel width to increase and channel migration to occur more rapidly than historically when riparian and floodplain vegetation was intact. As the rate of channel migration increased into the newly cleared floodplain, efforts to halt the erosion using bank armoring increased. Through mapping efforts by Whatcom County and aerial photo interpretation, the sequence and timing of the bank hardening can be determined. Early projects began before the first aerial photographs in the 1930s and consisted of wooden pilings and debris piles to protect infrastructure (R. Knudsen, Acme-Van Zandt Flood Control Sub-zone, personal communication). By the 1960s, bank protection projects used almost exclusively rock and began to focus on protecting private landowners from channel migration. This led to long

stretches of river with armor along the edge of the active channel, narrowing the active channel width and halting further migration.

Changes in active channel width can have important impacts on the quality and quantity of aquatic habitat in the reach. The active channel area is where most of the secondary channel development occurs, as bars and vegetated islands separate the flow into smaller side-channels and braids. The Acme Watershed Analysis (Crown Pacific Ltd. 1999) indicates a loss of more than 37% of channel length in the South Fork Nooksack downstream of the Saxon Bridge since 1938, with nearly all of this representing secondary channel loss within the active channel area. The wide active channel width in 1938, which was likely a response to a loss of bank cohesion, probably led to an increase in secondary channel length over undisturbed conditions. Although these secondary channels probably provided a greater diversity of habitat, they appear to be highly unstable and most are not present from one aerial photo sequence to the next. In spite of the ephemeral nature of these secondary channels, their creation probably provided important habitat for a variety of species and life stages. One of the effects of artificially narrowing the active channel area is that these secondary channels are no longer formed and this habitat is lost without being recreated in another location. The greatest period of loss appears following the 1966 photos, when the channel narrows through Reach 2, showing a loss of all vegetated islands and a reduction in the length of secondary channels within the active channel area. This corresponds with a large-scale “stream-cleaning” project that removed wood and straightened the channel using gravel push-up dams to slow channel migration and halt flooding (see *Large Woody Debris* Section).

Another important aspect of active channel width is the deposition and storage of sediment and wood. The wide active channel area would have reduced the water depth of a given discharge. Because water depth relative to wood size is an important factor in wood stability in channels that are much wider than the length of wood, woody debris was likely stable for a greater range of flows than it currently is. This can readily be seen today by comparing the unconfined reach above Hutchinson Creek with the confined reach downstream of Hutchinson Creek. In the unconfined area, .23 pieces of large woody debris per foot of channel length were measured, compared to .06 pieces per foot in the confined area. Also, as mentioned earlier, bank protection projects halt wood recruitment to the channel and the formation of stable *in situ* jams, which act to collect and store transported wood and sediment.

The changes in unvegetated channel width are readily apparent through time. Table 4 and Figure 8 show the average and range of unvegetated, or active, channel width for each of the analysis reaches for a series of aerial photo years.

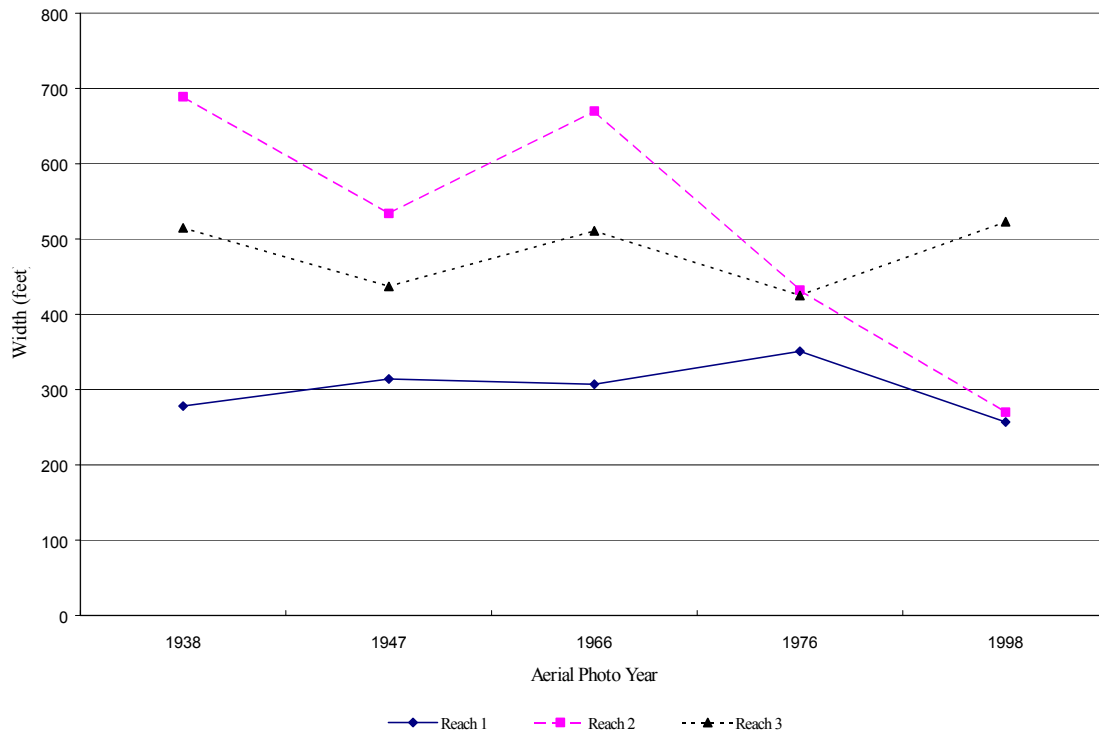
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Most of the channel widening visible in the 1938 aerial photos is likely related to lost bank cohesion due to land conversion of the riparian areas to agriculture. All of the widest areas of the active channel in the 1938 photos have all of the vegetation removed from at least one bank. In the four years of hydrologic record leading up to the 1938 photos, three bank-full events occurred (Figure 5). During the nine years between the 1938 and 1947 aerial photo sets, five bank-full events and two 5-year floods occurred. The two largest recorded peaks during the period occurred in October 1945 and October 1946, just prior to the photos. In spite of these floods, the mean channel width did not appreciably increase. This may indicate that the active channel width was responding more to a loss of bank cohesion than increased discharge, or that the channel was narrowing through the 1938 to 1947 period following a large event prior to the beginning of the hydrologic record in 1935. Although the active channel width did not increase between 1938 and 1947, the channel did increase in length in 1947, both through increased sinuosity and increased secondary channel length.

Table 4: Mean and Range of Unvegetated Channel Widths

Reach	Aerial Photo Year				
	1938	1947	1966	1976	1998
R1	278 (135-555)	314 (87-607)	307 (134-534)	351 (193-579)	257 (115-518)
R2	689 (406-1059)	534 (271-1005)	670 (267-1335)	432 (232-695)	270 (170-414)
R3	515 (204-1105)	437 (173-988)	511 (294-935)	425 (193-772)	568 (319-1243)

Figure 8: Unvegetated Channel Width in the Acme to Saxon Reach



Riparian vegetation had improved through the reach by 1966, and much of the length had been armored, greatly increasing bank cohesion and narrowing the channel. The only real trend in unvegetated channel width came in Reach 2 following the 1966 aerial photos, where the active channel decreased in width from 670 feet to 432 feet to 270 feet by 1998. The narrowing of the active channel in this reach can be attributed directly to bank protection as projects were constructed along Hutchinson Creek to protect the City of Bellingham waterline. This is an area where prior to 1976 the active channel area was split into several channels with small, forested islands separating the flow. By 1998, the average active channel width in both Reach 1 and Reach 2 were reduced to less than 300 feet, while Reach 3 remained the only unconfined reach where the channel can still adjust its width in response to changes in discharge, sediment supply and local conditions.

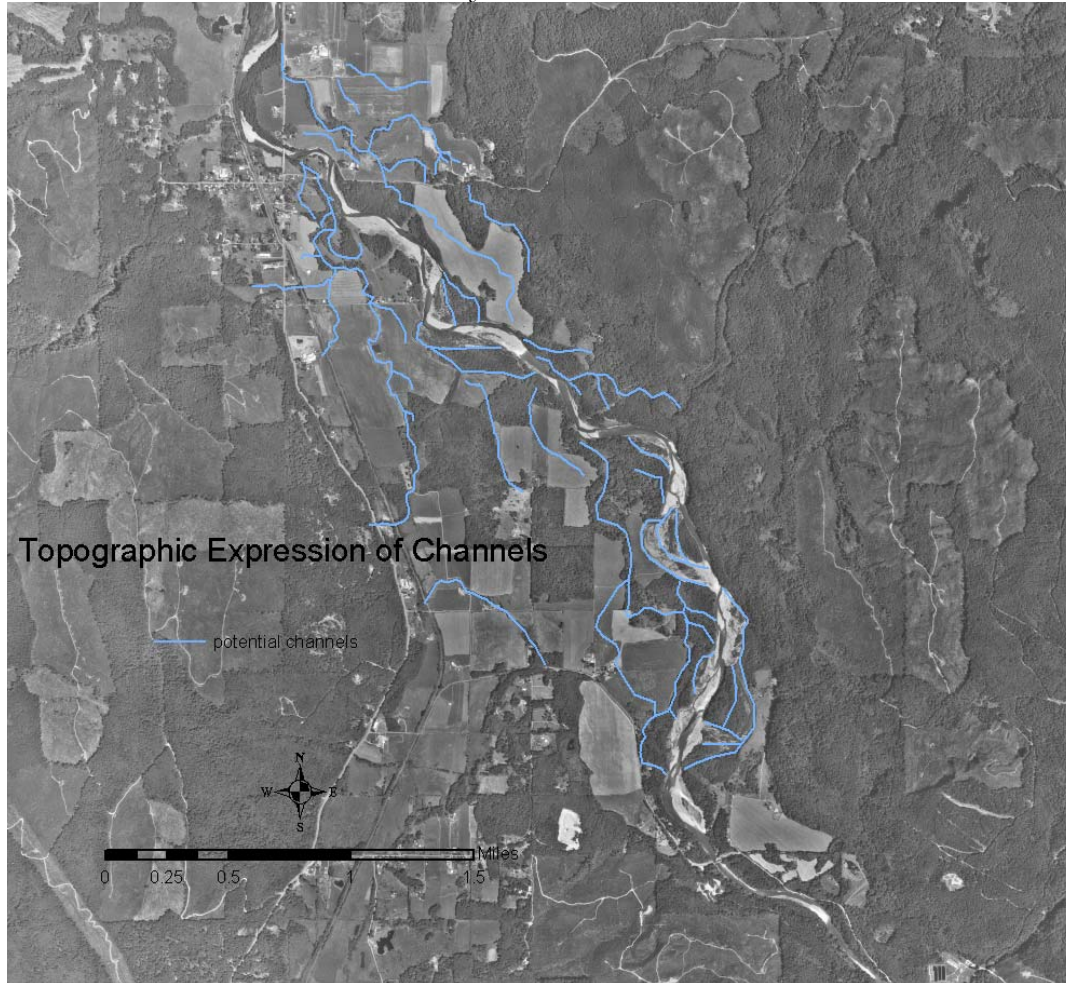
Channel Migration

The channel migration area is the area on either side of the river where the channel has historically migrated, or would be expected to migrate in the near future. The channel migration area width has been altered substantially from pre-development conditions. Topographic evidence of South Fork Nooksack channels exists across the entire 100-year floodplain from valley edge to valley edge (Figure 9). In many cases, these channels are abandoned by the South Fork and occupied by tributaries, creating low gradient areas that are protected from the forces of the main channel. An example of this is lower Hutchinson Creek, which currently occupies a relict channel, which was occupied by the South Fork as recently as the 1970s. In other cases, these old older channels become sloughs fed by groundwater, likely hyporheic flow, and the extensive wetlands that still exist in the valley. An example of this is Rothenbuhler Slough, a channel that was abandoned by the South Fork in pre-historic times, but still maintains surface flow from groundwater sources. These channels were likely formed through a combination of channel migration and channel avulsion, or the rapid shift of the river to a different channel position. Channel avulsions generally occur during larger flood events and are often caused either by the blocking of the main channel, by the breaching of a wood and sediment plug in a relict channel, or by local aggradation. Since the earliest aerial photo flights in the 1930s, all of these processes have been active in the Acme-Saxon Reach.

In an undisturbed system, channel morphology should be relatively stable (a dynamic equilibrium) and reflect the balance of sediment, flow, bank conditions and woody debris. Because this reach is a channel response area, the balance would reflect upstream watershed inputs as well as direct local impacts on the channel. The low gradient, unconfined valley would have been an area where wood and sediment would have been stored because the channel lacked the transport capacity, a function of slope and channel depth, to efficiently move the

material through the channel. The low gradient would be countered by the large channel size, which would tend to make the reach an area where single pieces of woody debris would have acted more like sediment, and be transported through the system rather than be independently stable. Turn-of-the-century descriptions of the reach describe large open bar areas that provided easy transportation routes for early settlers and frequent logjams in the channel, conditions indicative of a response reach (Royer 1982).

Figure 9: Relic channels across the Acme Valley.



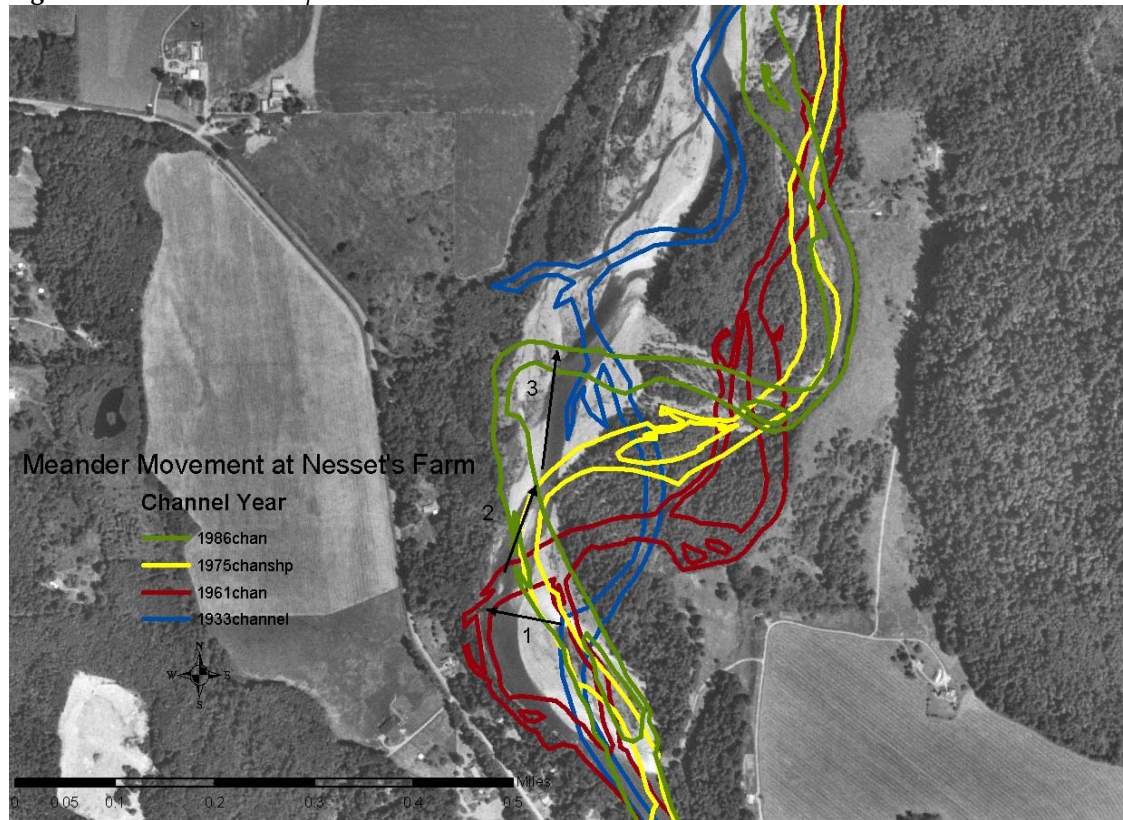
Since the late 1800s, land use has had a powerful impact on the channel morphology and channel migration. The earliest aerial photos show extensive land clearing for agriculture and timber harvest in the remaining riparian areas. Removal of large vegetation and roots from the banks of the river through most of the reach has decreased the resistance to erosion and left banks of unconsolidated alluvium exposed to the river. The loss of bank cohesion associated with these activities appears to have led directly to a widening of the active channel area in cleared areas and a subsequent increase in sinuosity. The

increase in sinuosity led to the formation of several tight angled bends, which were likely short-lived as more frequent channel avulsions severed the bends to re-establish a balance in the channel form. While these tight bends persisted, the increased centrifugal force would have created deep pools along the outer edges of the bend. Unfortunately, since these bends appear to be predominantly associated with the loss of streamside vegetation, pool cover would have been lacking unless woody debris was present. In at least one case, a logjam appears to have caused the tight-angled bend, creating an environment with deep scour from the bend and the logjam, with complex woody cover. Jams such as this would have likely been common prior to land clearing and formed persistent barriers to channel migration, slowing bank erosion, while providing more stable and complex in-stream habitat.

Channel migration in the reach occurs both laterally into the banks and longitudinally down the channel, depending on the curvature of the flow relative to the curvature of the channel, which changes depending on flow. In a curved channel as discharge increases, a lag develops between the channel curvature and the flow curvature, changing the location on the bend where erosion occurs. This becomes increasingly relevant as sinuosity increases, often changing the direction of channel migration as the high flow causes more downstream migration. As the channel migrates, it becomes longer and less able to balance the channel form with its sediment regime, water and roughness elements. In some cases, the channel will avulse into a new channel configuration to reach a better balance. When the channel avulses, the river appears to occupy relict channels, where it begins to migrate and adjust its length toward balance again.

Evidence of this process is present on the bend immediately upstream of Nessel's farm (Figure 10). This meander migrated 490' between 1933-1961 (17'/year), 575' between 1961-1975 (41'/year), and 700' between 1975-86 (64'/year). Between 1933 and 1961, the meander developed by lateral movement into the recently cleared banks. Following 1961, the meander changed direction and progressed downstream, without continued lateral migration. This is likely due to the lag between the curvature of the flow and extreme curvature of the channel. The increase in rate may reflect the channel moving through more recent alluvium, rather than the terrace that it was formerly migrating through. The rate of migration may have also changed as the channel sinuosity increased and scour intensified due to increased cross-stream flow from the increasing lag between the flow and channel bends. Between 1986 and the next channel map in 1994, the channel avulsed through a large meander jam that had formed on the bend and the meander was cut off. Since the channel avulsed, the meander is redeveloping and beginning to migrate laterally again. This sequence of channel lengthening and shortening has likely been the driving habitat-forming process since the stream-banks were cleared and large logjams removed from the channel.

Figure 10: Meander Development near Nessel's Farm.

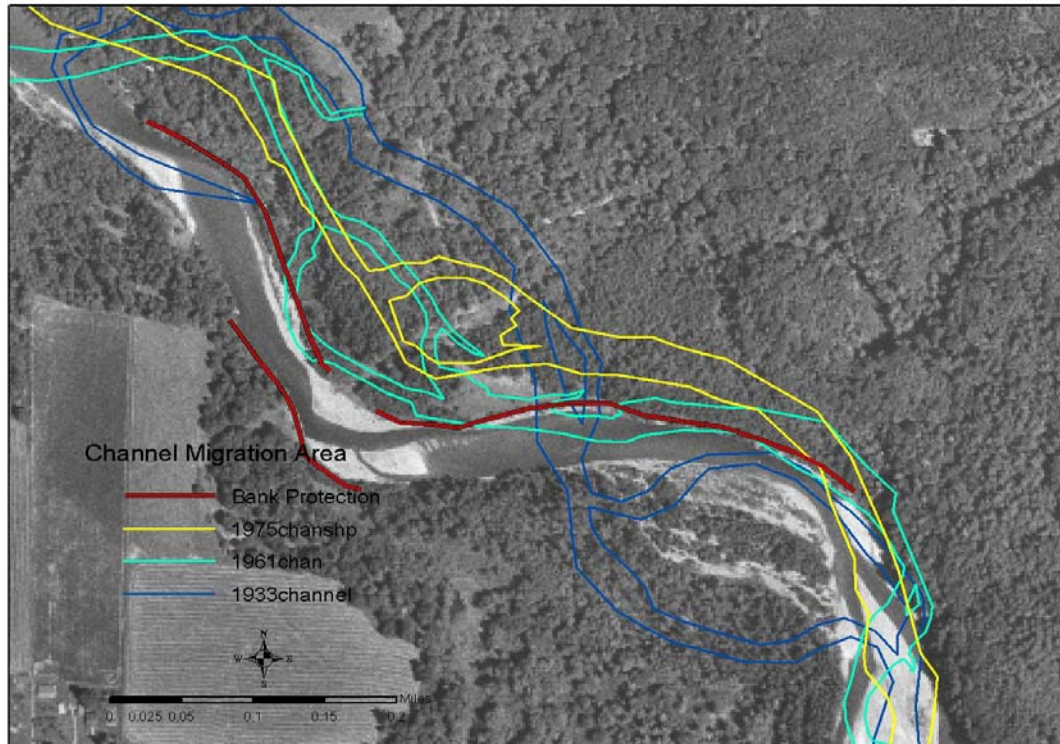


Bank protection followed quickly on the heels of bank clearing for agriculture and timber. The rapid channel migration and wide active channel area associated with the 1938 photos began to decrease as bank protection projects were constructed and riparian vegetation began to recover following timber harvest. Early bank protection projects were fairly limited, using pilings to control channel migration, and can be seen in the 1938 photos protecting the Valley Highway near the town of Acme. Wide-scale bank protection began in the 1950s, to provide protection for infrastructure, such as the gas pipeline that crosses the river at the Acme Farm, Mosquito Lake Road and the Valley Highway Bridge at Acme. Beginning in the 1960s, extensive bank protection was constructed in the reach to protect private property from channel migration. For example, nearly 4000 feet of bank protection was installed at Nessel's Farm to protect the fields from further erosion (Whatcom County Public Works 1999). Most of the earlier installations mark the farthest extent of historic lateral migration at the site, although topographic evidence suggests that pre-historically the South Fork occupied the area behind the revetments.

Of greater concern is where bank protection projects do not lie at the extent of the historic channel migration area, but rather constrict the channel and force it to adapt to a channel position not created by the discharge, sediment supply and in-channel wood. An example of this is lower Hutchinson Creek, where three

projects covering nearly 4000 feet were constructed to protect the City of Bellingham waterline and control channel migration. These projects reduce the historic channel migration area width from 1200 feet to 200 feet, while effectively halting the downstream migration of two meanders and severely impeding the primary means of habitat-formation for the area (Figure 11).

Figure 11: Bank protection adjacent to Hutchinson Creek, showing historic channel positions.

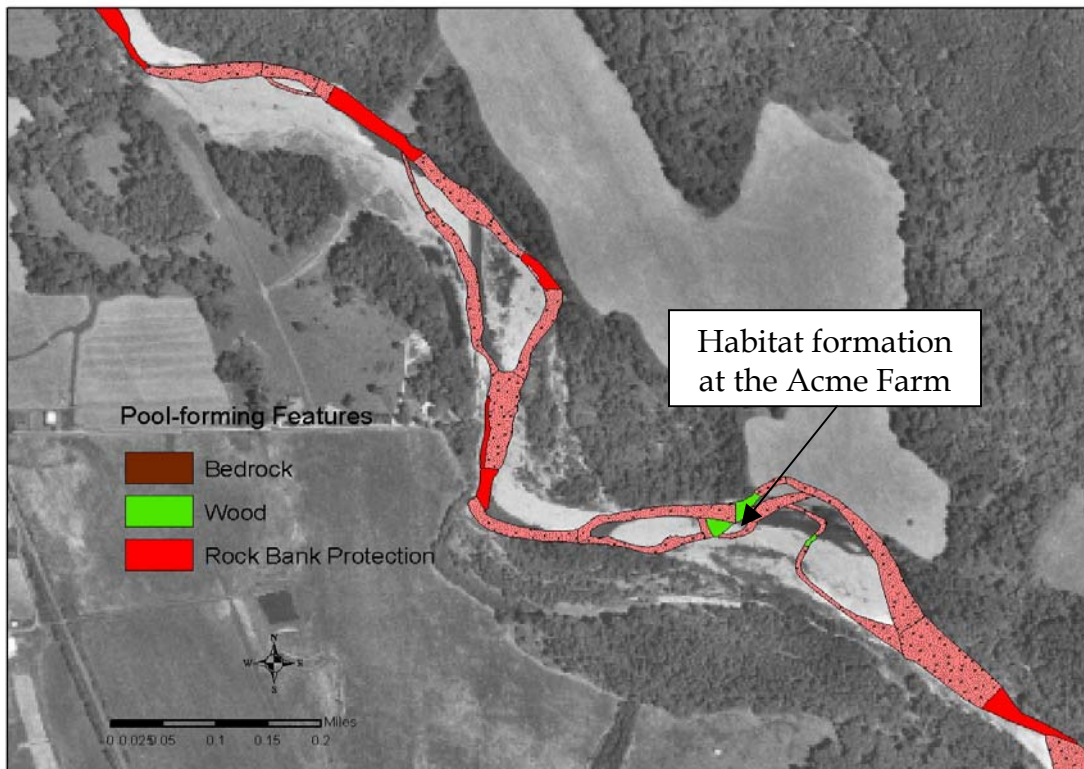


The area adjacent to the Acme Farm also illustrates another impact of bank protection- the loss of habitat diversity (Figure 12). Erosion at this site has led to the exposure of a relict logjam that is providing high quality habitat, and begun to tighten the radius of the bend, forming a deep pool with complex woody cover. The connection between riprap and habitat formation is reflected in the number of habitat units per mile of channel. The number of habitat units per mile of channel in a confined reach (the Roos property to Acme Bridge- 1.15 miles) was 20.9 units per mile, while in an unconfined reach (Knudsen's sloughs to Curtis Slough- 1.26 miles) it was 46.8 units per mile. This habitat diversity is critical because it reflects the capacity to support a variety of life-stage needs for a variety of species throughout a variety of flow conditions.

Another area where the channel migration area has been narrowed is located immediately downstream of the Roos property where a revetment on the left bank designed to protect a home and bank armoring on the right bank to protect

a gas pipeline reduce the width to approximately 350 feet. In another area, upstream of the Mosquito Lake Road, bank protection has narrowed the migration zone to less than 200 feet by cutting off a large secondary channel. Unfortunately, in these areas the bank armoring has allowed for development of the floodplain making removal more risky. The consequence of not allowing the planform of the channel to reflect the watershed conditions is that the channel must dissipate energy in different ways than it would under self-created conditions. One of the common effects is to adjust vertically through scour and fill when planform adjustments are not permitted.

Figure 12: Bank erosion and habitat formation near the Acme Farm.



Due to two major channel avulsions in the Acme-Saxon Reach between 1986 and 1998, the channel is currently shorter than it has been at any time in since the earliest aerial photos in the 1930s. Both of these avulsions occurred in the area where no bank hardening reduces the historic migration zone of the river: the Nessel Farm and the Lawson Curtis properties. The avulsion between 1986 and 1994 has lead to a loss of nearly 1400 feet of channel. This doubled the gradient from .002 to .004. Because the channel sinuosity is low through this area, the primary process for habitat formation would be from channel migration, as the river works to increase channel length, decrease slope and balance the roughness elements with sediment supply and discharge. The increased slope has also lead to an increase in stream power (a function of discharge and slope) for this reach.

Since the last major avulsion at the Nessel Farm site, between 1986 and 1994, the channel has gradually been gaining channel length through bank erosion. The channel length has increased from 5947 feet in 1994 to 6077 feet in 1998 and 6210 feet in 2000. Lowering the stream power and diversifying the channel form will likely increase woody debris and sediment retention while improving connectivity of the floodplain (GeoEngineers, 2002).

Sediment

Natural processes and human activities affect the volume, distribution and frequency of sediment transport in stream channels. While sediment transport processes are episodic over some time scale, channel response to sediment depends on the channel's ability to transport and store material relative to the amount of sediment supplied. When the sediment supply is greater than the ability to transport sediment, channel responses such as aggradation, channel widening, substrate fining, pool filling and channel braiding have been observed. Attributing these changes to changes in sediment is difficult, because a variety of variables influence channel transport capacity, including wood loading, hydrology, riparian vegetation changes and channel type. Local effects such as bank conditions or channel alteration for navigation or flood control further complicate the picture. The spatial scale of the disturbance is important because sediment perturbations can be dampened with increasing drainage area, meaning a modest local impact can have as great an impact locally as a large watershed-scale disturbance.

The Acme-Saxon Reach has seen a variety of sediment-producing disturbances through time. Prior to settlement, massive wildfires and landslides produced episodic pulses of sediment that the channel responded to. Early descriptions of the reach note large gravel bars that were used for transportation, indicating that prior to wide-scale human disturbance this reach was an area where large amounts of sediment were stored. On an early expedition through the reach Morse (1883) commented on the gravel bars, describing one that was a half-mile long in the reach. Settlement in the Acme-Saxon Reach began shortly before 1885 when the Government Land Office conducted the first surveys. An early description of the valley from the 1885 survey notes (Iverson 1885, cited in Royer 1982):

"The bottomlands on the South Fork are similar to bottomlands in the Puget Sound basin in general, with rather less sand and more clay in composition. In the Samish River bottoms the clay decidedly predominates-in either valley the land is very fertile."

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I think most of the upland will produce good crops. The only land unfit for cultivation is on the abrupt, stony mountain slopes. The water in all the streams in the township is clear and pure. Skookum Creek and the upper parts of Hutchinson Creek are very rapid and swarming with trout and salmon of very fine quality.

Nearly all the bottomlands are claimed and settled upon, and considerable land is cleared and in cultivation. In many instances the improvements of the settlers are located away from the lines of the survey and cannot be correctly noted without making special survey. The whole township is densely covered in timber- in places very large and fine. On the uplands fir, cedar and hemlock predominate. On the bottoms alder, maple, poplar, and birch with a dense jungle of vine maple, willow, crabapple and salmonberry brush. Undergrowth very thick."

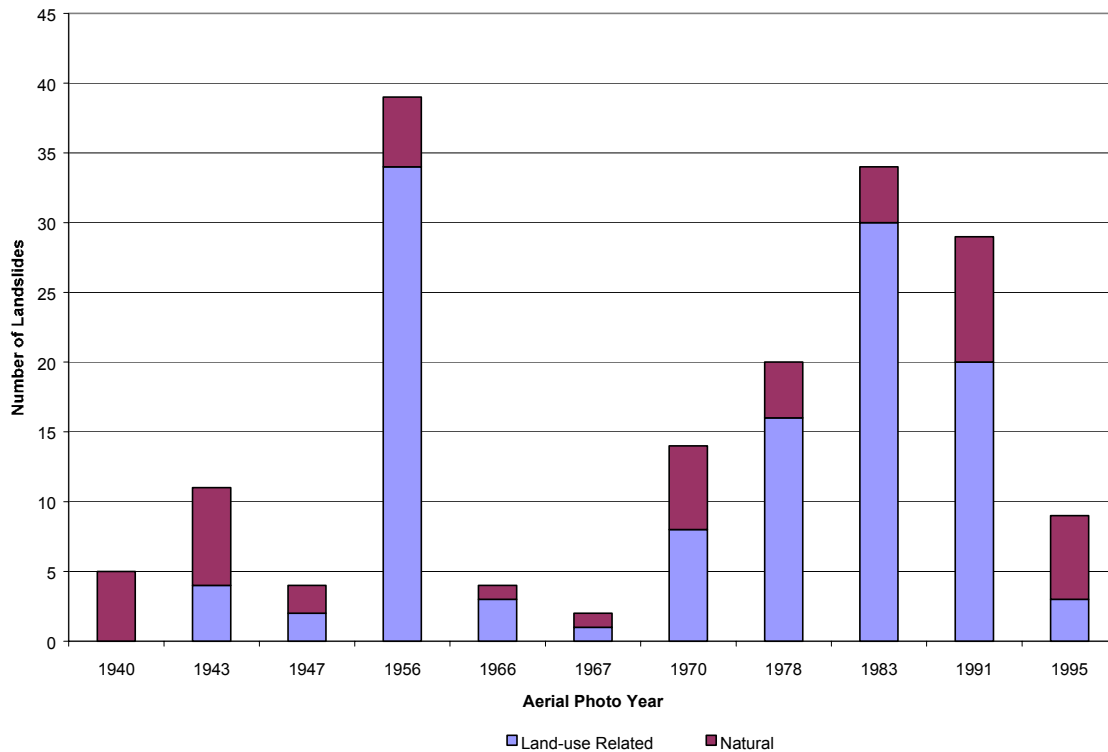
Early accounts of settlers describe extensive forest fires that occurred almost annually through the area, some of which covered the entire area from Bellingham north past the Canadian border. These fires were attributed to lightening strikes that left huge areas deforested and exposed to surface erosion. The earliest settlers came to the Acme-Saxon area to farm and began clearing and draining bottomlands of the South Fork Valley in the early 1880s. Clearing began slowly as trees were cut and stumps burned to open farmland. Following quickly on the heels of the pioneers came the loggers and the river and tributaries became one of the primary methods for transporting the logs to the mills located in the South Fork valley near Saxon. Early logging focused on cedar to fuel the more than 100 shingle mills in Whatcom County at the turn of the century. These early efforts were generally located near to a stream channel for transport or one of the railroad lines that sprung-up through the valley in the early 1900s.

Forestry and agricultural activities spread and intensified as new technology allowed greater access to undeveloped areas. By the time of the earliest aerial photos in the 1930s the entire valley was either in agriculture or timber production, likely having a large local impact on sediment production. The river was migrating rapidly into cleared land, eroding the fine-grained over-bank deposits that make up the terraces and former floodplain. This material was likely stored in the broad active-channel area of the river and episodically transported downstream. It is likely that the first aerial photos represent a channel that is responding to changes in bank cohesion and sediment supply from local sources. Widespread forest activity in the watershed upstream of the reach may also have had an impact by the 1930s, and certainly had an impact by the mid-1940s when landslides associated with timber harvest and road construction are apparent in the watershed (Figure 13). Landslide activity remained minimal in the South Fork between Skookum Creek and Howard

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Creek until the mid-1950s when a spike in landslides occurred rising from between 4 and 11 slides from 1940-1947 to 39 slides in 1956, probably in response to a large storm event (Watts 1996). Landslide activity returned to the earlier levels until the 1970 aerial photo year when they began to steadily increase, reaching another peak in the early 1980s with 34 recorded slides.

Figure 13: Landslide Activity in the South Fork between Skookum and Howard Creeks (Watts 1996).



It is difficult to determine the impact of sediment cumulative effects on the Acme-Saxon Reach. The large basin area can dampen the local response and the lag time between disturbance and response can vary. In spite of these complications, it is likely that the aerial photos from the late 1930s reflect more local sediment production than basin-scale sediment production, with later flights having an increasing watershed component. This is particularly true following the mid-1950s when road construction and timber harvest, the dominant human-caused disturbance in the watershed, intensified and land-use related sediment production increased. Current conditions probably reflect increased local bank stability from bank armoring and lessening sediment production from forest practices. The transport of stored sediment through the channel is generally episodic with periods of storage followed by pulses of movement, and it is likely that sediment produced earlier is still being transported through the South Fork and into the Acme-Saxon Reach from upstream. Because the Acme-Saxon Reach is characterized by a pool-riffle

channel morphology, which is dominated by channel roughness elements and has a low transport capacity, it exhibits more persistent change in response to altered sediment supply (Montgomery and Buffington 1993). Based on this, it is likely that the effects of past land use will be felt for a long time in the reach.

Stream Bed Material

The surface grain size in the Acme-Saxon Reach is useful for characterizing sediment supply in the reach, although the surface material is generally coarser than the underlying material, which better represents the actual bedload. Pebble count data were collected at a number of cross-sections through the reach. Data indicate that median grain size at cross-sections varies between 72.3 and 9.3mm. The percent of material less than 2mm varied from 0 to 48% of the clasts counted, depending on the cross-section, and the distribution is often bimodal with high proportions of sand. In the Acme-Saxon Reach, sand-sized material and smaller tends to accumulate in any backwater environment, as well as on the surface of shallow riffles and pools through the reach. In swifter water, fine sediment tends to accumulate on the downstream side of boulders and larger cobbles, or adjacent to woody debris. This would indicate a fairly high sediment supply in the reach.

Subsurface samples were collected within the reach using two methods. The Nooksack Natural Resources Department (NNR) collected samples using a McNeil sampler at two cross-sections in the reach, one near the Hutchinson Creek confluence and the second near the Williams pipeline crossing near Acme farm. The NNR effort identified the amount of material less than 1.7mm ranged from 15 to 32% of the sample volume (NNR, unpublished data). The higher percentage of fine material would indicate a high sediment load for the channel, which would be expected in the low gradient, unconfined area of the Acme-Saxon Reach.

As a part of the 2000 habitat data collection, NSEA estimated the percent embeddedness of the riffle areas. Percent embeddedness refers to the degree that fine sediment has filled the interstitial spaces of the larger substrate, for example fine sand filling the pore space in the gravel bed. Seventy-six percent of the riffle area mapped was in excess of 50% embedded with fine sediment. These estimates further suggest that the reach is an area where fine sediment impacts habitat quality and emphasizes the importance of local hydraulics for cleaning and sorting gravel. The local effects of rock, bedrock and wood can winnow away fine sediment and leave well-sorted, clean patches of gravel ideal for spawning. The loss of stable accumulations of wood and a diverse planform of the river has likely reduced the gravel sorting by local hydraulics and led to a more homogeneous substrate.

Gravel Bar Characteristics

Most of the readily available sediment in moderate to large channels is stored in gravel bars -- accumulations within the channel that are one or more channel widths long. Bars may lie in the center of the channel, along one side, or across the entire channel width, thereby forming pool-riffle sequences. Differential patterns of entrainment, transport and deposition of sediment during floods set up the general morphology of the channel bottom, which then determines flow characteristics at low flow (Sullivan et al. 1987). Bars may be forced by flow divergence associated with in-channel obstructions or freely formed, and include point, medial, multiple or forced bars. The location and area of gravel bars reflects the sediment load of the stream as well as the presence of flow obstructions. The type of gravel bars present in the reach, their association with obstructions, vegetation type and age and their relative proportion of the active channel area reflect the activity level of gravel bars. The current area of unvegetated bars in the reach varies between the three reaches (Table 5).

Table 5: Bar Area in the Acme-Saxon Reaches (1998).

Reach	Total Bar Area (ft ²)	Channel Length (ft)	Bar Area/ Channel Length (ft ² /ft)
R1	731799	5298	138
R2	661664	7747	85.4
R3	2503739	8914	281

Through the Acme-Saxon Reach, the bars are generally alternating lateral bars. The lateral bars give the channel a different channel pattern depending on the stage of the river. At low flow, the channel is generally single thread and the bars increase the channel sinuosity of the reach. At higher flow, the reach loses sinuosity, but gains channel length from secondary channels in the active channel area. The extent of the bars, along with the historic un-vegetated channel width indicates a fairly high sediment supply that is stored almost entirely in the active channel area. The narrowing of the active channel area from channel incision and bank protection has decreased the area where sediment can be stored. Reach 3 is the only reach where the channel migration area has not been narrowed by bank hardening and this is reflected in the amount of bar area, more than double that of Reach 1 and more than three times that in Reach 2 (Table 5). The loss of bar area through Reach 2 has been almost entirely related to narrowing the channel to protect the City of Bellingham waterline.

Riparian Function

In 2000, Duck Creek Associates conducted a riparian function assessment for streams in the Nooksack River watershed using 1991 (federal ownership) and 1995 (all other ownerships) 1:12,000 scale aerial photos (Duck Creek Associates

2000). Riparian vegetation within 100 feet of the apparent channel migration areas (in many cases the active channel) of stream channels was classified by type, size, and stand density; the combination of these three attributes was used to derive near-term LWD recruitment potential (Table 6). Stream shading (percentage canopy cover) was also estimated. Coe (2001) summarizes results of the assessment and presents additional analysis. Vegetation data were also compared to channel width (as calculated from cumulative precipitation, watershed area, and gradient) to determine whether adjacent riparian vegetation could supply large woody debris of sufficient size to form a pool (T. Hyatt, Nooksack Natural Resources, unpublished data, using Beechie and Sibley 1997 and Beechie et al. 2000). In this analysis, riparian stands were classified as “Pass” (riparian vegetation can supply pool-forming wood to adjacent stream), “Fail” (riparian vegetation cannot supply pool-forming wood), and “Threshold” (ability to provide pool-forming wood uncertain, given the resolution of riparian vegetation size estimates). Ability to supply pool-forming wood was not determined for large mainstem reaches, where single LWD pieces are unlikely to form pools by themselves, or ponds and wetlands, where pool-forming function of LWD is irrelevant.

Table 6: Relevant attributes from the Nooksack river Basin Riparian Function Assessment GIS Database.

Attribute	Values
Percentage canopy cover	0-20%, 20-40%, 40-70%, 70-90%, >90%
Vegetation Type	Conifer (>70%), Hardwood (>70%), Mixed, Pasture, Regenerating Conifer, Shrub, Urban, and Water
Vegetation Size Class	Large (>20" dbh [†]), Medium (12-20" dbh), Small (3-12" dbh), Not applicable
Vegetation Density	Dense (less than 1/3 ground exposed), Sparse (more than 1/3 ground exposed)
Near-term LWD recruitment potential	High, Moderate, Low

[†]Diameter-at-breast height (4 feet).

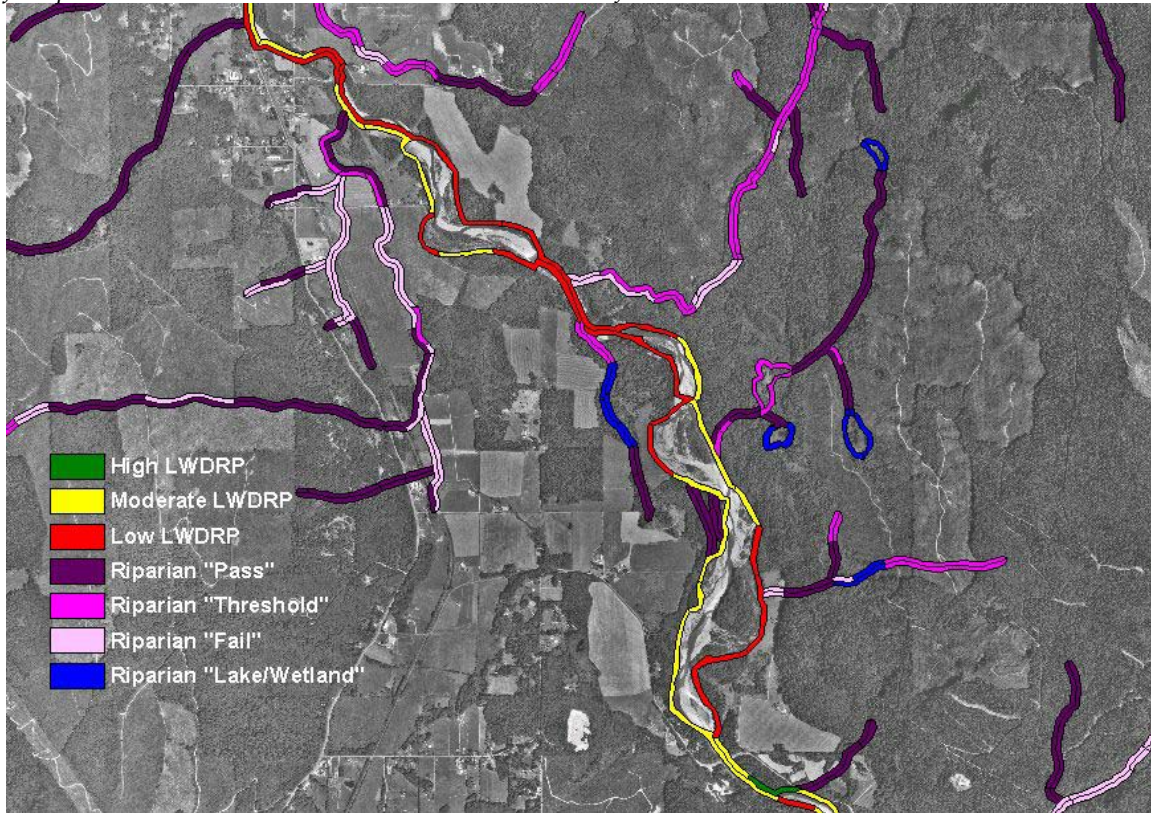
Riparian Condition

South Fork

The available riparian function data for the South Fork are limited to the 100-foot zones on either side of the active channel and, as such, characterize only a portion of the total area of potential riparian influence to the South Fork. Nonetheless, especially given that artificial confinement impedes channel migration through much of the reach, the results are informative. Along the Acme-to-Saxon reach of the South Fork, most riparian stands are dominated by small (50% of riparian area) and medium-sized (37%) hardwoods; the remainder is either pasture or grass (10%) or large hardwoods (2.6%). Most (62%) of the riparian area has low potential for near-term LWD recruitment; the remainder has moderate potential (Figure 14; Coe 2001). Notably, no areas with high LWD recruitment potential were found along the mainstem South Fork downstream of

the Saxon Road Bridge. Shading to the South Fork in the reach is minimal: 73% provides 0-20% canopy coverage and 25% provides 20-40% canopy coverage to the channel (Figure 15). While riparian shading is less likely to significantly influence water temperatures in wider channels such as the South Fork, infrared images produced from a recent overflight of the South Fork suggests that riparian shading can be associated with localized cooling, especially in secondary channels of the mainstem South Fork that have lower discharge (see Figure 46D).

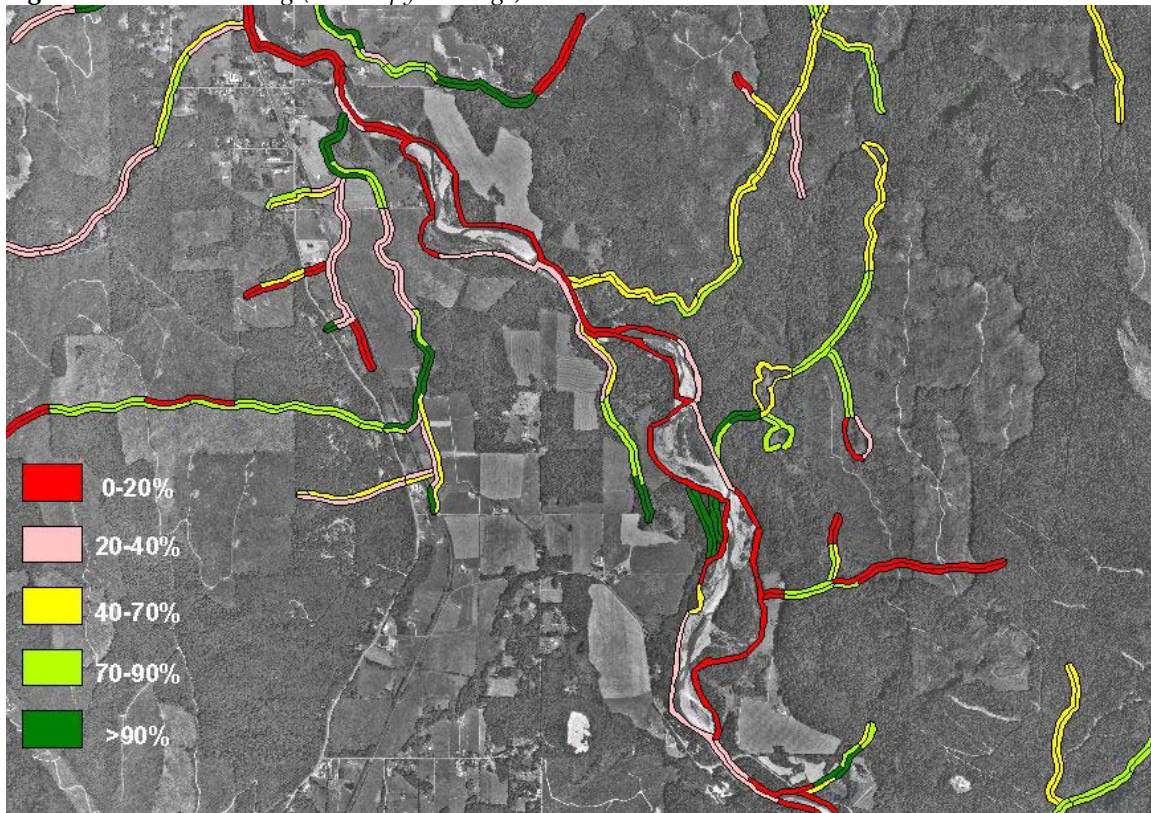
Figure 14: LWD recruitment potential (High/Moderate/Low LWDRP) along the South Fork and pool-forming potential of riparian vegetation (Riparian "Pass"/"Threshold"/"Fail"/"Lake/Wetland") along floodplain tributaries in the Acme-Saxon reach. See text for details.



Tributaries

Most (62%) of the riparian area associated with the Nessel's Slough complex is dominated by shrubs or regenerating conifers, followed in order of predominance by medium-sized mixed composition stands (25%), pasture/grass (6.4%), and medium-sized conifers (5.8%). Only 27% were dominated by vegetation that could supply pool-forming wood; 48%, 9.9%, and 15% fell into the "threshold", "fail", and "lake/wetland" categories, respectively (T. Hyatt, unpublished data; Figure 14). Most (69%) of the riparian area provided less than 20% canopy coverage, although 25% provided 70-90% canopy coverage (Figure 15).

Figure 15: Stream shading (% canopy coverage) in the Acme-Saxon reach.



In the Pond Creek watershed, most of the riparian area (61%) is dominated by medium-sized trees, including 50% of mixed composition and the remainder evenly distributed between conifer- and hardwood-dominated stands. Large trees dominated only 7% of the riparian area, although composition was mixed, and the remainder was small hardwoods (20%), small conifers (7%), or shrubs or regenerating conifers (4%). Most (60%) of the riparian area could supply pool-forming wood to the adjacent stream, while 17% was classified as "threshold" and 23% classified as lake or wetland (T. Hyatt, unpublished data; Figure 14). Riparian shading was largely 70-90% (48%) or 40-70% (36%); the remainder of the riparian area was evenly distributed between that providing >90% canopy coverage and that providing <40% (Figure 15).

Along the overflow channels feeding into Lawson-Curtis side channel, all riparian vegetation was dominated by medium hardwoods that had ability to supply pool-forming wood to the channel (T. Hyatt, unpublished data; Figure 14). Stream shading was high, as canopy coverage exceeded >90% throughout (Figure 15). Riparian vegetation along the lower end of the Lawson-Curtis complex was analyzed as part of the riparian zone of the South Fork.

Along Rothenbuhler Slough, riparian vegetation was dominated by small hardwoods (74%), or medium-sized (19%) or small (7.4%) trees of mixed

composition. About a third of the riparian area (34%) could supply pool-forming wood, 24% was classified as "threshold", and 42% was classified as lake or wetland (T. Hyatt, unpublished data; Figure 14). Canopy coverage was at least 20% throughout, and most met or were close to target shade levels of 80-90% (WFPB 1997), including 41% and 19% of the riparian area providing 70-90% and 90%, respectively, canopy coverage (Figure 15). The remaining 40% was fairly evenly distributed among 20-40% and 40-70% (WFPB 1997).

Along that portion of Hutchinson Creek surveyed for habitat and wood by NSEA (roughly that which flows across the floodplain), medium hardwoods, at the "threshold" for supply pool-forming wood, dominated 56% of the riparian area and the remainder was small hardwoods, which would not supply pool-forming wood (Figure 14, T. Hyatt, unpublished data). Canopy coverage along this portion was largely 40-70% (comprising 83% of the riparian area; Figure 15), although target shade levels were 80 to 90% (WFPB 1997). In the larger Hutchinson Creek watershed, riparian stands were dominated by mostly medium-sized trees (67%), including mixed composition (45%), hardwoods (14%) and conifers (9.4%). 20% was classified as either shrub or regenerating conifer, while large conifers dominated only 1.3%. 58% of the riparian area was dominated by vegetation that could supply pool-forming wood to the adjacent stream, 25% classified as "threshold" and 7.6% was too small to supply pool-forming wood (T. Hyatt, unpublished data). With regards to stream shading, percentage canopy coverage exceeded elevation-range-specific target levels in 32% of the riparian area in the watershed, but most (56%) was at least 10% below target, including 20% that was at least 40% below target (Coe 2001).

Along Landingstrip Creek, only 6% of the riparian area was dominated by large hardwoods and 35% was dominated by medium-sized trees, including 23% hardwood, 7% conifer, and 5% of mixed composition. The remainder was dominated by pasture/grass (31%), shrubs/regenerating conifers (14%), or small-sized conifers (6%) or hardwoods (7%). Half of the riparian area could supply pool-forming wood, 13% were at threshold levels, and 37% could not supply pool-forming wood (T. Hyatt, unpublished data, Figure 14). Target stream shading levels of 90% canopy coverage were met in only 12% of the riparian area (Figure 15). Of that remaining, 19%, 26%, 18%, and 25% of the area provided 0-20%, 20-40%, 40-70%, and 70-90% canopy coverage. In the larger Landingstrip Creek watershed, only 32% of the riparian area was dominated by vegetation that could supply pool-forming wood; most of the area (59%) classified as failing and 9.3% was in the threshold range.

LWD Recruitment

Recruitment of wood to the South Fork Nooksack is influenced by bank conditions through the reach. Of the 21,900 feet along the right bank of the South Fork through the Acme-Saxon Reach, there is currently 6,040 feet (27%) where the channel can recruit wood through channel migration. This is due to flood control and bank protection measures, as well as a bedrock outcrop that naturally halts recruitment from 4,755 feet of the channel. Of the 6,040 feet of length where recruitment can occur, 92% of that length is classified as small, dense hardwood stands that have a “low” recruitment potential and 8% is medium-sized, dense hardwood-dominated stands that have a “moderate” recruitment potential (Duck Creek Associates 2000).

The left bank of the river is in better condition than the right bank in terms of river recruitment of LWD from its historic riparian recruitment area. Of the 22,765 feet of length along the left bank, 17,450 feet (76%) of the length is accessible to channel migration. Fifty-five percent of the length accessible to migration is classified as “moderate” recruitment potential; 51% of the length is comprised of medium-sized, dense hardwood stands and 4% large-sized, dense hardwood stands (Duck Creek Associates 2000). The remaining 45% of accessible length have low potential for wood recruitment, with 32% classified as small, dense hardwoods, 7% agricultural land, and 6% small, sparse hardwood stands (Duck Creek Associates 2000).

Barriers to Natural Recovery

Lack of Nurse Logs and Seed Sources

Anecdotal field observations indicate that a majority of the Acme-Saxon riparian stands are lacking adequate nurse-log and seed source elements, which are the primary factors limiting conifer regeneration within a deciduous understory (Beach and Halpern 2001). Given the current predominance of deciduous stands in the riparian zone, active conifer re-planting and release should be prioritized.

Invasive Non-native Plants

An obstacle to restoring native riparian species that will eventually form and maintain improved habitat conditions in the Acme to Saxon Reach is the rapid spread of non-native invasive plants. Persistent invasive species include Japanese knotweed (*Polygonum cuspidatum*), Himalayan blackberry (*Rubus ursinus*), reed canary-grass (*Phalaris arundinacea*), and Canadian thistle (*Cirsium arvense*). These species, as well as other invasive species that develop a monoculture, displace native shrub, grass and forb communities and disrupt the natural establishment of native tree species. Among the most pernicious of the invasive species is Japanese knotweed, which is having a particularly adverse impact on emergent gravel bar habitat where it displaces early successional native plant species. Of particular severity is the extent and vigor of knotweed

colonies on the banks of lower Hutchinson Creek, which have spread downstream to the South Fork Nooksack. Controlling non-native species is an ongoing challenge for riparian stand restoration projects. Details on the characteristics, impacts and control methods for Japanese knotweed and giant knotweed (*Polygonum sachalinense*) can be found in *Riparian Habitat Restoration: Control of Japanese Knotweed on the Mt. Baker-Snoqualmie National Forest* (U. S. Forest Service 2001). Lummi Natural Resources has completed the first year of a one-acre-sized knotweed control pilot project on the Whatcom Land Trust Roos parcel and initial indications of success and cost effectiveness are promising.

Large Woody Debris

General Abundance and Distribution

Historic Conditions

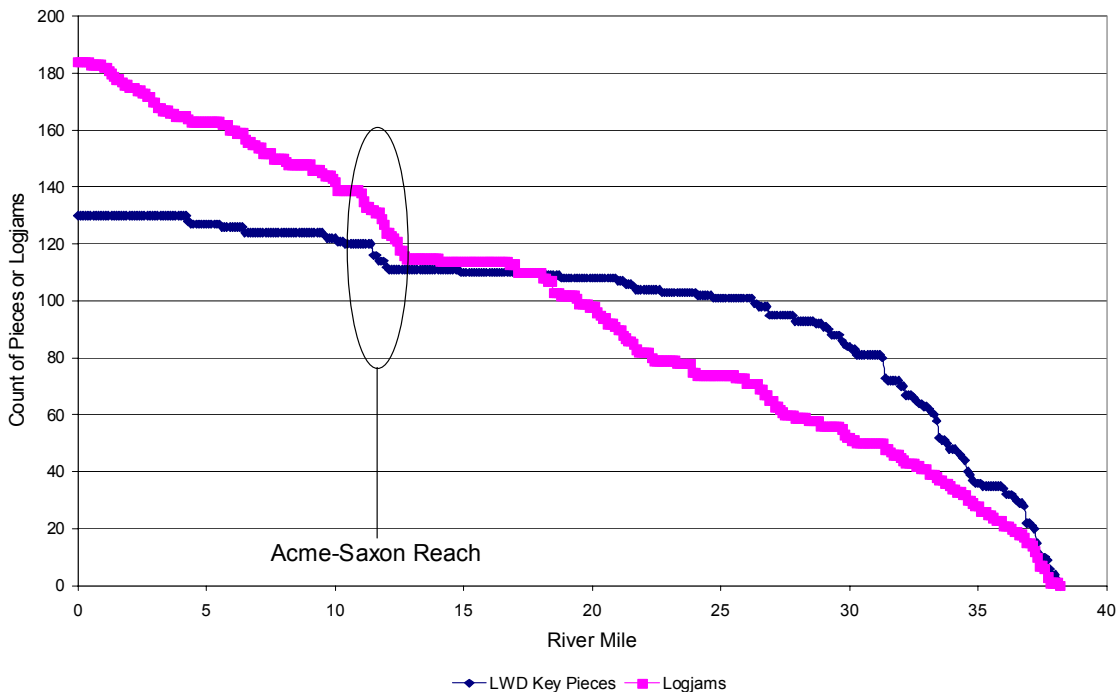
Accumulations of large woody debris play an important role in influencing stream channels and fish habitat in the Acme-Saxon Reach. As channels increase in size, the ability of single pieces of wood to alter the channel becomes more limited and the importance of semi-stable accumulations to habitat formation increases. In larger channels, like the Acme-Saxon Reach, debris jams can influence streambed and bank scour or aggradation, side-channel development and maintenance, bar stability and island formation (Abbe and Montgomery 1996). The functions provided by woody debris change based on channel width, channel type, confinement and gradient (Montgomery and Buffington 1993). Because the Acme-Saxon Reach is low gradient and unconfined, it is an area where large woody debris is deposited and stored (Figure 16); historically forming large drift jams (Figure 17). When wood was abundant in the Acme-Saxon Reach, it likely provided a variety of functions to the channel that were lost when the wood was removed and riparian vegetation cleared.

In the Nooksack Basin, riparian wood recruitment has been altered or interrupted by land use activities. Riparian forestry, road building, channel cleaning, land clearing, bank hardening and invasive species have slowed, and in some cases completely halted, wood recruitment to the channel. The earliest descriptions of the wood in the reach come from the 1880s, prior to wide-scale development of the Acme Valley. This reach is downstream from where Morse (1883) first described the South Fork Nooksack having channel-spanning logjams. It is within the area where Morse describes logjams “across the river nearly every mile for the next 20 miles downstream”. Morse also describes many millions of feet of sound timber on the gravel bars that could be cut in low water and transported downstream in the winter. The Acme Watershed Analysis states that the South Fork downstream of the Saxon Bridge at one time contained a woody debris jam that was several miles long (Crown Pacific Ltd. 1999).

Acme-Saxon Restoration Planning: Analysis and Recommendations

Another account describes the occurrence of a full river-spanning log jam that children of the Saxon area had to walk across to reach the first public school in the South Fork valley, which was built on the east side of the river north of the current Mosquito Lake Road, with teaching begun in 1888 (Royer 1982).

Figure 16: Wood Distribution in the South Fork Nooksack 2002.

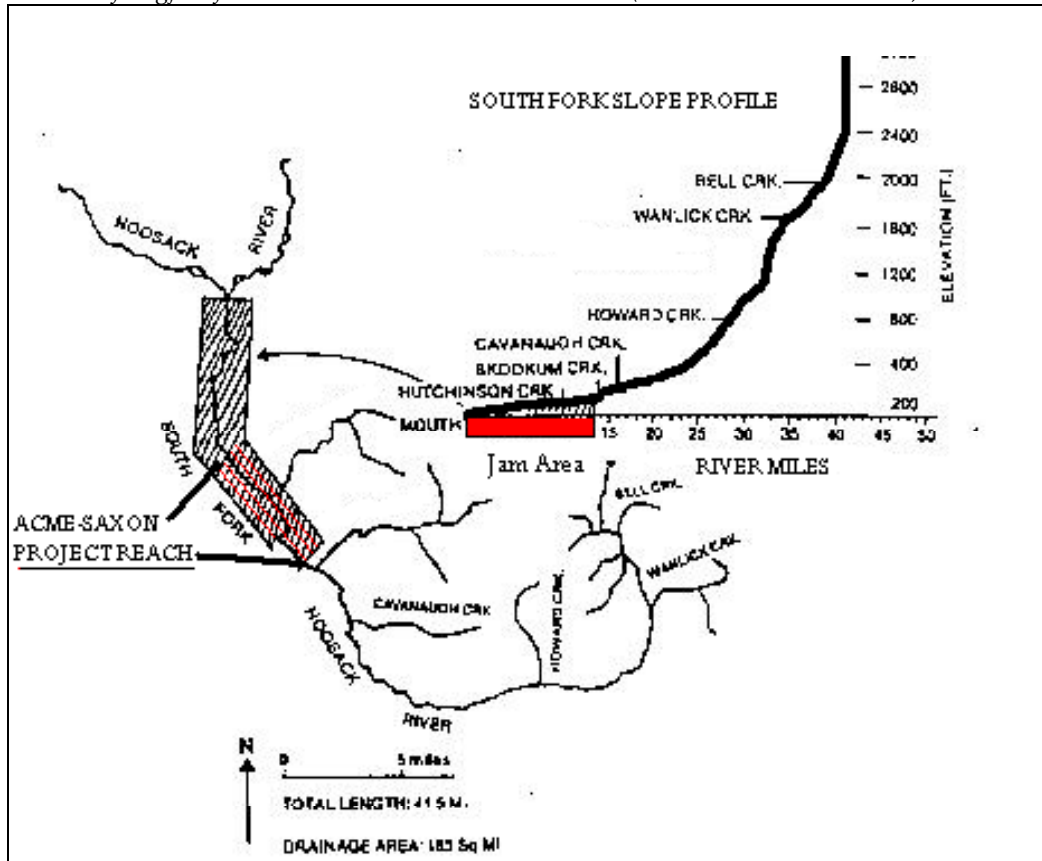


During the twentieth century, logjams were actively removed from the channel, which resulted in virtually 100% of the large wood being taken from within the channel and floodplain of this portion (downstream of Skookum Creek) of the South Fork Nooksack (Crown Pacific Ltd. 1999). All of the major logjams had been removed from the lower South Fork Nooksack in the Acme Watershed Administrative Unit (WAU) beginning in the late 1800s (Crown Pacific Ltd. 1999). This work probably completely changed the South Fork Nooksack by the time of the earliest aerial photos in the 1930s. There is also evidence of substantial transport of wood from logging operations down the river. A salmon hatchery egg eyeing station was built on the South Fork near Acme in 1908, but owing to winter freshets and the “immense quantity of shingle bolts driven down the river”, the report discouraged any further attempts to rack the South Fork to obtain broodstock (20th and 21st Annual WDF Report, 1909).

In aerial photos from 1938, wood was already fairly sparse in the active channel area and does not reflect the descriptions from the turn of the century. Wood that can be seen on the aerial photos is largely in loose accumulations on the tops of the bars. Two large logjams appear to be stable and have had an impact on the channel. In both cases, the jams are located on the outside of meander bends and

have tightened the radius of the bend as they slowed channel migration. The first of these was located in Reach 3 on the left bank immediately upstream of the Lawson Curtis property; the second is located in Reach 2, downstream of Hutchinson Creek. Other accumulations occur at the upstream heads of small, vegetated islands within the active channel area of the South Fork. These accumulations appear to be fairly stable and many persist through the 1943 aerial photos. Single large pieces are also present in the low-flow channel and along the banks of the river.

Figure 17: Drift logjam formation in the South Fork Nooksack (Sedell and Luchessa 1982).



A similar pattern of wood distribution appears in both the 1943 and 1947 aerial photos. Wood is sparse compared to early descriptions and located on the bars adjacent to the main channel or in small accumulations associated with vegetated islands in the active channel area. Through both of these photo years, the two large meander jams appear to be present. By the mid-1950s the first evidence of “stream-cleaning” is present on the aerial photos. Sections of the active channel are bare of wood and several earthen barriers have been constructed to contain the flow to a single channel and improve routing of floodwater through the reach. In aerial photographs from 1966, it is possible to see the upstream progression of the channel cleaning work, which had reached the Acme Farm area by the time of the photos. Oblique aerial photos taken during the summer

of 1967 show the reach immediately following a channel cleaning operation where all wood and vegetation has been removed from the channel and gravel “push-up” dams have been constructed to create a high flow channel for the river. The bar area has been leveled and the channel straightened. This activity essentially reset the clock for in-stream wood and the riparian conditions have not allowed for the local recruitment of large wood to replace the wood that was removed.

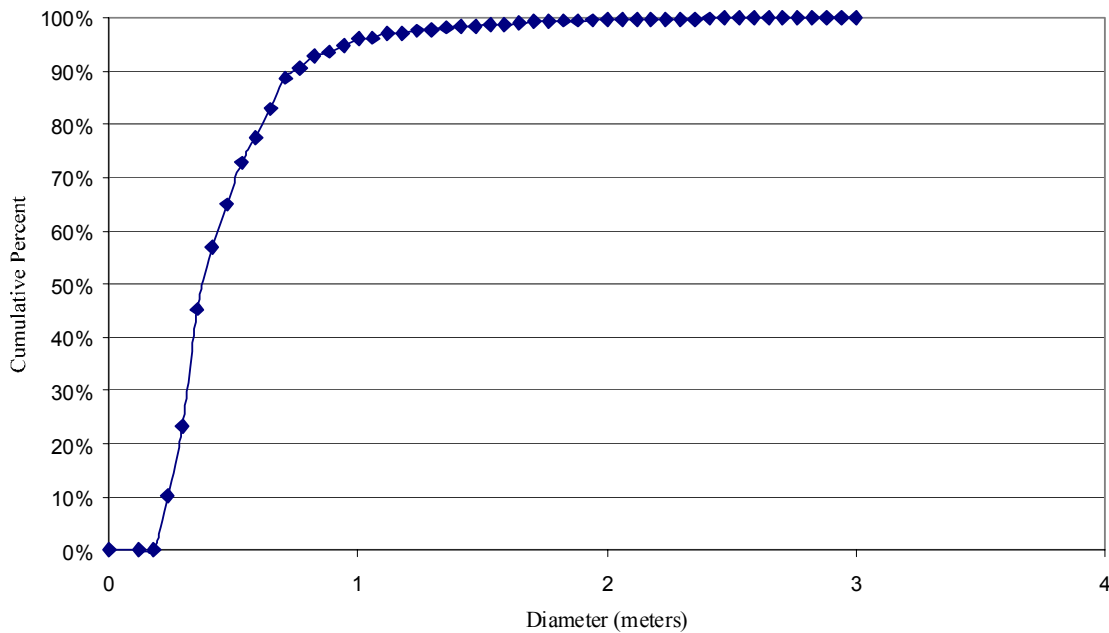
Aerial photos taken in the mid-1970s show the channel planform still in essentially the same configuration created by the stream-cleaning activities of the prior decade. Very little wood is present in the photos and the active channel area is still narrow from the channel work. In the unconfined portions of the reach, the channel has continued to migrate and avulse since mid-1970s and wood levels appear to be increasing in these portions of the reach. Large meander jams began to reform after the channel cleaning activities. For example, along the outside of the meander located adjacent to Nessel’s Slough a large meander jam was described in the brood collection reports for the Skookum Hatchery (Lummi Fisheries, 1980-1988). Associated with this jam was a deep pool known as “Saxon Hole”, and noted to be one of the more productive sites for capturing holding chinook for brood stock. In the 1998 photos, wood is still relatively sparse in the more confined portions of the channel and much of the natural recruitment has been lost to bank protection. For much of its length, the Acme-Saxon Reach has no wood recruitment from bank erosion due to bedrock outcrop or bank protection projects. Approximately 24% of the left bank and 73% of the right bank do not actively contribute wood to the channel except through wind-throw or landslides (see *Riparian* and *Channel Migration* sections). This loss of recruitment area has eliminated the formation of certain types of accumulations and likely altered the distribution and function of wood in the channel.

Current Conditions

Single Pieces

In the summer of 2000, NSEA mapped woody debris in the active channel of the Acme-Saxon Reach, measuring wood that was greater than .2 meters (.7 ft) in diameter. NSEA identified more than 2500 pieces in the reach, 90% of which were less than .76 meters (2.5 feet) (Figure 18). Only 38 pieces of wood were large enough to be considered “key-sized” (those greater than .7 meters [2.3 ft dbh] and 24 meters [79 ft] long). Wood of this size is considered stable for channels with up to a 20-meter bank-full width- the channel width below which a single piece of wood is considered functional (WFPB 1997). Since the Acme-Saxon Reach has a bank-full width well in excess of 20 meters these dimensions were chosen to represent a “key-sized” piece for logjam initiation.

Figure 18: Cumulative percent plot of large woody debris breast-height diameter.



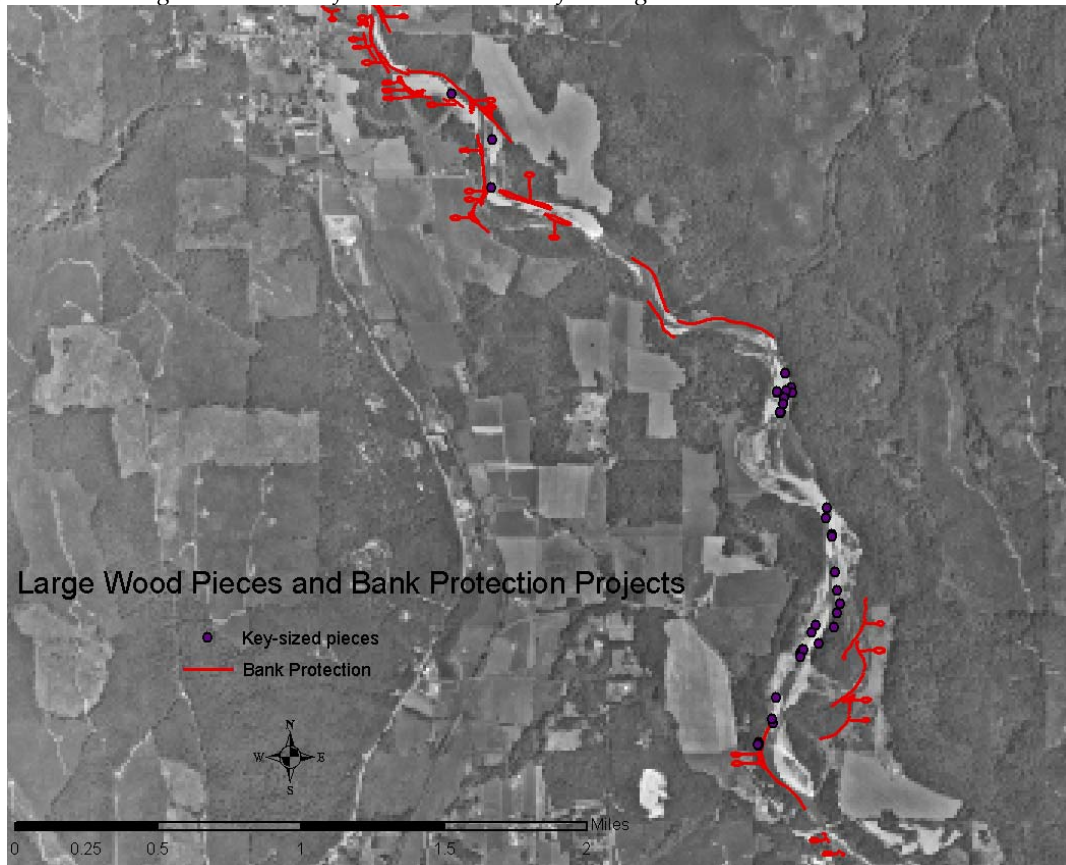
From the NSEA wood data, piece size appeared to have little to do with apparent stability in the reach. Of the more than 2500 pieces, 402 pieces (16%) appeared to be stable, in spite of their small size. Most of these pieces were buried in the bank or channel bottom. Stable pieces ranged in size from .15 to 3 meters (.5 to 9.8 feet) in diameter, while unstable pieces ranged in size from .12 to 2 meters (.4 to 6.6 feet). Since stability does not appear to be a function of piece size, this indicates the importance of accumulations of wood for near-term habitat restoration of the reach.

Few of the 38 “key-sized” pieces were identified in the active channel of the Acme-Saxon reach and most were located in sections of the channel that lacked artificial confinement of the channel migration area (Figure 19). Total wood abundance also appeared to be impacted by the narrowing of the active channel area. The number of pieces per linear foot of channel changes from .16 pieces per foot in the area with a broad active channel area to .07 pieces per foot in the confined portion. This could be due to the reduced recruitment in the lower reach because of lost channel migration area and bank protection, or may be related to increased transport of wood through an incised channel (GeoEngineers, 2002).

Piece size also varied by decay class of the wood (Figure 20). Pieces that were identified as “Class 4” were pieces that lacked bark and the wood had a worn accordion texture. Pieces that were identified as “Class 3” were missing most of their bark and the wood was worn. “Class 2” pieces still had sound wood and

some bark present, while “Class 1” pieces had most of their bark intact. The plot of size decay class indicates that the largest wood in the channel was either “Class 4” or “Class 1”, and that the least decayed material had a greater range in wood size when compared to the more decayed material. This increased range may indicate that a portion of the size range is depleted more rapidly and that the mean diameter may change through time.

Figure 19: Pieces greater than 2.3 feet diameter and 79 feet length.



Wood distribution within the active channel area indicates that the majority of the wood is not interacting with the low flow channel (Figure 21). Only 7% of the wood mapped in the reach was in contact with the low-flow channel, and the majority of this is single pieces (61%). At its narrowest, the Acme Reach is greater than 35 meters wide, making it highly unlikely that a single piece of wood would remain stable in the low-flow channel. This implies that only 72 pieces of wood (2.8%) of the more than 2500 mapped are potentially stable enough to alter the channel and provide habitat. The lack of stable wood in the active channel represents a marked change from the historic descriptions of the channel.

Acme-Saxon Restoration Planning: Analysis and Recommendations

Figure 20: Size of conifers by decay class in the Acme-Saxon Reach with 95% confidence interval.

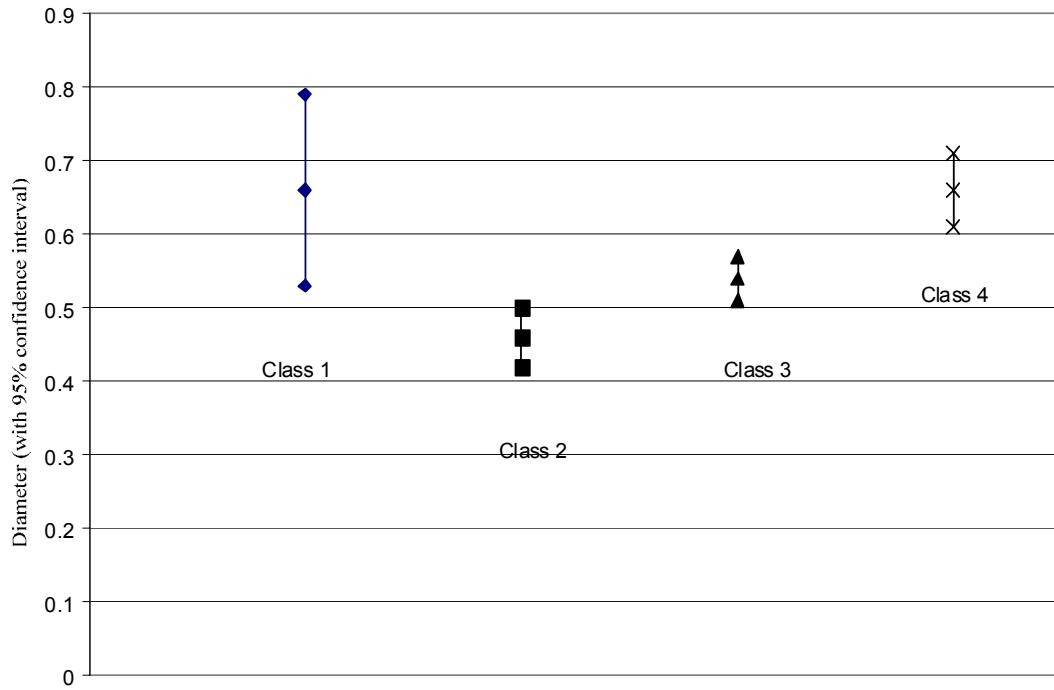
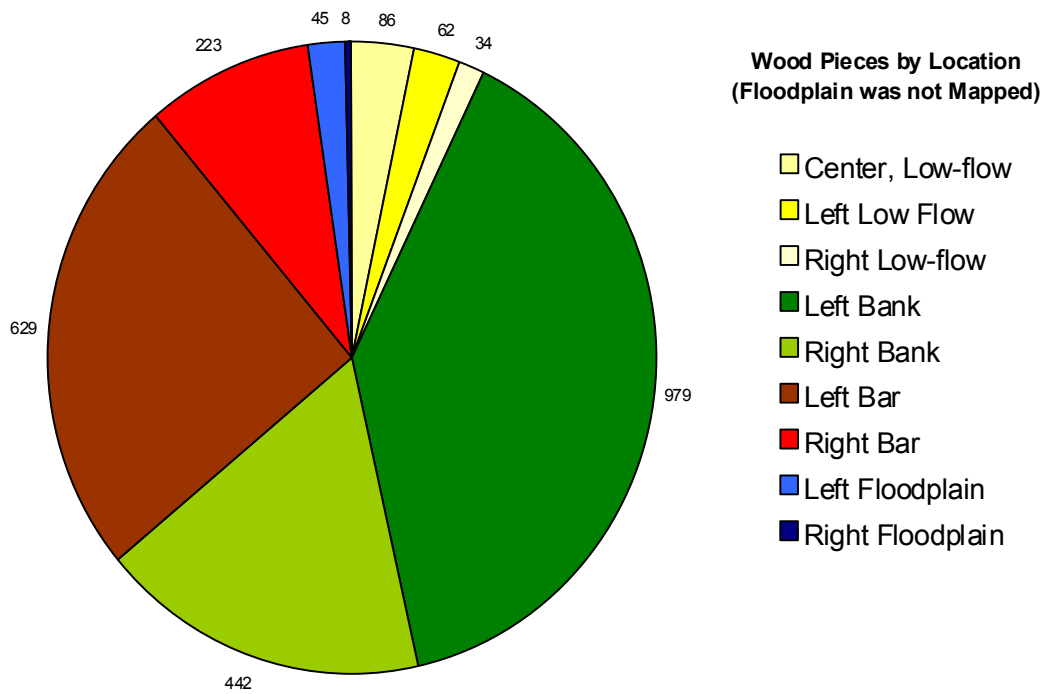


Figure 21: Wood piece counts by channel location. Each color group represents a general channel location



Log Jams

The importance of accumulations of wood, rather than individual large pieces, to habitat stability is evident in the Acme-Saxon Reach. Logjams provide a variety of functions to the channel in the reach, including channel avulsion, channel aggradation, pool formation, cover for fish and bank protection. Three general types of accumulations occur in the reach: logjams formed by stabilized drift moving through the system, relic logjams that were formed when the river was in a different channel configuration and logjams formed in-situ where the river has migrated into a forested terrace or floodplain. The latter tend to form in the areas where bank protection is absent and a forested floodplain or terrace exists. In areas where there is no local source for recruitment, only accumulations formed by the exposure of relic logjams or deposition and stabilization of drift occur. In general, the in-situ jams provided bank stability, and deflected flow away from the banks, in cases metering flow into side channels behind the jams. The drift-formed jams are often associated with mid-channel bars where they are deposited in loose piles as the stage drops following a flood. These different types of logjams likely have different habitat values associated with them.

Wood accumulations are evident on every aerial photo flight from the late 1930s to the 1998 photos. Because the reach is a natural area of wood deposition and storage, wood tends to accumulate as scattered bar-top debris, as in-situ logjams on the outside of meander bends and occasional depositional logjams that form at the head of or create mid-channel bars. Many logjams do not appear to be stable in the active channel with very few persisting from photo sequence to photo sequence. Those accumulations that do persist tend to be meander jams formed along forested banks. These types of jams are heavily reliant on bank conditions and local recruitment of “key pieces” to the channel (Abbe 2000).

Logjams are still common in the Acme-Saxon Reach, although their stability and function has likely changed from historic conditions, when large “drift jams” spanned the channel. Now logjams are most commonly formed from small drift piled into loose accumulations on the tops of bars. The Nooksack Salmon Enhancement Association mapped 30 logjams through the Acme-Saxon Reach in the summer of 2000, ranging in size from 2120 to 28250 cubic feet in volume. These thirty logjams accounted for 44% of the wood mapped in the reach. Key-sized pieces were often associated with logjams; 15 of the 38 key pieces were located in 8 different logjams. The association of large members with a logjam did not ensure stability of these accumulations. Of the 8 logjams with key-sized pieces in them, only 3 were present in 1994 (37%). This was actually less than the percent of logjams lacking key-sized members that were present through the 6-year period (50%).

Acme-Saxon Restoration Planning: Analysis and Recommendations

Of the 30 logjams mapped in the Acme-Saxon Reach, 16 interacted with the low-flow channel, including a logjam bank protection project near Acme. Most of these accumulations were located at the edge of the channel and were described as “touching” the channel, rather than actually in the low-flow channel. Only two of the logjams were actually identified as in the low-flow channel, one of which was a relic logjam being eroded out of the bank by active channel migration at the Acme Farm site (Figure 22). The impact of artificial confinement of the width of the channel migration area is also reflected in the number of logjams in the channel. Eight of the 30 mapped accumulations were in the confined portion of the channel (Figure 22), while 22 logjams were located in the unconfined portion of the channel (Figure 23).

Figure 22: Logjam locations in Reaches 1 and 2– each cluster of points represents a jam (NSEA 2000 data).

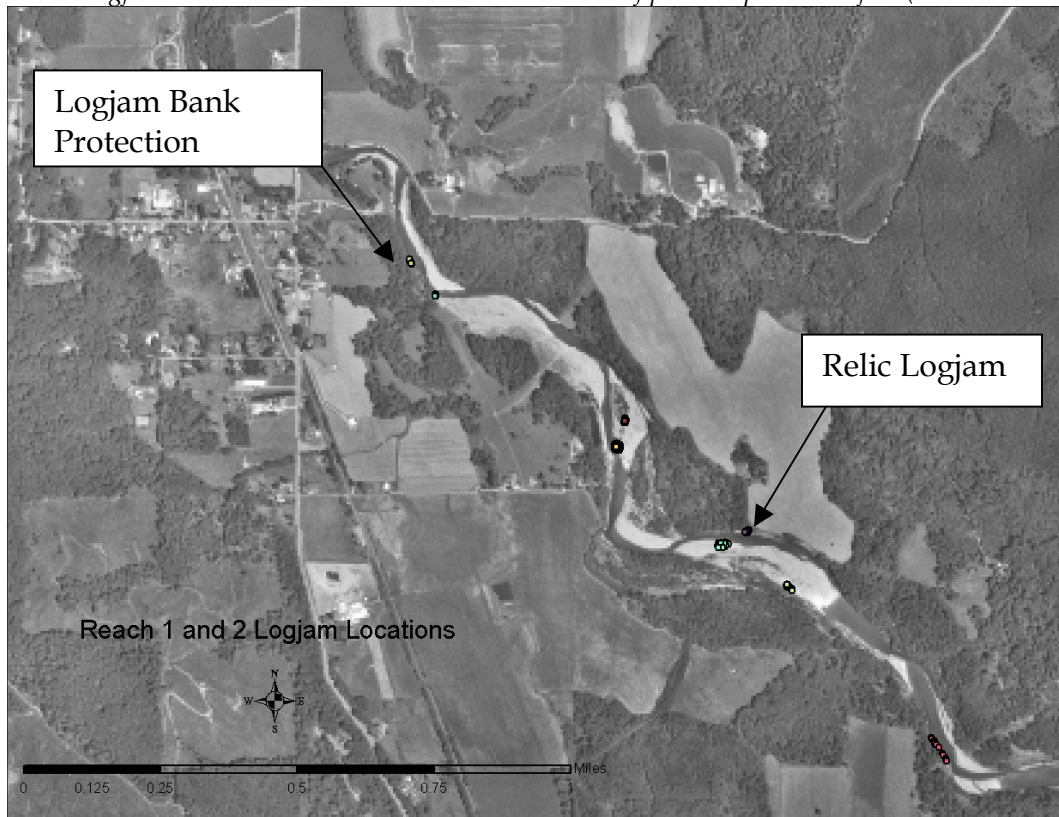


Figure 23: Logjam Locations in Reach 3. Each cluster of points represents a jam (NSEA 2000 data).



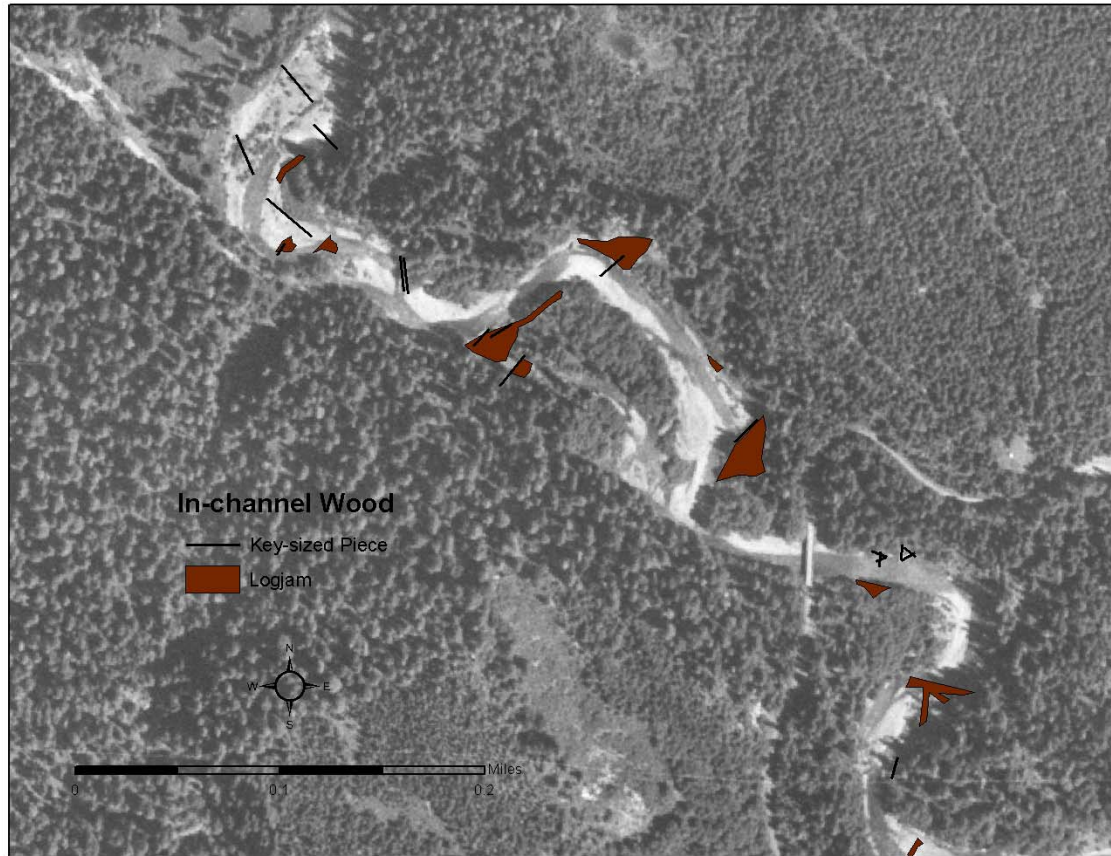
Wood Function

Channel Morphology

During the past, logjams acted as persistent hard points in the channel that would have provided a variety of beneficial functions to the channel from slowing channel migration, to causing local scour that formed pools with high quality cover (GeoEngineers, 2002). The removal of in-stream wood and the interruption of local wood recruitment to the reach by land use activities have likely changed the habitat quality in the reach. In other unconfined, low gradient sections of the South Fork Nooksack, debris jams still provide many of the functions lost in the Acme-Saxon Reach (Figure 24). In these areas, logjams form on the outside of meander bends and slow channel migration, change the channel geometry and often meter flow into side channel areas. Logjams also form along the banks of the river, where large trees are recruited due to bank erosion and deflect flow away from easily eroded banks. Accumulations of wood associated with mid-channel bars form and protect vegetated islands, while splitting the flow into multiple channels across the floodplain. The protection afforded by the logjams has created a patchwork floodplain where protected pockets of forest have persisted much longer than unprotected areas. All of these situations can be seen as analogs for how wood probably functioned

in the Acme-Saxon reach when large wood was being recruited to the channel and the channel was free to respond to watershed and local conditions.

Figure 24: Example of wood function in South Fork Nooksack RM 37.



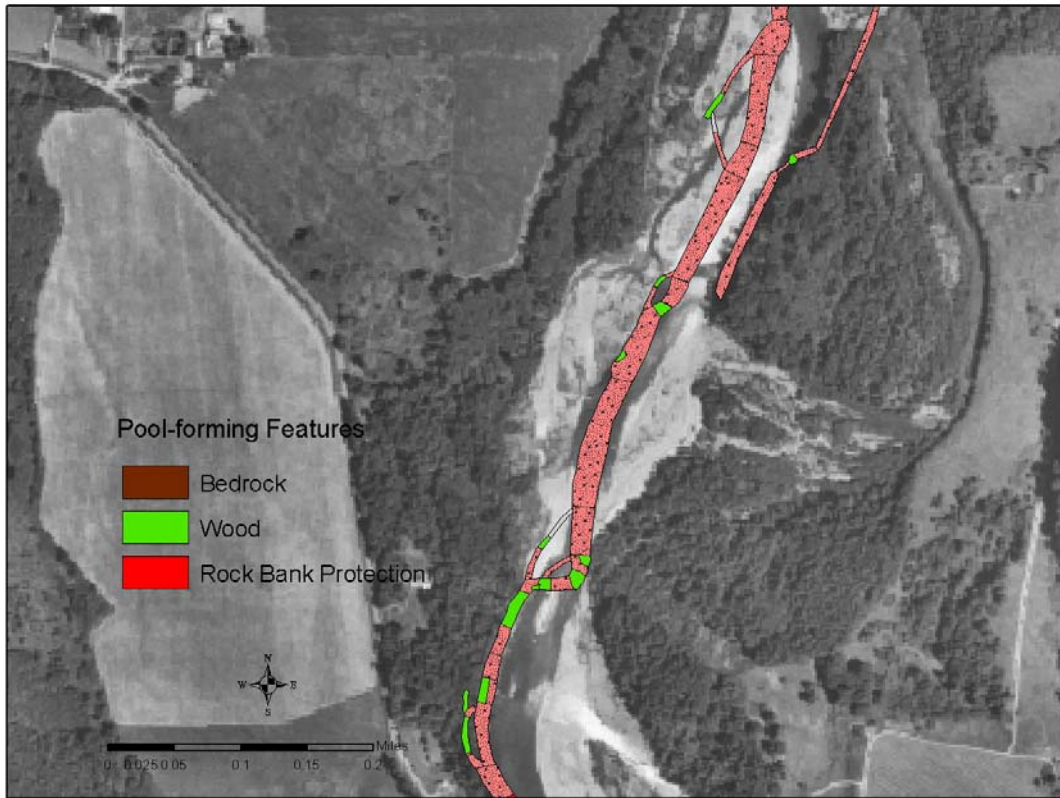
Pool Formation

Pools can be formed from a variety of mechanisms or “pool-forming features”, including local scour caused by bedrock, boulders, wood, or they can be freely formed by channel hydraulics. The different pool-forming features represent the process of pool habitat creation and maintenance in the reach, each process yielding different habitat characteristics, such as cover and nutrient retention, as well as different pool bathymetry. Three different types of pool-forming feature were identified in the 2000 surveys: wood, bedrock or riprap (rock associated with bank protection projects).

The type of pool-forming feature was strongly associated with bank conditions in the reach. In the unconfined portion of the channel, where bedrock was not present, wood was the primary pool-forming feature (Figure 25). This was the case even when immature vegetation was present on the banks. In the area where the channel interacts with bedrock, wood plays less of a role in pool-formation and bedrock becomes the most common pool-forming feature with

wood being the secondary pool-forming feature (Figure 26). In areas where riprap is present it becomes the dominant pool-forming feature. In these confined areas, bank protection impacts pool quality and potentially impacts adult holding and juvenile rearing habitat quality (Figure 27).

Figure 25: Pool-forming feature in an unconfined portion of the Acme-Saxon Reach.



Since the method of pool formation likely impacts habitat quality of the pool, improving the distribution of high quality pools through the reach may improve adult holding and juvenile rearing conditions in the reach. The lower portion of the reach would be the highest priority for increasing the number and persistence of wood-formed pools, because the process of wood recruitment has been completely halted in this sections and pool formation from wood does not occur. In the upper reach, wood dominates pool formation, so the focus should be on conserving and improving future wood recruitment to the channel.

Figure 26: Pool-forming features where the channel interacts with bedrock.

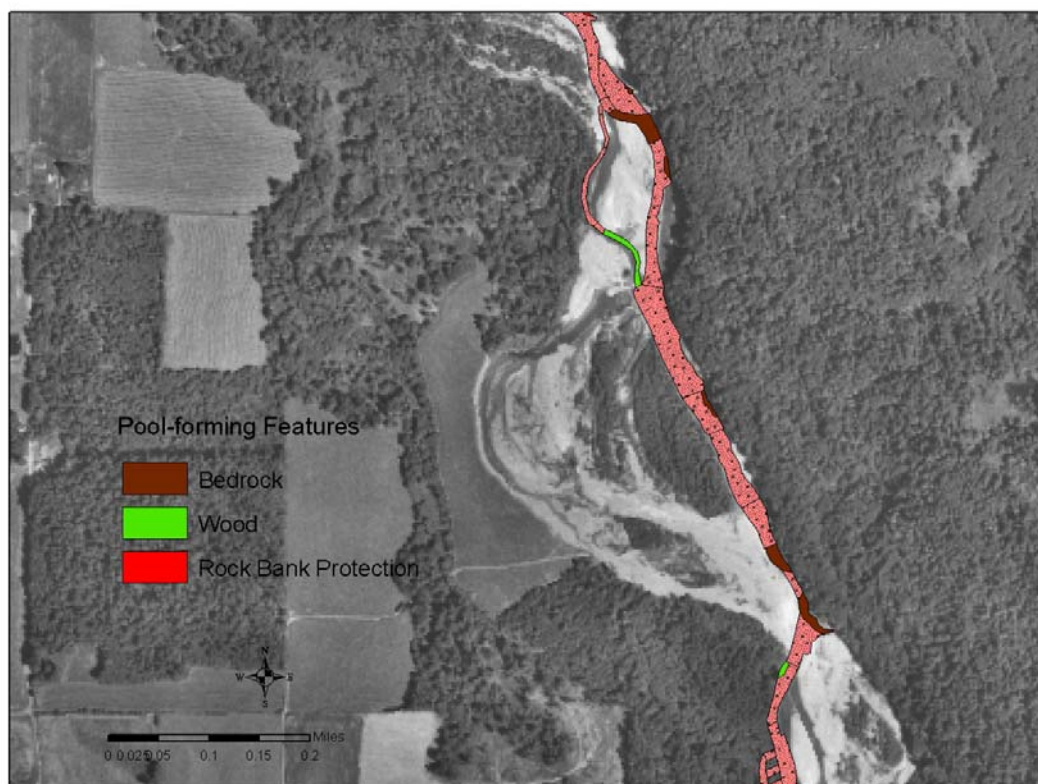
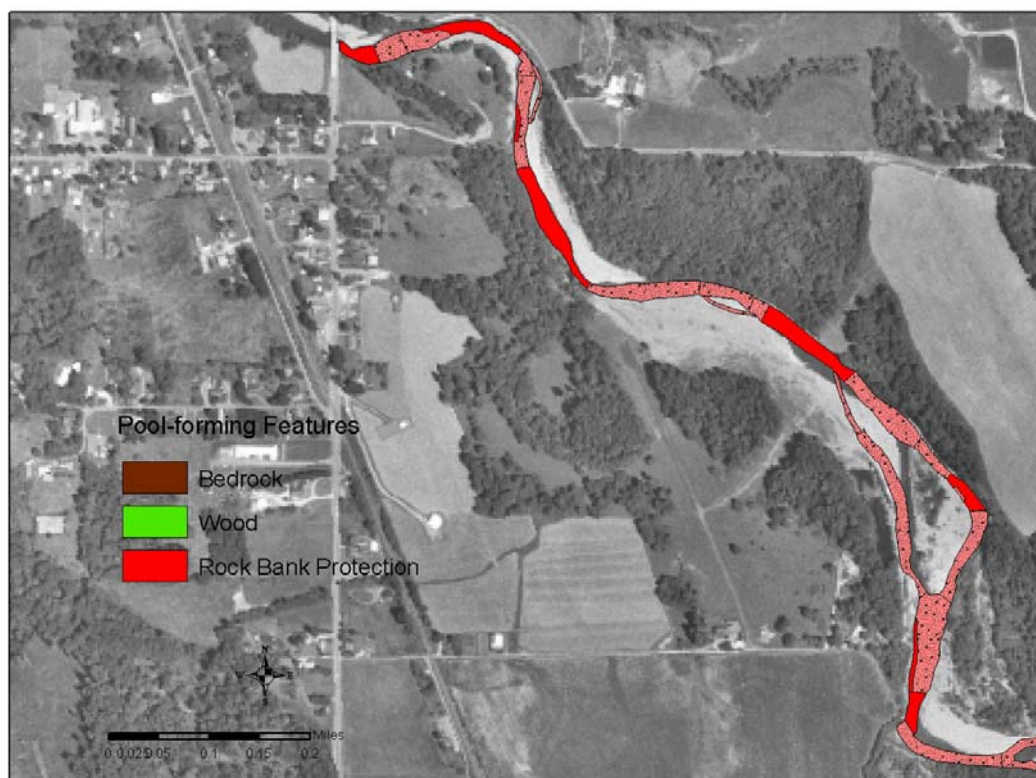


Figure 27: Pool-formation in a bank-hardened reach.



Channel/Floodplain Interaction

The floodplain is a strip of relatively flat land bordering a stream that is overflowed at time of high water. Three general types of processes form floodplains: point bar deposition as the river meanders, over-bank deposition of sediment during floods and local deposition associated with flow obstructions such as logjams. Floodplain attributes can give information about the history of catastrophic events or changes in channel bed elevation. Channel-floodplain interaction can change slowly as watershed uplift and denudational processes change the inputs of water and sediment, or quickly as a channel avulsion increases the channel slope and leads to channel incision and subsequent floodplain isolation. As mentioned previously, the reach has a long history of sediment deposition, with thick alluvial deposits overlying glacial material. Through this long period of aggradation and floodplain development, it is likely that the channel has undergone periods of incision as climate has changed from wetter to dryer patterns. These regional influences on channel-floodplain interaction are imprinted with catastrophic events, such as floods, that can drastically alter the channel in a much shorter timeframe.

The Acme-Saxon Reach shows evidence of both long-term changes (decades) to floodplain-channel interactions and short-term changes (inter-annual). The entire South Fork Valley likely served as the floodplain for the river prior to land use changes in the watershed, but has since begun to incise into the valley floor and left the valley floor a broad terrace. This terrace slopes gently away from the river and down to the south, so that floods that access the valley floor on the west will drain down-slope toward the town of Acme to the Jones Creek fan. The slope of the valley floor means that as the South Fork migrates to the west, to widen its current floodplain, it will be slowly lowering the elevation required to inundate the South Fork Valley floor. Short-term changes in channel length through migration and avulsion, can lead to changes in the channel bed elevation relative to its floodplain. Evidence of these changes exist in accumulations of wood that are being excavated from the banks and bed of the channel through much of the reach, indicating that deposition had occurred at a lower elevation in the past and that the channel has since aggraded and incised to expose the relic logjams.

Entrenchment

Entrenchment reflects the relationship between a channel, its valley, and surrounding hillslope features. Channel entrenchment is the degree to which the channel is incised in the valley floor, defined by the relation of the current channel floodplain, related to the bank-full flow depth, and the topographic terrace associated with the valley bottom. The channel is not entrenched when these two features are roughly coincident and frequent floods would inundate both the floodplain and the terrace. A moderately entrenched channel has a

small active floodplain established within a larger trench cut by the channel and the terrace level will be inundated during moderately frequent (i.e. 20-year) discharge events. An entrenched channel is effectively isolated from the terrace level during even rare discharge events. Bank and valley bottom disturbance are the most common causes of historic channel entrenchment.

In low-gradient portions of a watershed where terraces are formed primarily by fluvial processes, the floodplain and the terrace should be coincident, unless there has been a relatively recent change in either one of the channel input factors (wood, sediment or water) or in external boundary conditions, such as base level changes or changes in bank conditions. In the Acme-Saxon Reach, the channel is generally moderately entrenched to entrenched, with few places where the alluvial terraces that form the valley floor are coincident with the floodplain. A geomorphic analysis of the Acme-Saxon Reach (GeoEngineers, 2002) found channel incision to be a primary concern in the Acme-Saxon Reach using vegetation encroachment on the active channel as an indication of floodplain isolation. For example, between the 1943 and 1966 aerial photo years “large patches of river bars and terraces have been reforested, indicating further disconnection between the river and these developing terraces, and an overall narrowing of the channel” (GeoEngineers, 2002).

The current reduction in sinuosity together with the loss of wood debris may have serious long-term impacts on channel incision and entrenchment. Ideally, as the channel migrated across the floodplain, it would have increased its flow resistance both by increasing the channel length and by continually recruiting large wood to the channel. These processes would have likely slowed incision. Channel incision can isolate the active thalweg channel from numerous secondary channels and its floodplain. Floodplains that were once flooded several times a year are rarely flooded at all and begin to resemble low terraces. When this process begins it can be difficult to reverse, and peak flows can become more flashy and exaggerated because of a loss of floodplain storage. Further, as a channel incises, similar discharges result in increasing water depth. The increased water depth increases basal shear stress and sediment transport, thus further contributing to incision. Increased flow depth also destabilizes wood debris that may have previously been stable.

The history of channel incision is difficult to decipher in the Acme-Saxon Reach due to land-use impacts on the banks and floodplain and active channel migration. Because of these processes, various geomorphic surfaces have been removed or disturbed giving a patchy and incomplete history for much of the floodplain. Using aerial photos and floodplain topography it is possible to roughly date several surfaces through the reach and infer a history of channel incision dating back prior to the earliest aerial photos in the 1930s.

The general process that appears to be occurring in the Acme-Saxon Reach since the 1930s is one of incision and subsequent floodplain establishment at a lower elevation, followed by another period of incision and floodplain establishment. This process can be seen on both Figure 28 and Figure 29 where relatively flat terraces lie adjacent to historic channel positions and likely represent the floodplain elevation of those channels. Evidence of floodplain development within a larger terrace feature normally indicates a historic change in channel condition and sediment supply. Through much of the reach, the floodplain inundated by an annual flow is developed between higher terraces and the degree of entrenchment varies. This entrenchment is thought to have an adverse impact on habitat quality by increasing shear stress through the reach resulting in reduced floodplain-channel interaction, increased sediment transport and the abandonment of many floodplain tributaries (GeoEngineers, 2002). The composition of terrace material indicates that the terraces are alluvial and largely over-bank deposits with lenses of coarser material, probably representing pre-historic channel deposits. The elevation of the terraces suggests a long history of aggradation, with subsequent incision into the alluvial plain.

A history of channel incision can readily be seen on Cross-section 1705, located near Nessel's Farm (Figure 28). On the 1938 aerial photos, the channel had recently avulsed and abandoned a channel located to the left of the 2000 channel, which was approximately where the 1938 channel was located. This abandoned channel was the apex of a tight-angled meander bend and likely would represent a topographic pool, while the 2000 channel represents a topographic high (riffle crest) in the channel, so differences between 1938 and 2000 bed elevations are likely underestimated. The elevation of the surface adjacent to the pre-1938 channel is approximately 5 feet above the 1989 channel surface, and 3 feet below the elevation of the valley floor (~348 feet). This implies that the channel incision was well on its way prior to the 1938 aerial photos and that the valley floor may have already been isolated as a terrace by that time. Since 1989, the channel has again avulsed, although there is little indication of dramatic channel incision since the avulsion (less than .5 feet in over ten years).

Further downstream, Cross-section 1507 lies where Nessel's Slough re-enters the South Fork and marks the downstream portion of the channel avulsion that occurred in the late-1980s (Figure 29). This cross-section reflects the local incision accompanying the slope increase and head-ward erosion caused by the channel shortening. The difference in base elevation between the 1989 channel position and the 2000 channel position is nearly 3 feet, compared to the .5 feet difference upstream in Figure 28. The valley floor elevation at this cross-section is approximately 342 feet, and the current channel base level is 16 feet below the terrace level. Another channel apparent on the cross-section pre-dates the 1885

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GLO surveys, where it is shown as a flowing side channel. This channel is set about 5 feet into the valley plain and terrace elevation appears to coincide with a floodplain elevation.

Figure 28: Channel incision on Cross-section 1705, near Nessel's Farm.

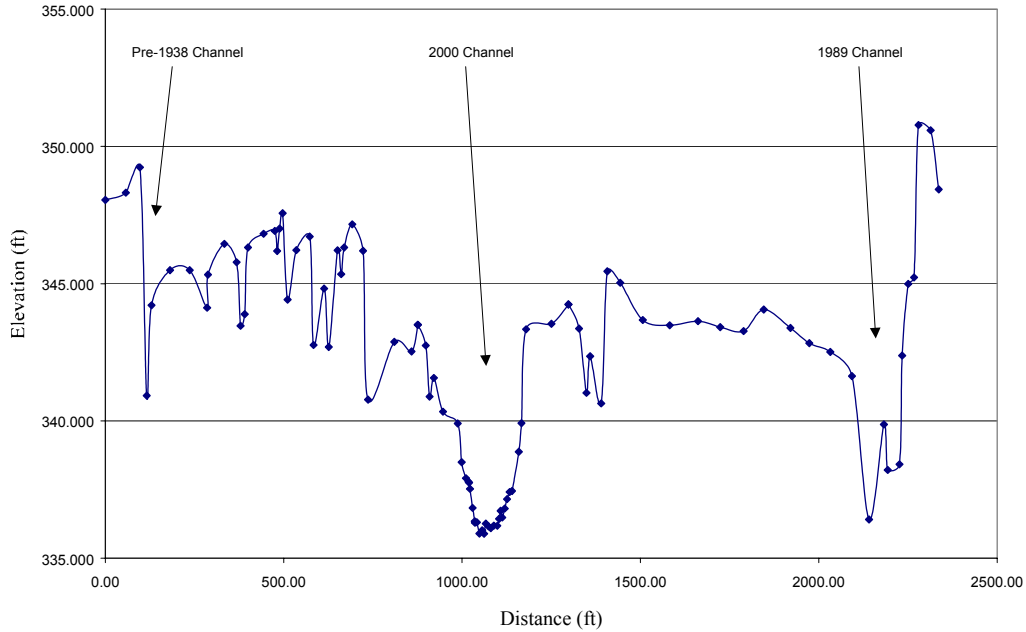
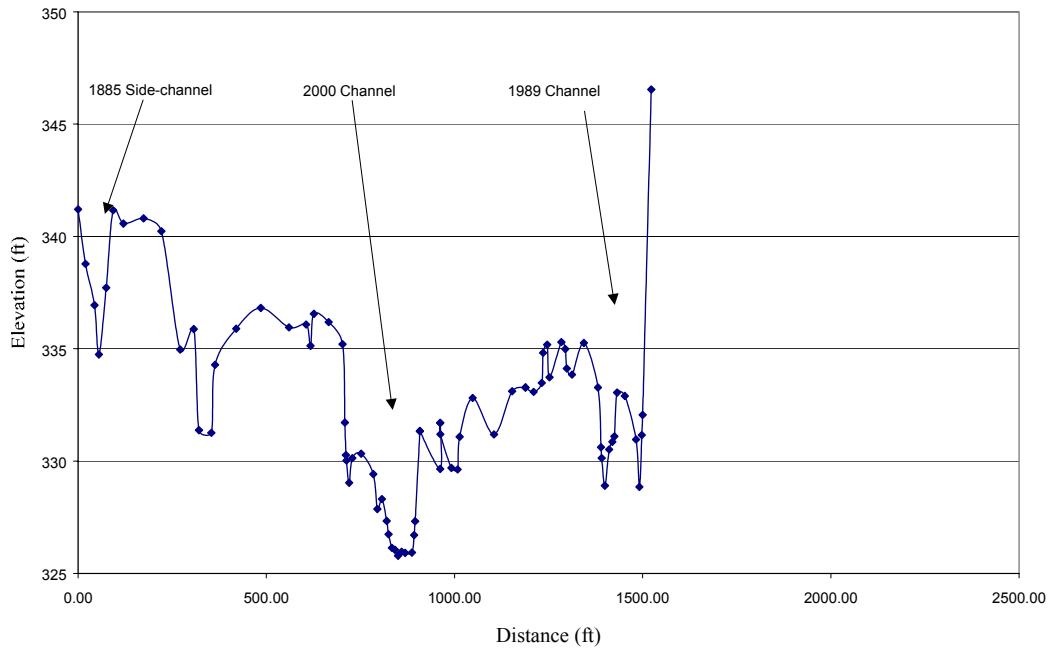


Figure 29: Channel incision on Cross-section 1507, near Lawson Curtis Property.



Floodplain Habitat Connectivity

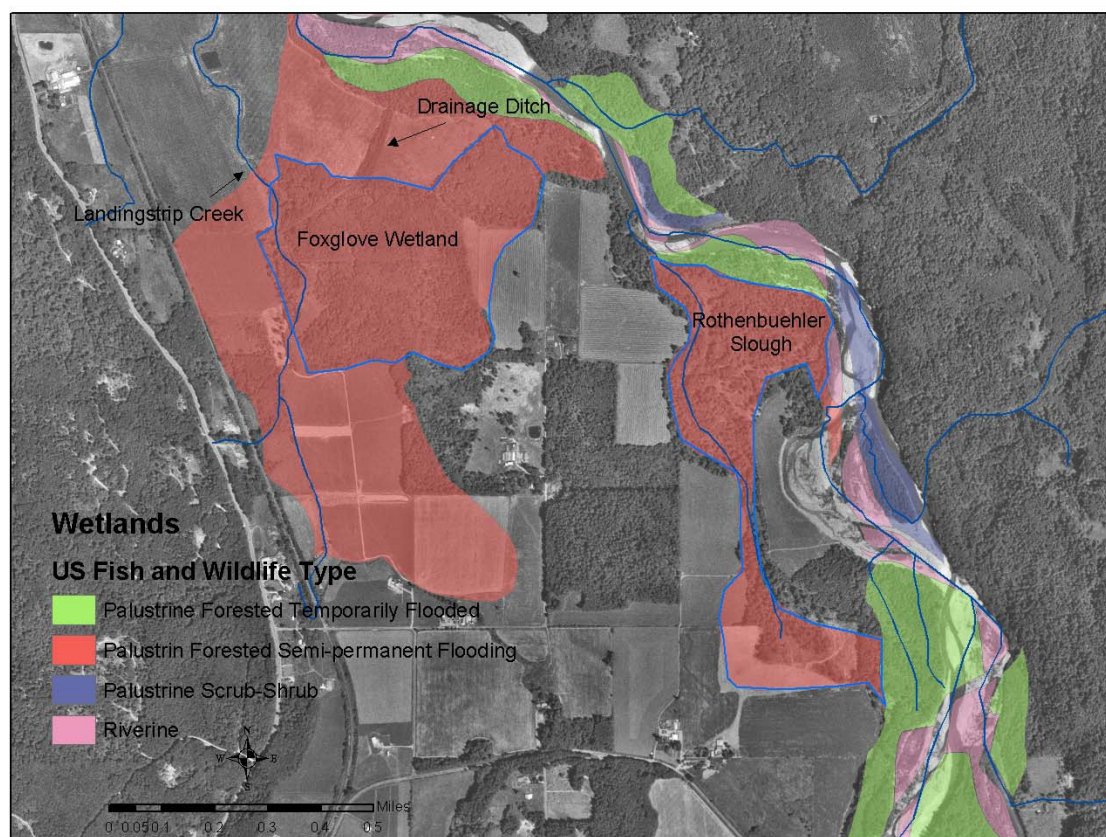
Floodplain habitat connectivity has been negatively impacted both directly and indirectly by land use through the Acme-Saxon Reach. The primary impacts come from main channel incision, levee construction, wetland draining and floodplain channel filling. Topographic evidence suggests that when the South Fork was connected to the alluvial valley floor, extensive floodplain channels existed across the entire valley floor. The very low gradient and wide floodplain of the South Fork Valley would have been an ideal place for floodwater storage. Extensive channels drained the broad floodplain of the Acme-Saxon Reach back into the South Fork mainstem or south into the wetland headwaters of the Samish River.

The creation of floodplain habitat has likely been altered by continued channel incision, which has not allowed the channel to reestablish a wide, well connected floodplain. It is possible that the reduction in flow resistance from channel straightening and wood removal, in addition to bank protection projects that halt floodplain development through channel migration have contributed to the channel incision through the reach. Whatever the dominant causes of incision, it is apparent that the process of incision has been occurring through the reach for more than 70 years and restoring the connectivity of the channel with the valley floor is a difficult task. In spite of this, re-establishing the processes of floodplain formation could be accomplished by allowing the channel lateral room to migrate into terraces and broaden the floodplain area, while increasing the flow resistance through increased channel length and woody debris recruitment.

Another important type of floodplain habitat is wetlands. Forested wetlands still exist on the South Fork floodplain and several of them provide year-round discharge to floodplain channels, although few remain connected to river. The largest and likely the most important floodplain wetland in the Acme-Saxon Reach is the Foxglove wetland, which helps maintain flow into Landingstrip Creek. An attempt was made to drain this wetland into the South Fork, but beavers have currently blocked the ditch and restored the water depth in the wetland (Figure 30). Protecting these areas from conversion to agriculture is an important step in restoring the quality of floodplain habitat in the Acme-Saxon Reach.

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Figure 30: Forested wetlands on the Acme-Saxon floodplain.



Salmonids in the Acme-Saxon Reach

The reach is used throughout the year by a variety of salmonid species, including early (spring) chinook, late (fall) chinook, coho, pink, chum and sockeye salmon, summer- and winter-run steelhead, bull trout, and sea-run cutthroat (Table 7). Winter steelhead, coho, early and late-timed chinook, pink, sockeye and chum salmon use the reach for spawning, rearing, and adult holding. Steelhead, coho, chinook, and sockeye juveniles also rear in the reach year-round. Anadromous bull trout and sea-run cutthroat use the reach for rearing, adult holding and migration from their spawning areas to the lower river and marine waters, and back to their spawning areas, which are primarily located higher in the watershed. Bull trout may spawn in Hutchinson Creek, and sea-run cutthroat are expected to spawn in the floodplain tributaries within this reach as well. Summer-run steelhead utilize the reach, at a minimum, for adult holding and juvenile out-migration. The diversity of fish species that use the Acme-Saxon reach indicates the need for diverse habitat and the restoration of the natural processes that create and maintain the habitat.

Table 7: Preliminary Nooksack River anadromous salmonid periodicities (Anchor Environmental 2001).

Spring Chinook	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
River Entry												
Upstream Migration / Holding												
Spawning												
Intragravel Development												
Age-0 rearing ^a										????	????	
Age-0 outmigration ^a												
Age-1+ rearing ^b												
Age-1+ outmigration ^b									????	????	????	????

Fall Chinook	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
River Entry						????					????	
Upstream Migration / Holding						????						????
Spawning												????
Intragravel Development												
Fry <~55mm												
Juvenile Rearing												
Outmigration												

Coho	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
River Entry		????										
Upstream Migration / Holding												
Spawning		????										
Intragravel Development												
Fry <~55mm												
Juvenile Rearing												
Outmigration												

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Table 7 (cont).

Chum	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
River Entry												
Upstream Migration / Holding												
Spawning												
Intragravel Development												
Fry												
Juvenile Rearing (not applicable)												
Outmigration												

Pink	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
River Entry						????						
Upstream Migration / Holding						????						
Spawning												
Intragravel Development												
Fry												
Juvenile Rearing (not applicable)												
Outmigration												

Sockeye	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
River Entry												
Upstream Migration / Holding												
Spawning												
Intragravel Development												
Fry and Juvenile Rearing												
Outmigration												

Summer Steelhead	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Upstream Migration												
Holding												
Spawning												
Adult Outmigration												
Intragravel Development												
Fry <~55mm												
Juvenile Rearing												
Juvenile Outmigration												

Winter Steelhead	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Upstream Migration												
Holding												
Spawning												
Adult Outmigration												
Intragravel Development												
Fry <~55mm												
Juvenile Rearing												
Juvenile Outmigration												

Acme-Saxon Restoration Planning: Analysis and Recommendations

Table 7 (cont.).

Coastal Cutthroat	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Upstream Migration												
Holding												
Spawning												
Adult Outmigration												
Intragravel Development												
Fry <~55mm												
Juvenile Rearing												
Juvenile Outmigration												

Bull Trout/Dolly Varden	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Upstream Migration												
Subadult Upstream Migration												
Subadult Overwinter Holding												
Holding												
Spawning												
Adult Outmigration												
Intragravel Development												
Fry <~55mm												
Juvenile Rearing												
Juvenile Outmigration								???				

Notes:

- a) Age-0 refers to fish that outmigrate as subyearlings.
b) Age-1+ refers to fish that outmigrate as yearlings or older.

Legend: Months in which the species life stage occurs in WRIA 1.
 Months in which there is a question whether the species life stage occurs in WRIA 1.

Chinook Salmon (Oncorhynchus tshawytscha)

South Fork early-timed chinook are considered native, and NMFS describes them as essential for recovery of the threatened Puget Sound Evolutionarily Significant Unit (ESU) (64 FR 14308, Mar. 24, 1999). South Fork native early chinook have sufficient genetic uniqueness, life history diversity and geographic separation to comprise one of only five genetic diversity units (GDU's) in Puget Sound (Marshall et al. 1995). Adult escapements continue to be very small with 164, 283, 268 adults spawning, respectively, for 1999-2001 (MacKay and Pfundt 2002). In the 1980s, the Skookum Creek Hatchery cultured native spring chinook (as well as larger numbers of Kendall/Samish fall chinook) to augment the dwindling population, but this appeared to have had little impact on adult returns, and supplementation was discontinued in 1993. There is evidence of geographic and temporal overlap with the late-timed chinook that appear to closely resemble Soos Creek stock, and with North/Middle Fork spring chinook, and maintaining a viable gene pool is a high concern for native South Fork spring chinook. Estimates from genetic analysis of juvenile chinook

outmigrating through the South Fork screw trap in 2000 indicate less than 9% most closely resembled the native South Fork early chinook population (Young and Shaklee 2002), with the remainder more closely resembling North Fork early chinook or Kendall/Samish late-timed chinook. As a result of the fragile status, unique and essential nature, and absence of hatchery supplementation for this ESA-listed chinook population, the South Fork Nooksack River has become the focus of strategic habitat restoration.

Late-timed chinook also utilize the South Fork Nooksack River and the Acme-Saxon reach. Survey effort for late-timed chinook is limited, due in part to poor survey conditions due to higher flows and increased suspended sediment, but enumerated redds indicate a minimum of 305, 263, and 303 adult late-timed chinook spawned in the South Fork, respectively, in 1999-2001 (Mackay and Pfundt 2002). Additionally, Hutchinson Creek has been surveyed consistently since the early 1950's and spawn survey records indicate a relatively consistent history of late spawning chinook to present. The NMFS considers all naturally spawned populations in the Puget Sound region to be within the ESU (64 FR 14308, Mar. 24, 1999). It is not clear to what extent these late-timed chinook adults were naturally produced or are hatchery strays from releases in other locations such as the lower river, Lummi Bay, or Samish River, as mass marking has only recently been initiated. Recent genetic analysis indicates that late-timed chinook samples taken from Kendall and Samish Hatcheries (where broodstock are interchanged) are significantly different from Green River/Soos Creek summer/fall chinook (considered the primary original broodstock source), although they appear to be closely related to it (Young and Shaklee 2002). Genetic analysis of a limited number of adult tissue samples collected from adult chinook on Nooksack basin spawning grounds did not show strong evidence for a distinctly different group of chinook from the three established population baselines (North Fork early chinook, South Fork early chinook, Kendall/Samish late chinook). The analysis concluded that the aggregate collection of South Fork late-timed chinook were not significantly different than the Kendall/Samish strain. The analysis also indicated that about 84% of chinook that outmigrated through the South Fork screw trap in 2000 most closely resembled the Kendall/Samish late-timed chinook stock, and less than 9% were of South Fork spring stock origin. These late-timed chinook juveniles are all naturally produced, as there are no hatchery chinook releases in the South Fork.

Analysis of otolith and coded wire tag data also show that North/Middle Fork native spring chinook from the Kendall hatchery and associated releases have recently strayed substantially into the South Fork to spawn. From 1999-2001 43.5%, 24.0% and 36.5% of carcasses recovered by Oct. 7 (those considered early chinook) were North/Middle Fork chinook (MacKay and Pfundt 2002). Kirby (2002) analyzed survival and straying for Kendall Hatchery North Fork spring

chinook by release location, and all returning adults from all of the release strategies and locations strayed to some extent into the South Fork to spawn. Young and Shaklee (2002) determined that about 7% of chinook that outmigrated from the South Fork in 2000 most closely resembled the North/Middle Fork early chinook population. Concerned about the genetic impacts of such straying, given that North Fork and South Fork early chinook are quite different, WDFW and the tribes have agreed to substantially scale back the number of hatchery origin North/Middle Fork spring chinook produced at the Kendall Hatchery, starting with the 2002 brood year.

Upstream Migration

Historical catch records in Bellingham Bay and the Nooksack River indicate that adult wild chinook were present through most of the year. Early arrivals appeared to show up in February with a peak river entry in May to June. For a 1981 radio-tagging study of chinook, fishing in the lower Nooksack River began in early April, and spring chinook were caught the first week (Barclay 1981). Catch-per-unit-effort increased through mid-May, and the highest catch per day occurred the first week of June, after which fishing ended.

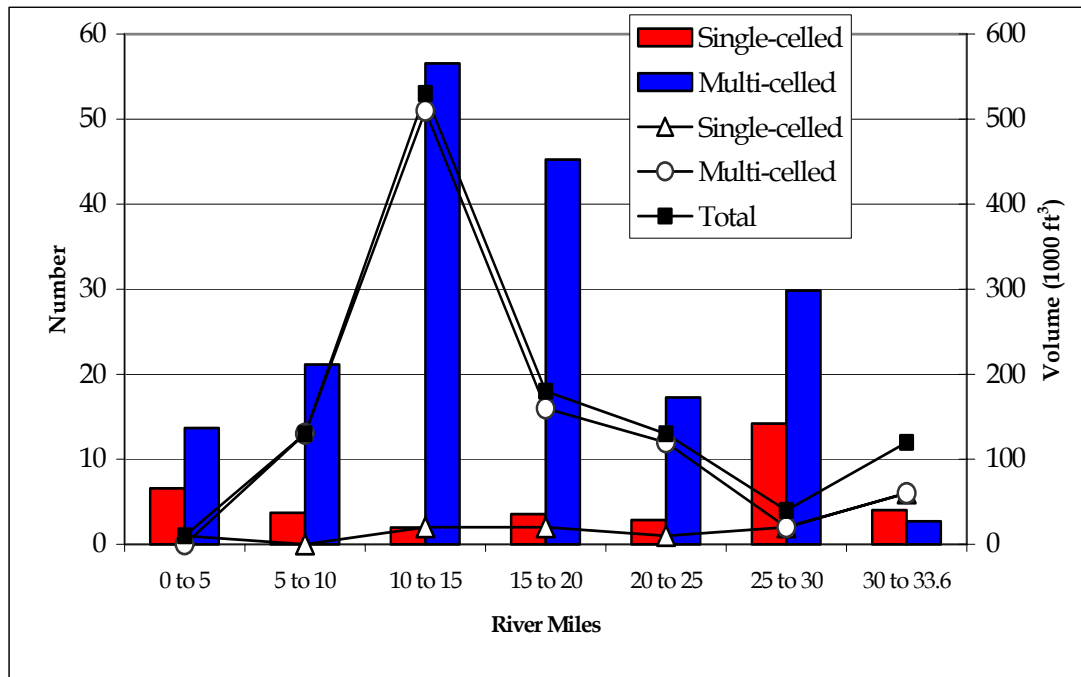
Adult upstream migration of early chinook occurs in four stages – river entry, upriver migration, holding, and spawning (Barclay 1980). Some spring chinook that were radio-tagged in the lower mainstem Nooksack River in 1980 and 1981 moved directly upriver after tagging, while others remained in the lower mainstem, even moving back out to saltwater. After the chinook were acclimated, though, they moved upriver at fairly uniform rates of 1.7 (1980) and 1.5 (1981) miles/day average (range 0.97 to 3.7 miles/day) for a total of 30 to 40 days transit time to the Forks confluence (Barclay 1980, Barclay 1981).

Holding

Early chinook hold for long periods during the summer in freshwater prior to spawning. The Acme-Saxon reach is very important for early chinook holding. The 1980 and 1981 radio tagging studies found that, once migrating chinook reached holding areas, migration dropped sharply (Barclay 1980, Barclay, 1981). Some fish held in the same pool for 2 to 4 weeks. Of the 19 spring chinook captured in 1980 in the lower Nooksack River that were tagged and tracked upstream to at least the South Fork confluence, 5 entered the South Fork. One died prematurely in the first river mile, but 2 of the remaining 4 were tracked to their spawning locations and held in the upper portion of the Acme-Saxon reach for at least part of the time, and one of the 4 spawned in the reach (Barclay 1980). Schuett-Hames et al. (1988b) also found appreciable spring chinook holding in this reach of the river, especially above RM 10; the highest number and greatest volume of chinook holding habitat occurred between RM 10 and RM 15 (Figure 31). Prolonged holding in the reach is evidenced by records from earlier this

century of local resident Tom Nasset catching chinook in the reach in June. It is also noteworthy that in 1921, a one-time survey of Hutchinson Creek in July recorded an adult chinook, indicating that holding historically occurred in this tributary as well (Norgore and Anderson 1921).

Figure 31: Number of holding chinook adults (points) relative to holding site volume (columns) in the South Fork Nooksack River (Schuett-Hames et al. 1988b). Single-celled were those considered too small to warrant detailed measurement. Multi-celled sites were relatively large holding sites.



Schuett-Hames et al. (1988b) found that holding South Fork chinook had a clear preference for the deepest pools, and less than 2% of the chinook were holding in areas that did not have cover. Cover consisted of bedrock, boulders, undercut banks, large woody debris, rootwads, surface turbulence, or small woody debris. Holding chinook sought the deepest water available. Only 12% of the fish selected cells containing neither instream wood cover nor maximum depth (Schuett-Hames et al. 1988b). While chinook selected the deepest pools, the average maximum depth of these pools in the Acme-Saxon reach was only 7.5 feet (n=6), and the deepest pool (which held the most chinook) was only 8.8 feet.

Anecdotal evidence indicates both the historic presence in the Acme-Saxon reach of deep pools formed under log jams and the affinity for chinook to hold in such pools. In the mid-1940's, Bob Knudsen recalls lying on top of jams in the upper part of the reach and seeing numerous chinook holding underneath; estimated depths were 15 to 20 feet, as he could touch the bottom with long alder poles (R. Knudsen, personal communication). Knudsen called this Nasset's Jam, which were actually three jams. Mackay (1985) describes a more recent log jam that

formed a large pool that held the second highest count of holding chinook (21 adults) in the South Fork that year, which was also located in the upper portion of the Acme-Saxon reach, downstream of the Saxon Bridge. The chinook were holding below and behind a framework of four 8-12" diameter logs. A nearby pool with similar depth and bottom substrate (sand to gravel) but without such cover contained no chinook. MacKay also states that counts in deep pools find the chinook located very close to the bottom.

Spawning

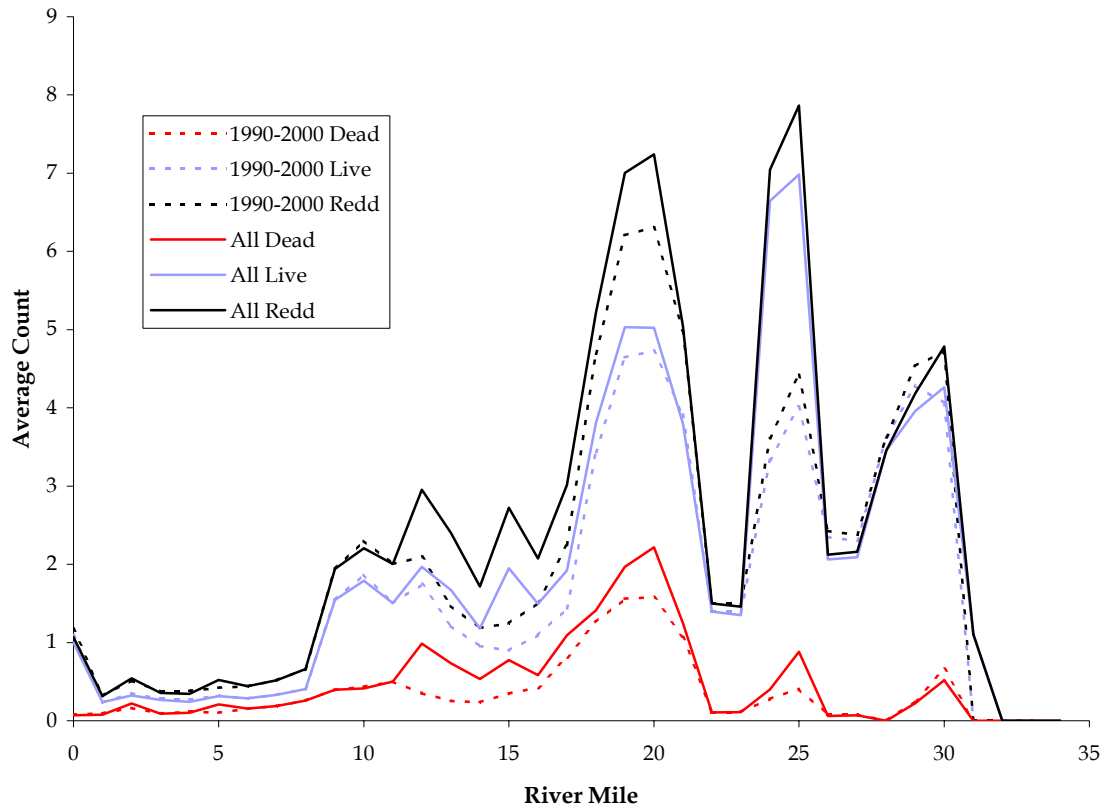
In mainstem South Fork, chinook spawning occurs from the confluence (RM 0) to RM 30.4. Sylvester's Falls at RM 25 constitutes a partial blockage, and chinook apparently do not get upstream of these falls every year. While steelhead and bull trout get upstream of RM 30.4, chinook have not been recorded upstream of this partial blockage.

The South Fork and its tributaries are extensively surveyed for chinook, attempting to consistently and regularly enumerate redds for essentially all known spawning areas throughout the spawning period (August through early Nov). While survey conditions and effort decline late in this period, the survey data enable comparisons among reaches (Figure 32). Of the 33 miles of habitat that are surveyed, 4.3 miles are in the mainstem Acme-Saxon reach, and 0.8 miles are in lower Hutchinson Creek. From 1999-2001 an average of 21.1% and 12.7% of the chinook redds that were recorded in the South Fork drainage were located in the Acme-Saxon reach and Hutchinson Creek, respectively, which together comprised only 15.5% of the surveyed stream miles (MacKay and Pfundt 2002). Spring or early chinook are considered those that spawn prior to Oct. 1st. From 1999 to 2001, 22.2% of the early chinook redds recorded in the mainstem were located in the Acme-Saxon reach (14.1% of the available habitat), and 66.7% of the tributary redds were located in Hutchinson Creek. Only the mainstem reach from Larson's Bridge (RM 20.7) to RM 18.0 consistently supported a higher percentage of early spawning chinook, and Hutchinson Creek is by far the most heavily utilized tributary to the South Fork.

Emergence

Fry are present over the general time frame of early February through early May (Wunderlich et al. 1982), suggesting a prolonged emergence period. More recent data recorded earlier emergence, as young-of-the-year juvenile chinook were captured in the lower South Fork (RM 0.95) on Dec. 7, 2001 (Nooksack Natural Resources, unpublished data).

Figure 32: Densities of spring chinook adults and redds (through 9/30) in South Fork Nooksack River from foot spawner surveys (WDFW 2000). Comparison of recent averages with total averages (densities averaged by river mile).



Juvenile Rearing

Scale analysis of returning adults indicates that percentage of North Fork and South Fork chinook with stream-type life history strategy (long freshwater residence, smoltification as yearlings) differ significantly (Marshall et al. 1995). From 55% to 67% of South Fork chinook returning 1980 to 1994 had outmigrated as yearlings, compared to 5% of North Fork chinook from 1980 to 1983. While estimates may be confounded by inclusion of hatchery-origin fish and small sample size, these data suggest a significant contribution of a stream-type life history strategy in the South Fork and emphasize that freshwater rearing habitat, through both summer low-flow and winter high-flow periods, may be substantially more important for South Fork chinook.

Distribution of rearing chinook may vary between years depending on abundance of juvenile chinook and other species, hydrologic conditions and resource availability (various authors, cited in Healey 1991). Small fry are expected to use channel margins, especially backwaters and areas with bank

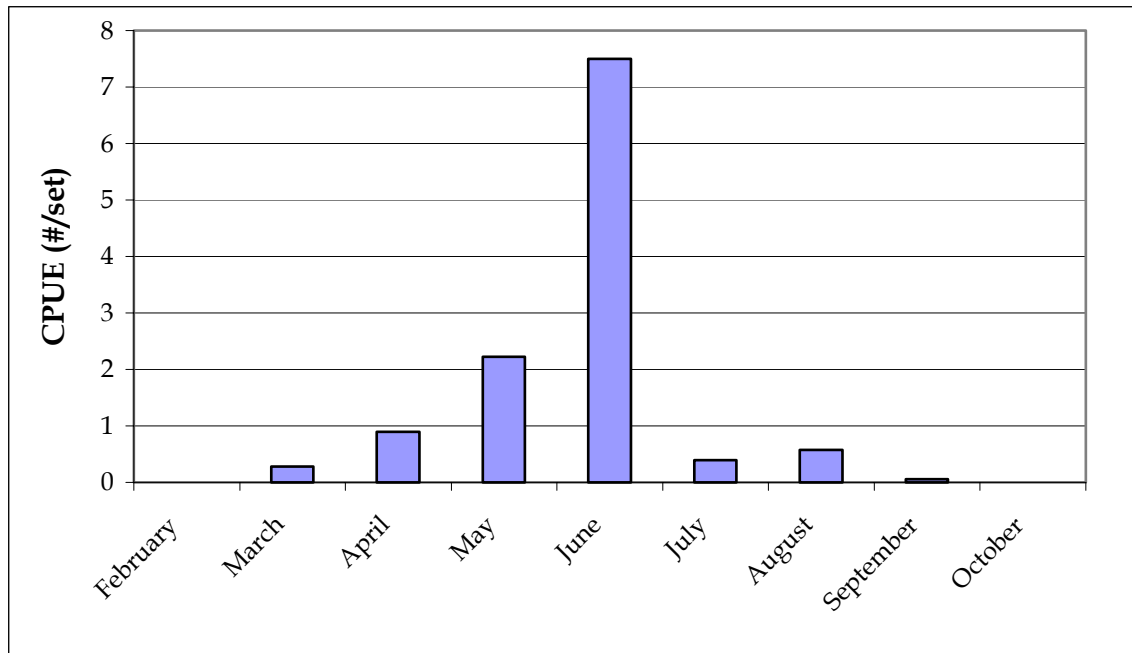
cover, and off-channel habitats. Fry surveys conducted during the spring from 1994 to 1996 suggest a shift to off-channel habitats after emergence, especially in the South Fork (Castle and Huddle 1996). From March to June 1994, spring chinook fry (34-45 mm length) were found in more than half of the spring seeps feeding into the South Fork between RM 15.1 and 29.8 (Castle and Huddle 1994). These sites were generally small in size, clear, and 5 to 11 °F warmer than in the river. Additional areas with high concentrations included valley-wall tributaries, side channel complexes, abandoned channels, and terrace tributaries in the reach. Chinook fry were far less abundant in similar surveys in 1995 and 1996 on both the North Fork (RM 39.4-63.4) and South Fork (RM 11.9-30), which was attributed to reduced availability and connectivity of off-channel habitats since both years were relatively dry (Castle and Huddle 1995; Castle & Huddle 1996). Habitat use generally shifts offshore into higher velocity midstream areas as fry increase in size (various authors, cited in Healey 1991).

During summer in the South Fork, juvenile chinook often occupy higher velocity areas midstream than juvenile coho, although there is a strong association with cover (Ecotrust, unpublished data). During 2001, three snorkel surveys were carried out along approximately 1000m in the South Fork, within the WRIA intensive site at the upper end of the Acme-Saxon reach (Naef 2002). A total of 1504 chinook juveniles were enumerated, on August 8 and 9 and September 11. August surveys were conducted by Lummi Natural Resources personnel using “non-quantitative, single pass methodology” (Naef 2002). The September survey, conducted by Ecotrust personnel with numerous passes, was more rigorous and enumerated 548 chinook in 693 m of the sampled reach (Ecotrust, unpublished data), for an average density of 79 juvenile chinook per 100 meters of channel length. Detailed mapping of fish and habitat indicate that 76% of the juvenile chinook were associated with wood cover, including 51% with complex cover (wood jams and aggregations) and 25% with simple cover (single logs and rootwads) (Ecotrust, unpublished data).

Beach seining is limited to relatively shallow marginal areas along gravel bars with sand to small cobble substrate, but allows for direct identification and measurement of individual fish and can be conducted in low visibility conditions at a range of flows. During 2001, 91 beach seine sets were conducted in 19 sites in the reach. A total of 85 juvenile chinook were captured, and in every month from March to September, with peak catch-per-unit-effort in June (Figure 33, Naef 2002).

Minnow trapping was the primary means of sampling chinook in most floodplain habitats in 2001 (Naef 2002). Chinook were captured in every month sampled (January through October) in 2001 (Figure 34). Juvenile chinook were captured by minnow traps in Hutchinson Creek (1 in March, 4 in August, 1 in

Figure 33: Catch-per-unit effort (CPUE) of juvenile chinook by month from beach seine surveys in Acme-Saxon reach in 2001 (Naef 2002). Numbers of sets by consecutive month from February through October were: 5, 14, 10, 9, 4, 10, 19, 17, and 2.



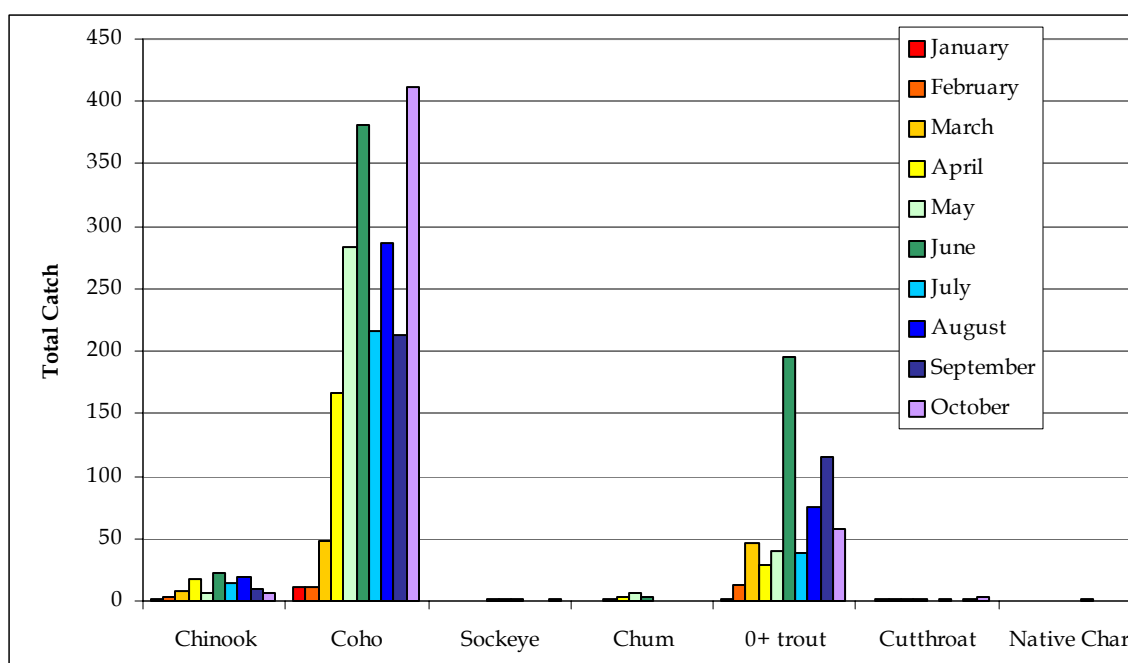
November), Roos slough (5 in April), Nessel's side channel complex (4 in September, 1 in November), Landingstrip Creek (2 in March, 1 in May), and Rothenbuhler slough (2 in April). No chinook were captured in minnow traps deployed in Pond Creek or Curtis Slough (Naef 2002). Total catches of coho in minnow traps far outnumbered those of chinook. Notably, snorkel surveys enumerated 438 juvenile chinook (9/11/01) in the side channel downstream of Nessel's slough (part of the Nessel's side-channel complex described in *Habitat Characterization* section) and 199 juvenile chinook (9/12/01) in a 300m-long reach in the floodplain portion of Hutchinson Creek (Ecotrust, unpublished data).

Outmigration

Chinook salmon can outmigrate as fry (migrating to estuaries soon after emergence), fingerlings (rearing for weeks to months, prior to outmigrating to estuaries in spring or summer), or as yearlings. The smolt outmigration period for individual stocks and subpopulations of chinook from the Nooksack is not well defined, although chinook outmigration generally occurs between January and mid-August. From 1994 through 1999, the Lummi Nation has operated a rotary screw trap in the lower Nooksack River, from around March 1 through mid-August (Conrad and MacKay 2000). Chinook smolts have been identified over this entire period, and outmigration is likely to have begun before initiation of trap operations in any given year. The Nooksack Tribe operates a smolt trap

on the lower South Fork, and outmigrating fry were recorded as early as mid-January (NNR, unpublished data). Recent advances in stock discrimination methods, including microsatellite DNA analysis that can successfully differentiate among Nooksack chinook stocks, will prove invaluable in providing quantitative estimates of stock composition of outmigrants.

Figure 34: Total minnow trap catch by species and month in Acme-Saxon reach in 2001 (Naef 2002).



Downstream movement of chinook in other systems appears to occur predominantly at night, often in conjunction with periods of high river discharge (various authors, cited in Healey 1991). In the Nooksack River, while the relationship is not strictly linear, higher catches of chinook at the lower mainstem smolt trap generally occur with higher flow (Conrad and MacKay 2000). There is no strong evidence of difference in catch between day and night, although small sample size precludes definitive conclusion. Intraspecific (within-species) competition may also stimulate downstream migration (Healey 1991).

The Nooksack Tribe has operated a smolt trap in the lower South Fork from 2000–2002, with pilot operations also occurring in 1999. Downstream-migrating chinook have been recorded from mid-January through mid-July, which constitutes the entire period of operation (NNR, unpublished provisional data). The peak catch-per-unit-effort (CPUE; number of fish/hour) in 2000 was 37.85 on April 12, in 2001 was 240.69 on April 26, and in 2002 was 19.61 on May 1. Data from the Skagit River indicate chinook outmigrate in January, although the Lummi Nation’s smolt trap in the lower mainstem Nooksack River has not yet

caught chinook this early in limited sampling (Conrad and MacKay 2000). The observation of chinook leaving the South Fork earlier than they have been recorded in the lower mainstem Nooksack River suggests that they may be migrating to rearing areas in the mainstem rearing is likely occurring. Indeed, yearling juvenile chinook have been captured from December through February in the Mainstem Nooksack, especially in the upper reaches where there is greater habitat complexity (NNR, unpublished data).

Native Char (S. confluentus / S. malma)

The U.S. Fish and Wildlife Service list bull trout as a threatened species, and North Puget Sound's large rivers clearly have stronger runs than South Sound. The majority of anadromous bull trout in the Puget Sound Region of the Distinct Population Segment (equivalent to ESU) appear to occur in Skagit, Snohomish, Stillaguamish, and Nooksack drainages. Bull trout exist in all three forks of the Nooksack River, with spawning in the South Fork from Edfro Creek upstream (WDFW 1998). Nooksack bull trout include anadromous, probably fluvial, and possibly resident life history strategies. No abundance estimates are currently available.

The South Fork Nooksack River supports both bull trout and Dolly Varden, although apparently not in the same areas. Both of these stocks are native and wild. Genetic analysis indicates that there is an isolated population of Dolly Varden in an upper South Fork tributary named Bell Creek (Spruell and Maxwell 2002). Earlier genetic analysis of a very small number of native char samples from another upper South Fork headwater stream (Pine Creek) also identified the char as Dolly Varden (Sewell Young, WDFW, personal communication). Both of these resident populations of Dolly Varden are upstream of natural barriers to anadromous use.

The native char that utilize the Acme-Saxon reach are considered bull trout, and primarily anadromous in nature, based on genetic analysis of a very small number of native char collected from the South Fork, upstream from the two partial anadromous barriers (RM 25, RM 30.4) but downstream of permanent barriers (S. Young, WDFW, personal communication). Additionally, bull trout can attain larger size, and a native char (bull trout) of 28-30 inches was recorded in lower Wanlick Creek in 2002 (Ecotrust, unpublished data). Native char were also recorded in 2002 in Hutchinson Creek, upstream from the cascades at RM 0.8 (Ecotrust, unpublished data). Juvenile native char were captured by minnow traps in lower Hutchinson Creek in November 2001, including 2 at the mouth (81mm, 89 mm fork length; Nooksack Natural Resources, unpublished data) and another slightly upstream (52mm; Naef 2002). A sub-adult native char was also observed in the lower 0.5 mile of Hutchinson Creek in 1976-1977 (C. Kraemer,

WDFW, personal communication). While known bull trout spawning in the South Fork is located further upstream, the presence of young juveniles in Hutchinson Creek suggests spawning occurs in Hutchinson Creek, possibly upstream from the cascades located at RM 0.8.

Rearing also occurs in the Acme-Saxon reach of the South Fork, at a minimum by juveniles prior to outmigration, and by foraging sub-adults. In the South Fork main channel, at the upper end of the reach in the WRIA 1 Watershed Management Project intensive instream flow assessment site, a native char parr (possibly sub-adult) was observed in August or September 2001 (Naef 2002). Additionally, on 8/15/02 and 8/16/02, snorkel surveys in the same reach recorded bull trout (Ecotrust and Nooksack Natural Resources, unpublished data), including one approximately 6-8 inches in length (T. Cline, Nooksack Natural Resources, personal communication). The size suggests that these are likely sub-adults.

Sub-adult and adult bull trout also hold and forage in the reach. Adults would be expected to hold through the summer prior to migrating to natal spawning grounds, where they spawn in the fall. After spawning, they migrate back downstream to overwinter in mainstem areas (including this reach). Sub-adult bull trout would be expected to occupy the Acme-Saxon reach to forage from summer until the outmigration period the following spring. Sub-adult bull trout would be expected to forage in floodplain tributaries in the Acme-Saxon reach as well as within the mainstem South Fork. In the lower South Fork, a native char of likely sub-adult size was caught in lower Black Slough in Nov. 2001 (Nooksack Natural Resources, unpublished data). Foraging sub-adult bull trout have wider distributions than other life stages, and these opportunistic feeders could be found in any streams that are accessible to anadromous fish of their size (Curt Kraemer, WDFW, personal communication). Bull trout smolts have been recorded at the lower South Fork trap in April and May (Nooksack Natural Resources, unpublished data).

In summary, bull trout are highly migratory, and one or more life history phases utilize the Acme-Saxon reach at all times of the year. The reach is used for: summer upstream migration and holding by anadromous adults, overwintering by adults post-spawning, upstream migration and rearing (foraging) by anadromous sub-adults after returning from estuary and nearshore areas in summer, sub-adult rearing (including overwintering) until the following spring, and rearing during downstream migrations by juveniles (at a minimum) prior to smolting. Lower Hutchinson Creek also has juvenile rearing by young-of-the-year bull trout, which also suggests nearby spawning.

Coho (O. kisutch)

The Acme-Saxon reach supports all freshwater life stages of coho salmon: spawning, incubation, summer juvenile rearing, winter juvenile rearing, adult migration and holding, and juvenile outmigration. SASSI lists Nooksack coho as mixed stock origin, composite production type, and unknown status (WDFW & WWTT 1994). No formal coho escapement estimates are conducted. The Lummi Nation releases approximately 1,000,000 coho smolts annually from the Skookum Creek Hatchery, all of which are released at the hatchery site. Limited genetic analysis of Nooksack coho is underway, including establishing baselines from Skookum and Kendall hatchery broodstocks.

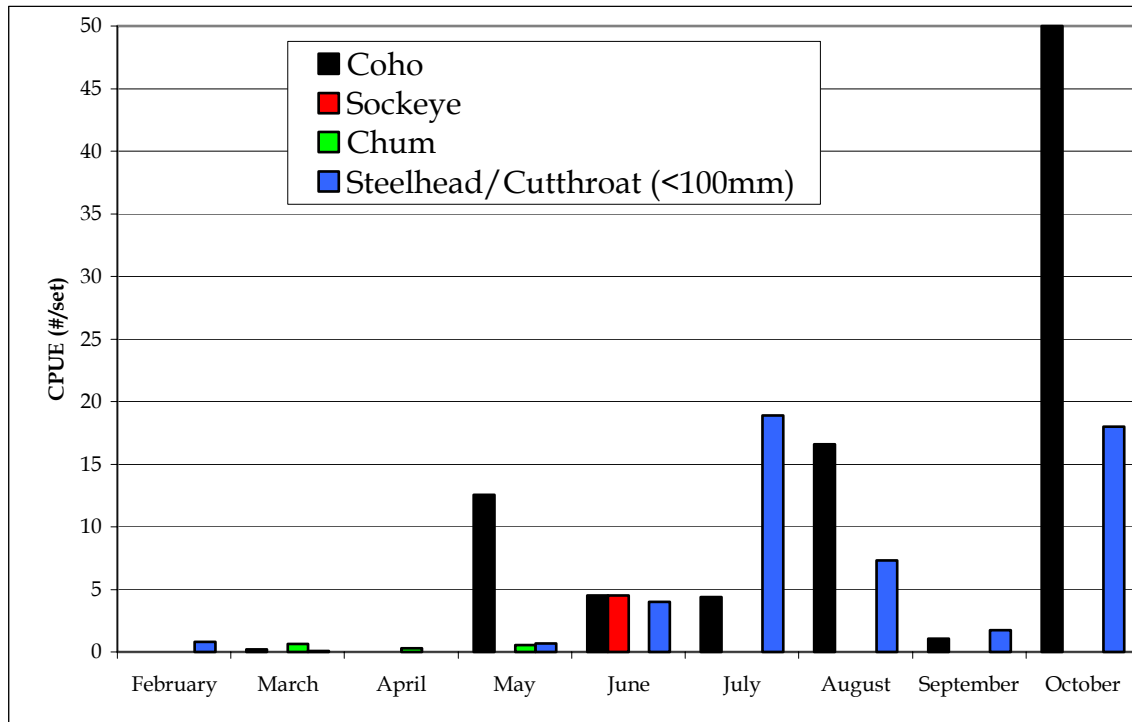
In the Acme-Saxon reach, coho spawning occurs in the South Fork Nooksack River, Hutchinson and Nessel's Creeks, in the side channel that Nessel's Creek flows into, in "Smith" Creek (a tributary to Landingstrip Creek), and in Landingstrip Creek (at RM 1.6-1.7). Spawning is also likely in Pond Creek during periods when the South Fork migrates away from the east valley wall. Spawning in several of these tributaries is discharge-dependent. Hutchinson Creek has been a WDFW coho spawn survey index area for many years. While the presence of juvenile coho upstream of the cascades in Hutchinson Creek was primarily attributed to hatchery releases (WDNR 1998). Ecotrust (unpublished data) has recorded them upstream to at least the first Mosquito Lake Road Bridge during snorkel surveys in summer 2001 and 2002.

The low-gradient tributaries, sloughs and wetlands constituting the floodplain habitats of the Acme-Saxon reach appear to present high coho rearing potential. In addition to providing rearing for juvenile offspring from locally spawning coho, these habitats may provide rearing for juveniles that move downstream from the more confined areas of the South Fork upstream. The Lummi Nation caught large numbers of coho year-round in minnow traps and, to a lesser extent, beach seines during juvenile salmonids surveys in the reach in 2001 (Naef 2002, Figures 34 and 35). Highest beach seine catches-per-unit-effort (CPUE) were recorded in May and October. From minnow traps, the following juvenile abundances were recorded, in order of CPUE (# fish/trap): Roos slough (187 coho, n=2), Curtis slough (332 coho, n=5), Hutchinson Creek (309 coho, n=5), Landingstrip creek (37 coho, n=4), and Pond Creek (5 coho, n=2).

From 2000 to 2002, wild yearling coho were recorded at the smolt trap in the lower South Fork from late January through late June, with a peak CPUE (# fish/hour) in 2002 of 77.44 on May 31 (Nooksack Natural Resources, unpublished provisional data). The peak hatchery yearling coho was also recorded May 31, and the CPUE was 1257.58. The overwhelming majority of hatchery coho were caught was during a 2 to 3 week period from May 29 to June 14. Wild yearling coho CPUE was generally highest from early May to early

June in 2002. The data also indicate substantial downstream migration of wild coho fry throughout the trap season (mid-February to July), with appreciably more wild fry enumerated than wild yearlings (although catch efficiencies are almost certainly different).

Figure 35: Catch-per-unit effort (CPUE) by species and month from beach seine surveys in Acme-Saxon reach in 2001 (Naef 2002).



Pink (O. gorbuscha)

South Fork Nooksack odd-year pink salmon are considered native, wild, and unknown stock status (WDFW & WWTT 1994). No genetic analysis of South Fork pink salmon was available at that time, but results from analysis of samples from the North and Middle forks indicated Nooksack pink salmon were clear genetic outliers, quite different from other odd-year Puget Sound pink salmon (Shaklee et al. 1995). Nooksack pink salmon also have earlier river entry timing than other Puget Sound pink salmon stocks. Based on the genetic distinctiveness, geographic distribution, run timing, and adult size, Nooksack odd-year pink salmon were considered a separate genetic diversity unit (GDU), with the rest of North Puget Sound comprising another GDU (Shaklee et al. 1995). More recent testing included samples from the South Fork Nooksack River, and a comparison with other Nooksack collections found some genetic heterogeneity, but no compelling evidence of more than one pink salmon stock (Jim Shaklee, WDFW, internal memorandum dated Nov. 15, 2001).

Odd-year pink salmon spawn in the lower gradient reaches of the South Fork to RM 25, and in larger tributaries including Hutchinson Creek. Escapement estimates are not made specific to the South Fork, but rather for the Nooksack basin, with the South Fork represented through an index on lower Hutchinson Creek. Recent escapement estimates for the Nooksack basin have been 26,000, 95,000, and 226,000 for 1997, 1999, and 2001, respectively. The South Fork run is much weaker than that of the North Fork. Pink salmon were apparently formerly very abundant in the South Fork, as Morse (1883) described them as completely filling the river; literally, there were millions of them. Naef found concentrations of adult pink salmon adjacent to Acme Farm, and near the outlets of Nessel's and Pond creeks in 2001 (Naef 2002). As expected, given their almost immediate outmigration after emergence, no juvenile pink salmon were found in juvenile surveys conducted in the reach throughout 2001 (Naef 2002).

Over the past three brood years, small numbers of spawning even-year pink salmon have also been recorded in the South Fork Nooksack River, and small numbers of outmigrating juveniles were recorded at the lower South Fork smolt trap in March and April 2001 (Nooksack Natural Resources, unpublished data). The peak CPUE was 1.78 fish/hour, recorded on April 3. Even-year pink salmon are common further north, but unusual in Puget Sound; however, abundances have been rapidly increasing for the population in the Snohomish basin, and small numbers are recorded now in at least the Skagit, Nooksack, and Stillaguamish drainages. Recorded spawning in the South Fork Nooksack has been downstream of the Acme-Saxon reach.

Pink salmon outmigrate soon after emergence. Juvenile pink salmon were recorded at the South Fork smolt trap at the start of operations in 2002, which was Feb. 19 (Nooksack Natural Resources, unpublished provisional data), through to May 21. The peak CPUE was 44.81 fish/hour on April 25.

Chum (O. keta)

South Fork chum salmon are presently grouped together with mainstem Nooksack River chum as a stock, and this stock is considered native stock origin, wild production type, and unknown stock status (WDFW & WWTT 1994). No genetic analysis has been conducted on South Fork chum, but considerable genetic differences from other Puget Sound chum were found in a small 1992 collection from the mainstem Nooksack River (n=35) (Phelps et al. 1995). Collections from Kendall and Maple Creeks in the North Fork also showed the North Fork stock to be genetically distinct. Both of these stocks are in the North Puget Sound GDU.

No escapement estimates are made for this stock, but the South Fork abundances are clearly small, described as having less than 200 adults per year for the past 30

years (Pete Castle, WDFW, personal communication). Available records suggest that the Acme-Saxon reach is likely the primary use area for South Fork chum. Chum spawn in side channels in the South Fork between Acme and Nessel's Creek (WDNR 1998). When flows permitted, they spawned in Curtis Slough, which is sometimes called Pettigrew Slough (Doug Huddle, WDFW, personal communication). The spawn survey records indicate that small numbers spawn in Hutchinson Creek in some years, and a chum has also been recorded in Nessel's Creek. Concentrations of spawning chum were recorded adjacent to Acme Farm, in a side channel near Nessel's Creek, and in a highly braided reach at RM 12.5 (Naef 2002). At least 15 redds were later de-watered when discharge dropped. Some juvenile chum rear for a few weeks in freshwater prior to outmigrating, and juvenile chum were caught in side channel and tributary habitats in the Acme-Saxon reach during juvenile salmonids surveys in 2001 (Figures 34, 35; Naef 2002). The chum were captured from March to June and in South Fork, Rothenbuhler and Curtis sloughs, and Hutchinson Creek. More chum were captured in beach seines than minnow traps. Outmigrating chum were recorded at the South Fork smolt trap in 2002 from late February through mid-June, with a peak CPUE of 36.2 fish/hour on May 9 (Nooksack Natural Resources, unpublished provisional data). In 2001 the trap was operated earlier and chum were recorded by the end of January, with peak CPUE of 22.49 on April 13th.

Sockeye (O. nerka)

While they are not yet formally considered stocks, the Nooksack and Skagit drainages are now known to support small riverine populations of sockeye. Genetic analysis of adult spawners collected from these drainages in 1996 indicates they are much more closely related to river-sea-type populations in British Columbia and Alaska than to lake-rearing populations nearby (Gustafson and Winans 1999). Of the rivers that have adult sockeye, but do not have lakes available for rearing, the Nooksack and Skagit drainages had the most persistent evidence of consistent spawning, with spawning in both the North and South Forks of the Nooksack River, and in terrace tributaries. In contrast to lake-type sockeye populations, all river-sea type populations were genetically closely related, from the Skagit drainage north to northern Southeast Alaska (Gustafson and Winans 1999). Riverine sockeye had not previously been confirmed south of the Fraser River.

Riverine sockeye salmon stocks are frequently a mixture of river-type and sea-type life history patterns. River-type sockeye juveniles use side-channel river habitat for one or two years of juvenile rearing prior to outmigration, and sea-type sockeye outmigrate as sub-yearlings (Gustafson and Winans 1999). Gustafson and Winans note that LWD-clearing, log jam removal, and isolation of sloughs and swamps have led to elimination of most rearing habitat for river-sea

type sockeye, which may explain the small population sizes in Washington rivers. Scale analysis of a very small number of adult sockeye from the Nooksack indicated that they were river-type, rather than sea-type (Doug Huddle, WDFW, personal communication). Sockeye captured at the smolt trap on the lower Skagit River have primarily been yearling outmigrants that are presumed to be river-sea-type, although sub-yearlings have also been observed (Jim Repoz, WDFW, personal communication). Jim also reports that small numbers of yearling sockeye smolts have also been observed at a smolt trap on a wetland-dominated floodplain tributary to the Skagit River named Manser Creek. Small numbers of juvenile sub-yearling sockeye have been recorded at the South Fork trap (Nooksack Natural Resources, unpublished provisional data). Naef (2002) caught 18 juveniles during June in beach seining in the Acme-Saxon reach (Figure 35), and two in Hutchinson Creek by minnow trapping: one on May 30, 2001, and one on Nov. 1, 2001. She also caught small numbers of juvenile sockeye in May, June, July, and October in minnow trap surveys (Figure 34). The observations in October and November indicate river-type rearing strategy in this reach.

While no escapement estimate is produced in the Nooksack drainage, the Acme-Saxon reach consistently supports sockeye spawning. Naef (2002) describes sockeye as among the earliest spawners in the reach, and spawn surveys in recent years have recorded redds as early as August. Naef observed a concentration of sockeye spawning near Acme Farm, with other spawners sparsely distributed throughout the study reach. Sockeye spawning over multiple years has also been observed near this location, upstream of the SR 9 Bridge in Acme. Spawn survey records have also occasionally recorded sockeye in lower Hutchinson Creek.

Steelhead (O. mykiss)

The South Fork Nooksack River supports two stocks of steelhead: summer-run steelhead and winter-run steelhead. Both stocks are native, have wild production type, and have unknown stock status (WDFW & WWTT 1994). No genetic analysis has been conducted on either stock. The summer-run stock likely comprises an important genetic reserve because it has not been supplemented with Lower Columbia River's Skamania strain summer-run steelhead, as has occurred for long periods with many other summer-run stocks in Washington. While WDFW releases winter-run steelhead with origins from Chamber's Creek in South Puget Sound into the North and Middle forks, no supplementation occurs in the South Fork.

Summer-run steelhead stocks are uncommon, and most of the summer-run steelhead in the Nooksack basin appears to utilize the South Fork. Total run size has been estimated at less than 200 adults (Pete Castle, WDFW, personal

communication). Prior to construction of the diversion dam, they also utilized the upper Middle Fork. It is considered possible that small numbers also utilize upper reaches of tributaries to the North Fork. They are excellent migrating fish, and summer-run steelhead, as well as bull trout appear to access habitat in the South Fork that are unavailable to other anadromous species. Summer-run steelhead are thought to mostly spawn in the upper South Fork, upstream of the partial passage blockage at Sylvester's Falls (RM 25). They also access habitat upstream of the partial blockage at RM 30.4 that appears to limit upstream use by spring chinook. Summer-run steelhead distribution is poorly understood, but spawning has been observed upstream of Wanlick Creek in March. It is possible that summer-run steelhead also utilize upper Hutchinson Creek, as three adults were recorded at the base of the cascades during chinook spawn surveys in September 2001 (Nooksack Natural Resources, unpublished data). Puget Sound summer-run steelhead generally have river entry timing from May through October, so these fish have extended adult holding periods. At a minimum, this stock utilizes the Acme-Saxon reach for upstream migration and adult holding, downstream migration as kelts¹, and for rearing as smolts migrate downriver.

While no escapement estimate is conducted for winter-run steelhead, they are more common than summer-runs. The Nooksack River has been described as having one of the largest runs of winter-run steelhead in Washington, and was 5th in the state in steelhead catch in 1947 (Bradner 1950). Run size appears to have declined, though, and the River had not ranked in the top 25 rivers in Washington for sport catch in the years leading up to 1984 (WDG 1984).

Winter steelhead enter rivers from November through May, with spawning generally from January through June. They utilize habitat downstream from summer-run steelhead and are likely limited by the partial blockage at RM 25 on the South Fork, perhaps attributable to lower metabolisms due to cooler water temperatures during their migration period. Winter-run steelhead use the South Fork mainstem and moderate- to larger-sized tributaries. In the mainstem South Fork, spawning primarily occurs from RM 8 to RM 25 (WDG 1984). Of the 468 miles of habitat that was accessible to steelhead in the larger Nooksack River watershed, 99 miles were in the South Fork watershed.

The Acme-Saxon reach and lower Hutchinson Creek are important spawning areas, and steelhead also access habitat upstream of the cascades in Hutchinson Creek (RM 0.8). A total of 3 carcasses and 12 apparent redds (size and timing) were documented in the South Fork in the reach (Naef 2002). There is an impassible 8- foot bedrock falls at RM 5.7 on Hutchinson Creek (WDNR 1998). In

¹Post-spawning adults heading back to sea, a phase for which feeding is important to rebuild body condition.

recent years when adequate spawn surveys were conducted (1984-1989, and 1995), the numbers of wild winter-run steelhead redds recorded in the lower 0.7 miles of Hutchinson Creek were 21, 25, 19, 30, 22, 24, and 20, respectively (WDNR 1998). This reflects a remarkably consistent level of spawning. Suspended sediment levels in the South Fork in spring 2002 prevented WDFW from enumerating mainstem redds, although they were able to do so in the North and Middle forks (Pete Castle, WDFW, personal communication). Steelhead have been known to spawn in Nessel's Creek and have also been recorded in the small amount of accessible habitat in lower Pond Creek, likely when the mainstem South Fork channel was shifted away (WDNR 1998).

Juvenile steelhead rear for 1 to 4 years prior to outmigrating. Young-of-the-year (0+) trout² were captured year-round in minnow traps and beach seining, with highest catches from June to October (Naef 2002, Figures 34 and 35). 0+ steelhead or cutthroat trout were found in Hutchinson Creek, Nessel's Creek, and Pond Creek, with very few (<3) in each of Rothenbuhler Slough, Roos Slough, and Landingstrip Creek (Naef 2002). Steelhead have been caught at the lower South Fork smolt trap the entire period of operation (mid-January through July), with the majority in April and May (Nooksack Natural Resources, unpublished provisional data). The peak CPUE in 2002 was 7.44 fish/hour, recorded on May 13. It is unknown what percentage of the outmigrants derives from each of the two steelhead stocks. By late June, young-of-the-year (0+) downstream migrant steelhead or cutthroat were also recorded.

Cutthroat Trout (O. clarki)

Nooksack Coastal Cutthroat are considered mixed stock origin, composite production type, and unknown stock status (Blakley et al. 2000). The anadromous cutthroat are considered native and wild production type. Cutthroat collections in 1995 from Double Ditch Creek (n=47) were analyzed for allozymes, and were significantly different from all other Washington collections ($P < 0.001$).

Cutthroat life histories include resident (generally in headwater areas), fluvial, adfluvial, and anadromous. Acme-Saxon supports all freshwater life history phases of anadromous cutthroat, with resident populations occurring higher up in the tributaries to the reach, including Hutchinson, Nessel's and Pond creeks (WDNR 1998). Anadromous cutthroat in the Nooksack drainage generally have river entry timing from August through October and spawn from January through April, so they have a prolonged holding period. Non-anadromous forms generally spawn from January through July (Blakley et al. 2000).

² Steelhead and cutthroat trout <80mm in fork length are virtually indistinguishable through visual observation.

Like bull trout, anadromous cutthroat can be repeat spawners, and have a sub-adult life history phase where they re-enter rivers and streams in summer or fall to overwinter. These sub-adults then outmigrate again the following spring without spawning, then after further growth, return to spawn in their natal streams. Cutthroat spawning streams are primarily located in lower elevation settings than bull trout spawning streams though, probably due to their lower temperature sensitivity. Similar to coho, juveniles use wetlands and beaver ponds to overwinter in the Nooksack River watershed, and spend summers in small tributary pools and mainstem side channels (Fox 1993, citing personal communication with Jim Johnston, Washington Department of Fish and Wildlife).

The sloughs and smaller floodplain tributaries, including Landingstrip Creek would be expected to support anadromous cutthroat spawning. Two trout-sized redds were recorded in Rothenbuhler Slough on Jan. 3, 2002 (Naef 2002), which were most likely cutthroat. Naef mentions that unoccupied trout-sized redds were occasionally detected in the Acme-Saxon reach. An unoccupied trout-sized redd was observed during spring surveys of lower Hutchinson Creek (Loren Roberts, Nooksack Natural Resources, personal communication). The timing suggests that this was cutthroat.

Like steelhead, anadromous cutthroat spend at least one year in freshwater prior to outmigrating. Young-of-the-year (0+) trout (see footnote previous page) were captured year-round in minnow traps and beach seining, with highest catches from June to October (Naef 2002, Figures 34 and 35). 0+ steelhead or cutthroat trout were found in Hutchinson Creek, Nessel's Creek, and Pond Creek, with very few (<3) in each of Rothenbuhler Slough, Roos Slough, and Landingstrip Creek (Naef 2002). Cutthroat parr were predominantly found within massive LWD complexes, or in beaver ponds and their associated slough systems (Naef 2002). Bob Knudsen, a long-time resident, reports that trout were formerly very abundant in Rothenbuhler Slough (in the 1940's), when it had abundant beaver dams and impoundments (personal communication). Yearling and older cutthroat that were migrating downstream (presumed smolts) were caught at the South Fork smolt trap from early April through early July in 2002, with young-of the year steelhead or cutthroat trout enumerated from late June onward (Nooksack Natural Resources, unpublished data). There were substantially fewer cutthroat than steelhead smolts outmigrating. The peak CPUE for cutthroat smolts was 0.50 fish/hour on June 3 and June 10.

Habitat Characterization and Implications for Salmonids

General Habitat Availability

Habitat surveys of the Acme-Saxon reach, covering the active channel of the South Fork and major floodplain habitat complexes, were conducted by NSEA during the 2000 summer low-flow period using a modified version of the TFW Ambient Monitoring Methodology (Pleus et al. 1999). Habitat units were classified as either pool or riffle³, categorized by channel location⁴, and measured for length and average width, from which unit area was calculated. For side-channel areas, a bank-full width was measured and it was noted whether the unit was wet or dry.

South Fork Habitat

A total of 251737 m² of wetted habitat area was mapped in the South Fork active channel (Table 8, Figures 36 and 37). Habitat was distributed among primary (83% by area, 56% by number), secondary (14% by area, 42% by number), and side channel (3.2% by area, 1.5% by number) habitat units. Among reaches, distribution of wetted area among primary and secondary habitat units was similar. Notably, the only side channel units mapped were in reach 1. Habitat diversity, as measured by the number of habitat units per unit channel length, was substantially greater in reach 3 (15 primary and 27 total habitat units per 1000 m) than in either reach 1 (8.9 primary and 12 total units per 1000m) or reach 2 (7 primary and 14 total units per 1000m). Habitat diversity is also evidenced in the distribution of habitat across the active channel: reaches 2 and 3 had a relatively higher number of secondary units (50% and 45% of total number of habitat units in the reaches, respectively), while most (72%) of the habitat units in reach 1 were primary units.

Relative proportions of pool and riffle habitat types also varied by reach and channel location (Figure 38). Riffles dominated total area (82%) and, to a lesser extent, total number (69%) of habitat units in the reach. Riffles also dominated the number and wetted area of secondary and side channel units. Reach 1 had the greatest proportion of pools by area (37%) and number (31%) than the other two reaches (reach 2: 25% of units were pools, 16% of area; reach 3: 26% of units

³ Per TFW methodology, all wetted habitat units not considered pool are characterized as riffle by default.

⁴ Channel location categorized thus: (1) Primary units, dominant channel units >50% of channel width; (2) Secondary units, subdominant channel units <50% channel width; units can be physically adjacent to primary units (i.e. in main low-flow channel) or separated by gravel bar; and (3) Side channel units, separated from the main low-flow channel by a vegetated island. Subsurface units were excluded from analysis.

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were pools, 11% of area). It should be noted, however, that many of the units classified as pools, especially in the lower reaches, exhibited a “glide-like” character (NSEA field crews, personal communication).

Table 8: *Habitat availability in the South Fork Acme-Saxon Reach.*

Reach†	Location	Wetted Area (m ²)	Length (m)	Number
Reach 1	Primary	49341	1799	16
	Secondary	1772	295	4
	Side Channel	7974	390	2
	Total	59088	2483	22
Reach 2	Primary	80908	2264	16
	Secondary	18184	1205	16
	Total	99092	3470	32
Reach 3††	Primary	79363	2826	42
	Secondary	14195	1681	35
	Total	93557	4506	77
GRAND TOTAL		251737	10459	131

† Habitat units were assigned to reach if >50% of habitat area fell within boundaries.

†† Habitat survey extended ~220m upstream of Saxon Rd. Bridge, habitat that was included in Reach 3 calculations.

Figure 36: *Mainstem habitat in Reaches 1 and 2*

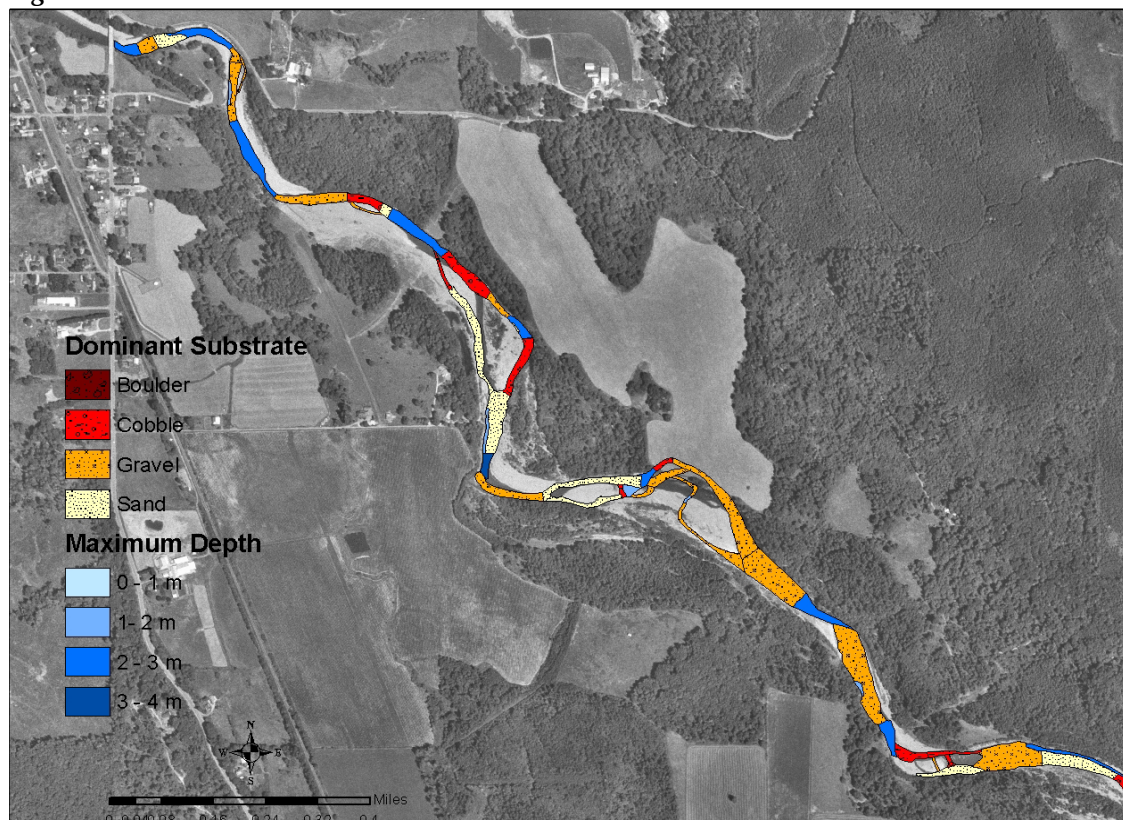
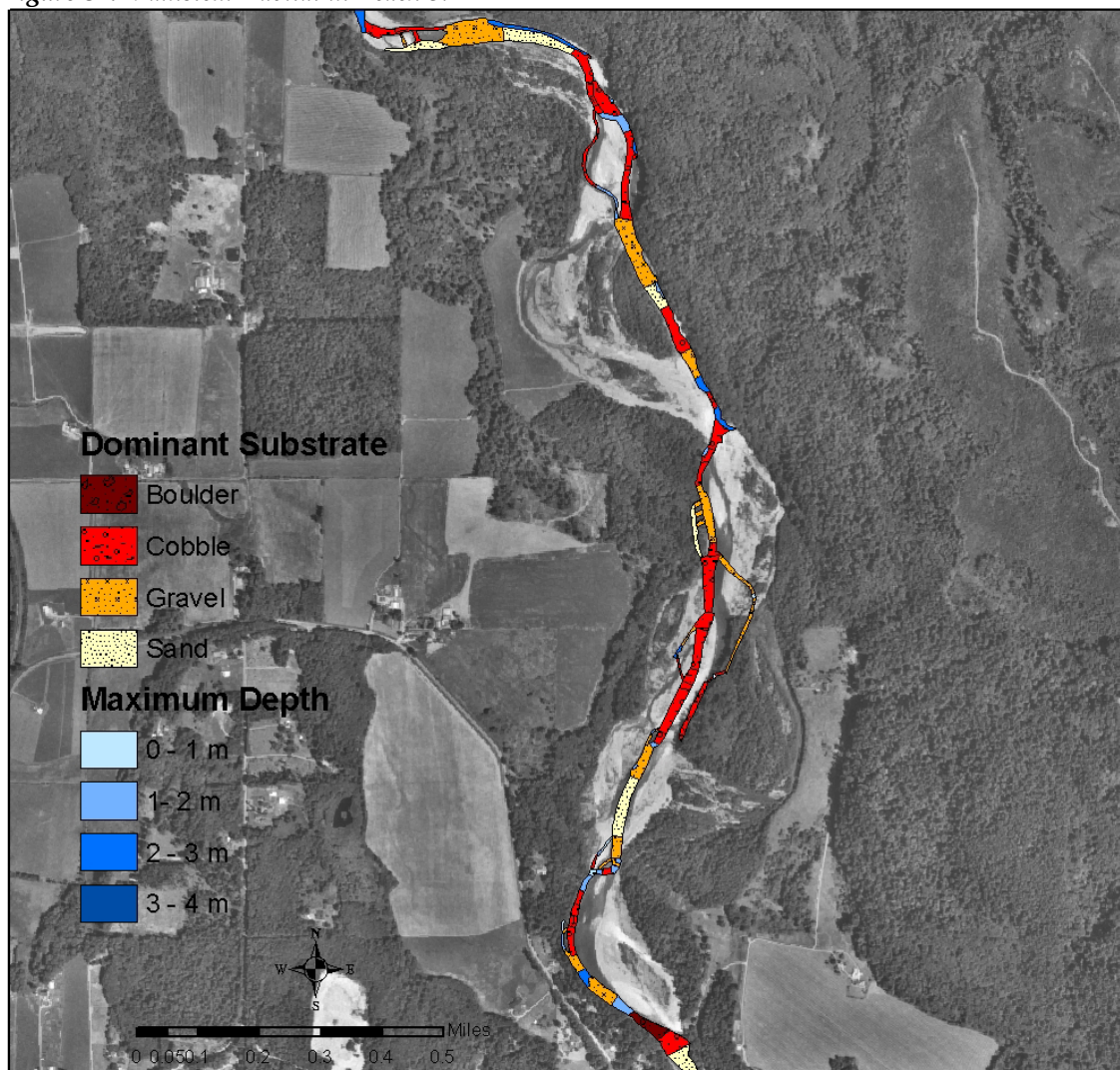
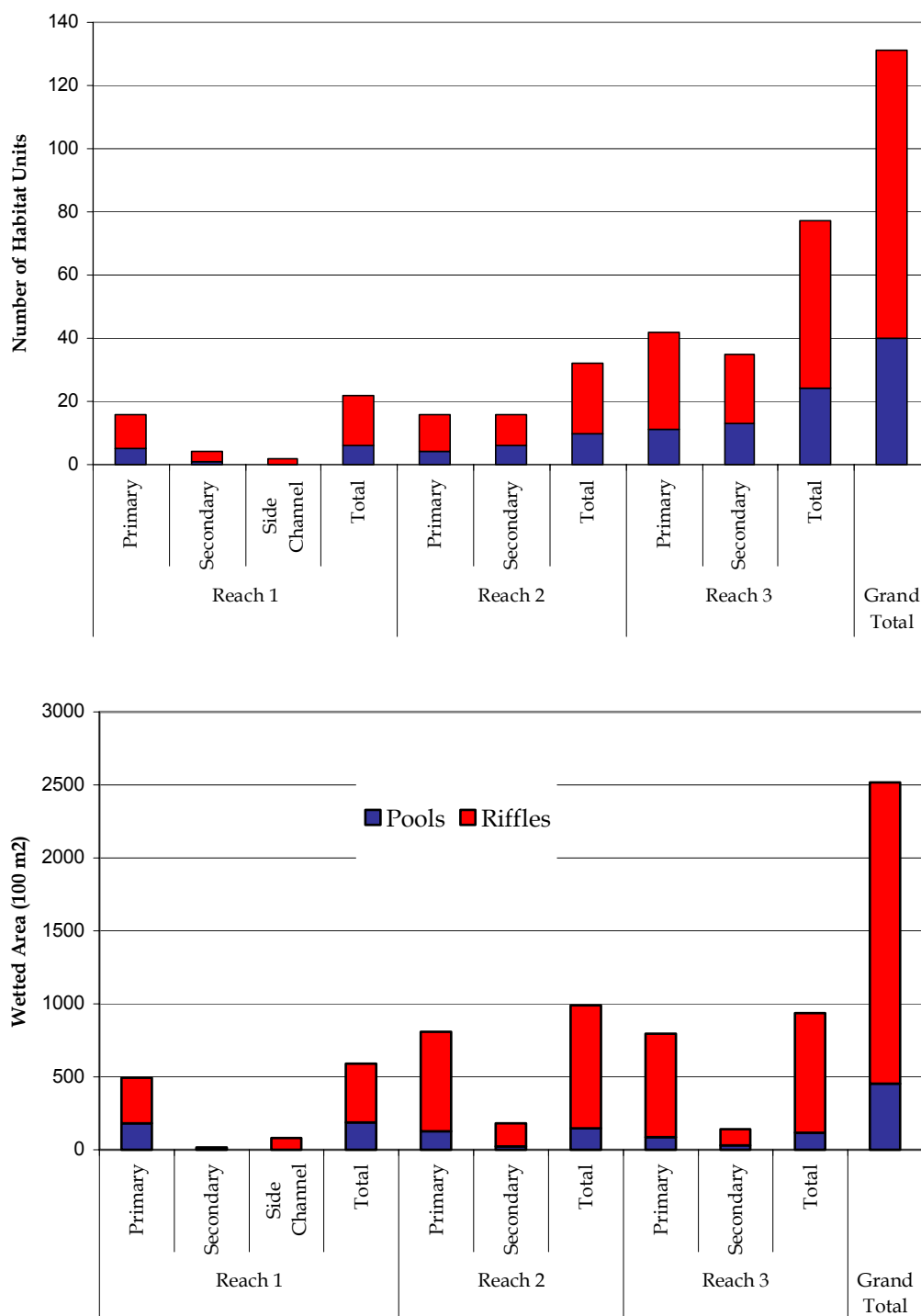


Figure 37: Mainstem Habitat in Reach 3.



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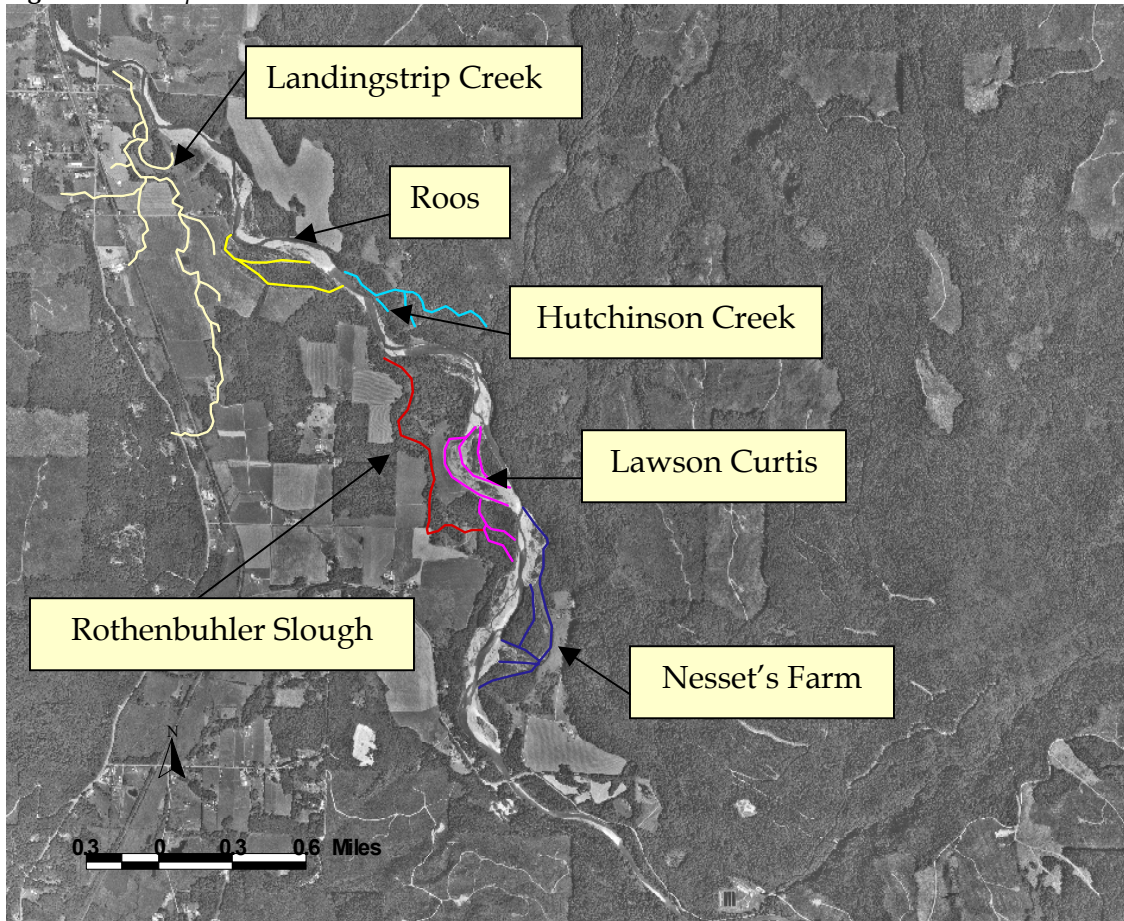
Figure 38: Relative contribution of pool and riffle habitat types to the total habitat unit number (top) and wetted habitat area (bottom), by reach and channel location, in the Acme-Saxon reach of the South Fork.



Floodplain Habitat

Floodplain habitat in the Acme-Saxon Reach occurs in 6 major locations in the Acme-Saxon Reach: Nessel's Farm, Lawson Curtis Sloughs, Rothenbuhler Slough, Hutchinson Creek, Roos Side-channel and Landingstrip Creek complex (Figure 39). Each of these areas was created by the main South Fork channel, but channel migration and avulsion have now separated these channels from the forces of the main channel.

Figure 39: Floodplain habitat distribution in the Acme-Saxon Reach



Nessel's Side-Channel Complex

The Nessel side-channel complex is located on the right bank of the South Fork Nooksack River near RM 12, adjacent to Nessel's Farm (Figure 39). This side channel consists of an extensive beaver pond fed by a small perennial tributary, Nessel's Creek (sometimes referred to as Saxon Creek). The portion of the side-channel below the beaver pond is seasonally occupied by flow from the South Fork as high winter flow enters the channel. The outlet of the beaver pond also provides a metered supply of water from the 490-foot long pool to the lower side

channel area for much of the year. During the summer, this lower side channel area is ephemeral with small pools of water that persist throughout the year. Many of these pools are inhabited by iron bacteria, which oxidize inorganic ferrous iron as a source of energy. The bacteria remove oxygen from the water and could impact fish stranded in the pools. During summer 2000 habitat surveys, the Nessel's side-channel complex was wetted over 35% of its length; the downstream end and the overflow channels feeding into the beaver pond were dry. Within the wetted portion, 35% of the area was in pool units.

Above the beaver dam, sand and organic matter dominates the substrate. The beaver pond has been the focus of a modest restoration project that includes the placement of stumps and small evergreens in the pond primarily to provide cover for coho juveniles. Currently, the South Fork channel is migrating toward the pond and will likely undercut the dam soon, and may drain the pond until a new beaver dam is constructed. The pond is fed by Nessel's Creek, which provides perennial flow to the beaver pond. Nessel's Creek drains roughly 4 square miles of hillside before entering the South Fork floodplain about halfway along the length of the pond. The gradient is initially low, with spawning gravels, and then shifts to steep with impassible cascades located approximately RM 0.3, just off the South Fork floodplain. Above the ponded area, the channel splits into a series of high flow channels. These channels are blanketed in sand and gravel and thickly covered in willows and alders and are dry through most of the year. Nessel's Creek and a smaller tributary both provide spawning habitat where it crosses the South Fork floodplain, and the beaver pond provides year-round sheltered juvenile rearing habitat (S. Seymour, WDFW, personal communication).

The Nessel side-channel area has been a location where the South Fork has historically adjusted channel length through channel avulsion and migration. Based on this, it is likely that the main channel will once again occupy the current Nessel side-channel to gain channel length through this area.

The Nessel side-channel complex has been the focus of several restoration projects. The Nooksack Salmon Enhancement Association, the Boy Scouts of America and Fourth Corner Flyfishers have done in-stream enhancement work on the Nessel Farm property (S. Seymour, Washington Department of Fish and Wildlife, personal communication, 2001). NSEA installed numerous large root wads in the pond, the Boy Scouts installed truckloads of Christmas trees in the beaver pond for cover. Fourth Corner Flyfishers has worked on Nessel's Creek, replacing logs installed by Tom Nessel years ago and planting in the riparian area. The Nooksack Natural Resources Department has also done some riparian enhancement work along the side channel.

Lawson Curtis Sloughs

The Curtis property includes several side-channels that currently take flow only during high events. These channels are located on the left bank near River Mile 11 of the South Fork (Figure 39). The slough is seasonally connected to the South Fork at the downstream end and receives flow through the upstream end at close to an annual discharge. During 2000 habitat surveys by NSEA, only 38% of the surveyed habitat was wetted; the downstream end of the complex was dry, as were the overflow channels from the South Fork at the upstream end. Of that wetted, 85% of the area was in pools, suggesting that low-flow habitat is largely lentic (still water) rather than lotic (flowing).

The forested portion of the slough is a slightly lower risk with the current channel configuration, having been abandoned for at least 50-years. The heads of these channels are very close to the 'bank-full' elevation of the South Fork, so a change in configuration of the main channel could easily change the frequency of flow into this slough. The channels connect with the Rothenbuhler Slough and may present an opportunity for enhancing flow into both the Curtis and Rothenbuhler channels.

A potential of 1562 meters of channel length and 11210 square meters of habitat exist in the Lawson Curtis slough complex. There is currently no physical barrier to fish use of in this area and juvenile chinook, chum, coho, cutthroat trout and steelhead have been identified in the channels when the slough is connected to the South Fork at the downstream end (Lummi Natural Resources 2000 data). When flows have permitted, this slough has supported chum spawning. The side-channel complex has 1665 square meters of gravel-cobble riffle substrate, most of which is located in the downstream, open bar area of the channel.

The lower section of the complex has been the focus of some restoration work. Several large pieces of wood have been placed in the channel and have formed small local scour pools. These pools lose connectivity during the summer months and trapped juveniles are isolated. The slough is isolated from the river except at higher flows (Naef 2002).

Rothenbuhler Slough

Rothenbuhler Slough is an abandoned South Fork mainstem channel that is fed by a wetland and, during high water events, mainstem flow (Figure 39). The earliest channel map, dating from 1885, shows that Rothenbuhler slough was a well-connected side channel at that time. Through landscape evolution and land-use activities, the slough has lost some of its connectivity to the mainstem. During 2000 habitat surveys by NSEA, 97% of the surveyed habitat was wetted, of which 89% of the area was in pools, suggesting, as with Lawson Curtis, that the available habitat is lentic (still water).

Land clearing has impacted some of the wetlands that once fed the slough and channel incision has decreased the upstream connection to the mainstem. The City of Bellingham revetment that protects the waterline has truncated the downstream connection of the slough, so that it only outlets when enough water is in the channel to flow around the revetment and reach the river.

Rothenbuhler Slough consists of a large pond, and small perennial floodplain creek. Beavers and beaver dams were much more abundant historically and the slough also had greater spring source water (R. Knudsen, Acme-Van Zandt Flood Control Sub-zone, personal communication). This indicates a former high quantity of highly productive juvenile coho, cutthroat, and possibly sockeye rearing habitat. The disconnection of the slough from the main channel has led to filling of the pond and choking of the small stream with vegetation. In spite of the reduced flow, the slough still provides a cooler water refuge from summer rearing (see *Temperature* section). Recent juvenile fish surveys of the slough have shown that it is devoid of all fish, likely due to the connectivity issue (Lummi Natural Resources 2000 data).

Hutchinson Creek

The lower portion of Hutchinson Creek occupies an older South Fork channel, abandoned in the mid-1970s. This area (Figure 39) was created artificially by the construction of rock revetment upstream that drastically narrowed the channel migration area and isolated a large part of the South Fork floodplain. The width of the South Fork migration area in the vicinity of the creek has been reduced from 1200 to 200 feet. The riprap areas between Hutchinson Creek and the river, and nearby in the river, have been constructed to protect the City of Bellingham's waterline for diverting water from the Middle Fork to Lake Whatcom.

The portion of Hutchinson Creek flowing across the South Fork floodplain was characterized as part of the Hutchinson Creek Watershed Analysis (WDNR 1998). The channel is a low-gradient pool-riffle channel that currently has low wood loading. LWD is the dominant pool-forming mechanism, although lateral pools can form without it. Indeed, most pools are currently formed by lateral scour on the outside of meanders. Dominant substrates range from small gravel to small cobble, and spawning habitat is abundant. Increasing LWD levels will increase the volume and frequency of pools. Habitat surveys conducted by NSEA during 2000 indicated that 39% of surveyed habitat area was in pools. Lack of LWD as roughness may increase bedload mobility in some areas (WDNR 1998).

Lower Hutchinson Creek has been subject to LWD removal by Washington Department of Fisheries. One such removal was done perhaps 30-40 years ago

(Gail Everett, personal communication), and indeed there is a record of a 1982 selective woody debris removal project to “benefit” 1.2 miles of habitat (WDG 1984). Low gradient, suitable spawning exists to the cascades located about 1390 meters up.

Attempts to improve passage through the series of cascades in the gorge above these cascades have occurred over recent decades. Three or 4 concrete fish ladders were poured in narrow places in Hutchinson Creek at the WDNR campground in the gorge to backwater areas in the early 1950’s (Fox 1993). An existing ladder was apparently repaired in 1980 (WDG 1984). It was again worked on in the late 1990’s. Steelhead have been reported to spawn nearly to headwaters in Hutchinson Creek (WDG 1984), and in addition to the main creek, 1.13 miles of habitat are reported accessible in a tributary (WRIA 0265).

Roos Side-Channel

The Roos side-channel area (Figure 39) is another artifact of land use. Attempts to drain a large forested wetland (the Foxglove wetland) resulted in increased flow into this side-channel area. Currently, a beaver dam constructed in the ditch has cut off most of the flow out of the wetland, diverting it into the Roos side-channel area. The ditch drains through a perched culvert and onto the South Fork floodplain. The wetland did provide enhanced flow to the side-channel area, but at a cost of flow into the Landingstrip Creek complex, which is the natural outlet for the wetland. Juvenile use in the slough is flow limited, as the slough was dry by May 2001 (Naef 2002). During 2000 habitat surveys by NSEA, 75% of the surveyed length was wetted, of which 67% of the area was in pools; the downstream end was not connected at that time.

Landingstrip Creek

The Landingstrip Creek complex is formed from pre-historic and historic South Fork channels (Figure 39). While habitat has been altered, the complex supports appreciable coho spawning and provides a large amount of existing and potential floodplain habitat. In 2000 habitat surveys by NSEA, 85% of the area was in pools. Its use is clearly flow limited, as the creek is described as nearly dry with dissolved oxygen less than 2.0 mg/L in September 2001 (Naef 2002). The complex drains most of the floodplain to the west of the river and south of Acme. This area is the natural outlet for floodplain wetlands and floodwater that tops the elevation of the valley floor. The channels have seen extensive alteration from agricultural land use, including channel straightening, and placing 1000 feet of an accessible floodplain tributary into a buried culvert in a poplar plantation. Two tributaries have partial passage blockages under SR 9. The channels that are accessible in the Landingstrip Creek complex lack shade and LWD, and are often choked with reed canary grass and silt. In spite of the general poor quality of the habitat, the area sees extensive fish use.

Habitat Structure and Complexity

Pool Frequency and Spacing

South Fork habitat surveys conducted during summer 2000 documented 40 pools between the Acme and Saxon bridges, together comprising 18% of the 251737m² total wetted active channel area. There were 20 each of primary and secondary habitat units, although 87% of the pool area was in primary units. A comparison to pool mapping conducted in 1986 indicated very little change in pool habitat quality (Table 9).

Average primary pool spacing is 330m (6570m active channel length/20 primary pools), with 306m, 530m, and 266m spacing in reaches 1, 2, and 3, respectively. Rock-formed pools dominate the frequency and area of primary-channel pools in reaches 1 and 2 (Figure 40). In reach 3, LWD-formed pools are most frequent, but bedrock-formed pools comprise the largest area.

Table 9: Comparison of 1986 pool statistics with 2000 pool statistics.

<i>1986 Acme-Saxon Residual Depth</i>		<i>2000 Acme-Saxon Residual Depth</i>	
Mean	1.38	Mean	1.27
Sample Variance	0.23	Sample Variance	0.31
Minimum	0.61	Minimum	0.46
Maximum	2.47	Maximum	2.96
Count	24.00	Count	40.00
Confidence Level (95.0%)	0.20	Confidence Level (95.0%)	0.18

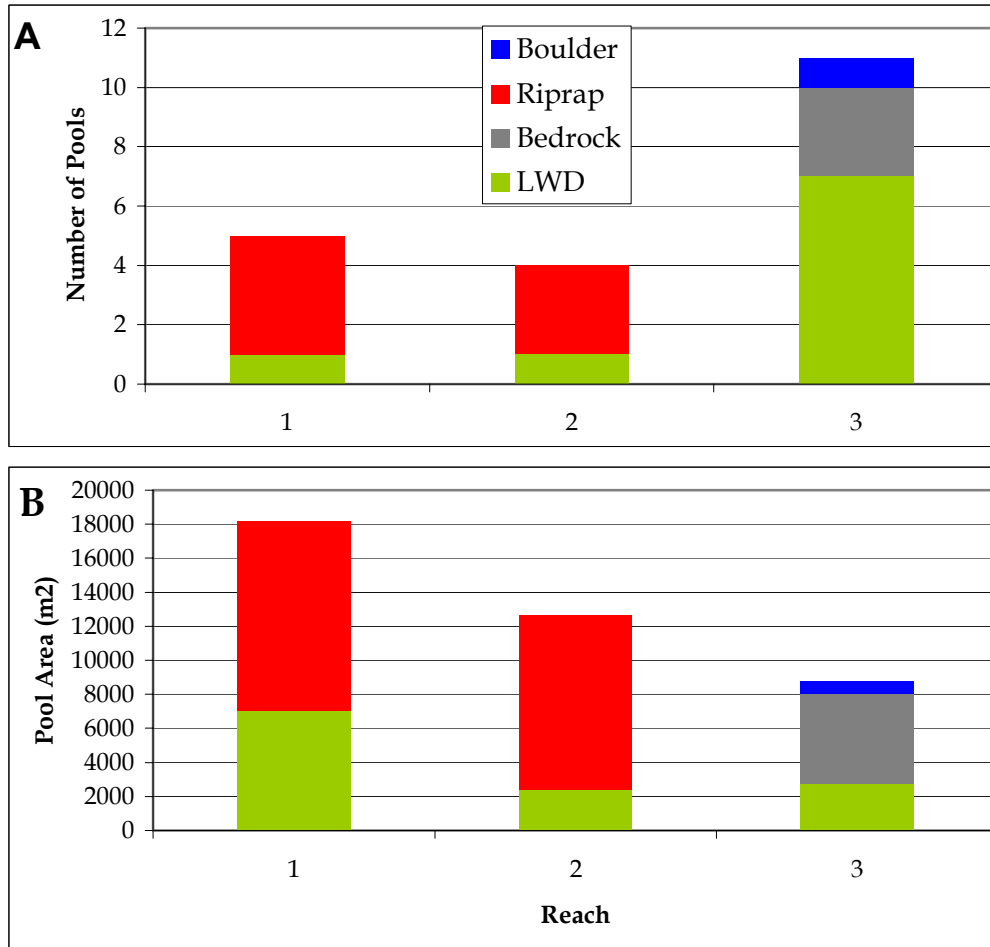
Pool Quality

Pool quality is a function of size, depth, and presence of cover, among other characteristics. In the main South Fork channel, average pool area was 1978m²; pools in reach 1 were largest on average (3635 m²), followed by those in reach 2 (3158 m²) and reach 3 (796m²). Average maximum pool depths were 2.22m, with deepest pools in the lower two reaches (2.60m in reach 1 and 2.79m in reach 2, compared to 1.85m in reach 3). Average residual pool depths were 1.48m over the whole reach, with similar patterns to maximum depth among reaches: 1.92m in Reach 1, 2.10m in Reach 2, and 1.05m in Reach 3.

The largest pools in the main South Fork channel by far were formed by riprap (3056m² average area), followed by bedrock (1771m²), large woody debris (1349 m²), and boulders (722 m²). Riprap also formed the deepest pools with 2.77m average maximum and 2.07m average residual depths. In contrast, LWD-formed pools were the most shallow at 1.82m average maximum and 1.04m average residual depths. Pool depths are presented in Figure 41.

Of 20 secondary channel pools in the reach, most were formed by LWD (13). There were more pools documented in reach 3 (13), followed by 6 pools in reach 2 and only 1 in reach 1; similarly, 52% of the 5868m² areas of secondary channel pools were in reach 3, followed by reaches 2 (38%), and 1 (10%). Average depths in secondary channel pools were 1.48m maximum and 1.06m residual.

Figure 40. Frequency (A) and area (B) of primary pools in the South Fork from Acme to Saxon by reach and pool-forming element.

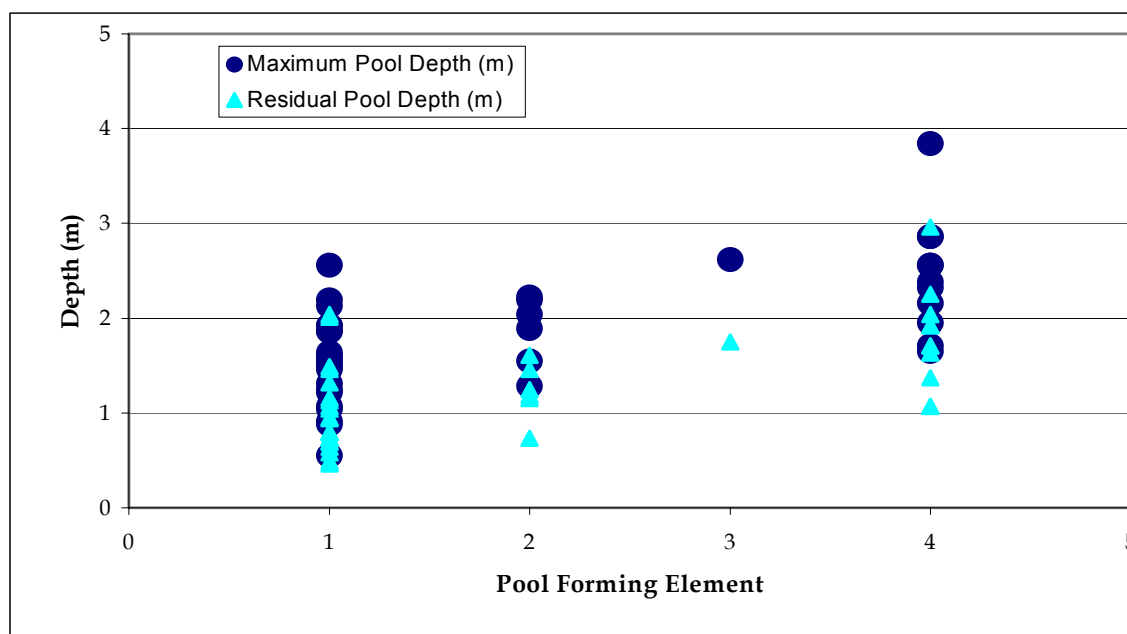


Cover And Hydraulic Complexity

Cover was not quantified during summer 2000 habitat surveys, although presence of cover was noted. Among both main and secondary channel pools, most had large woody debris cover, although 4 in each of main and secondary channels had no cover (Figure 42). Unsurprisingly, cover type was related to pool-forming element: 8 of 9 LWD-formed pools had LWD cover, while 4 of 7 riprap-formed pools had boulder or riprap cover (2 riprap pools had no cover, 1 had LWD cover). Bedrock-formed pools had no cover (2) or boulder cover (1).

It should be noted that pools were mapped in 2000 based on the topography of the channel bed (the difference between the maximum depth and the pool tail-out depth), rather than slower water velocity. Because of this pool definition, some areas may be topographic pools, but do not provide the velocity refuge normally attributed to pool habitat. Generally, this is true for pools that are highly elongate in the direction of flow.

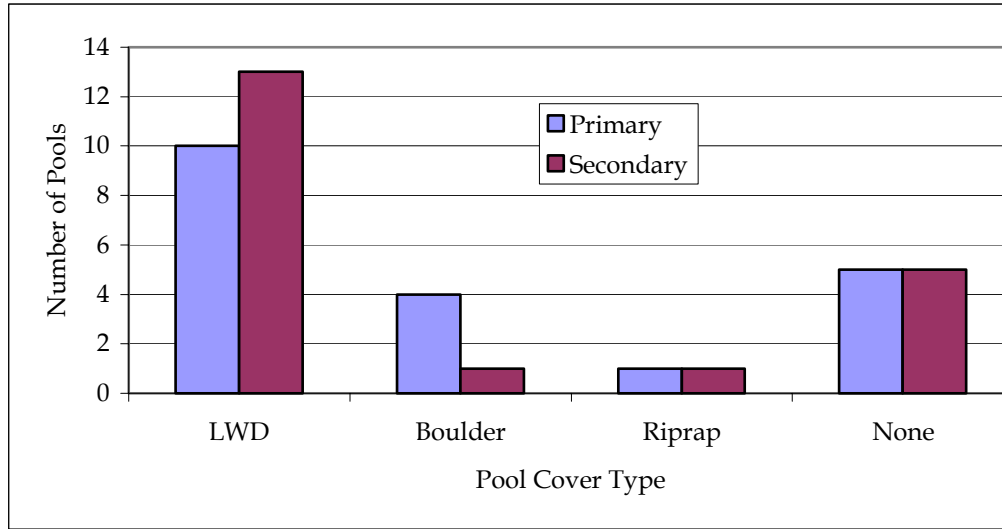
Figure 41: Maximum and residual pool depths by pool-forming element. (1: LWD, 2: boulder, 3: bedrock, 4: riprap)



Amount of large woody debris cover can be indirectly quantified by overlaying habitat unit survey and large woody debris inventory datasets. Of the 9⁵ main channel pools in which “in-water” LWD was inventoried, there were four pools in reach 1 (3 with 1 piece of in-water LWD, 1 with 6 pieces), one in reach 2 (17 pieces of wood), and four in reach 3 (1, 6, 7 and 10 pieces of LWD). Most in-water LWD was not associated with debris jams; in fact, there was only one instance of an in-water LWD jam (16 pieces in the reach 2 pool). Average length of in-water LWD by pool ranged from 2.3 to 9.5m, except for an 18m average length for a reach 3 pool.

⁵ NOTE: This is one pool less than the 10 identified in mainstem habitat surveys as having LWD cover, due either to differences in discharge between surveys or to visual assessment during habitat surveys of wood that did not meet minimum size criteria for LWD inventory.

Figure 42: Cover types in pool habitats of Acme-Saxon reach.



Pool-forming feature also yielded different pool dimensions. The pools formed by wood tended to be deeper relative to their area (4.6 m depth per 1000 m² of area) than pools formed by either riprap (1.2m/1000m²) or bedrock (1.8m/1000m²). Pools formed by bedrock or wood also tended to be less elongated than pools formed by riprap; length:width ratios for wood- and riprap-formed pools was 2.7 and 4.2, respectively. These differences in pool dimensions likely impacts the water velocity in the pool and, thus, associated fish use.

Implications for Salmonids

The loss of deep pools has been documented in the Acme to Saxon reach in particular and the South Fork in general. Filling of deep holes in the South Fork was observed following extensive logging in the 1920s to 1930s (Doughty 1987). Local resident Aadne Bakke described holes in the stretch of river between Skookum and Howard creeks (RM 14.3 to 27.5) that were 15 to 30 feet deep; returning home after WWII, he found that the deep holes in the South Fork were gone (A. Bakke, personal communication to Joanne Schuett-Hames; Wunderlich 1983). Sedimentation and high rates of pool filling were also described between Larson Bridge and Skookum Creek in the early 1980s (Wunderlich 1983); one former holding pool was entirely filled between 1982 and 1983 and another filled in several feet (Doughty 1987). While Schuett-Hames et al. (1988b) describe a clear chinook holding preference for the deepest pools, it is worth noting that the deepest pool in the South Fork that held chinook was only 9.4 feet deep. In the Acme-Saxon reach, the maximum pool depth measured was 3.84 m (12.60 ft), although average maximum pool depth was 2.22 m (7.28 feet).

The lack of deep pools with complex cover (i.e. pools associated with log jams) limits holding by all species, but especially early chinook, summer steelhead, and bull trout. Holding habitat in the reach has been degraded due to loss of habitat complexity, including bedform variation and woody debris cover, coupled with low flows and high water temperatures which together can stress the fish and render them vulnerable to disease, predation and poaching (Doughty 1987). Lack of large woody debris jams and deep pools may also affect the distribution and abundance of thermal refugia in the reach, since structural elements and substantial pool depth are two important factors that can promote thermal stratification in pools.

Lack of pools and habitat complexity may also limit spawning by chinook in the reach. Through monitoring associated with logjam construction in the North Fork Stillaguamish, it was observed that greater than 80% of chinook spawned within one channel width of a pool (Pess et al. 1998). In Skagit River tributaries, spawning abundances of both chinook and coho were inversely related to pool spacing (Montgomery et al. 1999).

While lack of deep pools is likely most limiting for holding adult salmonids, it also affects juvenile life history stages, including chinook. In a 5th order river in Oregon, age 0 juvenile chinook were heavily concentrated in pool habitat (as opposed to riffles, runs or glides); indeed, mean densities of age 0 chinook within a reach were strongly affected by the amount of pool habitat available (Roper et al. 1994). Preference for pool habitat was not readily discernible from recent snorkel survey data, although observed densities of most juvenile species tend to be highest in pools (Charley Dewberry, Ecotrust, personal communication).

Juvenile rearing habitat quality is also limited by the lack of cover in the reach. As described in the *Chinook Rearing* section, 76% of the juvenile chinook enumerated during a snorkel survey of the upper Acme-Saxon reach were associated with wood cover, including 51% with complex cover (multiple logs; Ecotrust, unpublished data). Similar preference for cover has been documented elsewhere (Morgan and Hinojosa 1996), including the Skagit River, where abundance of juvenile coho and chinook was positively correlated with wood cover (Beamer and Henderson 1998).

The predominance of riprapped form pools, which comprised the largest and deepest pools in the reach, is also detrimental to juvenile salmonids. Riprap contributes to salmonid habitat degradation, impeding the development of undercut banks and overhead cover preferred by rearing salmonids, as well as reducing channel floodplain interaction and large woody debris recruitment (Schmetterling et al. 2001). Riprap also provides poor quality cover for juvenile salmonids, as evidenced by lower abundances at riprapped than at natural banks

(Peters et al. 1998). Densities of juvenile chinook in the Skagit River were significantly higher in backwater and natural bank habitat than in hydromodified banks and bars; density estimates using peak counts yield 0.97 chinook/m² in natural banks and 0.348 chinook/m² in hydromodified banks (Hayman et al. 1996). In 5 study streams in western Washington, densities of coho salmon, juvenile steelhead and cutthroat trout declined following riprap installation (Knudsen and Dilley 1987, cf Schmetterling et al. 2001). Even where wood cover is available along hydromodified banks, chinook abundances were lower than natural banks with similar amounts of cover (Beamer and Henderson 1998). Subyearling chum may also be impacted by riprap; they were found to prefer aquatic plants and cobble, cover types also more common in natural banks (Beamer and Henderson 1998).

Habitat complexity is more than relative frequency and size of pools, riffles and large woody debris. Although difficult to quantify, reductions in channel length (especially in secondary channels), gravel bar area, and slough length (Crown Pacific Ltd. 1999) has likely reduced the frequency and diversity of other types of meso- and microhabitat units (e.g. lateral channel margins for fry, transverse riffles). Simplification and isolation of floodplain habitats has reduced the availability and quality of overwintering habitat, especially for juvenile coho, cutthroat, and possibly sockeye.

Substrate

Spawning gravel availability

Recent stream surveys have estimated 8822 m² (29,000 ft²) of suitable chinook spawning habitat in the Acme-Saxon reach (T. Hyatt, unpublished data). Reaches 1 (from Hwy 9 bridge at Acme), 2, and 3 comprise 21%, 35%, and 44% of available habitat (Table 10). Spawning habitat patches are both more numerous and generally larger in the upper two reaches. In summer 2001, pebble counts were conducted at each of 21 cross-sections evenly distributed along the South Fork through the project area. Median grain size (D₅₀) ranged from 9.3 (within gravel size range) to 72.3 mm (within cobble size range). Grain sizes were generally larger in the upper half of the project area, with a median D₅₀ of 54.3 mm for the upstream 11 cross sections and 30.9 mm for the downstream 10 cross sections. Further, median grain sizes in the cobble range (64-256 mm) were only found in the upstream half of the project area.

Table 10: Suitable chinook spawning habitat patches in the Acme to Saxon project area. Patch length and patch area ranges are denoted within parentheses.

	Number of patches	Patch Length	Patch Area (m ²)
Reach 1	8	556 (32-174)	1816 (62-522)
Reach 2	9	699 (25-125)	3112 (25-1500)
Reach 3	12	1504 (44-462)	3894 (62-1386)
Total	29	2759	8822

Fine sediments

The South Fork is currently considered an impaired water body on the 303(d) list for fine sediments (WDOE 1998). Mainstem habitat surveys were conducted in the Acme to Saxon reach in summer 2000. Habitat units were classified (pool, riffle, subsurface), mapped, and characterized per TFW methodology (Pleus et al. 1999). For each riffle, average percent substrate embeddedness and average percent refuge habitat (i.e. substrate with large enough pore spaces to provide refuge for juvenile fish. Although not quantitative and subject to observer bias, the information is nonetheless useful in ascertaining general patterns in substrate conditions. Percent embeddedness and percent refuge in riffles did not differ considerably among reaches; reach averages were 38 to 45% for embeddedness and 4 to 5% for refuge. Most (87%) of the riffle area identified had less than 10% refuge. Similarly, average embeddedness exceeded 50% for most (76%) of the riffle area. Consistent with pebble count data, riffle areas are dominated by gravel (46% of riffle area) or sand (26%) substrate.

Fine sediment data were collected in the South Fork during the 1980s (Schuett-Hames et al. 1988a). Composition of fines in individual samples ranged from 4.81% near Larson's Bridge in 1983 to 31.71% near Skookum Creek in 1985. Averaging samples by site and year, fine sediments ranged from 9.74% (n=5, 1986, near Acme) to 13.39% (n=8, 1987, near Strand Rd.). Fine sediments in tributaries were as follows: Edfro Creek 11.21% to 20.29% site average (1982, 1983, 1985), Howard Creek 15.24% (1984), Hutchinson 11.73% to 12.16% (1982, 1984), and Skookum 6.95% to 12.3% (1982-1984). McNeil cores were also collected in the South Fork and selected tributaries during the summers of 2001 and 2002; processing and analysis of these samples is pending (T. Hyatt, personal communication).

Implications for salmonids

Suitable chinook spawning habitat appears to comprise a small portion of the wetted habitat in the reach. Total wetted area was not measured during the spawning habitat surveys, but spawning habitat patch area can be compared to total wetted area mapped during South Fork habitat surveys. 8822 m² of suitable spawning habitat was mapped in 2001, 3.5% of the 251737 m² of wetted area mapped in 2000. Comparison of the two estimates is complicated by the fact that the two surveys were conducted on different years and, likely, at different flow conditions. Further, a little under half of the 51 redds mapped in the reach in 2000 overlap with identified suitable spawning habitat patches in 2001, so spawning habitat area estimates are likely conservative. Even so, it indicates that only a small proportion of the wetted habitat constitutes suitable spawning habitat. Although pebble count data were not collected specifically to quantify spawning gravel quantity and quality, median grain sizes are within the size

range required for chinook (13 to 102mm; Bjornn and Reiser 1991), although smaller than preferred sizes.

Chinook redd sizes reported in the literature range from 0.5 m² in the Nechako River (BC) to 44.8m² in the Hanford Reach of the Columbia River, but typically less than 10m² (Healey 1991). No data exist for redd size for South Fork chinook, although anecdotal observations by spawn surveyors indicate redds are typically less than 3m² (L. Roberts, personal communication). Redd capacity estimates in the Acme to Saxon reach, as generated from redd size data, range from 197 (44.8m² redds) to 17644 (0.5 m² redds); the best estimate given 3m² redds is 2941. In addition to substrate size, however, depth and velocity must be considered. Depths and velocities were not measured during habitat surveys conducted in summer 2000. An assessment of spawning habitat availability at different flows is being undertaken through the Instream Flow component of the WRIA 1 Watershed Management Project, which will consider suitable depth, velocity and substrate size for all Pacific salmonids. This analysis is expected to be complete in late 2002, but spawning habitat quantity does not appear to be limiting for chinook in the reach, especially given the low escapement of South Fork spring chinook. Although not quantified, preferred spawning habitat for chum salmon – groundwater-fed side channels – is expected to have decreased appreciably from historic levels, given the altered groundwater hydrology (clearing of valley bottom forest, draining of wetlands) and loss of side channels.

Spawning habitat quality, however, may be of greater concern. Dissolved oxygen in redds is related inversely to the percentage of fines under 0.85 mm in diameter; coho redd survival to emergence was 32% from redds with less than 20% fines but 18% from redds with greater than 20% fines (Tagart 1976, 1984; cf Chapman 1988). Others have documented consistent and precipitous declines in survival with increasing greater % of fines less than 0.85mm. Survival of newly fertilized chinook eggs placed in the substrate was reduced when percentage of particles 6-12mm was greater than 10-15% and percentages of fines (<6mm) were above about 20-25% (McCuddin 1977, cf Chapman 1988). Fine sediment levels measured in the South Fork in the 1980s were not associated with poor survival to emergence, especially the site near Acme (Schuett-Hames et al. 1988b). More recent estimates of gravel embeddedness in riffles in the reach, although not quantitative, however, indicate fine sediments may be a problem.

Juvenile chinook and other salmonids have been found to use interstitial spaces of coarser substrates (rocks and cobble) during periods of cold stream temperatures (Hillman et al. 1987, cf Morgan and Hinojosa 1996). As indicated from the estimated percentage refuge in riffles in the reach – less than 10% in most riffles – such habitat may be limited by high embeddedness by fine sediments.

Water Quantity

Water quantity is a concern in the South Fork Nooksack River, which is considered an impaired water body on the 303(d) list for instream flows (WDOE 1998) and is closed to further water withdrawals (WDOE 1995). Low flows in summer reduce wetted habitat area, diminish access to and from off-channel habitats, and increase vulnerability to terrestrial predators through reduced depth, thereby negatively impacting juvenile salmonids. Low flows also impact adult salmonids, exacerbating high water temperatures, reducing holding pool quality (depth), and delaying or impeding upstream migration in the South Fork and tributaries, especially those with well-developed alluvial fans. Water quantity concerns are not being directly addressed through this project, but rather through the Instream Flow component of the WRIA 1 Watershed Management Program.

Migration and accessibility problems have been noted for several tributaries in the reach. Access for spawning in Hutchinson Creek can be limited by shallow depths near the mouth; the creek had been observed to go subsurface in September during pink spawning. During low flow years, fall chinook also will not enter Hutchinson Creek, instead spawning in the Mainstem near the mouth (WDNR 1998). During 1985, 1987, 1989, 1991, and 1993 stream surveys, the creek is noted as being either too low or too dry (WDNR 1998). Similarly, in the Landingstrip Creek complex, coho spawning hinges on freshets to provide adequate migration and spawning flows. Chum spawning in Curtis Slough also appears to be flow-dependent (Doug Huddle, personal communication). In addition to spawning, summer and fall rearing is also limited by low flow, with Landingstrip Creek, Roos Slough, and Curtis Slough all apparently dry, nearly dry, or consisting of isolated pools (Naef 2002).

Migration Barriers

Seasonal migration barriers exist on several of the floodplain channels of the Acme-Saxon Reach. Rothenbuhler Slough access has been truncated by a riprap levee and perched culvert outlet placed to protect the aqueduct tunnel conveying water from the Middle Fork to Mirror Lake. This riprap only allows access when water is high enough to flow around the wall from the slough and into the South Fork, or when river flows are elevated sufficiently to provide access through the perched culvert. The Rothenbuhler Slough could provide important rearing habitat. The large pond and cooler water temperatures make it ideal off-channel rearing habitat for juvenile salmonids, especially coho. In the past, there has been more substantial groundwater discharge to Rothenbuhler Slough, and anecdotal evidence suggests that it once supported substantially more beaver dams, with larger ponds and trout of 10 to 12 inches (R. Knudsen, Acme-Van Zandt Flood Control Sub-zone, personal communication, October 2001). The slough currently has very little fish use. Migration through the floodplain

channels of Landingstrip Creek is also hampered by an undersized, buried 1000 culvert in “Culvert Creek”, and two partial passage barriers under SR9 for “Smith Creek” and a tributary to “Culvert Creek”.

Implications for Salmonids

The loss of access to floodplain channels for spawning coho, chinook, and pink salmon results in lost spawning use of tributaries during years of low-flow summers and falls. The loss of access to floodplain channels impacts juvenile over-wintering by reducing the sheltered habitat available for use, and reduces the availability of cooler water areas for summer rearing. The loss of access to slough habitat also impacts species that rely on these areas for spawning, such as coho and cutthroat. Loss of floodplain habitat has been directly linked to declines in coho population abundance (Beechie et al. 1994).

Water Quality

Temperature

Temperature has a profound effect on salmonids and other aquatic biota, influencing metabolism, growth rates, timing of life-history events, biotic interactions, disease resistance, and food availability (Spence et al. 1996). Maximum water temperatures typically occur from July 15th to August 15th, after which lower sun angle increases riparian shading (Sullivan et al. 1990). Temperatures are influenced by season, latitude, topography, watershed orientation, local climate, riparian vegetation, groundwater and tributary inputs (Spence et al. 1996). Topography can provide significant shading, particularly in north-facing drainages and when sun angles are low. The effect of riparian shading on stream temperatures decreases downstream as streams become larger and wider and a smaller proportion of the water surface is shaded.

Stream temperature generally increases downstream. Tributary or groundwater inputs, however, can measurably change local water temperature. Since temperature changes occur in proportion to the discharge and temperature of the individual sources (Sullivan et al. 1990), the influence of such inputs on stream temperature tends to diminish downstream as total stream discharge increases. Even where there are no measurable effects on mainstem temperatures downstream of the mixing zone, cool tributary or groundwater inputs can provide localized thermal refugia (Spence et al. 1996). Further, at a given location, subsurface flow inputs can contribute a substantial component of the total stream discharge during low-flows when groundwater recharge rates are highest, even in the largest rivers (Ziemer and Lisle 1998)

Temporal Patterns

The South Fork is currently considered an impaired water body on the 303(d) list for temperature (WDOE 1998). Recently, summer temperatures in the South

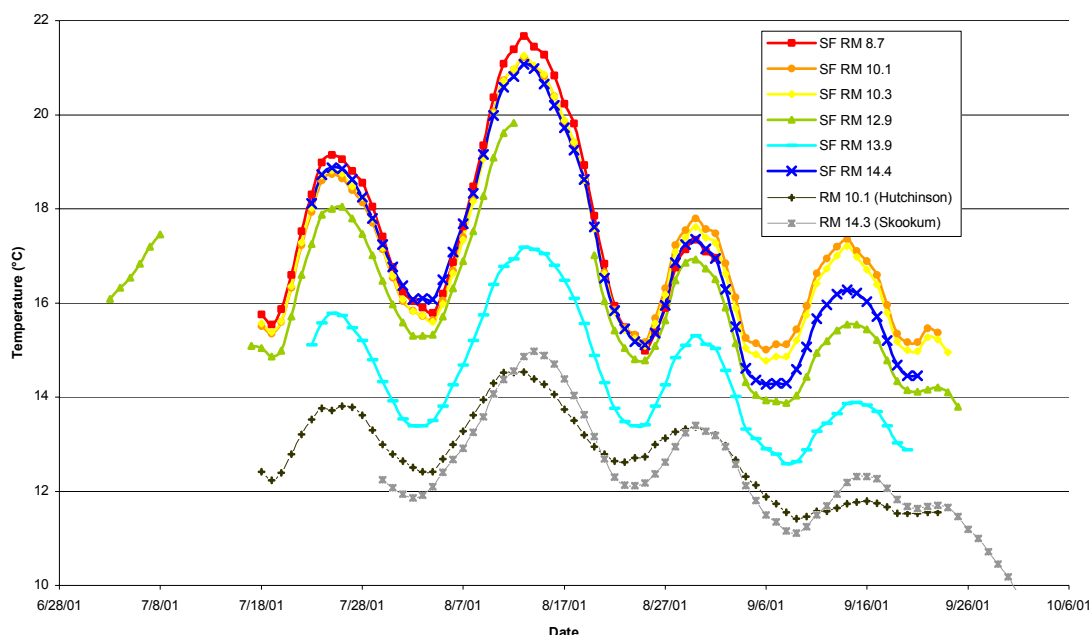
Fork have regularly exceeded water quality standards (WQS) of 18°C for downstream of Skookum Creek (Class A) and 16°C for upstream of Skookum Creek (Class AA) (Chapter 173-201A Washington Administrative code; 11/18/97). During August 1985, daily temperature maxima in a holding pool at river mile (RM) 14.7 ranged from 16.9°C to 19.2°C, and minima remained above 16.1°C (Doughty 1987). In August 1986, Schuett-Hames et al. (1988a, as cited in Neff 1993) recorded a maximum water temperature of 21.7°C at RM 18.45. In August 1990, Sullivan et al. (1990, as cited in Neff 1993) recorded a maximum water temperature of 19.1°C. Neff (1993) reported that, in summer 1992, the South Fork (RM 19) exceeded WQS on 29 of 31 of the days monitored; on 12 of these days (3 occasions of 4 days each), daily minima even exceeded WQS. Maximum temperature recorded for the South Fork (RM 19) in 1992 was 24°C. During 1993, a maximum/minimum thermometer placed at the Acme bridge recorded excursions from WQS on 5 of 7 days (Lummi Natural Resources, unpublished data). Of 6 instantaneous measurements taken in the South Fork between 7/19/94 and 8/17/94, 5 exceeded WQS. Temperatures measured at four locations from Acme Bridge to Larson's Bridge in the South Fork during 1995 (7/20/95 to 9/18/95) indicated exceedances of at least 1 day; maximum temperatures were 21.8°C at Saxon Bridge (8/3), 18.3°C at Acme Bridge (7/20), 17.8°C at Larson's Bridge (9/18), and 17.8° at New Bridge (9/18) (Shull 1996). From continuously recording thermographs deployed in the South Fork near Potter Road Bridge from 7/17/96 to 7/31/96, 37% of the temperature measurements exceeded the WQS (LNR unpublished data, cited in USU's WRIA 1 Surface Water Quality Data Collection and Assessment, Phase II Summary Report (Preliminary Draft)). Similarly, temperatures exceeded WQS at 3 sites along the South Fork (near Hutchinson and McCarty Creeks and at Potter Road bridge) in 1998. Indeed, South Fork temperatures exceeded 18°C on 30 days during the summer of 1998, with a peak temperature above 22°C; these data underestimate temperature degradation in the reach, given that thermographs were deployed 8/15/98 to 9/21/98 (Soicher 2000). From 8/5/99 to 9/21/99, South Fork temperature exceeded WQS for 8 days, with a max recorded temperature of 19.4°C (Soicher 2000). Finally, in 2001, maximum temperatures ranged from 20.3° to 22.3°C, with exceedances on from 18 to 42 days, at all 11 sites sampled in the South Fork from the confluence to RM 20.7, with the exception of the site at RM 13.9, downstream of Skookum Creek (no exceedance, max temp 17.6°C; Nooksack Natural Resources, unpublished data).

Insufficient analysis has been conducted to determine conclusively that there is a temporal trend in South Fork water temperatures, although evidence indicates water temperatures may be increasing (Neff 1993). Stream temperatures were higher in 1992, than 1985, 1986 and 1990, even though maximum air temperatures at Upper Baker Dam were higher in 1987 and 1990 than 1985 and 1992 (Neff 1993). Four years of sampling at Potter Road between 1996 and 1998

indicate that highest temperatures occurred in 1998, followed by 1996, 1997, and 1999 (LNR unpublished data, cited in USU's WRIA 1 Surface Water Quality Data Collection and Assessment, Phase II Summary Report (Preliminary Draft)). Differences in sampling locations and measurement periods, however, limit comparisons among different years. Comprehensive and systematic analysis of available temperature data for the South Fork is needed.

Since effects of high temperatures on salmonids are a function of duration of exposure, temperatures averaged over longer time frames may be more meaningful than instantaneous maxima. A number of thermographs were deployed in the South Fork during summer 2001 and 7-day moving averages of the daily maximum temperature calculated (Nooksack Natural Resources, unpublished data; Figure 43).

Figure 43: 7-day moving averages of the daily maximum temperatures in and near the Acme-Saxon reach, including Hutchinson and Skookum Creeks.



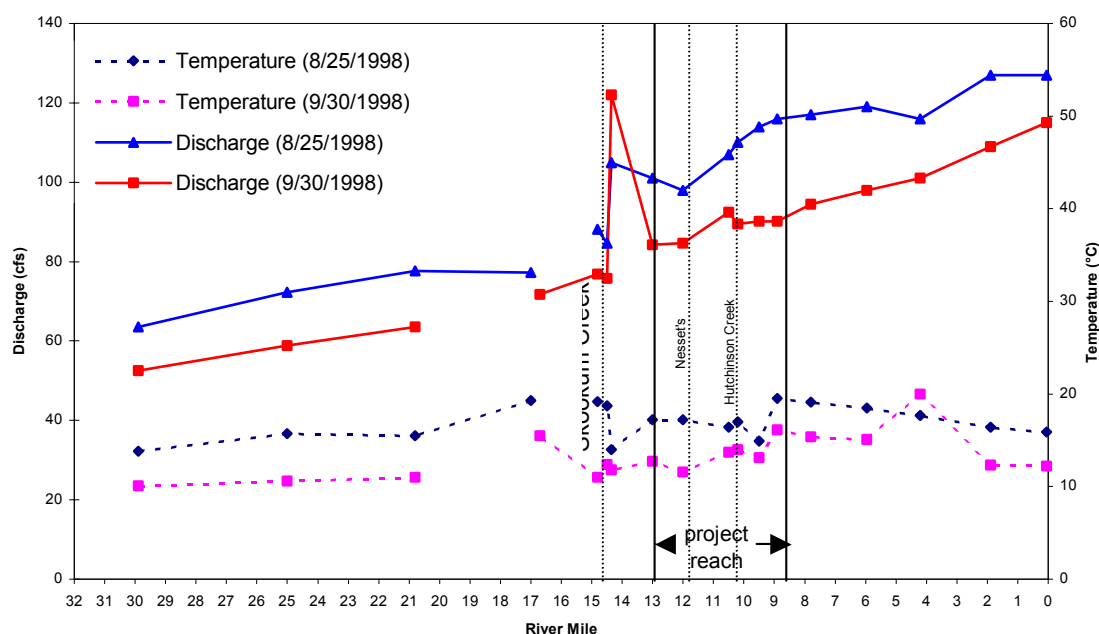
Longitudinal Profile

Temperatures and discharges were measured in the South Fork on two dates during 1998 (LNR, unpublished data). Data from these seepage runs were used to construct longitudinal temperature and discharge profiles (Figure 44).

Temperature increases through the Acme-Saxon reach were 2.3°C on 8/25/98 (17.2°C at RM 13, 19.5°C at RM 8.9) and 3.1° (12.7°C at RM 13, 16.1°C at RM 8.9) on 9/30/98. Localized reduction in South Fork temperatures were recorded downstream of Hutchinson Creek both months, Nessel's Creek in August, and Saxon Bridge in September. The sharp temperature decrease of 2.1°C from RM 10.2 (17°C) to 9.5 (14.9°C) in associated with Hutchinson Creek in August was

overshadowed by a precipitous increase from RM 9.5 to RM 8.9 of 4.6°C, to a measured 19.5°. On balance, the reach is a gaining reach, with discharge increasing 15% from RM 13 to RM 8.9 on 8/25/98 (101 cfs to 116 cfs) and 7% (84.3 cfs to 90.2 cfs) on 9/30/98; however, measurable drops in discharge occurring in the upper mile of the reach in August and just upstream of Hutchinson Creek in September indicate groundwater or hyporheic recharge (routing of surface flow to subsurface flow paths).

Figure 44: Longitudinal temperature and discharge profile of the South Fork Nooksack River, as derived from 1998 seepage runs.

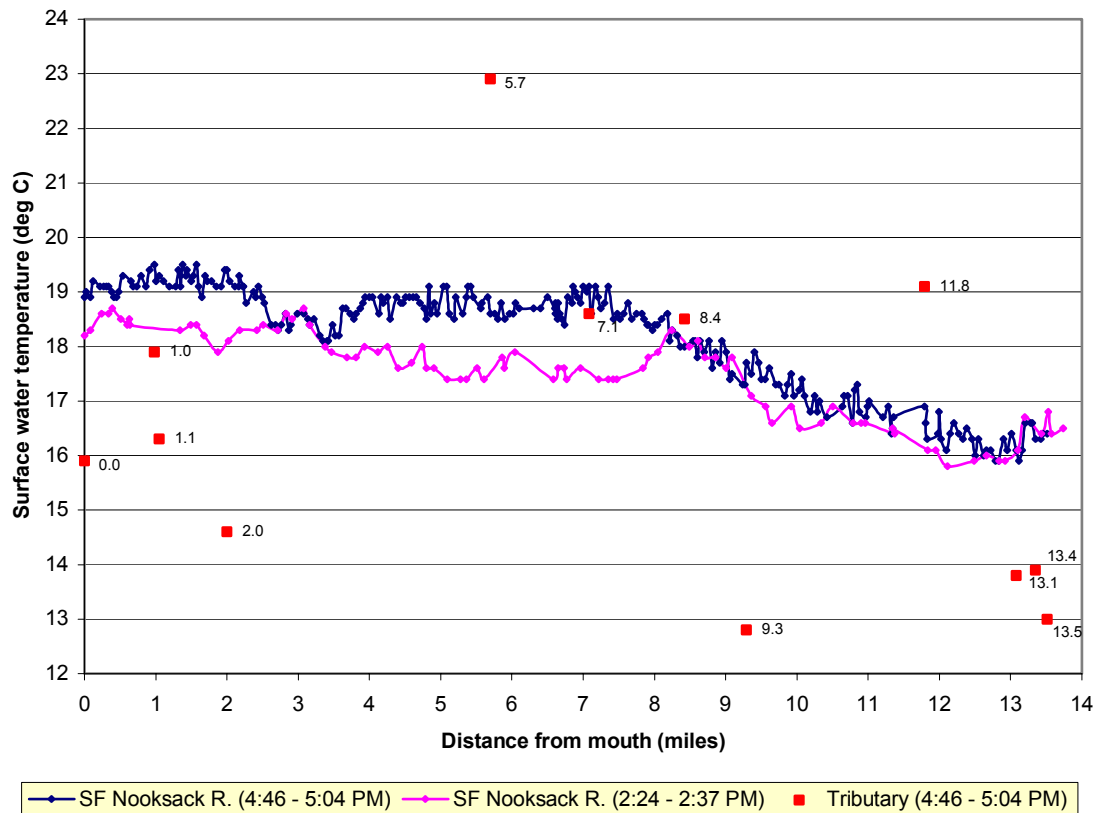


More recently, continuous longitudinal temperature profiles were created from surface temperature data obtained during an overflight of the South Fork on 8/20/01, using a thermal infrared sensor mounted on a helicopter, along with a visible band color video camera to aid in interpretation (Figure 45; Table 11). Just upstream of the Acme to Saxon reach, from RM 16 to 13.1, median temperatures⁶ decreased from 18.6°C to 15.9°C, a cooling trend likely due to both Dyes canyon and surface water inputs (Watershed Sciences 2002). Downstream from Skookum Creek influences, water temperatures in the South Fork increased steadily to RM 8. The slight depression in temperature downstream of Hutchinson Creek did not persist over any substantial distance. Highest median temperatures in the South Fork occurred near the confluence with the North Fork. Median temperatures recorded in the Acme to Saxon Reach were 16 to

⁶ Longitudinal profile was developed by “sampling” each TIR image in the center of the channel and calculating the median temperature for that image.

18°C (Watershed Sciences 2002). It is worth noting that the flight over these South Fork reaches was conducted from 2:24 to 2:37 pm, prior to the observed daily stream temperature maxima (4:30 pm, 19.7 at RM 1.8), and after the seasonal window for maximum water temperatures (7/15 to 8/15; Sullivan et al. 1990). It is noteworthy that the coolest temperatures in the South Fork downstream of RM 25 (which constitutes a partial barrier to chinook passage) were recorded in the upper part of the reach to just upstream of the Saxon Road bridge (Watershed Sciences 2002).

Figure 45: – Median channel temperatures versus river mile for the South Fork Nooksack River, WA for low (4:46 – 5:04 PM) and high (2:24 – 2:37 PM) altitude surveys conducted in the lower 13.5 river miles (8/20/01; Watershed Sciences 2002). Temperatures were measured using a thermal infrared sensor mounted on a helicopter. NOTE: Distance from mouth was derived from an EPA 1:10,000 routed hydrolayer, and deviates from river miles marked on USGS topographic quads.



The spatially continuous temperature dataset generated from the FLIR overflight has also been useful for examining spatial temperature patterns. Much of the temperature data collection to date had been focused in the main-channel. Temperatures are elevated in channel margins and secondary channels (Figure 46A, B) relative to the main channel. Riparian vegetation and hyporheic (subsurface) flow may mitigate heating in such habitats (Figure 46C, D, E). Localized areas of lower temperatures due to apparent groundwater/hyporheic

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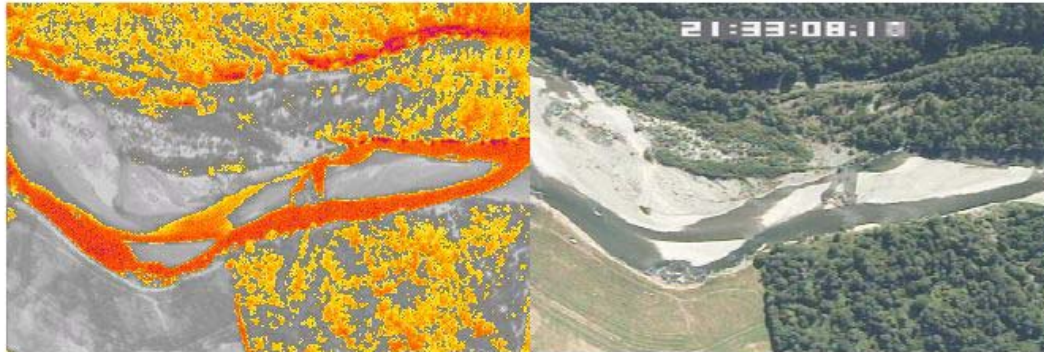
seeps and tributary inputs may represent small-scale temperature refugia (Figure 47), although association with secondary channels, floodplain habitats, and channel margins likely limits utilization by adult salmonids.

Table 11: - Tributary and side channel temperatures for the Acme-Saxon reach South Fork Nooksack River, WA (Watershed Sciences 2002). FLIR RM (river miles) correspond to data labels shown in Figure 45, while USGS RM are approximate river miles derived from examination of USGS topographic quads.

Tributary Name	Image	km	Mile	Tributary Temp °C	SF Nooksack R. Temp °C	Difference Temp °C
Side Channel (LB)	Sfn0369	13.6	8.4	18.5	18.0	0.5
Hutchinson Creek (RB)	Sfn0403	14.9	9.3	12.8	17.7	-4.9
Side Channel (RB)	Sfn0483	18.8	11.8	19.1	16.9	2.2

Figure 46: Select images of the South Fork Acme-Saxon reach from the high-altitude FLIR overflight. See colormap for corresponding temperatures. River miles are derived from EPA 1:100,000 hydro layer and do not correspond with those derived from USGS topographic quadrangles. A) RM 8.9, elevated temperatures in margins. B) RM 10.0, elevated temperatures in secondary channel with no riparian cover. C) RM 9.6, apparent influence of riparian vegetation on temperatures in secondary channel. D) RM 10.9, apparent influence of hyporheic flow on temperatures in a secondary channel. E). RM 11.0, just upstream of image D; apparent influence of hyporheic flow on temperatures in an isolated pool.

A)

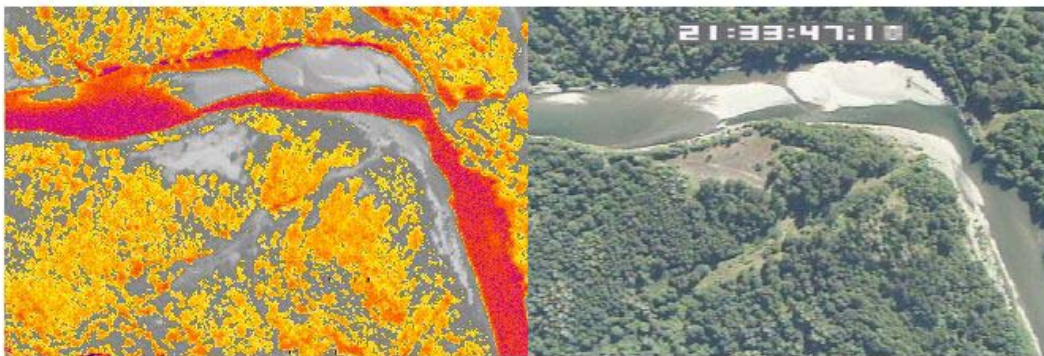


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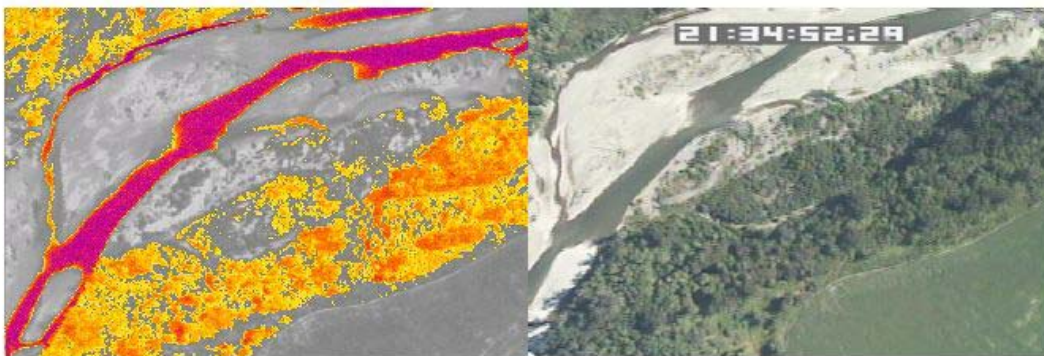
B)



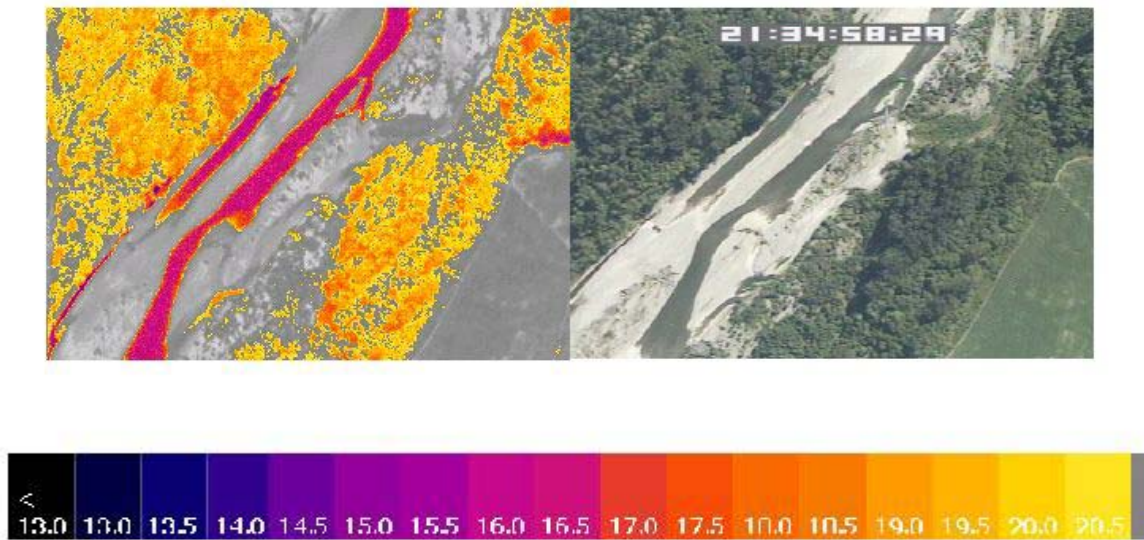
C)



D)



E)



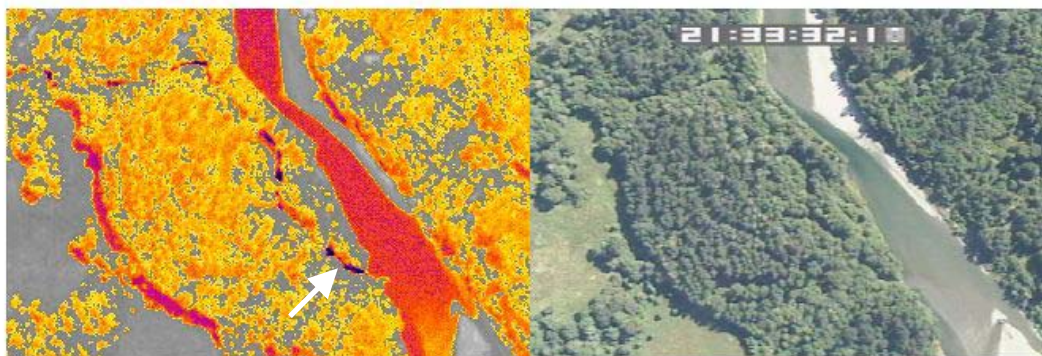
Floodplain Tributaries

Hutchinson Creek was found to be in compliance with WQS in 1992 (continuously recorded thermographs, LNR unpublished data), 1993 (max/min thermometers, Neff and Edwards 1993) and 1994 (instantaneous measurements, LNR unpublished data). Indeed, Hutchinson Creek is substantially cooler than the South Fork (4.9°C temperature difference, Table 11), although shallow depths and low flows in the lower extent during summer likely limit its use as a thermal refugia by adult salmonids. Although not included in habitat surveys conducted by NSEA in 2000, Landingstrip Creek stayed the coolest of all floodplain tributary sites instantaneously sampled for temperature in 1998, with a maximum of 16.8°C, as compared to 21.1°C in Caron Creek, 19.8°C in Black Slough, and 18.8° in lower McCarty Creek (Soicher 2000). Hutchinson and Landingstrip Creeks and Roos and Rothenbuhler Sloughs are all cooler than the South Fork at the lower ends, and may therefore represent temperature refugia for juvenile salmonids (Figure 47).

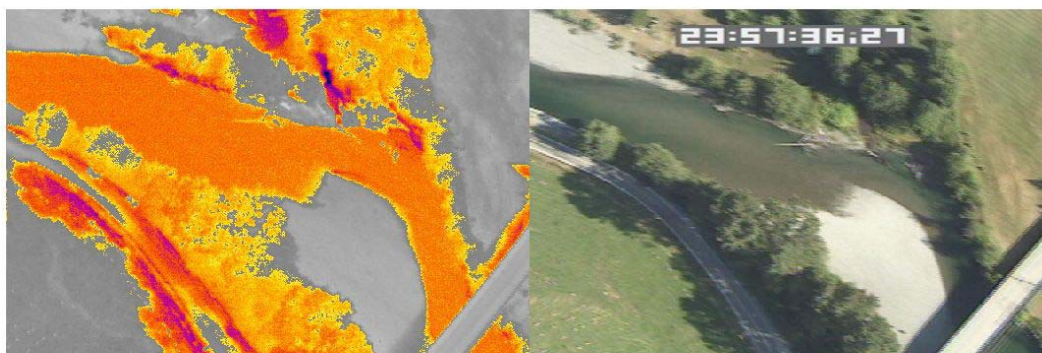
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Figure 47. Select images from the low-altitude FLIR overflight illustrating floodplain tributaries and other potential thermal refugia in Acme-Saxon Reach. A) Hutchinson Creek, B) Landingstrip Creek, C) Roos Slough, D) Rothenbuhler Slough [1: excavated channel, 2: truncated natural channel], E) RM 11.8, cool temperatures associated with secondary channel, F) RM 10.7, cool temperatures associated with main channel. NOTE: River miles derived from EPA 1:100,000 hydrography, which deviates from USGS-derived river miles. See Figure 46 for color map.

A)



B)

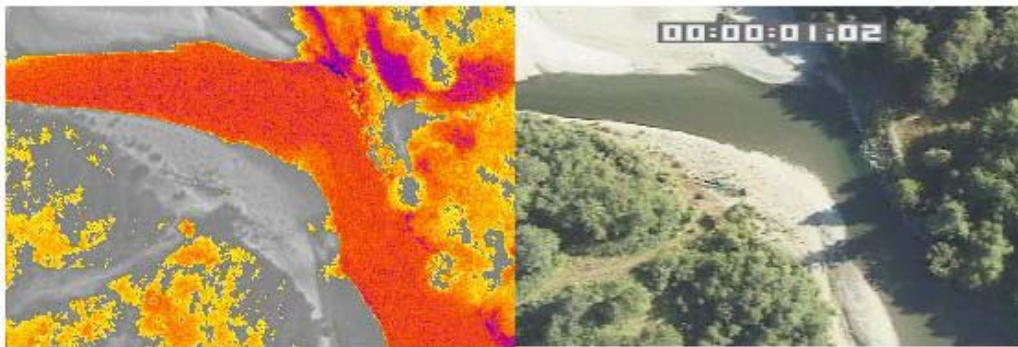
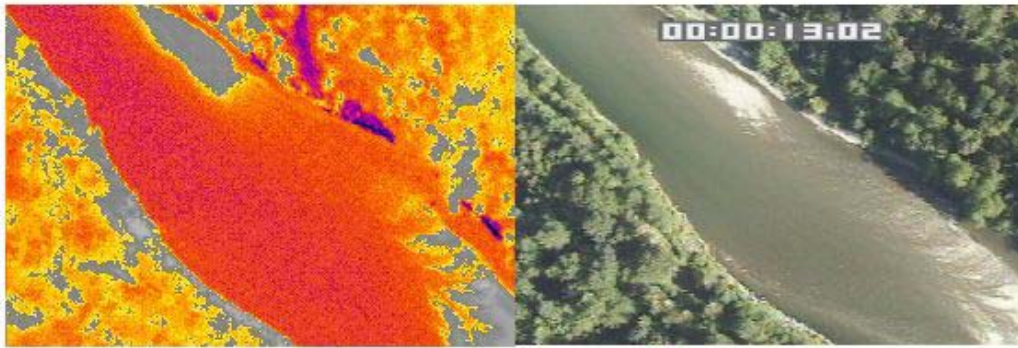


C)

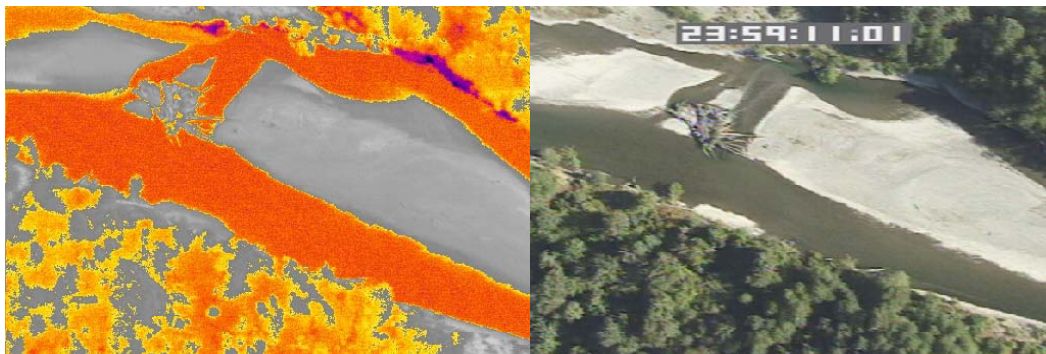


D)

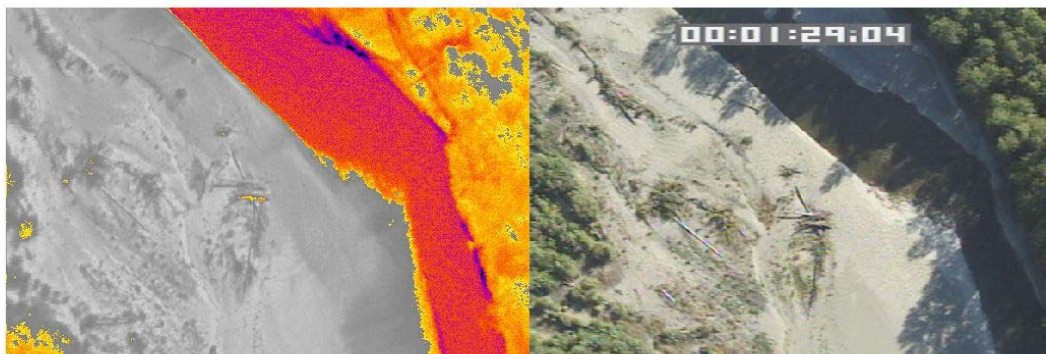
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E)



F)



Turbidity and Suspended Solids

Turbidity is caused by inorganic and organic materials that become suspended, typically during high flow conditions (Spence et al. 1996). Effects of siltation and turbidity include reduced primary production and reduced fish feeding efficiency due to diminished light penetration (Spence et al. 1996).

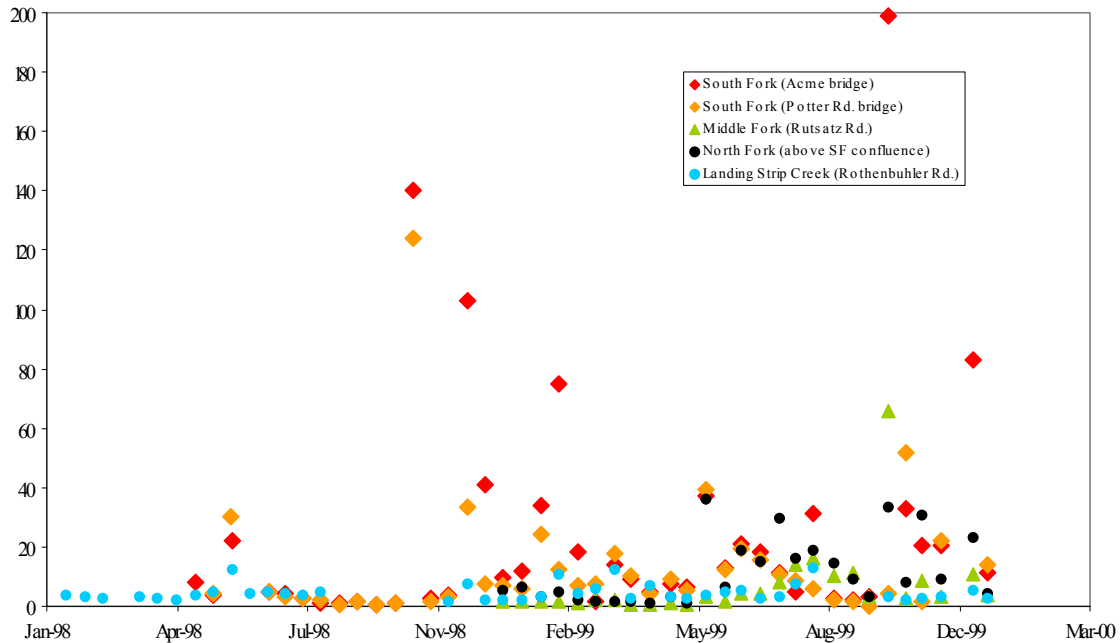
South Fork

Soicher (2000) measured instantaneous turbidity at various locations during 1998 and 1999, including the South, Middle and North Forks, as well as tributaries to the South Fork (Figure 48). The lower South Fork (Potter Rd. Bridge) had the highest measured turbidity, at 632 nephelometric turbidity units (NTU), whereas maximum turbidity in the glacially turbid North and Middle Forks were 66 NTU and 36 NTU, respectively. Minimum and mean turbidity levels among forks were comparable, at 0.2 NTU (SF, Potter Rd. Bridge) to 1.0 NTU (NF) and 6.8 (NF) to 9.5 NTU (SF, Acme bridge), respectively. In most cases, South Fork turbidity exceeded that of either Middle or North Forks, often significantly. Turbidity levels in the mainstem river sites responded dramatically during storms. In the South Fork, during a storm in November 1998, turbidity fluctuated from 951 NTU to 99 NTU to >1000 NTU. In the South Fork at the Acme bridge in 1999, turbidities were 1.5 to 74.8 NTU (19.3 NTU mean) and 2.5 to 13.1 NTU (6.1 NTU mean) during fry emergence (February through May) and adult holding and upstream migration (June through September), respectively. Anecdotal observations indicate high turbidities, which limit spawn and snorkel surveying, can persist in the South Fork through mid to late summer.

Floodplain Tributaries

In floodplain tributaries, turbidity varied over time (Soicher 2000). In general, floodplain tributary turbidity levels were higher than in mountain channels but lower than South Fork mainstem. Floodplain tributaries sampled downstream of the Acme-Saxon reach were Caron Creek and Black Slough. Seasonal patterns varied. For instance, Caron Creek turbidity was highest during summer months at peak biological productivity, while Black Slough turbidity was higher in winter and spring. In Landingstrip Creek, the only sampled tributary in the Acme-Saxon reach, turbidity ranged from 1.4 to 13.1 NTU (4.6 NTU mean) in 1998 and 1999, with the maximum measured on 8/6/99. In 1999, turbidities were 2.6 to 12.6 NTU (6.0 NTU mean) and 2.5 to 13.1 NTU (6.1 NTU mean) during fry emergence (February through May) and adult holding and upstream migration (June through September), respectively; these levels were lower than in the mainstem South Fork.

Figure 48: Turbidity measurements in Nooksack River watershed, 1998-1999.



Implications for Salmonids

High temperature during summer is likely one of the most important salmonid limiting factors in the reach. The upper end of optimal temperature ranges by salmonid species and life history stage, developed from a synthesis of the available literature (Hicks 2000), is presented in Table 12. Overlaying these requirements with species/life history stage periodicity charts (Table 7) and 2001 thermograph data (Figure 43) indicates that **on no occasion** during the measurement period (mid-July to late September) were South Fork 7-day maximum temperatures within optimal ranges for bull trout incubation, rearing, and fry/smolt migration, as well as chinook incubation. Optimal bull trout adult migration temperatures were exceeded most days between RM 8.7 and RM 12.9. Optimal temperatures for chinook smoltification were exceeded all days below RM 12.9, all but a few days at RM 12.9, and on most days at RM 13.9. Optimal temperatures for chinook holding were exceeded most days at RM 12.9 and below, and before mid- to late August. Optimal chinook rearing temperatures were within range some days from RM 8.7 to RM 12.9, especially after mid to late August. Chinook spawning temperatures were exceeded often early in spawning season (mid-August) (except at RM 14.4), but within optimal range during peak spawning. Steelhead, coho, and rainbow trout optimal temperatures were similar or less restrictive than those for chinook, but pink and sockeye adult migration temperatures were exceeded most days in the reach.

Clearly, there is considerable evidence that temperatures in the reach are suboptimal for most salmonid species. Suboptimal temperatures lead to thermal

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stress of individuals, which can be lethal, limiting (interfere with metabolism or respiration), inhibiting (interfere with normal functions such as reproduction or feeding), or loading (increase metabolic burden, thereby reducing growth and activity). The latter three can also increase mortality if sustained over a long period (McCullough 1999). Observation of young (0+) juvenile bull trout in lower Hutchinson Creek, but not in the South Fork in Acme-Saxon reach (see *Native Char* section), is likely attributable to the cooler temperatures in Hutchinson Creek.

Table 12: The upper end of optimal temperature range (°C) by life stage and species (converted from Fahrenheit values reported in Hicks (2000)). Top line is the maximum 7-day average of the daily maximum temperatures, while bottom line is the daily maximum temperature.

Species	Life History Stage					
	Incubation	Rearing	Fry/Smolt Migration	Smoltification	Adult Holding	Adult Migration
Bull trout and Dolly Varden	5.5 - 6.5 7 - 8	10 - 12 13 - 14	11 - 12 13 - 14			14 - 17 19.5 - 20
Chinook	11 - 12 13.5 - 14.5	14.2 - 16.8 20 - 21		12 - 13.8 20 - 21	14.2 - 15.6 20 - 21	14.2 - 16.8 20 - 21
Coho	9 - 12 13.5 - 14.5	14 - 17 20 - 21				14 - 17 20 - 21
Chum	10.44 - 12 13.5 - 14.5					
Pink	10 - 12 13.5 - 14.5					12.5 - 13.5 19 - 20.5
Sockeye	10.5 - 12 13.5 - 14.5	12 - 16 20 - 21				13 - 14.5 20 - 21
Steelhead	13 - 14 13.5 - 14.5	16.5 - 17.5 21 - 23		13.3 - 13.4 21 - 23		16 - 17 21 - 23
Rainbow trout	9 - 12 13.5 - 14.5	15.5 - 18 21 - 23				
Cutthroat trout	10 - 11 13.5 - 14.5	13 - 15.5 19 - 20				14.5 - 17.5 19 - 20

Exceedances of optimal temperature for chinook upstream migration are also apparent, especially July to mid-August. Temperatures of approximately 21-22°C constitute migration barriers to most adult salmonids (McCullough 1999). Temperatures at the Acme Bridge were high enough to block upstream migration for 4.5 hours (3-7:30pm) on 8/13/01. Exceedance of optimal temperatures can increase stress and vulnerability to disease, as well as delay migration as fish expend energy seeking cool areas or halt migration until temperatures drop (McCullough 1999).

Temperatures in the reach regularly exceeded 15.6°C, above which depressed growth rates and increased mortality rates in chinook occur (McCullough 1999).

Thermographs (registering at 30 minute intervals) recorded temperatures greater than 15.6° for 44%, 33%, 32%, and 29% of the time between 6/27/01 and 9/30/01 at RM 8.7, 10.1, 10.3, and 12.9, respectively.

Given the severe temperature impairment, it is unlikely that high temperatures can be ameliorated throughout the Acme-Saxon reach in the near-term. While restoration of watershed processes that affect stream temperature, including floodplain hydrology, riparian shading, and sedimentation, should be pursued, significant effort should be expended to create smaller-scale coldwater refugia. Sources of cold water for warm stream reaches during summer include: lateral and pool bottom inflow from seeps, mouths of cold tributaries, and intragravel flow in the streambed (Nielsen et al. 1994). Intragravel flow is important for smaller fish and where substrate interstices are not filled with fine sediments. Inputs from seeps and tributary mouths (especially Hutchinson Creek) are likely to be more important for the majority of salmonids, especially when coupled with structural elements and/or deep pools where immediate mixing is inhibited. In Northern California streams, juvenile rearing steelhead and adult summer-run steelhead have been observed to hold in the lower, cooler area of thermally stratified pools (Nielsen et al. 1994). In the Middle Fork Eel River, pools deeper than 3 meters stratified when flows dropped, and coldwater pockets averaged 3.5 degrees cooler than surface temperatures. It is unknown whether such refugia exist in the South Fork Nooksack, and this warrants additional investigation.

Implications of high turbidity on salmonids in the reach are less clear. Effects of turbidity depend on the duration and frequency of exposure, temperature, life stage, particle characteristics, background turbidity and availability of refugia (Bash et al. 2001). Background (i.e. natural) turbidity levels in the South Fork are unknown, although it is likely that the history of mass wasting events in the upper South Fork watershed have increased turbidities. Additionally, deep, oversteepened glacial deposits exist along the upper South Fork Nooksack River, and these appear to be chronic sources of suspended sediment. Measured turbidity levels in the South Fork greatly exceed levels that have caused avoidance behavior, breakdown of territories, gill trauma, and reduced growth rate and feeding ability in salmonids in laboratory and field studies (Bash et al. 2001). The timing of high turbidities, associated with storm events in fall and winter, is likely to most affect species with overwinter rearing life history stages as well as winter spawn timing (see Table 7). Tributaries, especially floodplain tributaries, likely provide some refuge from high turbidities in the South Fork Nooksack.

Biotic Factors

Competition

Competition occurs when two organisms use the same resources and when availability of those resources are limited (Spence et al. 1996). Salmonids compete for food and space resources both with members of their own species (intraspecific competition) and with other species (interspecific competition).

There have been no direct studies of competition in the Acme-Saxon reach. Competition within stocks is expected for habitat that is most limiting, such as holding pools for adults and habitat with cover for juveniles, although to a lesser extent than competition between stocks. Approximately 1 million coho are released annually from the Skookum hatchery; as yearling smolts, released fish are expected to move quickly out of system with little residualism (retention in freshwater) and thus little competition with natural-spawned stream-rearing juvenile salmonids. However, mass releases of coho may displace natural-spawned juveniles by their sheer numbers, driving wild fish off with their unfamiliar behavior, including a pack tendency (as referenced in Brown 1982, p. 119).

There is also concern about interactions of North Fork early chinook and Nooksack fall chinook with South Fork early chinook. Recent evidence indicates higher-than-expected stray rates of North Fork early chinook into the South Fork (MacKay & Pfundt 2002). Forty-four percent, 24%, and 37% of the total number of carcasses recovered from the South Fork to October 7th in 1999, 2000, and 2001, respectively, were marked carcasses, 99% of which were identified as North Fork chinook. Applying these percentages to redds counted in the South Fork through October 1st yields interim escapement estimates of 126 strays and 164 South Fork early chinook in 1999, 89 strays and 283 South Fork early chinook in 2000, and 152 strays and 268 South Fork early chinook in 2001.

Preliminary stock assignments from DNA analysis of fish captured in the rotary screw trap near South Fork RM 1.0 indicates that fall chinook (about 84%) and North Fork early chinook (about 7%) comprise a significant proportion of juvenile chinook outmigrating from the South Fork (Young and Shaklee 2002). Predominance of fall chinook is not surprising given hatchery practices in previous decades. From 1980 through 1990, the number of fall chinook released from the Skookum Hatchery outnumbered spring chinook releases twenty-four-fold (521,926 spring chinook salmon vs. 12,645,148 fall chinook). Although median date of spawning differs among stocks (North Fork early chinook before South Fork early chinook before fall chinook), overlap does occur, leading to possible hybridization and competition for spawning habitat. There have been no studies on the extent to which superimposition of redds by later-spawning fish is a limiting factor for any salmonid stock. Anecdotal observations, for

instance of broomtail (i.e. indicating previous redd-building) females associating with later-spawning chinook (which look recognizably different from earlier spawning chinook), indicate that cross-breeding may occur more than redd superimposition. Genetic impacts may thus outweigh competition impacts as cross-hybridization with North Fork early chinook or fall chinook, coupled with critically low population numbers, is likely resulting in loss of genetic diversity among South Fork early chinook.

Predation

Fish are consumed by birds, mammals, amphibians, reptiles and other fish (Spence et al. 1996). Fish piscivores prey on juvenile salmonids during rearing and smolt migration and include sculpin, bull trout, rainbow trout, cutthroat trout, northern squawfish, and possibly white sturgeon. Bird predators include ring-billed gulls, common mergansers, herons and kingfishers. There have been no direct studies of predation in the Acme-Saxon reach. Reduction in hiding cover, coupled with shallower depths, has likely increased vulnerability of juvenile salmonids to predation, especially by terrestrial predators.

Food Availability

Although often overlooked in habitat assessments, food availability is critical to salmonid productivity. Salmonids require sufficient energy to meet metabolic needs, to grow, and to reproduce (Spence et al. 1996). Food availability in streams and rivers is especially important to juvenile anadromous salmonids that rear in the freshwater environment, as well as for sub-adult and adult resident salmonids and adult iteroparous (repeat-spawning) anadromous salmonids. Among juvenile coho salmon, for example, larger size is associated with greater survival, both over-winter and in the marine environment. Juvenile salmonids are opportunistic in their feeding habitats, feeding largely on aquatic or terrestrial invertebrate drift in the freshwater environment (Spence et al. 1996). For salmonids rearing in backwater habitats closely associated with riparian vegetation, such as floodplain channels and secondary channels, relatively larger proportions of the diet come may from aerial drop, or terrestrial invertebrates that fall in from overhanging vegetation. Diets of adult salmonids include invertebrates and other fish. Post-spawned kelt steelhead, cutthroat, and bull trout will readily feed to rebuild body condition.

No information is available on food availability in the Acme to Saxon Reach. However, we surmise from existing information that food availability has been moderately impacted as a result of the following:

- Intrusion of fine sediment into substrate interstices, loss of habitat complexity, and increased channel instability, all of which reduce diversity and abundance of aquatic invertebrates

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- Reduced primary and, thus, secondary (i.e. invertebrate) productivity, due to removal of riparian vegetation (and associated allochthonous inputs) upstream and in floodplain channels and to diminished light penetration as a result of high turbidity
- Lack of riparian vegetation in proximity to floodplain and other backwater habitats, thereby interrupting a mechanism for delivery of terrestrial invertebrates to streams.
- Elevated temperatures, which increase metabolic demand.
- Increased bedload movement due to loss of roughness (LWD), and increased channel gradient (reduced channel length and sinuosity).

Implications for Salmonids

Of the biotic interactions discussed, competition and cross-hybridization with North Fork early chinook and fall chinook spawners is likely most limiting to South Fork early chinook. These impacts are being addressed directly through hatchery management planning efforts. Riparian revegetation along the South Fork and floodplain tributaries, addition of instream wood structures, and efforts to reduce substrate embeddedness are recommended to decrease incidence of predation and food availability.

Recommendations for Restoration

Two types of habitat restoration recommendations will be offered for the Acme-Saxon reach: (1) those that focus on restoring the processes which form and maintain floodplain and mainstem habitats in the reach; and (2) site-specific recommendations that address habitat deficiencies at specific floodplain or mainstem locations. The former are intended to restore historic habitat-forming processes to the reach, and the latter are intended to address location-specific habitat deficiencies, but do not necessarily address the underlying causes for habitat decline. It will be important in the long-term to restore habitat-forming processes, to ensure that functional habitats are self-sustaining. The recommendations for restoring habitat-forming processes are primarily discussed under Channel Floodplain Interactions.

Channel-Floodplain Interaction

- Restore the historic channel migration width within Reaches 1 and 2. Delineation of these boundaries is an important first step in long-term planning for the South Fork Valley. This will help restore channel length (primarily through increased sinuosity, but especially secondary channels including side channels), reduce hydraulic energy (through reduced gradient and increased roughness due to increases in functional LWD and bedform variation), increase habitat complexity and the number of pools with cover, restore the dominant LWD recruitment mode (bank undercutting through lateral channel movement), and restore interaction with the historic riparian recruitment area. Restore riparian conditions to a trajectory of recovery for the channel migration area for which access is eventually anticipated.
- Restore the historic anastomosing channel pattern in Reach 3. This was historically a wood and sediment deposition area that created an anastomosing channel pattern. Increasing flow resistance (through adding functional LWD) and increasing wood/logjam residence time should help reverse the recent channel incision, restore opportunities for avulsing channels, and improve pool habitat stability and quality (size, depth, cover). Allow room for adequate floodplain development within the terraces that form the valley floor. Channel migration is the primary mechanism that the channel has used to widen its floodplain and allowing adequate migration will be critical for creating a floodplain that is well connected to the channel. Restore riparian conditions, particularly beyond the edge of the channel migration area, as this area will provide the long term growing sites that can eventually provide the very large wood needed to maintain an anastomosing pattern and high quality floodplain habitats that form in response to it.

- The lower portion of the Acme-Saxon reach would be the highest priority for increasing the number and persistence of wood-formed pools, because the process of wood recruitment has been effectively halted in these sections and pool formation from wood mostly does not occur. Acquisition of properties that lie within the channel migration area will allow for restoration of habitat-forming processes. In the upper reach, wood dominates pool formation, so the focus should be on conserving and improving future wood recruitment to the channel. Where bank armoring dominates pool formation (Reaches 1 and 2), improving woody debris cover in associated pools in the short-term will improve holding conditions for adult salmon and trout, and rearing conditions for juveniles.
- Restore natural hydrology in channel and floodplain areas.

Mainstem Habitat Restoration

Reach specific recommendations for the mainstem South Fork include the following:

Reach 1

- Reach 1 has lost all variability in sinuosity and habitat formation is basically halted. Bank protection has enabled human encroachment within the channel migration area consequently reducing the opportunity for improving habitat conditions. In addition to altering the habitat formation processes it has come with the long-term financial costs of periodic bank protection measures. Acquisitions of available properties that create the need for bank protection (and consequent impacts to habitat and habitat forming processes) should be considered and pursued when possible.
- The greatest opportunity for restoring channel migration in Reach 1 lies in removing the bank hardening along the Acme Farm property where a second Williams gas pipeline crosses underneath the river channel. While one pipeline was re-buried in 2002 with setbacks to provide for restored channel migration opportunities, a second pipeline has not yet been re-buried. The riprap channel constraints are intended to protect these pipelines. The second pipeline crossing would need to be reburied (and no doubt eventually will be), and riprap removed to restore migration and habitat forming processes within an expanded channel migration area width. This would remove the need to restrict the channel and maintain the riprap bank hardening on both sides (which actually straddles Reach 1 and Reach 2). The area anticipated to again become available to future channel migration should be appropriately planted now with a native mixture including conifers and cottonwoods.

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- The second major constraint on the channel compared to historic conditions is created by Mosquito Lake Road on the northeast side, and properties on the southwest side, upstream from the SR 9 Bridge. These not only maintain the single thread simplified channel, to some extent they also prevent establishment of functional riparian areas. The feasibility of relocating the first section of Mosquito Lake Road east of SR 9 should be investigated, in association with envisioning what opportunities might be afforded with a future SR 9 bridge, and with possible property acquisitions.
- Reach 1 lacks high quality pools with woody cover, and the number and quality (depth, cover) of pools should be increased by increasing the number of LWD-formed pools. Reduce the pool spacing in the reach.
- Once the artificial channel confinement has been removed, restoration efforts can focus on slowing the process of channel widening and narrowing, and secondary channel development and destruction using in-stream LWD structures. Establish appropriate riparian stands now within areas that afford future channel migration.
- In areas where bank protection cannot be removed due to infrastructure, cover conditions could be improved for holding adults and rearing juveniles by utilizing LWD based bank protection projects. These need to include establishment, maintenance and protection of well-functioning riparian areas, so that the cover and bank protection provided by the LWD bank protection will be replaced as they decay through natural recruitment. Plant species that have the ability to grow to sizes that can provide these functions.

Reach 2

- Reach 2 presents opportunities to restore the process of channel migration and avulsion that has been lost due to narrowing the channel migration area. The bank hardening that was installed to protect the City's water pipeline (both along the South Fork and lower Hutchinson Creek) reduced the historic channel migration area width from 1200 feet to 200 feet. Among the effects has been the apparent translocation of bank erosion downstream to Acme Farm in reach 1. Lowering (re-burying) the City of Bellingham's water diversion pipeline from where it approaches Hutchinson Creek from the northeast to where it was re-buried under the South Fork would remove the need for the existing bank hardening, and potentially allow for its removal. Removal of the protection will restore the historic active channel width and restore the dominant habitat formation processes, including recreation of the secondary channels that were present prior to the construction of the bank protection projects. It would also restore the dominant historic LWD recruitment process (bank undercutting through channel movement), and

restore the historic LWD recruitment potential area. It would also address the impaired rearing conditions created by the riprap areas, and could restore floodwater storage to the area behind the only levee in the reach. Removal would also restore access to Rothenbuhler's Slough that has been cut-off by the riprap and a perched culvert.

- Once the artificial channel confinement has been removed, restoration efforts can focus on slowing the process of channel widening and narrowing, and secondary channel development and destruction using in-stream LWD structures. This should be considered particularly for lower Hutchinson Creek, as it affords high quality habitat that is limited in the South Fork. Establish appropriate riparian stands now within all areas that are anticipated to accommodate future channel migration.
- Reach 2 lacks high quality pools with woody cover, and the number and quality (depth, cover) of pools should be improved by increasing the number of LWD formed pools. Reduce the pool spacing in the reach.

Reach 3

- Reach 3 is currently well below its mean length and it is still unconfined, providing excellent opportunities to increase secondary channel length and channel sinuosity. It will be important to retain the variability in sinuosity because that is related to habitat formation in the reach. LWD structures should focus on replacing channel functions formerly provided by historic LWD jams. Stable logjams historically created opportunities for channel avulsion thereby creating secondary channels, probably creating stable islands within the dynamic floodplain environment, and they scoured very deep pools with cover. So wood accumulation needs to be promoted in the reach to reduce hydraulic energy (by providing channel roughness, and through altering the bedform roughness), to reverse the recent channel incision, and to restore an anastomosing channel pattern. In addition to reducing hydraulic energy through increasing roughness and decreasing gradient, sediment storage can be encouraged in the reach by increasing local storage by creating local LWD obstructions to flow. Lowering the stream power and diversifying the channel form will likely increase woody debris and sediment retention while improving connectivity of the floodplain (GeoEngineers, Inc. 2002).
- Channel width is largely unimpaired by development in Reach 3 and efforts could focus on creating hard-points in the channel to slow the creation and destruction of side channels, making them less ephemeral, while still allowing the river to adjust width in response to upstream and local disturbances. These in-stream structures should be considered interim

measures until the riparian area recovers and can provide large wood to the system that will form semi-stable accumulations and act as natural hard-points in the active channel area.

- Restore logjam related deep holding pools with cover, starting in Reach 3. While Reach 3 has the highest number of pools, they are smaller and shallower than downstream pools. The upstream portion of Reach 3 (and a short distance upstream of it) appears to have the coolest surface water temperatures of the South Fork downstream of approximately Sylvester's Falls (RM25). This presents the greatest potential holding habitat refugia within the primary spring chinook utilization area. The upper portion of this reach also formerly had a logjam formed pool (created by "Nesset's Jam") that held appreciable chinook and was much deeper than currently available pools. While the spacing of holding pools is almost certainly important, it is very important to improve holding habitat in this temperature refugia area. Hutchinson Creek also needs improved adult holding conditions, especially considering the potential temperature refugia, and considering that adults that migrate to upper Hutchinson Creek are likely to hold downstream of the cascades until passage conditions are suitable. So target development of deep pools with cover.
- Bank hardening along this reach is primarily along the edge/boundary of the historic channel migration area, rather than within it. In this reach, the historic migration area is largely intact, but recruitable large trees from outside of the historic migration area are lacking. Focus on restoring riparian areas beyond the historic migration area because these can provide wood to the channel from growing areas where trees can attain large sizes without disturbance by the river. Riparian areas to focus conifer establishment, maintenance, and protection include along Nesset's Slough and on the south side of the river, downstream from Saxon Bridge. Replant the field between Curtis and Rothenbuhler sloughs with species appropriate to attaining large diameter and height.
- When planning any use of the old road that exists between Nesset's Farm and Ponds Creek, try not to affect future LWD recruitment. Recognize that recruitment of whole, large trees is critical to recovering habitat forming processes in the reach, and that this area of the river has comparatively large conifers within 200 feet of the CMZ. Try to plan any trail layout with this in mind, and not re-build the road within 200 feet of the CMZ (potential LWD recruitment area).

Floodplain Habitat Restoration

- Enhance connectivity of current floodplain channels.
 - Restore unimpeded access to Rothenbuhler Slough. The revetment on the left bank at the City of Bellingham water pipeline crossing truncates Rothenbuhler Slough, leaving 1548 meters (5075 feet) of floodplain habitat seasonally unavailable to fish. Sequence this with any re-burial of the pipeline, and removal of the riprap which constrains the river and truncates the slough.
 - Complete the passage assessment for floodplain tributaries, and correct the blocking culverts in the Landingstrip Creek complex. The known passage problems are: 1000-foot culvert and two crossings under SR 9 of tributaries to it. Restoring a stream channel in place of the 1000-foot culvert should include excavating a suitable channel, providing woody cover, and re-planting. It is considered likely that beavers would impound this reach.
- Improve in-channel woody debris loading in floodplain channels to improve conditions in the near-term. Wood loading should approach levels described for small, forested channels, with sizing appropriate for pool formation in the respective channel sizes. For Hutchinson Creek and Curtis Slough, wood should be sized appropriate to the South Fork, especially if the City's pipeline is re-buried, and migration back into lower Hutchinson Creek is eventually anticipated. All of the floodplain channels mapped in the summer of 2000 contained low levels of wood.
- Improve riparian conditions along floodplain channels by planting a variety of native species most likely to result in the suite of desired future conditions. These include providing functional LWD over the long-term, improving shade and cover, providing nutrients, and providing bank stability.
- Address invasive species including Japanese knotweed and reed canary grass that occupy the growing sites along floodplain channels but do not provide the desired habitat benefits for salmon and trout.
 - Control Japanese knotweed along Hutchinson Creek and establish native conifers, as the existing alder stand is mature, but conifers are lacking to replace them after the mature alder dies.
 - Shade out reed canary grass to improve habitat and reduce suspended sediment settling in floodplain channels. The Landingstrip Creek complex is severely impacted by reed canary grass.

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- Establish functional riparian area including substantial conifers along Nesses Creek to provide long-term habitat benefits, and along sloughs including Nessel's Slough.
- Establish conifers along Curtis Slough.
- Restore natural hydrology in floodplain areas.
 - Floodplain wetlands should be protected and restored where possible. These are excellent focus areas for acquisition or establishing long-term easements. These are particularly important for maintaining flow in floodplain channels during the dry summer months, and rearing habitat is discharge limited during summer, and fall spawning use is highly flow dependent. The Landingstrip Creek area and the Rothenbuhler Slough areas are excellent focus areas for wetland acquisition or easements and restoration projects.
 - A ditch that drains the Foxglove wetland into the Roos side-channel area should be filled. The ditch is currently impounded by a beaver dam, but filling this ditch would improve water retention in the wetland and return flow to the Landingstrip Creek channels.
 - Discourage monotypic plantings including hybrid poplars that have high transpiration rates, to reduce impacts to instream flows.
 - Where possible, allow beavers to construct dams and impound water. This will increase the quantity of highly productive habitat and increase retention of water and groundwater recharge. These channels would be expected to have supported abundant beavers historically. Rothenbuhler Slough had more flow and many beaver ponds in the mid-1900's.
 - Avoid impacts to hydrology and water quality from road runoff. This can be accomplished through a variety of means: do not add impervious surface area (pavement or concrete); reduce cross drain spacing and direct surface runoff into natural channels in as short a distance as possible. Road runoff ditches pirate and concentrate flows, which alter hydrology by reducing groundwater recharge, and by diverting surface flow from one channel into another (thereby depleting one and overloading the other). Ditch flow also increases hydraulic energy, which can result in ditch erosion, increased sediment delivery, and downstream scour of channels and even

salmon redds. Inadequate cross drain spacing also delivers road pollutants to streams.

- The upper portions of the anadromous use section of the Landingstrip Creek area have been altered by the railroad grade that runs along Highway 9. Evaluate feasibility and desirability of addressing this.

Riparian Restoration

The following recommendations are additional to other specific recommendations listed above:

- Envision where channel migration is likely in the future, and restore riparian stands in the areas within and adjacent to this. It is important to re-plant within the potential recruitment area beyond the channel migration area, as this is where very large, recruitable trees are most likely to grow. It is important to consider that growing very large trees takes centuries, and that recruiting key piece size LWD will likely come from the outer portion or even beyond the channel migration areas. The potential recruitment zone beyond the CMZ is about 200 feet wide. Replant the areas within and adjacent to the CMZ now, so that the likelihood of habitat development is greatest when the river returns, and to naturally attenuate the rate of channel migration.
- Establishing tree species that have the ability to grow tall and cast a long shadow (e.g. Douglas fir, Sitka spruce, western redcedar, black cottonwood) will maximize future shade to the South Fork. These species will also provide large LWD that is critical to restoring and maintaining habitat formation.
- Recovery of target shade levels in floodplain tributaries is likely to occur more rapidly, and tributaries and their area of temperature influence within the South Fork may provide critical temperature refuge areas for salmonids in the near-term.
- It is important for riparian restoration to be conducted on property where there are assurances that the stand will be maintained and protected through land use regulations, purchase, conservation easement, or long-term landowner agreement. Public education about the critical need to restore riparian areas is also important to solicit interested landowners.
- Sequencing of riparian restoration will be important, including consideration of where existing stands are on a trajectory of recovery over time, and where conditions are unlikely to improve without active intervention. Efficiently restoring desired native species in riparian areas in agricultural areas

generally takes active intervention. It is also best accomplished by planting soon after stream-adjacent agricultural practices cease in order to minimize competition with invasive-non-native species.

- Riparian restoration measures should also be planned in association with instream projects or removal of any bank hardening. To the extent that bank hardening is removed, potential LWD recruitment area is likely to increase. In such locations, riparian restoration should include the entire potential channel migration area.
- It is important to consider that channel migration was likely the predominant LWD recruitment process in this reach, and the extent to which channel migration processes are restored will greatly influence the extent to which long-term habitat recovery occurs. In all cases, it is a high priority to restore functional riparian areas, including desired stand species composition, and restoring buffers wide enough to provide the majority of possible habitat benefits.
- In some stands, restoring riparian functions may be expedited through conifer release. Some conifer-deficient stands will also benefit from conifer interplanting. Some existing riparian areas are conifer limited due to a lack of seed source and nurse logs.
- In addition to restoring riparian areas along the mainstem South Fork, it is important to restore riparian conditions along tributaries which are both important salmonids refuge areas and also likely to recover comparatively rapidly. It is also important to consider the highest priority species, and to prioritize the streams and habitats that support these species.
- Fence out all livestock from the riparian buffer areas. Livestock not only eat beneficial vegetation, but they also trample banks, salmon redds, and discharge waste into the streams.

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