# Upper South Fork Nooksack River Habitat Assessment

Report by:
Melissa Brown and Michael Maudlin

Lummi Nation Natural Resources Department
August 31, 2007

# Upper South Fork Nooksack River Habitat Assessment

**Written by:**
Melissa Brown
Michael Maudlin

**Lummi Nation Field and GIS Assistance:**
Frank Lawrence III
Victor Johnson
Mike Williams
Frank Bob
Gregg Dunphy

**Submitted by:**
Lummi Nation
Natural Resources Department
2616 Kwina Road
Bellingham, WA  98226

**Submitted to:**
Salmon Recovery Funding Board
Office of the Interagency Committee
111 Washington Street SE    P.O. Box 40917
Olympia, WA  98504-0917
**IAC # 04-1487N**

**Funding Provided by:**

- WA State Salmon Recovery Funding Board
- Lummi Natural Resources
- Bureau of Indian Affairs
- U.S. Fish and Wildlife Service

**Special Thanks for Editing and General Advice:**
Jim Hansen, Habitat Restoration Supervisor, Lummi Natural Resources
Ann Stark, GIS Manager, Lummi Natural Resources
Mike MacKay, Biologist, Lummi Natural Resources
Adam Pfundt, Biologist, Lummi Natural Resources
Ned Currence, Biologist, Nooksack Tribe Natural Resources
Treva Coe, Biologist, Nooksack Tribe Natural Resources
Tim Hyatt, Ecologist, Nooksack Tribe Natural Resources
Roger Nichols, Geologist, U.S. Forest Service
Doug Huddle, Biologist, Washington State Department of Fish and Wildlife

# Table of Contents

## Table of Figures

# Table of Tables

# Executive Summary

The Upper South Fork Nooksack Habitat Assessment was developed in support of the WRIA-1 (Nooksack River and independent coastal drainages of Whatcom County) Salmon Recovery Plan. The assessment area covers 25 miles of the South Fork Nooksack upstream from the Saxon Road Bridge (RM 12.8), and contains the most heavily used spawning areas for Threatened chinook salmon (*Oncorhynchus tshawytscha*), steelhead (*O. mykiss*) and bull trout (*Salvelinus confluentus*) in the South Fork watershed. The assessment area is heavily forested and commercial forestry dominates the land use of the watershed. Land ownership is split between Federal lands managed by the U.S. Forest Service, commercial forestlands, and conservation property held by Seattle City Light as mitigation for its Skagit River hydroelectric dams.

Under the current state Forest Practice Rules and Federal Northwest Forest Plan, the upper South Fork Nooksack should be on a trajectory of recovery. However, the legacy of timber harvest and road construction in the watershed has disrupted several important habitat-forming processes and resulted in degraded habitat conditions. The loss of mature trees from over 90% of the riparian zone has reduced shading of the channel and increased the process of heat delivery to the channel. Streamside harvest has also slowed the process of recruitment of large wood to the channel, altering the distribution and abundance of instream wood and limiting its influence of habitat diversity. Bank protection installed to protect roads and other infrastructure have narrowed the channel migration area and further slowed the recruitment of wood to the channel. Naturally high sediment production from unstable landforms in the watershed has been augmented by human-caused slope failures related to road failure and timber harvest. Because of the underlying geology and physiography of the watershed, these processes will be slow to return to levels where habitat formation and maintenance can be self-sustaining.

The need to quickly improve instream habitat conditions is underscored by the listing under the Endangered Species Act of three fish species in the upper South Fork Watershed: chinook salmon, bull trout and steelhead trout. Near-term restoration projects should focus on improving habitat diversity in cooler water reaches of the river, controlling sediment sources, and initiating vegetation enhancement that speeds the growth of the riparian zone to provide shade and large wood the channel. The natural barriers to recovery, such as low channel migration rates and slow growth of riparian trees, make it likely that habitat improvement will need 50-100 years without active restoration.

Since the primary land-use regulations governing this portion of the watershed are the Forest Practice Rules, the habitat protection strategy should focus on monitoring the implementation and effectiveness of these rules that aims to provide high quality instream habitat for ESA-listed species. Protection and acquisition projects should focus on ensuring that the watershed remains in commercial forestry and conservation status, by purchasing development rights or conservation easements to stream-adjacent property that is at risk of development. Future threats to habitat and salmon stocks in the upper South Fork watershed will come from further watershed development as the population in the region continues to grow.

# Introduction

The Upper South Fork Habitat Assessment (upstream of RM 12.8) was undertaken as a key component to the Watershed Resources Inventory Area (WRIA) 1 chapter of the Puget Sound Salmon Recovery Plan (Shared Strategy 2006). The recovery plan was developed in response to the listing of chinook salmon and bull trout populations under the Endangered Species Act (ESA). The WRIA-1 plan calls for habitat assessment at the reach scale to characterize limiting habitat functions and target restoration and protection projects to best address these limitations. The Upper South Fork Assessment follows assessments in the Acme to Saxon reach (RM 8.5 to 12.8) completed in 2001 and the Acme to Confluence reach (RM 0 to 8.5) completed in 2006. The assessment methods applied in the Upper South Fork Assessment were designed to be consistent with the two downstream assessments and allow comparison of restoration and protection projects through the South Fork Nooksack watershed.

Basic direction for this assessment was taken from the Ecosystem Diagnosis & Treatment (EDT) model (Mobrand 2003) that was developed to assist in the identification and ranking of factors that limit chinook salmon (*Oncorhynchus tshawytscha*) production in the Nooksack River watershed.  Other documents referenced are the Bull Trout (*Salvelinus confluentus*) Recovery Plan adopted by the U.S. Fish and Wildlife Service (USFWS) in 2004 and the WRIA-1 Salmonid Recovery Plan finalized in 2005.  Careful assessment is necessary as a step between these planning documents and restoration project development because both of the ESA-listed have very low population sizes and are critical to recovering the population diversity of the Puget Sound population as a whole.

In the Nooksack basin and WRIA 1, it is clear that abundances of several salmonid stocks have diminished substantially from historical levels. The estimated historic abundance of early-timed chinook *(Oncorhynchus tshawytscha)*, based on likely historic habitat conditions, in the South Fork Nooksack basin was 13,000 (Mobrand Biometrics, 2003). Recent escapements of wild fish for the early population averaged 210 fish from 1997 through 2004 (Fisheries Co-managers, unpublished data). The South Fork early chinook stock status was deemed “critical” in the updated Washington Salmonid Stock Inventory (SASI; WDFW 2002). The Puget Sound chinook salmon Evolutionarily Significant Unit (ESU), of which WRIA 1 constitutes 1 of the 5 delineated geographic regions, has been listed as threatened under the Endangered Species Act (ESA). The South Fork Nooksack chinook stock is considered essential for recovery of the Puget Sound ESU (64 FR 14308, Mar. 24, 1999). Due to the small population size and the land use of the watershed, the SF Nooksack stock is considered the highest risk for near-term extinction of the Puget Sound populations (Puget Sound Technical Recovery Team, 2006 Working Paper).

Status of local bull trout (*Salvelinus confluentus*) populations is also reflected in recent ESA listings that affect WRIA 1. Bull trout in WRIA 1 constitute a component of the Coastal-Puget Sound Distinct Population Segment (DPS), listed as threatened (64 FR 58910, Nov. 1, 1999). WRIA 1 bull trout comprise two of the eight core areas that have been defined within the Puget Sound Recovery Unit: Nooksack and Chilliwack. The upper South Fork Nooksack alone contains 3 of the 59 individual local populations of bull trout in the DPS, making habitat restoration in the area important for recovering the greater Coastal-Puget Sound bull trout DPS.

NOAA Fisheries has also listed Puget Sound steelhead under the ESA. The upper South Fork is home to the only known summer-run steelhead spawning in the Nooksack basin and is almost certainly a genetic refuge for Puget Sound summer-run steelhead (Currence, pers. comm). Because the Nooksack basin represents such an important component of the Puget Sound diversity for both ESA-listed bull trout, chinook salmon and other salmonid species, it has become a major focus for salmon recovery.

This habitat assessment focuses on several aspects of fish habitat and habitat-forming processes in the upper South Fork reach of the Nooksack River, as well as characterizing the distribution and population of salmon stocks present in this portion of the watershed.  The assessment area covers the main channel of the South Fork from the Saxon Road Bridge (RM 12.8) upstream to the 1260 Road Bridge (RM 37.7) on U.S. Forest Service (USFS) land, and the major tributaries within the watershed (Figure 1). The area covered is consistent with the anadromous portion of the watershed, although much of the focus of the assessment will be focused downstream of the partial anadromous barrier at RM 32. This barrier is described in the WRIA-1 Stream Catalog (1974) at RM 31; however, for this assessment, the river miles were re-mapped in GIS along its 2005 thalweg from RM 0 at the mouth. The new mile mark for the barrier became RM 32. This report refers to the new GIS-generated mile marks for geographic reference.

The assessment reach also includes the upper-most reaches modeled using EDT to identify limiting factors for South Fork spring chinook. The EDT model analyzes the effects of reach level habitat conditions on the abundance, productivity, and diversity of chinook populations in the Nooksack River basin. Input data worked through the model include population characteristics (spatial and temporal distribution of life history stages) and the habitat conditions within each reach used by population (WRIA-1, 2005a). Results from the EDT are used to inform species recovery strategies and as a tool that assists managers in decision-making and restoration or protection project prioritizing. The results of the EDT model indicated that the following factors are negatively impacting chinook salmon production in the South Fork Nooksack River:

1. Elevated Water Temperature
2. Elevated Sediment Levels
3. Reduced Habitat Diversity
4. Reduced Channel Stability
5. Reduced High Flow Refuge

The upper South Fork Nooksack River habitat assessment will focus on these limiting factors and assess the processes that affect the factor. The objective is to better characterize the causes of the limitation and provide recommendations for habitat conservation and restoration actions that will support WRIA-1 salmon recovery objectives.

## Basin Characteristics and Land Use History

The Nooksack watershed drains the western slopes of the Cascade Range in northwestern Washington State. Although most of its watershed lies within the boundaries of Whatcom County, it also drains several streams in Canada and Skagit County (Figure 1). Elevations in the Nooksack watershed range from 10,778 feet at Mt. Baker to sea level, where the river enters Bellingham and Lummi Bays in the northern Puget Sound estuary. The Nooksack River is comprised of three forks (North, Middle, and South). The North and Middle forks flow westward through steep, heavily forested terrain and join to form a main stem channel 40 miles upstream of the estuary. The South Fork joins the other forks near RM 36 of the Nooksack River. While the upper 23 miles of the South Fork watershed is similarly steep and heavily forested, the lower 16 miles flows through a broad, gently sloping valley.

The gradients in this assessment area upstream of RM 12.8 range from 1 to 8% with moderately confined and confined channels (Figure 2). Many of the smaller tributaries in the upper South Fork watershed have limited access to anadromous salmonids due to the steeper terrain (Phinney and Williams 1975), although major tributaries, such as Skookum (RM 14.3), Cavanaugh (RM 16.5), Edfro (RM 16.2), Plumbago (RM 19.8), Roaring (RM 19.8), Howard (RM 27.5), Wanlick (RM 34.1), Bell (RM 37.3) creeks, provide accessible habitat. The geographic extent of this assessment encompasses the South Fork's watershed from the USFS 1260 Road bridge (RM 37.7), near the headwaters, down to the Saxon Bridge at RM 12.8. Within this assessment reach, referred to as the upper South Fork, the river's discharge is supplemented with flow from ten major tributary streams and many smaller drainages.

The South Fork watershed is made up of a combination of conifer and deciduous tree species. Tree communities found in this reach include Sitka Spruce (*Picea sitchensis*), Douglas Fir (*Pseudotsuga menziesii*), Western Red Cedar (*Thuja plicata*), Western Hemlock (*Tsuga heterophylla*), and Pacific Silver Fir (*Abies amabilis*). Hardwood species dominating the watershed and most areas that have been cleared by logging, road building or fire include Red Alder (*Alnus rubra*), Big Leaf Maple (*Acer macrophyllum*), and Black Cottonwood (*Populus trichocarpa*).

The upper South Fork channel is not heavily confined by infrastructure, such as bridges or stream-adjacent roads, although steep bedrock walls are a common and natural stream bank type, often confining the river to a narrowed, rigid shape. In the many stream miles absent of man-made infrastructure, the river moves freely across its migration zone. Areas within the unconfined channel migration zone (CMZ) have experienced significant movement of the main stem and its side channels from one side to the other, changing course along the lowest existing gradient. Active landslides along the CMZ influence the movement of the channel, as they contribute debris (wood and sediment) that can dam or deflect the channel and move the river from side to side in the valley.

The headwaters of South Fork lie on the eastern slopes of the Twin Sisters in Whatcom County. From RM 34.1 to 16.5, the South Fork Nooksack River flows south and west through Skagit County, before turning north and entering the Acme Valley in Whatcom County. The U.S. Forest Service manages the watershed from the headwaters to approximately RM 33. Further downstream to approximately RM 25, the stream-adjacent property is managed for conservation by Seattle City Light as mitigation for hydroelectric dams they built on the Skagit River. The Washington State Department of Natural Resources (DNR), Sierra Pacific Industries (SPI), Bloedel Timber-Hampton Affiliates, and the US Forest Service manage the majority of forested land in the watershed.

Land use practices in the watershed influence the distribution and abundance of vegetation. Logging has historically been the most significant land use and commercial activity in the South Fork watershed since European settlement in the 1880s (Whatcom County 1990). Euro-Americans began settling in the Whatcom County area in the 1850s, attracted by high quality timber coupled with an easy access to water transportation, and moved into the South Fork watershed in the 1880s (Whatcom County Planning and Development Services Dept. 1997). By the time of the General Land Office Surveys in the mid-1880s, much of the South Fork watershed was still undeveloped with small openings in the forest where homesteads were located. By the turn of the century, timber harvest had begun in earnest in the South

Fork valley with large cedars cleared from local homesteads fueling the shingle mills in the Acme Valley. The first logging camp in the area began operation in 1905 just downstream of the Saxon Bridge and wood was transported by rail from the valley (Royer 1982). Bloedel-Donovan was to eventually build over fifty miles of railroad in this Saxon-Nooksack river valley region between 1920 and 1937 (Thompson 1989). The Saxon area was operated by Bloedel-Donovan until 1940, when the accessible timber was exhausted. Following the end of railroad logging, some of the railroad grades were reconstructed into truck roads. These roads extended beyond the end of the rail lines into steeper and higher elevation portions of the basin. By the 1970s, virtually all of the upper South Fork watershed had become accessible by forest roads via Lyman Pass from the Skagit River. Forest practice rules developed in the 1970s, with significant improvements in resource protection in the 1990s, have strengthened the protection of fisheries resources through better protecting watershed drainages by establishing riparian buffers along watercourses, managing land uses on unstable slopes, and implementing monitoring guidelines for observation of conditions.

For this assessment, the upper South Fork reach is divided into seven sub-reaches (Figure 3 - Figure 9, and Table 1). Reach delineations are based primarily on the channel's geomorphic characteristics, including bedform, substrate, gradient, and meander. The characteristics that define each sub-reach are described in their respective sections below.

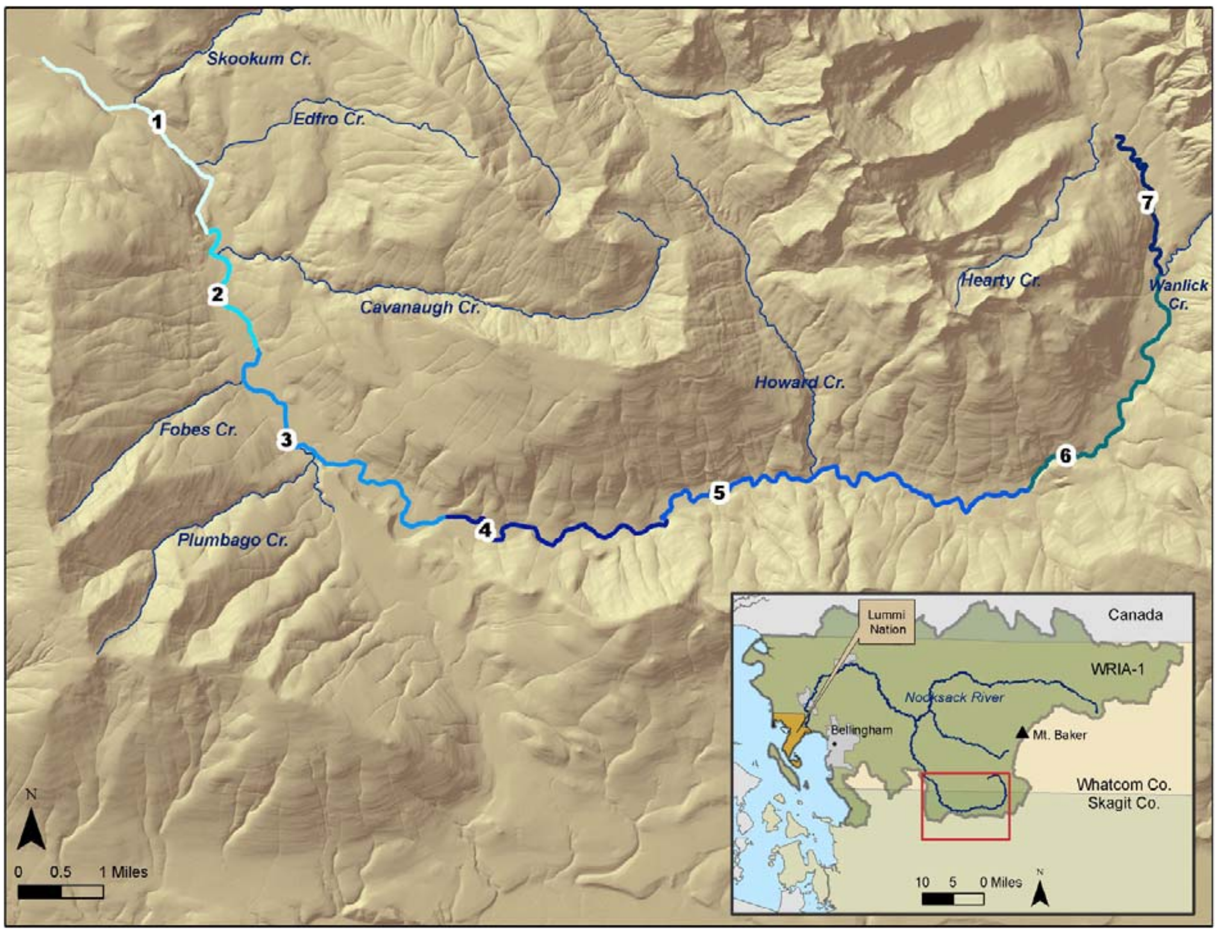


**Figure 1. The upper South Fork study area with sub-reaches 1 – 7 called out.**

**Table 1. Upper South Fork sub-reach information. *Drop in feet per river mile.**

| Sub-reach | Downstream Boundary | RM | Upstream Boundary | RM | Gradient Slope* |
|---|---|---|---|---|---|
| 1 | Saxon Bridge | 12.8 | Upper Dye's Canyon | 16.2 | 21 |
| 2 | Dye's Canyon | 16.2 | New Bridge | 18.0 | 25 |
| 3 | New Bridge | 18.0 | Elk Flats | 22.4 | 37 |
| 4 | Elk Flats | 22.4 | Sylvester's Canyon | 25.6 | 70 |
| 5 | Sylvester's Canyon | 25.6 | Falls/Barrier | 32.0 | 110 |
| 6 | Falls/Barrier | 32.0 | Wanlick Creek | 35.2 | 77 |
| 7 | Wanlick Creek | 35.2 | USFS 1260 Rd. Bridge | 37.7 | 56 |

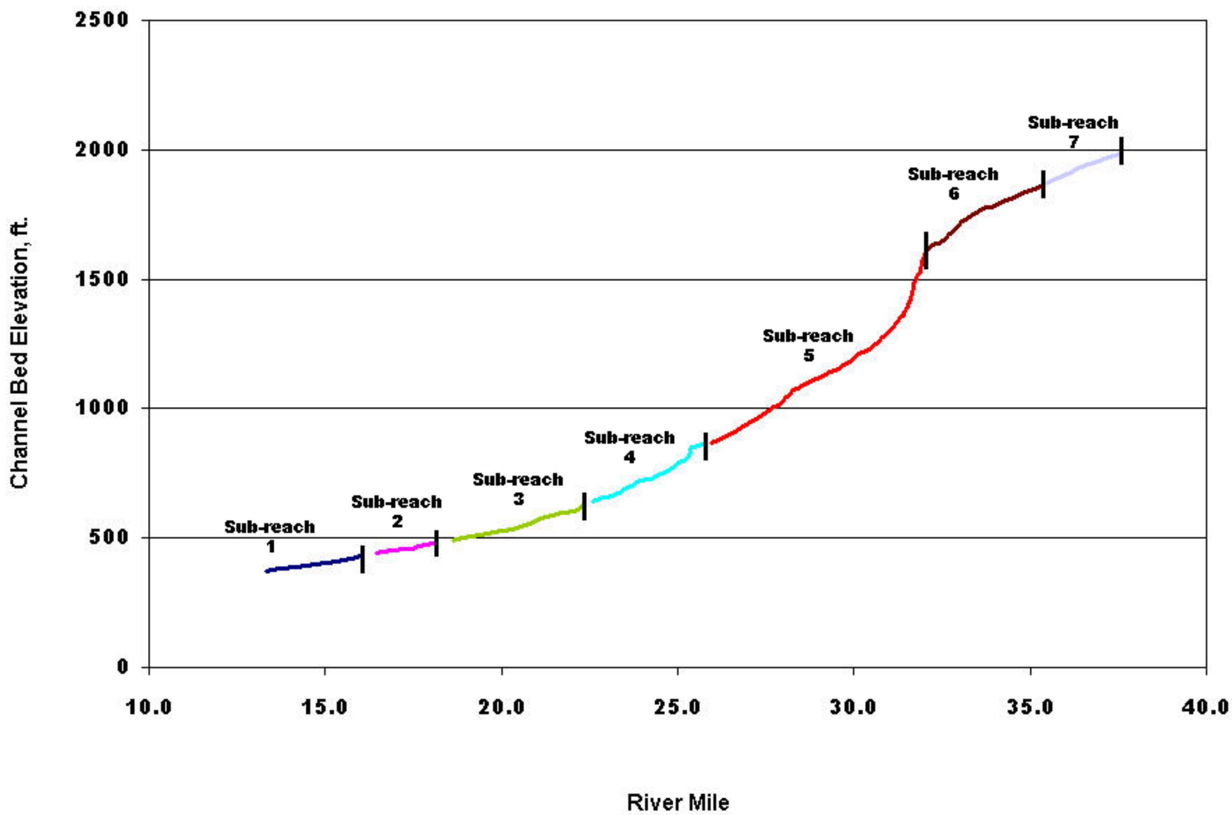


**Figure 2. Channel gradient of the upper South Fork Nooksack. The gradient average is 67 feet per river mile (SSHIAP 1995).**

### Sub-Reach One

This sub-reach is furthest downstream in the study area. It extends down from Dye's Canyon to the Saxon Road Bridge (Figure 3). Dye's Canyon is a bedrock formation filled with large boulders and distinguished by a mature riparian canopy. It does not often present a passage barrier to adult salmonids, and spawning activity in the canyon has been documented. Within this reach, Edfro and Skookum Creeks flow into the river, contributing water of high quality available to salmonids with good quality habitat. Skookum Creek Hatchery, a Lummi Nation-operated facility, collects, spawns, and rears salmon in partial flows diverted from Skookum Creek.

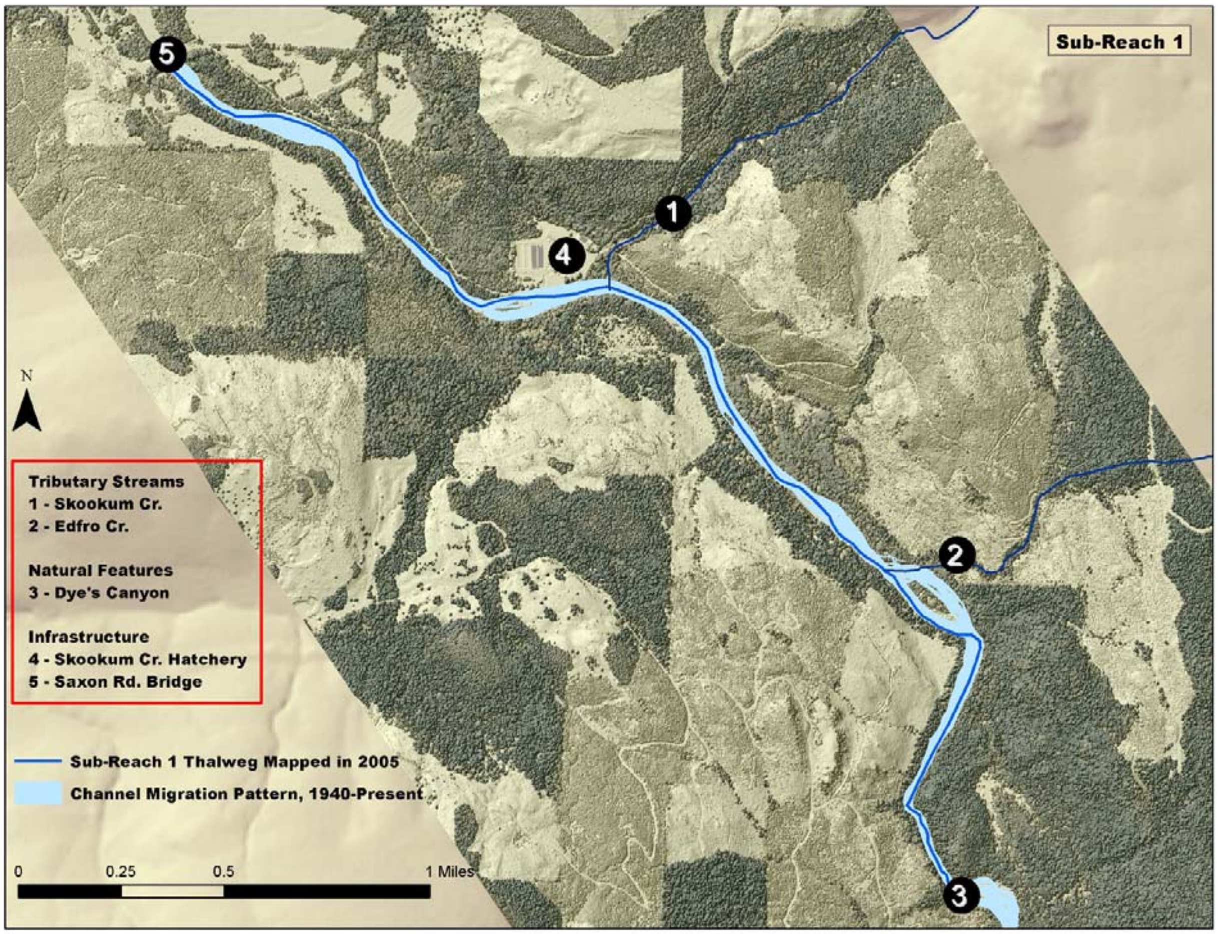


**Figure 3. Sub-reach one of the study area.**

The active channel continues through a narrow migration zone, partly due to the presence of Dye's Canyon, and partly due to county road infrastructure along the right bank down the lower half of the reach. The channel areas immediately above Edfro Creek and below Skookum Creek are wider, allowing for some channel migration and habitat diversity in the reach. Patches of spawning gravel were mapped in this sub-reach in 2005.

## Sub-Reach Two

Sub-reach two flows from New Bridge down through a narrow bedrock channel into a wide alluvial floodplain, past Cavanaugh Creek to the head of Dye's Canyon (Figure 4). Historic and current mapping indicate that the river's migration through the upstream half of the sub-reach is limited by steep bedrock walls. In contrast, the channel in the lower half of the sub-reach has migrated extensively across the migration zone. The channel migration zone (CMZ) in the lower half of sub-reach two is wide and allows for diverse channel development.

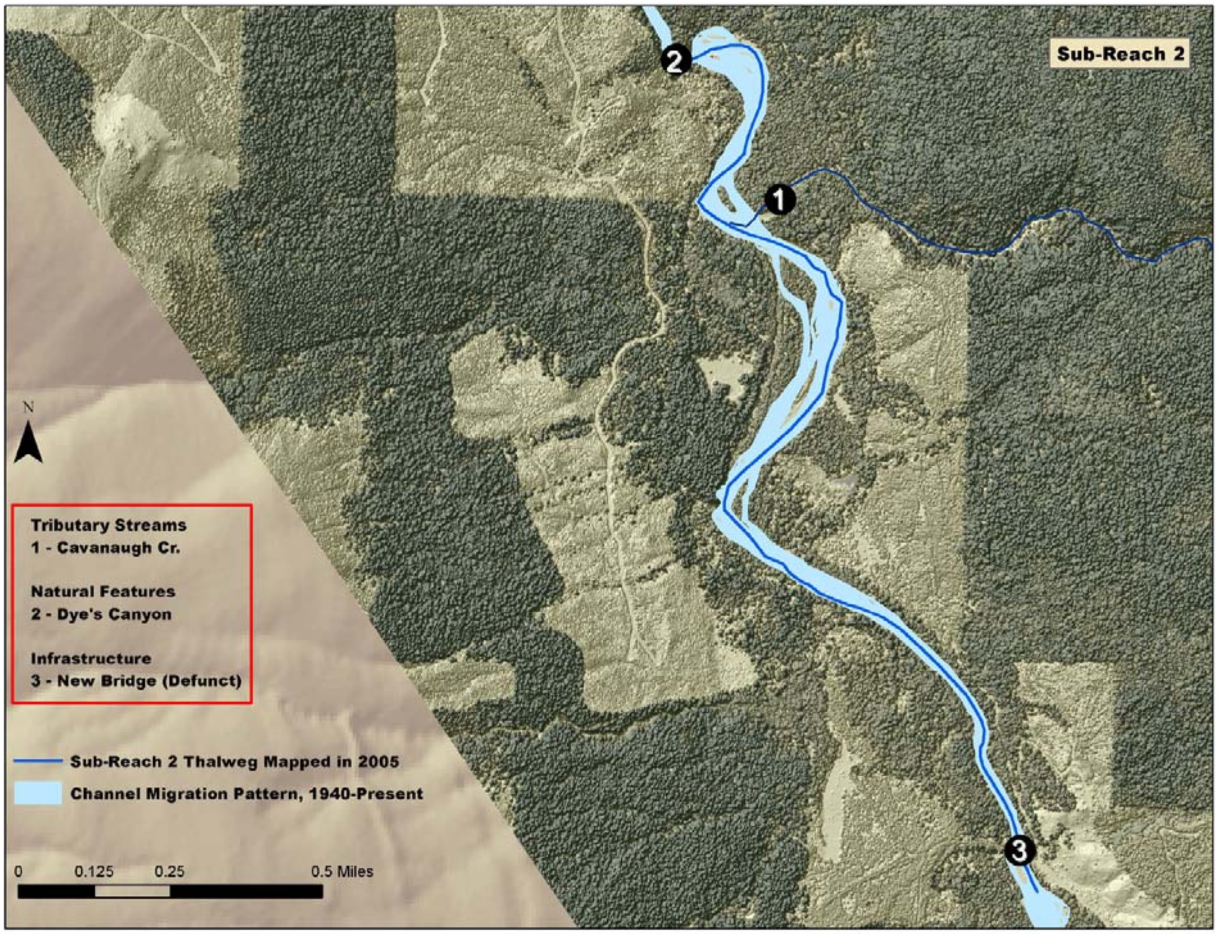


**Figure 4. Sub-reach two of the study area.**

## Sub-Reach Three

Sub-reach three flows from the Elk Flats area down to an area known as New Bridge (Figure 5). Two vertical concrete slabs, one on each side of the channel, are remnant footings for a forest road bridge removed by the private landowner in the mid 1990s. The gradient of the bed measured in sub-reach three is considerably lower than the gradient measured in sub-reach four; therefore, the valley widens and the channel braids. Gravel dominates the substrate type through this sub-reach.

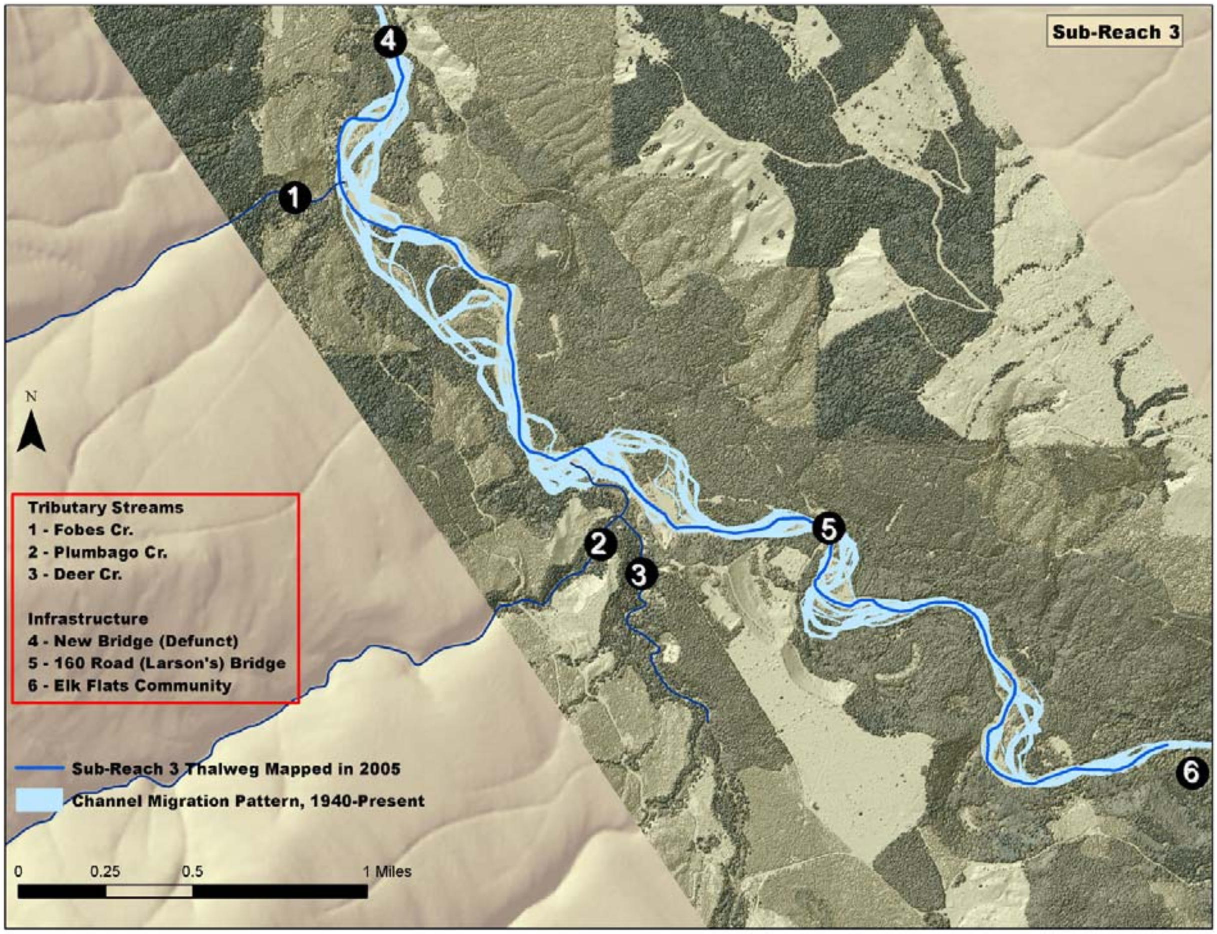


**Figure 5. Sub-reach three of the study area.**

## Sub-Reach Four

Sub-reach four flows from the top of Sylvester's Canyon down to the bottom of Elk Flats (Figure 6). Depending on stream discharge and run timing, this canyon can present conditions that prevent adult fish from advancing upstream to spawning grounds. The canyon is filled with large boulders, some with nearly 10-foot diameters, and empties into a deep, narrow bedrock channel. Escapement into habitat above the canyon may be compromised by hydrology; however spawning activity above the canyon is not uncommon. Immediately downstream of the canyon, the valley widens as the gradient decreases. Large cobble and boulders characterize habitat in the upper end of this reach. As the valley widens downstream, the channel spreads out into braids and meanders.

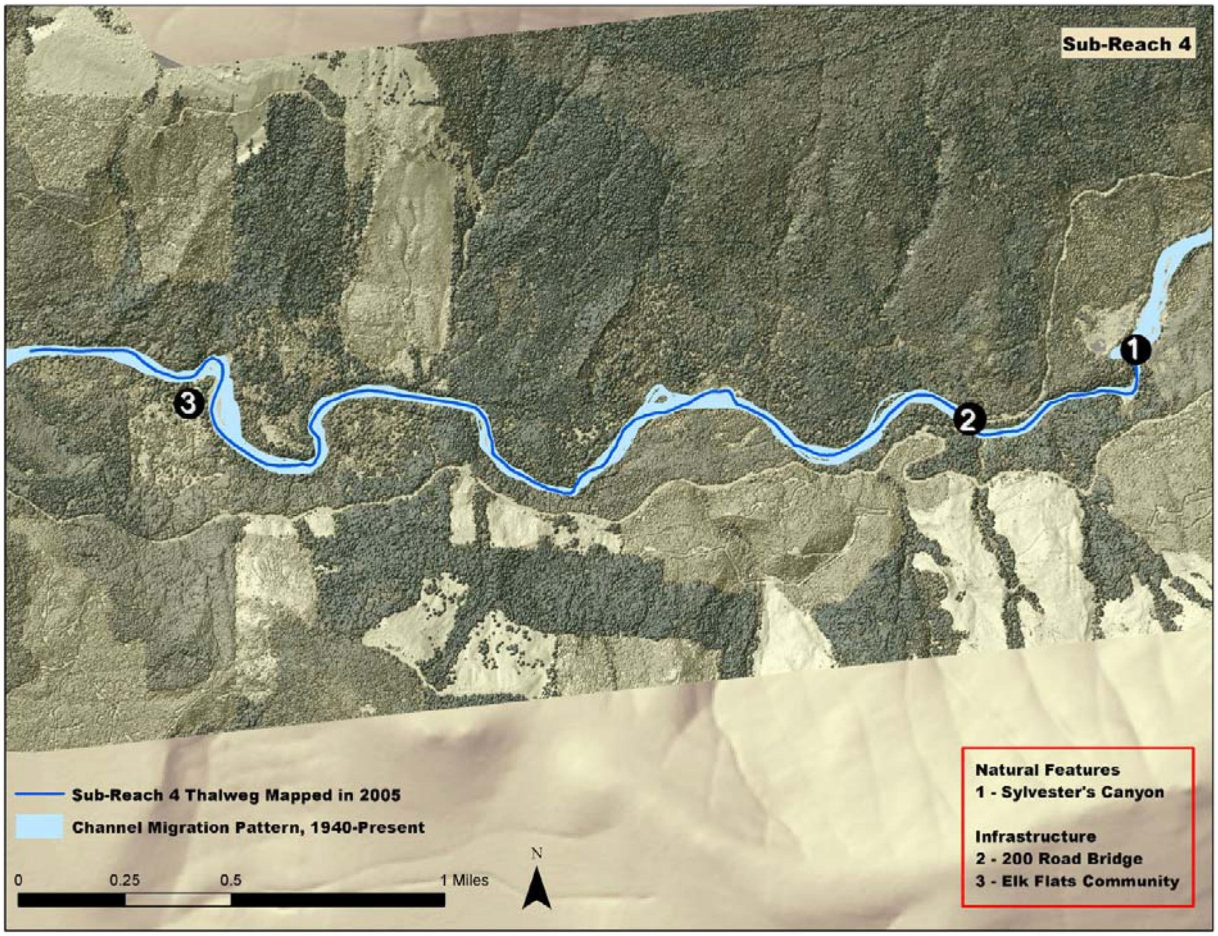


**Figure 6. Sub-reach four of the study area.**

## Sub-Reach Five

Sub-reach five flows from the passage obstruction at RM 32 down to the top of Sylvester's Canyon, an intermittent fish passage barrier at RM 25.6 (Figure 7). This sub-reach contains some of the steepest terrain of the seven sub-reaches, with a short segment of more than 20% slope; it includes a waterfall that blocks upstream chinook passage. Therefore, substrate mapped in this reach includes boulders and large cobble, in addition to the prominent bedrock that has been exposed through scour activity.

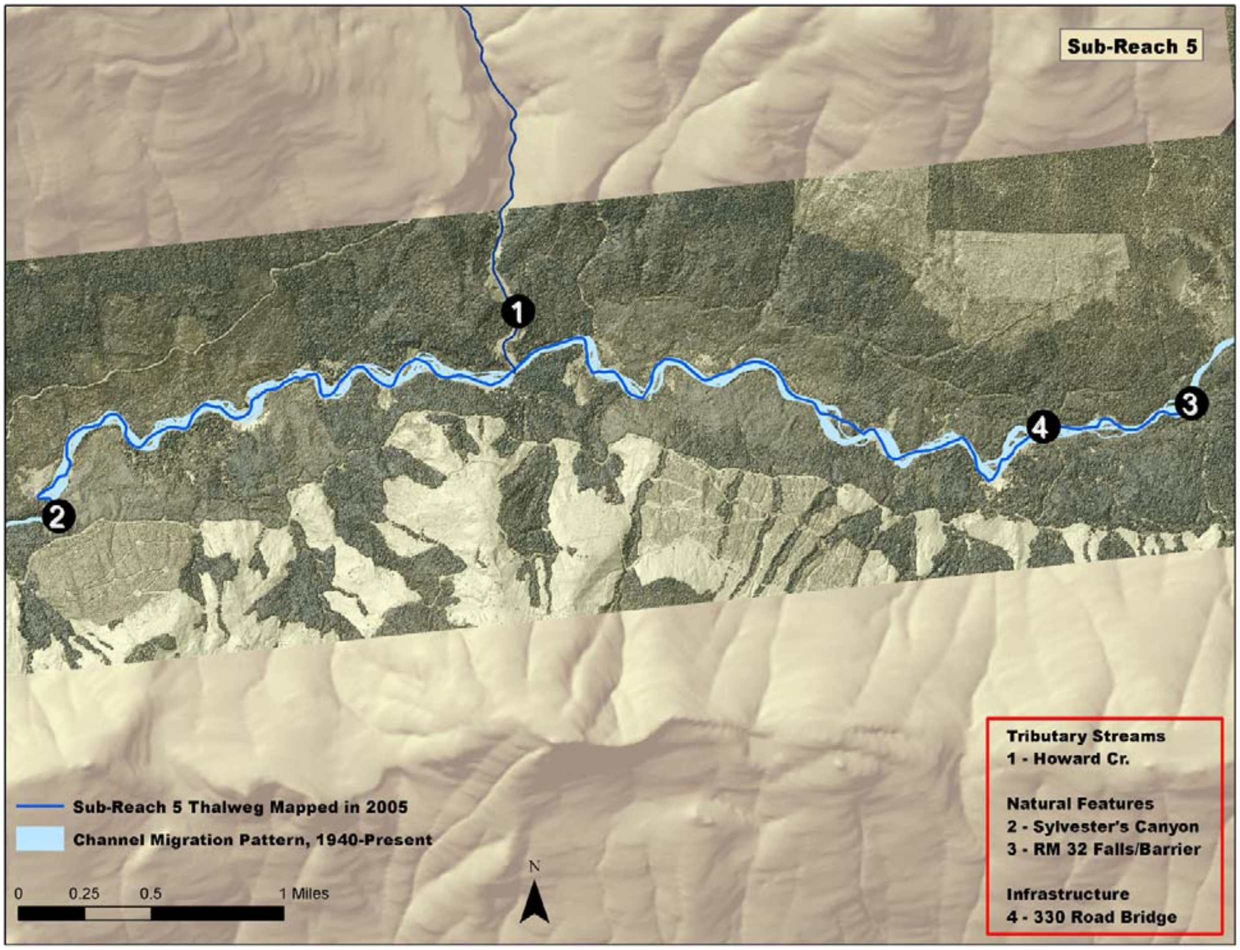


**Figure 7. Sub-reach five of the study area.**

## Sub-Reach Six

Sub-reach six flows from Wanlick Creek down to the bedrock falls at RM 32.0 (Figure 8). The gradient through this sub-reach is steep, giving rise to fast-moving water and large cobble and boulder substrate. The falls at the downstream end of this sub-reach act as a migration barrier to most species of Pacific salmon; however, anadromous bull and steelhead trout passage and presence above the falls is well documented. The reach is highly confined through the most downstream river mile as it cuts through the bedrock canyon to the falls. The channel through here has not been afforded migration to the extent that upstream areas have, and trench pools scoured by high velocity flows that are forced through the canyon are the signature habitat type in the lower section.

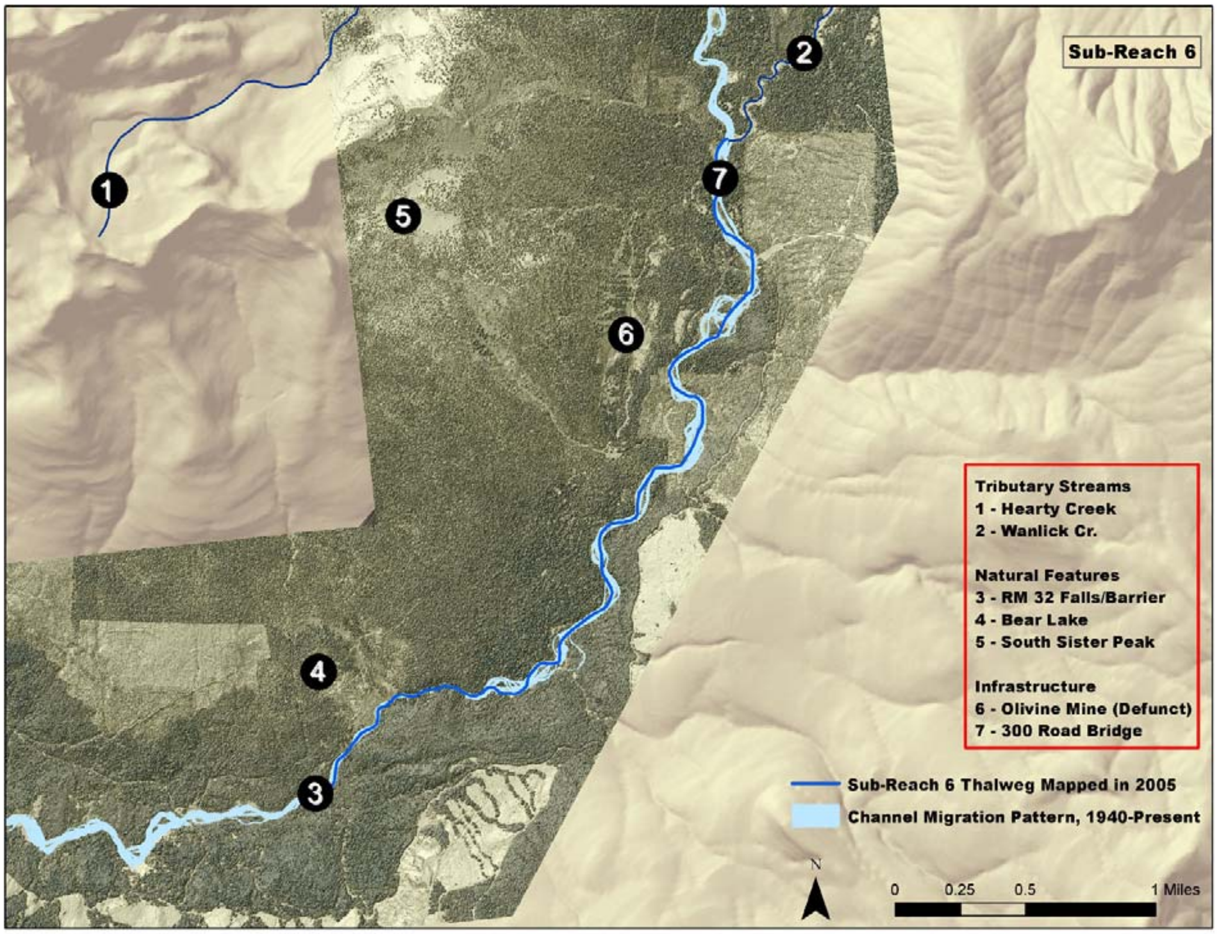


**Figure 8. Sub-reach six of the study area.**

## Sub-Reach Seven

Sub-reach seven is the most upstream reach in the study area (Figure 9). It flows between the USFS 1260 Road Bridge down to the river's confluence with Wanlick Creek. Slope decreases and the valley widens through this reach, allowing the channel to migrate back and forth. The meandering movement diversifies habitat through here and has resulted in coarse sediment deposition, wood accumulation, bank erosion, and debris flow deposition.

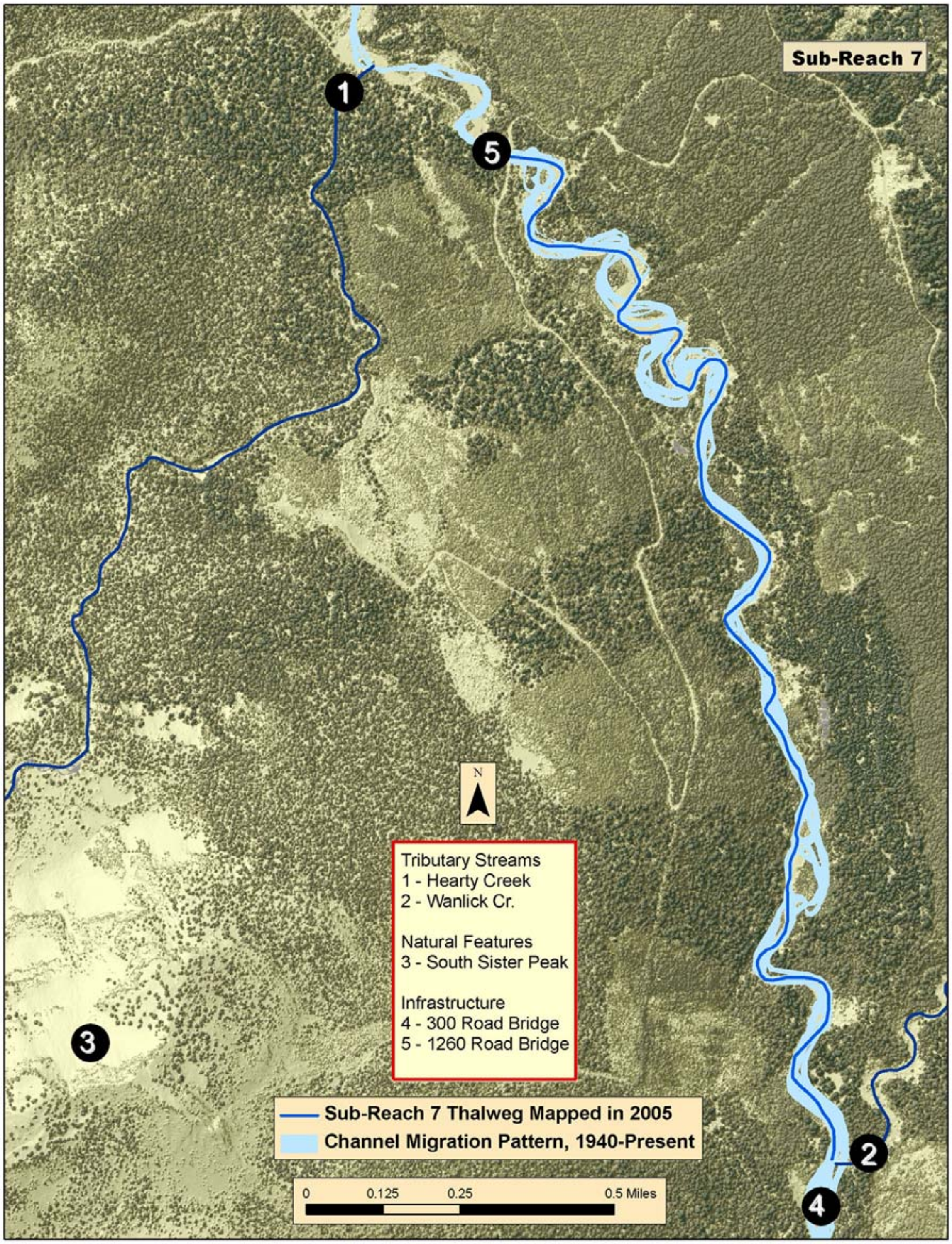


**Figure 9. Sub-reach seven of the study area.**

## Hydrology

The Nooksack basin lies within a convergence zone with Arctic weather from the north, and Pacific weather systems in the south (U.S. Forest Service 1995a). In the summer months, the Pacific systems dominate with mild, clear weather and low levels of precipitation. In the winter, Arctic systems move into the area bringing storms, high levels of precipitation, and occasionally very low temperatures. The hydrograph of the Upper South Fork Watershed is bimodal and reflects rain, spring snowmelt, and occasional rain-on-snow events (Figure 10). This means that the period of lowest flow also corresponds with the warm summer months, often leading to water quality impairment in the river. The hydrograph reflects regional climate patterns, with nearly 50% of the annual precipitation occurring between November and January and snowmelt occurring in April through June. The periods of high run-off are also the periods with the greatest variability of discharge (Figure 11). The Upper South Fork Nooksack assessment area receives between 60 and 125 inches of precipitation per year based on a regional precipitation model (Figure 12). Although monthly average precipitation is highest during November through January, extreme events bringing more than 4 inches per day are common outside of this period (Figure 13). For example, the two highest precipitation events recorded at nearby Baker Lake, both in excess of 6.5 inches over 24 hours, occurred outside of this period in October 2003 and February 2002.

Flow measurements recorded at the Wickersham Gage (USGS-12209000, RM 15) show the variability of annual peak flow, ranging from less than 5,000cfs to more than 20,000cfs (Figure 14). While sufficient data to tie precipitation events to the timing, duration and size of peak flow does not exist, it does appear that large floods are generated during large precipitation events, although large precipitation events do not necessarily lead to large peak flow events (Figure 15). The impacts of historic land use on this relationship are difficult to determine using precipitation and run-off records, although land use activities that can affect this relationship are prevalent in the watershed, so it is possible that this relationship has changed with time due to human impacts.

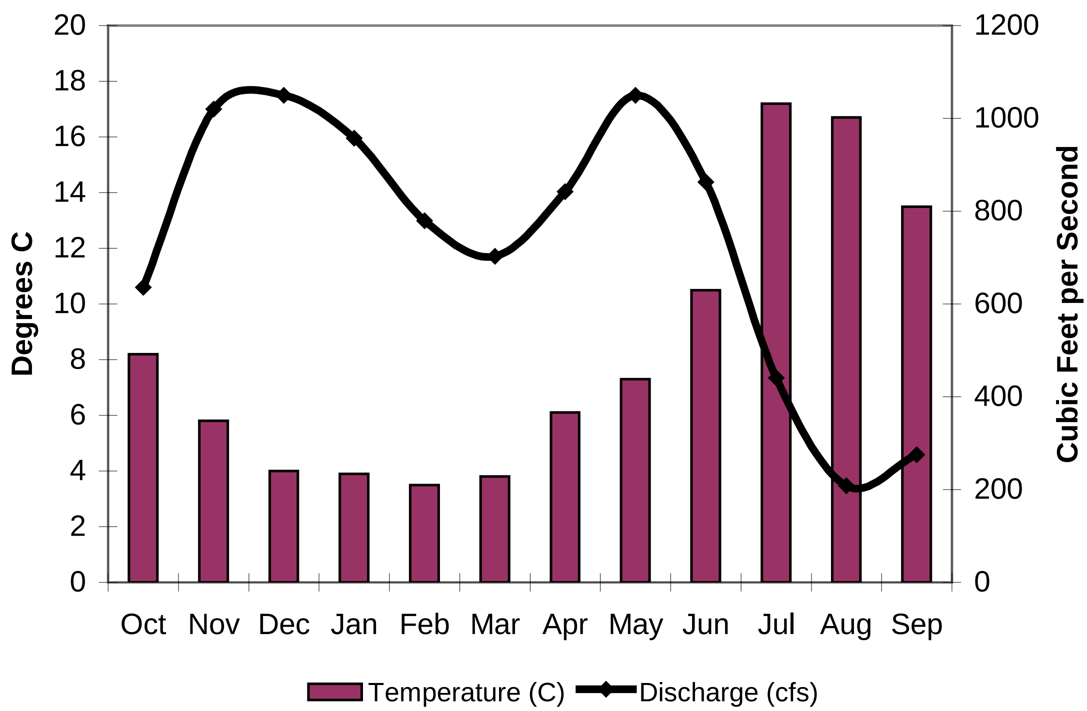


**Figure 10. Mean monthly discharge and temperature at the SF Wickersham gage (RM 15).**

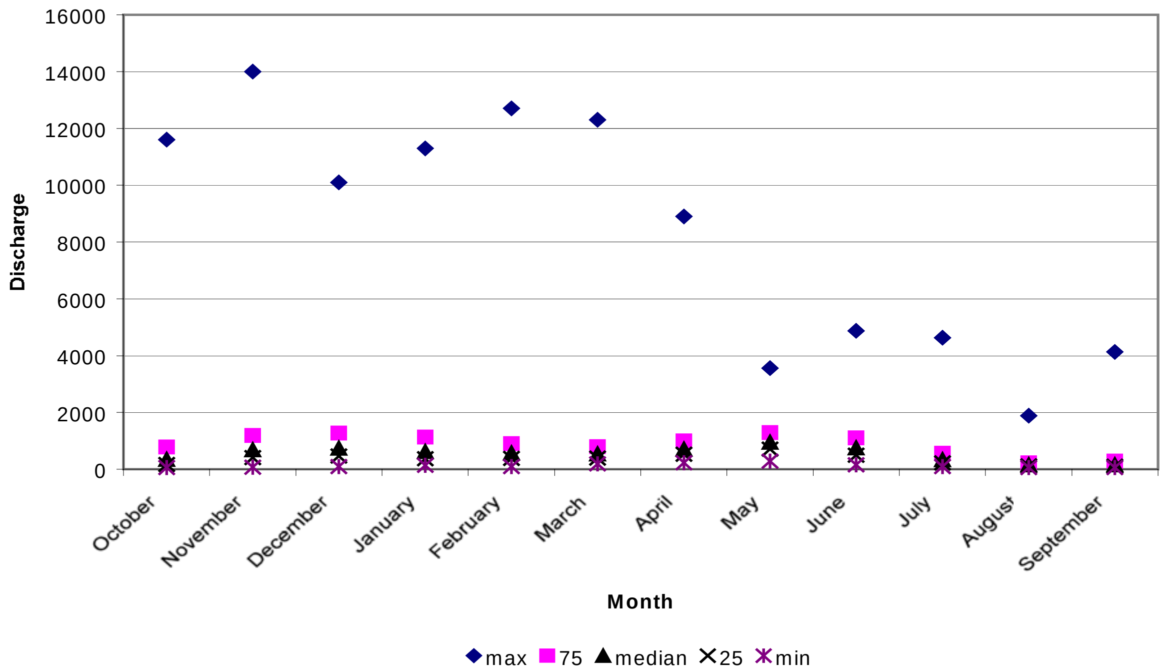


**Figure 11. Monthly discharge (minimum, lower quartile, median, upper quartile, maximum) for the Wickersham gage on the South Fork Nooksack.**

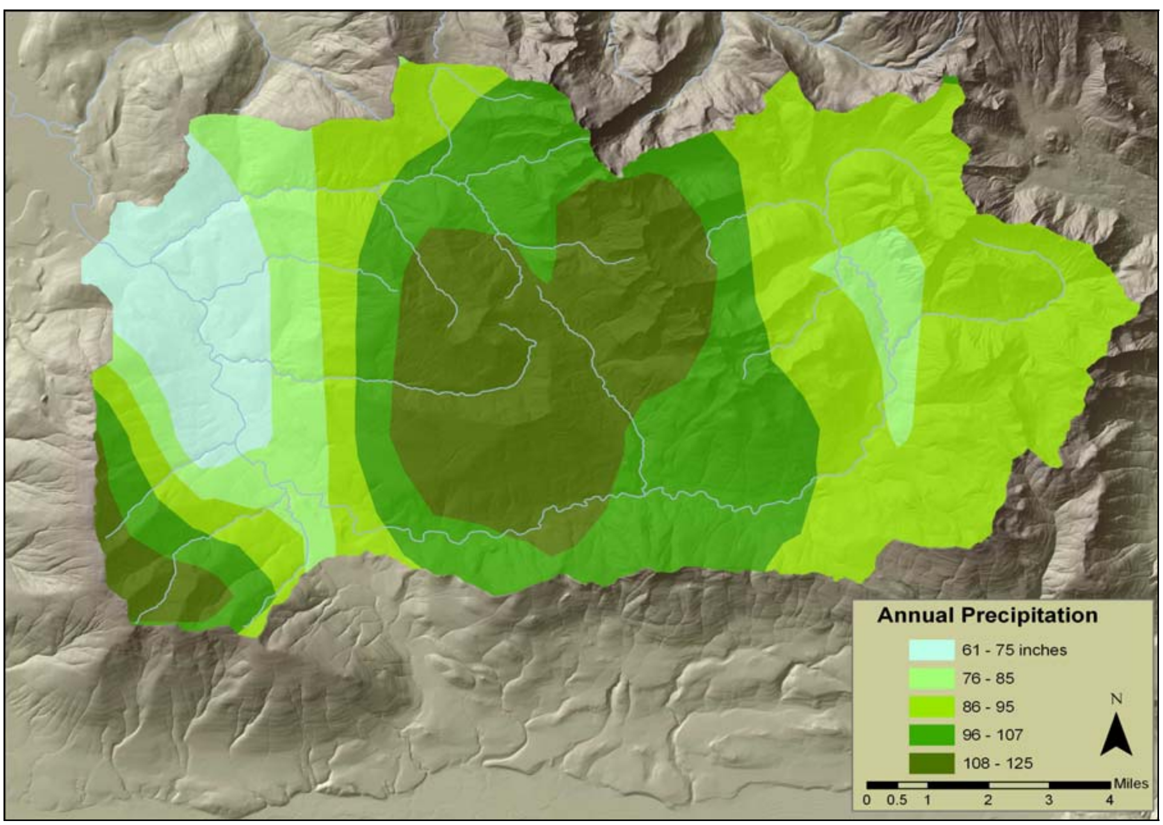


**Figure 12. Annual precipitation in the upper South Fork watershed (Spatial Climate Analysis Service, 1998).**

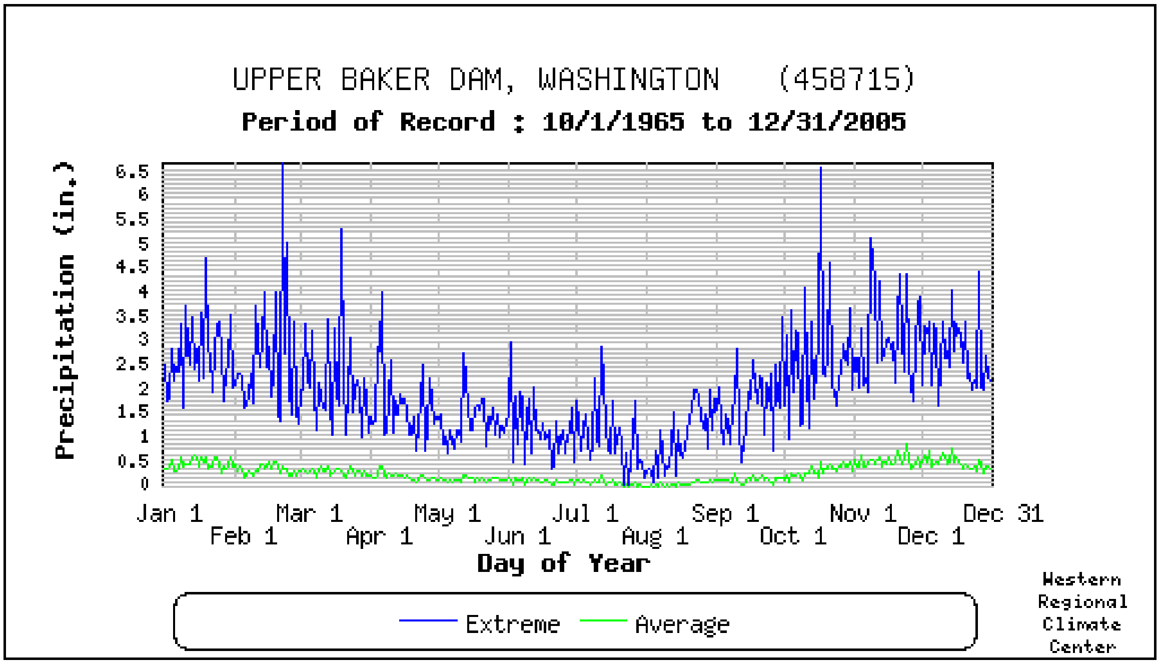


**Figure 13. Daily mean and extreme precipitation for the Upper Baker Dam Climate Station near the upper South Fork watershed.**

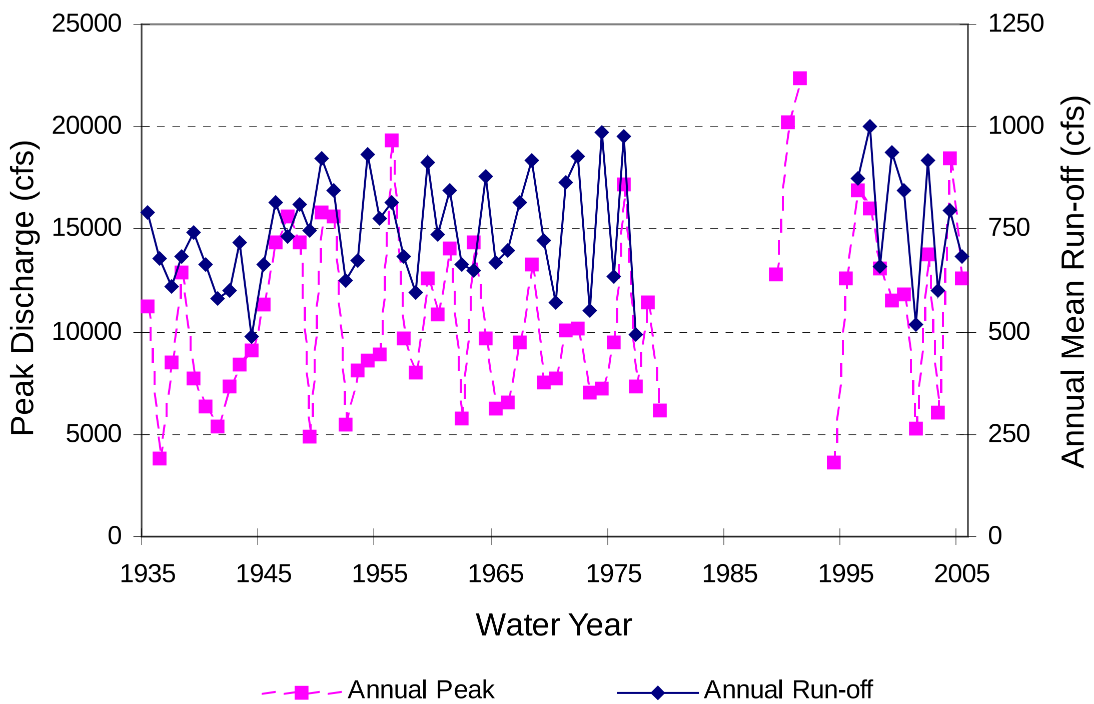


**Figure 14. Peak flow and annual mean run-off at the RM 15 gage on the South Fork Nooksack (RM 15).**

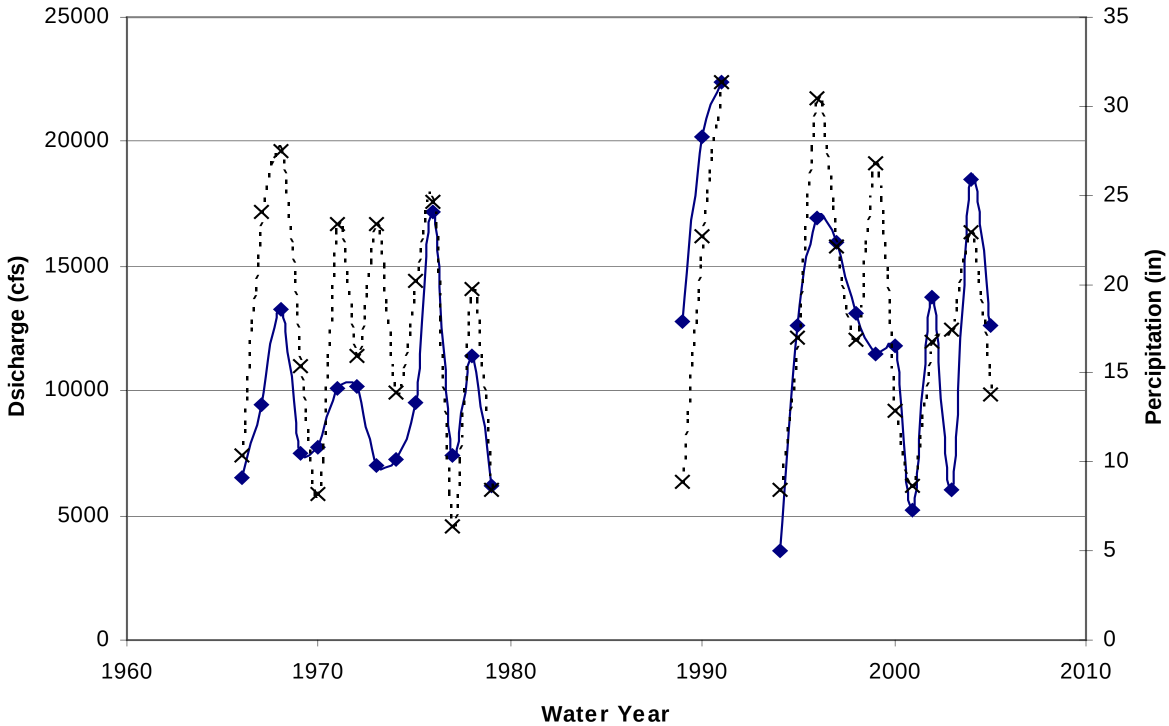


**Figure 15. Annual peak flow and corresponding monthly precipitation.**

The land use and resulting vegetation cover of the watershed is dominated by forestry, which has been described to have an impact on aspects of peak flow and annual water yield, or annual run-off from the watershed (Table 2). The hydrologic impacts of forestry consist of deforestation and alteration of the drainage network through forest road construction. Based on a review of 94 catchment studies, less than a 20 percent reduction in watershed forest cover does not result in a detectable increase in annual water yield (Bosch and Hewlett 1982). If watershed forest cover is reduced by more than 20%, increases in annual water yield may occur but will generally be too small to detect.

Based on 2000 LandSat data, Utah State University characterized land cover in the watershed and found 5.3% of the area in a "transitional" state, much less than the 20% suggested for an increase in annual water yield for the watershed. The trend for annual water yield has been increasing slightly in the South Fork through the last 70 years, although this likely reflects changes in precipitation rather than the influence of land use (Figure 14). For the shorter periods of record where both precipitation and annual water yield data are available (1966-1977, 1996-2005), both precipitation and water yield show declining trends.

**Table 2. Land cover in the Upper South Fork Watershed (Utah State University, 2004).**

| Land Cover Classification | Percent of Watershed |
|---|---|
| Mixed Forest | 45.9 |
| Evergreen Forest | 38.6 |
| Transitional | 5.3 |
| Bare Rock/ Sand/ Clay | 3.5 |
| Herbaceous Uplands | 2.3 |
| Shrub land | 2.0 |
| *Other* | *2.4* |

Rain-on-snow events have been identified as a common flooding mechanism in the Upper South Fork area (USFS 2006). Rain-on-snow conditions are more frequent in areas where the snow pack is transient and the air temperature is around 32°F during the winter (Brooks et al. 1991). Twenty-three percent of the upper South Fork Nooksack watershed lies within the transient snow zone, and is at a higher risk for rain-on-snow events (Figure 16). During rain-on-snow events, rapid snowmelt accompanies intense rainfall and can trigger rapid run-off and flooding. Land use activities can affect the rate of melting and run-off by altering the size of openings in the forest canopy and the snow area exposed to melting processes. More snow accumulates in small clearings in forest stands and in sparsely stocked forest stands than in dense conifer stands (Anderson et al. 1976; Brooks et al. 1991). Further, if the forest canopy is snow-covered when a rain-on-snow event occurs, a greater surface area is exposed to convection-condensation processes and snow melts more rapidly from the forest canopy in comparison to cleared areas (Berris and Harr 1987).

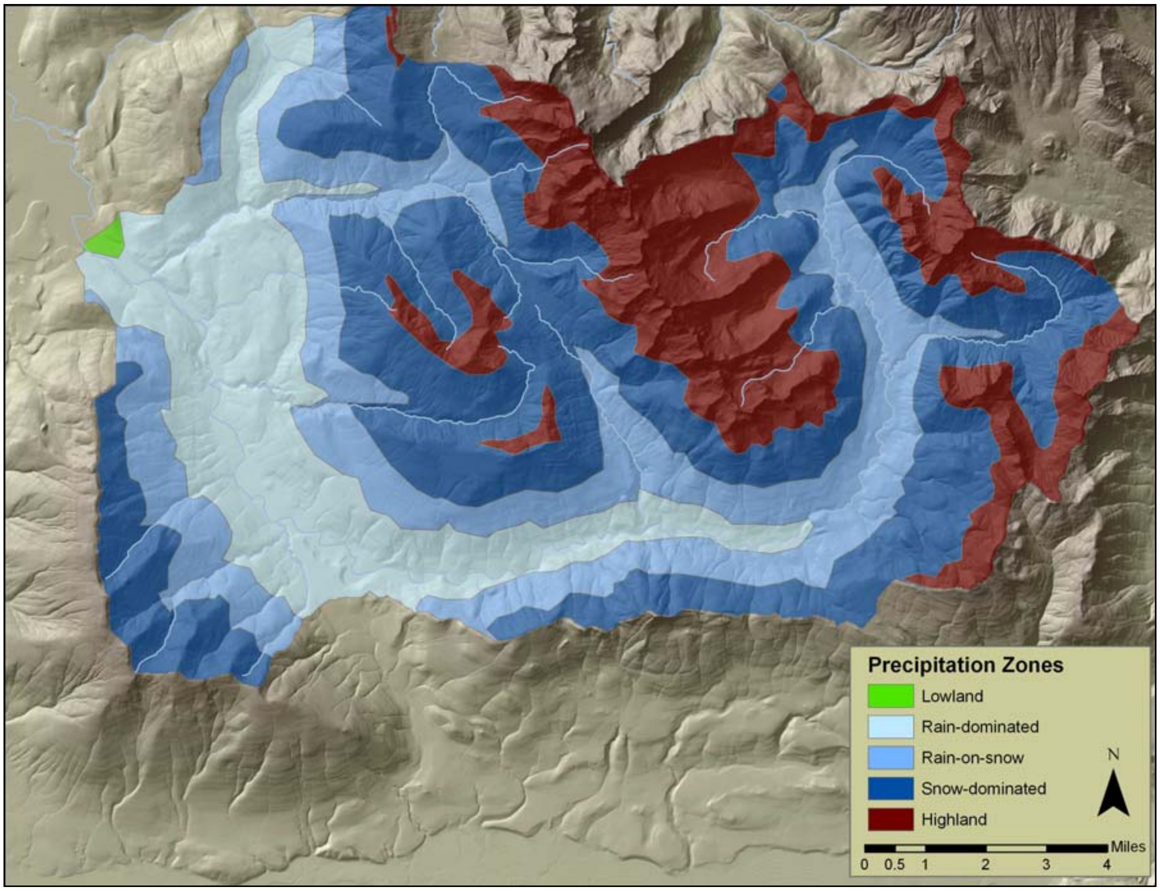


**Figure 16. Precipitation zones in the Upper South Fork Nooksack.**

A number of factors determine whether rain-on-snow events result in downstream flooding or increase the occurrence of landslides. These include basin characteristics that affect the timing and routing of flow and the condition of other parts of the watershed that contribute flow to flood-prone areas (Brooks et al. 1991). Watershed characteristics that affect the timing and routing of flow include differences in elevation, slope, aspect, soils, and vegetation cover. Because snow melt in cleared areas can be accelerated relative to forested areas, the timing of runoff over the watershed can be desynchronized by timber harvest. If runoff from the harvested area normally comes after the watershed's runoff peak, forest removal can result in higher peak discharges. However, if runoff from the harvested area is normally synchronized with the watershed runoff peak or precedes the runoff peak, the watershed runoff peak will either be reduced or not impacted by the harvest activity (Rice 1995b).

Determining the effect of land use on peak flow generation is difficult without an understanding of the timing and routing of water from the disturbed areas. The Washington State Watershed Analysis Manual was used to determine the effects of timber harvest on amount of water available for run-off (WFPB 1997). This method focuses heavily on snowmelt in patches of immature forest to determine the effect run-off has on peak flow generation in the watershed. The water released from the melted snow in these patches adds to rainwater to increase the delivered volume. If the water delivery exceeds the infiltration or storage capacity of a watershed, surface and subsurface runoff occurs. If the delivered water saturates soils, slopes can become unstable and landslides may result (Montgomery and Dietrich 1994).

In the upper South Fork Nooksack watershed, timber harvest activities have likely increased the water available to run-off (Table 3), and may have slightly affected peak flow generation in the watershed (Table 4). Before land management in the Upper South Fork became widespread, openings in the forest canopy would have resulted from landslides and fires. Maps from the General Land Office in the 1890s describe large areas that were burned or affected by the South Twin landslide (labeled "Red Rock Slide"). Both of these processes would have naturally influenced snow retention and melt. Historically, harvest likely had a greater effect when larger clearcuts dominated the rain-on-snow prone areas of the watershed and more openings in the canopy allowed for greater snow accumulation. The model results showed that the potential effect of current timber harvest on peak flows was less than one percent for an average storm event and generally less than two percent for an unusually large event. Although the effects of timber harvest on peak flows are likely slight, the watershed hydrology might also be influenced by the cumulative affects of other forestry related activities, such as road drainage.

**Table 3. Water available for run-off for the upper South Fork Nooksack.**

| Recurrence Interval | Storm Type | Water Available for Run-off (inches) | |
|---|---|---|---|
| | | Current Conditions | Fully Forested |
| 2-Year | *Average* | 5.93 | 5.90 |
| | *Unusual* | 6.53 | 6.46 |
| 10-Year | *Average* | 8.00 | 7.96 |
| | *Unusual* | 8.64 | 8.51 |
| 25-Year | *Average* | 9.12 | 9.08 |
| | *Unusual* | 9.79 | 9.71 |
| 50-Year | *Average* | 9.87 | 9.83 |
| | *Unusual* | 10.56 | 10.48 |
| 100-Year | *Average* | 10.76 | 10.72 |
| | *Unusual* | 11.47 | 11.39 |

**Table 4. Modeled peak flows related to changes in water available for run-off.**

| Recurrence Interval | Average Storm Event | | | Unusual Storm Event | | |
|---|---|---|---|---|---|---|
| | Current Conditions (cfs) | Fully Forested (cfs) | **Percent Change** | Current Conditions (cfs) | Fully Forested (cfs) | **Percent Change** |
| 2-Year | 13110 | 12990 | **0.9** | 15520 | 15240 | **1.8** |
| 10-Year | 21430 | 21270 | **0.8** | 24000 | 23480 | **2.2** |
| 25-Year | 25930 | 25770 | **0.6** | 28630 | 28300 | **1.1** |
| 50-Year | 28950 | 28790 | **0.6** | 31720 | 31400 | **1.0** |
| 100-Year | 32530 | 32370 | **0.5** | 35380 | 35060 | **0.9** |

Recent research suggests that the hydrologic effects of roads may be more important than the hydrologic effects of timber harvest (Jones and Grant, 1996). Harr and others (1979) found no increase in peak flow response until roads occupied more than 12% of the watershed. Another study found that no significant increases in the major channel-forming flows were observed in a rain-dominated hydrologic environment, even though over 15 percent of a watershed was compacted in skid trails, landings and roads (Wright et al. 1990). More recent research indicates that disconnecting road systems from the channel network can decrease peak flow response by 40% (Bowling and Lettenmaier, 2001). The mixed results indicate that the response in peak flow from roads is complex and dependent on the timing and routing of flow to the channel, although increased road density generally increases the risk of increased peak flow response. This is particularly true in areas with a high stream density and multiple stream crossings.

Road density in the upper South Fork Nooksack varies by watershed, although it is generally greater than three miles per square mile of watershed (Figure 17). Three miles per square mile resulted in a "Poor" rating in the WRIA-1 Limiting Factors Report (Smith 2002). The road density is likely under-representing the actual road network in the watershed because many of the older roads have become overgrown and lost from the managed road network (Figure 18). Many of these older roads and railroad grades predate forest practice rules and maintenance or abandonment is not required. Within the narrow area covered by the 2005 LiDAR, there are over 27 miles of unmapped road and railroad grades visible on the high-resolution terrain model. The status of these roads is largely unknown, although the lack of maintenance or abandonment increases the likelihood that these roads are having a negative effect on the hydrology of the watershed.

The highest road density is associated with the western portion of the study area, which is managed for commercial forestry by the Department of Natural Resources and several timber companies. The Skookum and Cavanaugh watersheds also have the highest drainage density in the upper South Fork, increasing the likelihood for stream-road interaction. These watersheds were pioneered in the late 19$^{th}$ century and intensively logged using railroad grades. By the 1940s, road construction began in earnest, and logging advanced further up into the watershed and into formerly inaccessible areas of the eastern portion of the assessment area. The longer history of land use practices, coupled with high impact techniques used in the early years of road construction, further increases the likelihood of impacted hydrology in this portion of the watershed.

The lowest road density lies in the upper reaches of the watershed (Bell, Wanlick, Heart Lake and Elbow Lake), managed by the U.S. Forest Service. This area of the watershed was initially accessed much later than the others, so road construction and timber harvest in these reaches did not begin in earnest until the 1960s. These activities largely ended with the enacting of the Northwest Forest Plan in the mid-1990s. The short history of logging in the upper basin is largely responsible for the low road density. This area also has the lowest drainage density in the Upper South Fork watershed, making it likely to have the least impact on peak flow generation.

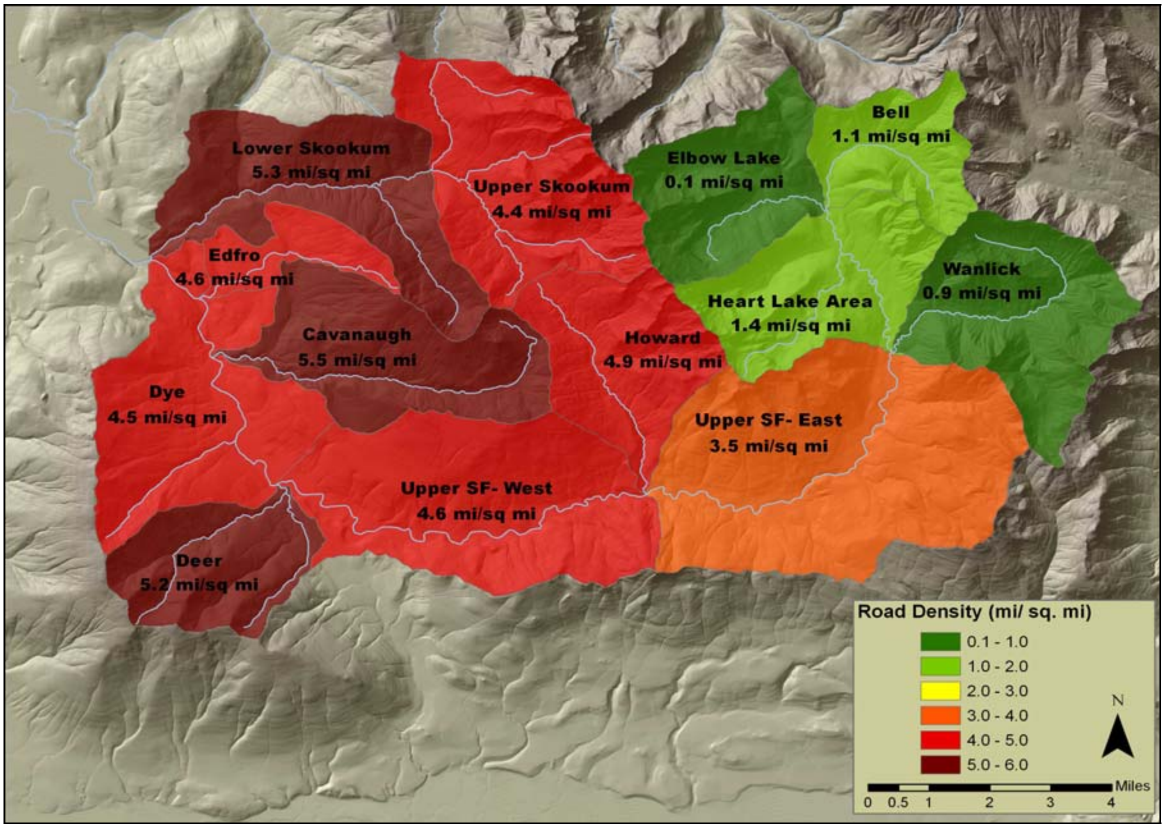


**Figure 17. Road density in South Fork watersheds (Coe 2002, Zander 1996).**

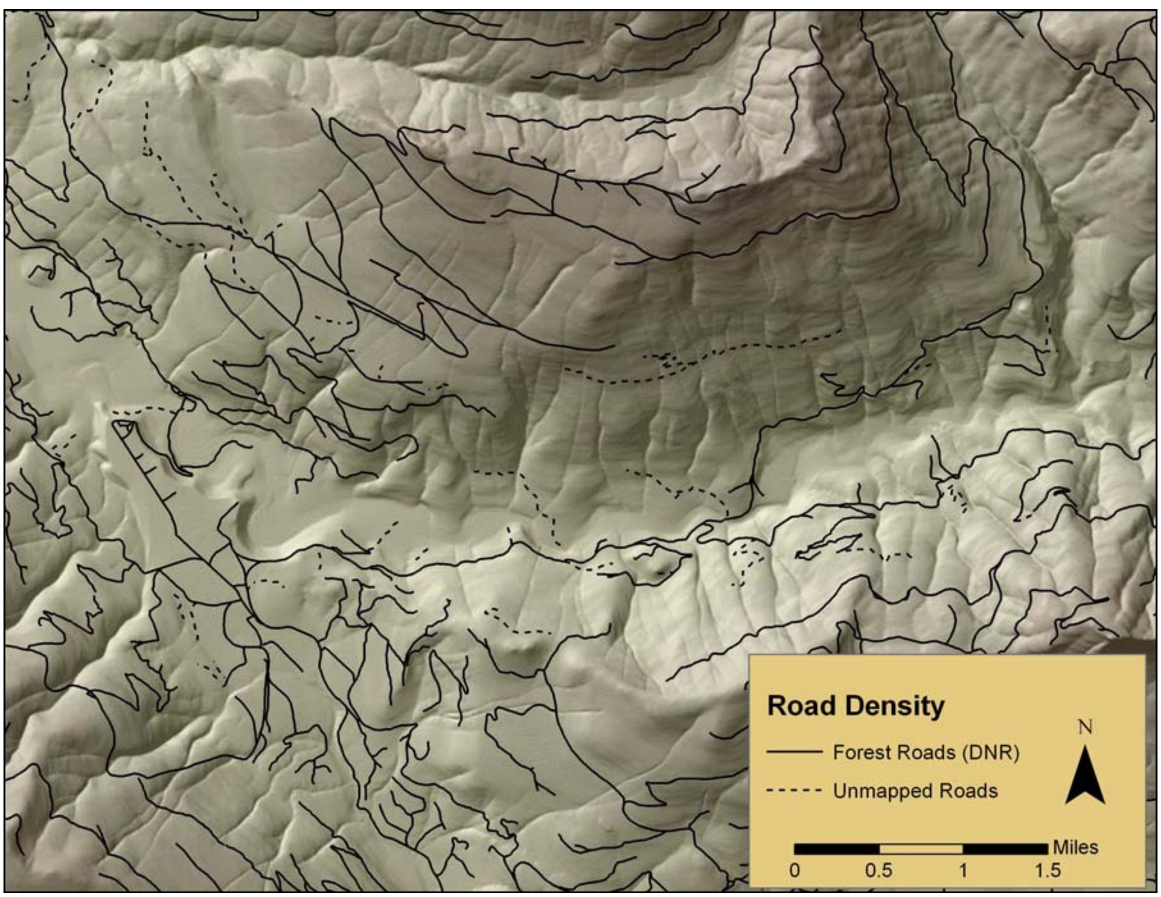


**Figure 18. Road density difference between mapped roads and those visible in the detailed terrain model.**

Several attempts have been made to assess channel response related to peak flow events in the South Fork watershed (Hyatt and Rabang 2003, Neff and Edwards 1992, Schuett-Hames et al. 1988). These efforts focused on measuring bed scour and salmonid redd failure in spawning areas of the river. The earliest effort was focused on the South Fork Nooksack between Skookum Creek and Saxon Bridge (the lower 0.7 miles of the assessment area). The eight scour monitors employed showed no significant bed scour during the winter of 1984-85, although three monitors showed burial by more than 24 inches of gravel when the channel migrated away from the sample site (Schuett-Hames et al. 1988). Using slightly different methods, Neff and Edwards (1992) again assessed bed scour and fill in the South Fork Nooksack, but failed to relocate any of the scour monitors and were unable to draw any conclusions. Most recently, Hyatt and Rabang (2003) assessed scour throughout the Nooksack River basin. Again, bed scour and fill was highly variable among and between sites. The authors were able to conclude that scour and fill was greater in main-channel areas than in side channels or tributaries and that there were a greater percentage of redd failures during the higher flow year of the survey. During the 2000-01 incubation period, over 50% of scour monitors recorded a redd failure, while in the milder 2001-02 incubation period 27% of sites recorded a redd failure. The availability of data on redd scour limits our ability to tie changes in land use activities to changes in redd failure rates, although there appears to be a link between higher peak flow and higher redd failure rates that warrants monitoring of forestry impacts on peak flow.

While it is possible that land use activities have had an impact on the hydrology of the Upper South Fork watershed, it is likely that these impacts are not severe under current conditions. It is also likely that any effect of increased peak flow from land use on spawning habitat is lost in the variability of scour and fill across the channel. The current level of harvest does not appear to create sufficiently large canopy openings to yield a large increase (less than 1% for an average storm) in water available for run-off. The rapid regrowth of harvested areas quickly reduces the affect of increased snow accumulation and water available for run-off on peak flow. New private and State road construction and maintenance of existing roads are managed under specific Road Management and Abandonment Plans and are currently being monitored to ensure effective drainage under the Forest and Fish Agreement. Forest road maintenance and abandonment on Federal lands is currently lacking sufficient funding and reflects a nationwide problem with land management on federal lands. The largest potential impact of land use on hydrology lies in roads that predate the 1974 Forest Practices rules and are not currently maintained or abandoned.

## Channel Characteristics

The geologic history of the South Fork watershed plays an important role in determining the channel characteristics of the river (Figure 19). During the glacial period, large lakes filled the valley through the assessment reach, leaving deposits of fine sand, silt and clay several hundred feet thick in places (Heller 1978, Kirtland 1995). In many reaches, large boulders (some too large for the channel to transport) brought by the glaciers remain in the channel and are an important component of channel roughness and habitat formation. Following deglaciation, the channel began to slowly incise and migrate into the lacustrine deposits as it began to remove the glacial fill from the valley, forming a series of floodplain terraces. The present-day topography shows this process preserved in stepped terraces along the valley walls (Figure 20). These terraces predate the historic period and are comprised of glacial deposits overlain with a thin (1-2 m) layer of alluvium. This shallow depth of alluvium is consistent with the current depth in the bed of the active channel, where glacial lake material that has not seen daylight in thousands of years is often exposed in the channel bed for long reaches of the river and contributes to the elevated turbidity of the river during high flow events.

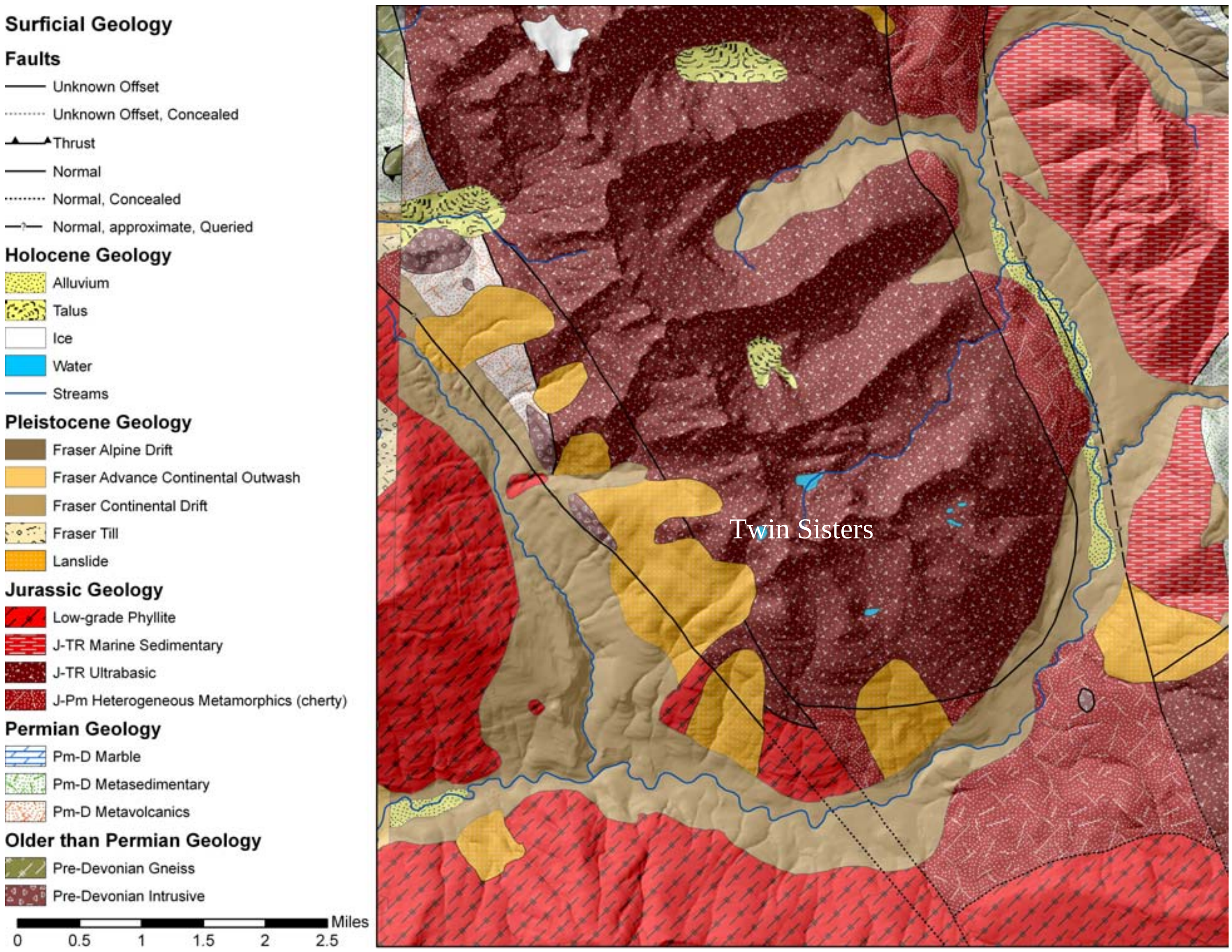


**Figure 19. Surficial geology of the upper South Fork watershed (DNR 2000).**

Where the channel flows around the Twin Sisters, it has preferentially followed the path of faults in the watershed. These fault contacts were previously scoured by glacial ice and filled with retreating glacial deposits. The fault zones are generally easier to erode because the movement along the faults has fractured and weakened the bedrock. As the river has cut down through the fault zones around the southern flank of the Twin Sisters mountain range, it has created a steep and narrow channel choked with boulders collected from unstable hillsides. This steep, boulder-dominated section represents the uppermost of the two passage barriers to some anadromous fish species, with only bull trout and steelhead identified upstream of the reach (Huddle, Currence; both pers. com).

Today, the upper South Fork Nooksack main channel (RM 12-39) lies in a largely low-gradient valley with a variable degree of confinement (Table 5). In several reaches, the channel flows through confined bedrock canyons (Figure 21) while in others it migrates across a wider alluvial plain. Most of the high gradient and confined length of channel is located where the river flows around the southeastern flank of the Twin Sisters. While much of the channel appears to be unconfined based on its relation to the valley width, often the terraces are highly resistant to erosion and severely limit channel migration (Figure 22). For much of the length of the channel, the width of the channel migration zone over 65 years is only slightly larger than the current active channel width (Figure 23). In other reaches, the channel has preferentially eroded into the hillside rather than through the armoured terraces that are present on the opposite side of the channel.

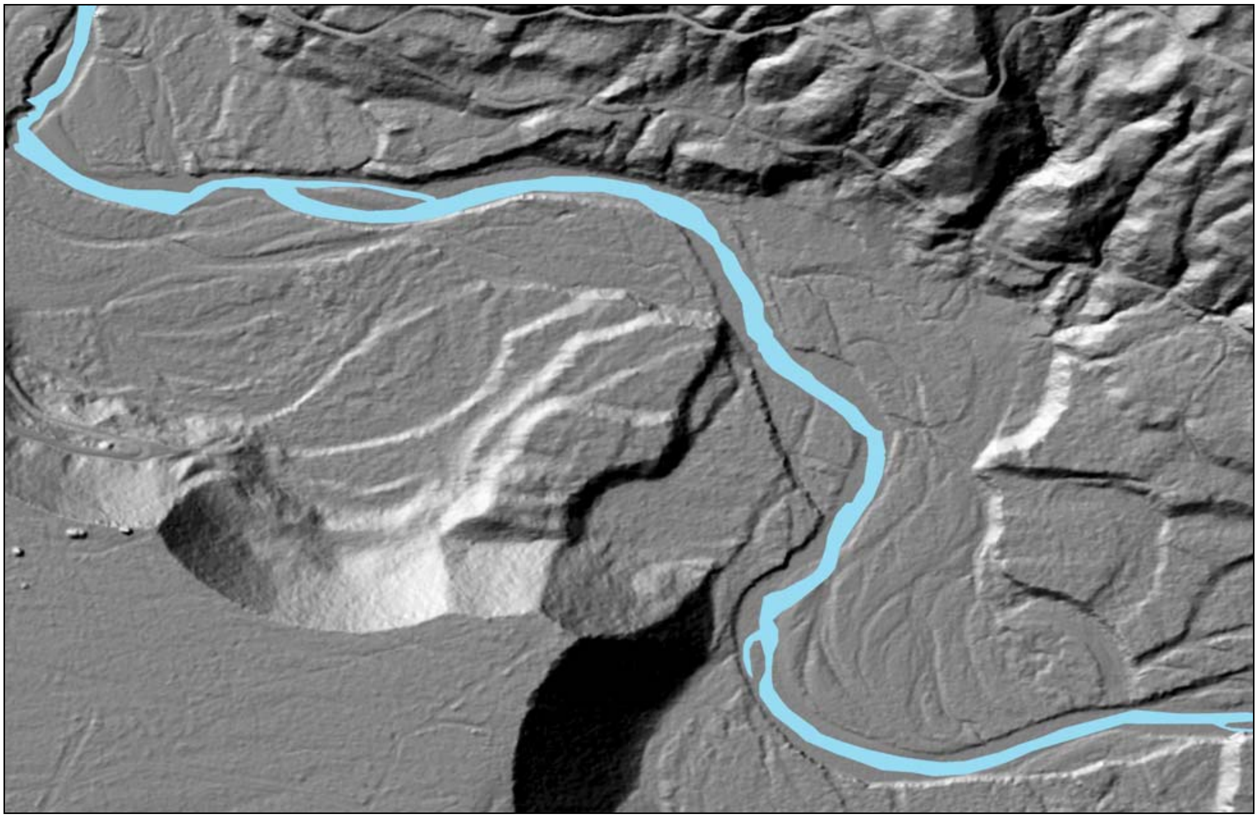

**Figure 20. Pre-historic terraces along the edge of the South Fork Valley.**

**Table 5. Channel gradient and confinement of the South Fork Nooksack (RM 12-39) [VW=Valley Width, CW=Channel Width] (SSHIAP 2001).**

| Gradient Class | Confinement Class | Length (feet) |
|---|---|---|
| <1% | Unconfined (*VW>CW*) | 45,880 |
| | Moderately Confined (*2CW<VW<4CW*) | 12,410 |
| | Confined (*VW<2CW*) | 7,230 |
| 1-2% | Unconfined | 6,870 |
| | Moderately Confined | 40,490 |
| | Confined | 4,140 |
| 2-4% | Moderately Confined | 10,170 |
| | Confined | 4,820 |
| 4-8% | Moderately Confined | 2,740 |
| | Confined | 2,450 |
| 8-20% | Confined | 1,170 |

**Figure 21. Confined reach near RM 25.**

There are only a few reaches where the channel has actively migrated during the historic period. The largest area of migrating channel lies immediately downstream of a large glacial outwash (glacial river deposit) that once flowed south to the Skagit River through Lyman Pass (Figure 24). This outwash deposit is a thick sequence of sand and gravel that is one of the few sources of coarse sediment to the South Fork channel. Substrate was mapped and characterized in the summer of 2005 and reflects this sediment source (Figure 25). The gravel is poorly distributed, with long stretches of river (~10 miles at one point) that have no spawning habitat at all and short reaches accounting for much of the volume of gravel (near RM 15.5, for example). The only place in the upper South Fork where gravel is uniformly distributed is the reach downstream of the outwash channel. Not coincidentally, this 2.6-mile reach (RM 18-20.6) has also been the most productive spawning area for salmon in the South Fork watershed and is one of a handful of core areas for ESA-listed chinook salmon spawning.

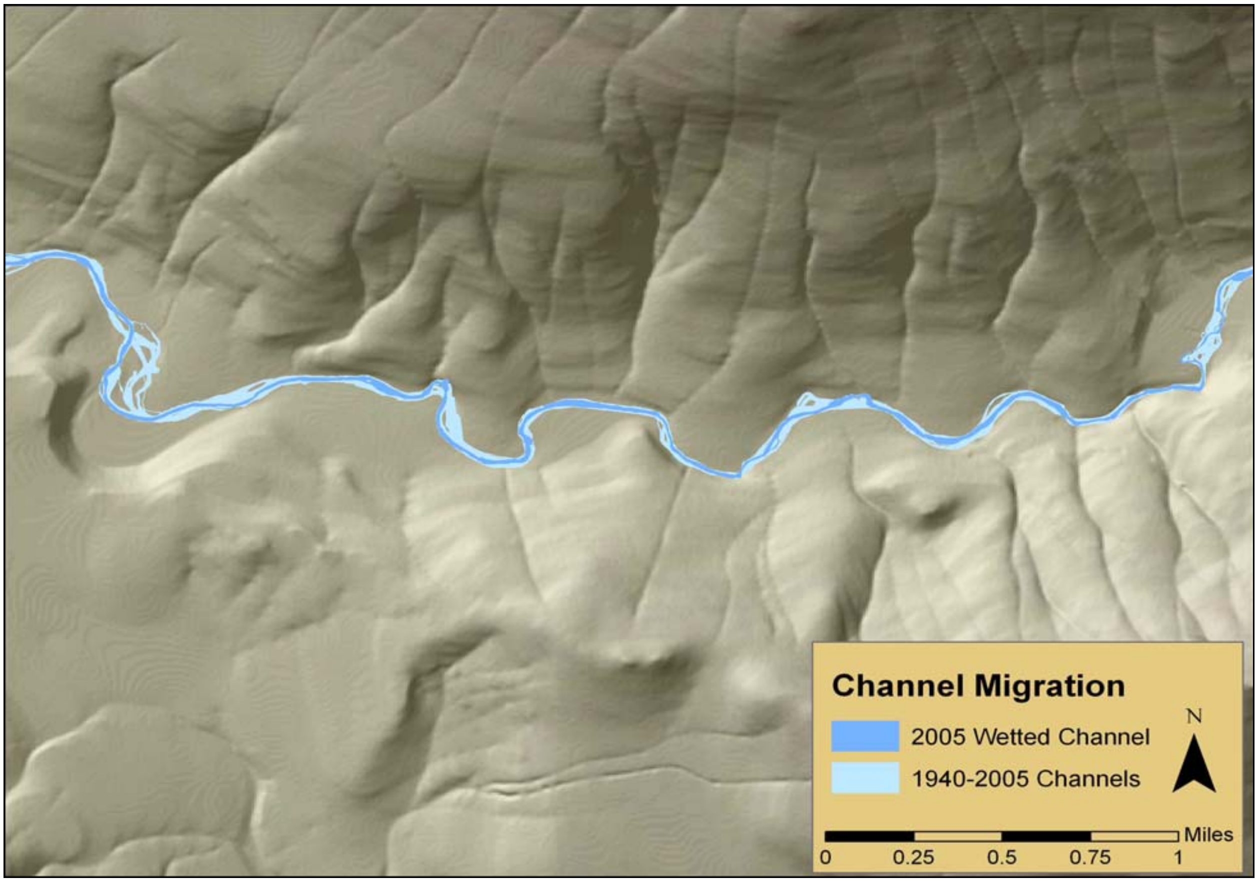


**Figure 22. South Fork channel positions between 1940-2005 showing lack of migration (RM 20-25).**

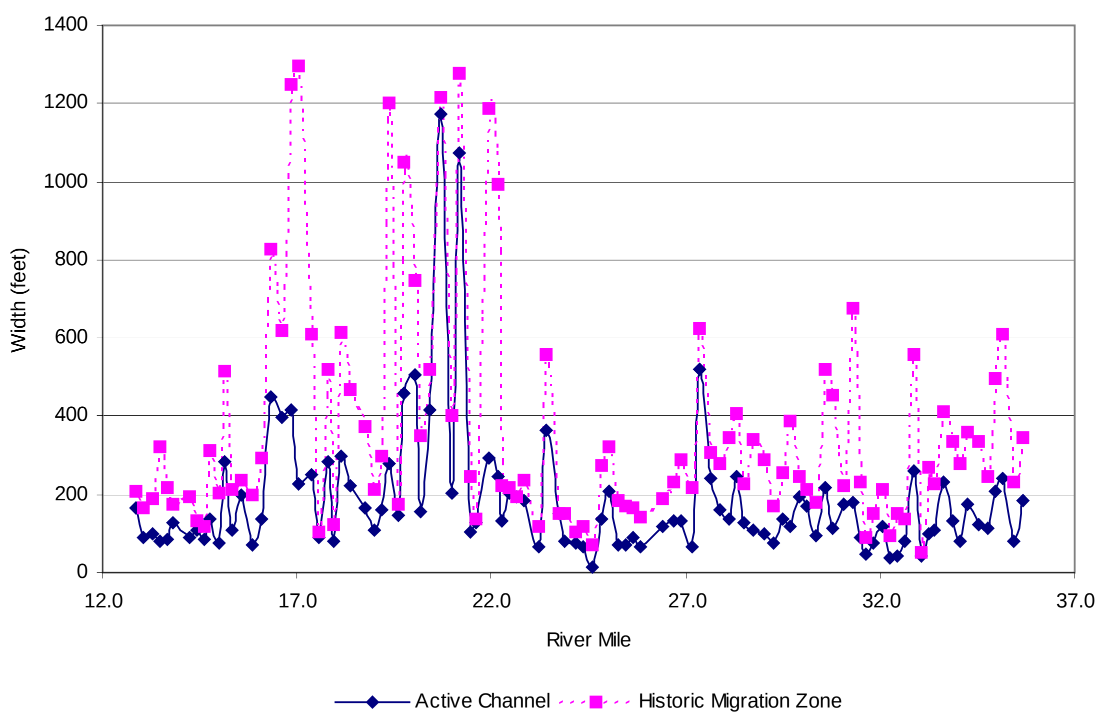


**Figure 23. Active channel and historic channel migration area in the upper South Fork Nooksack.**

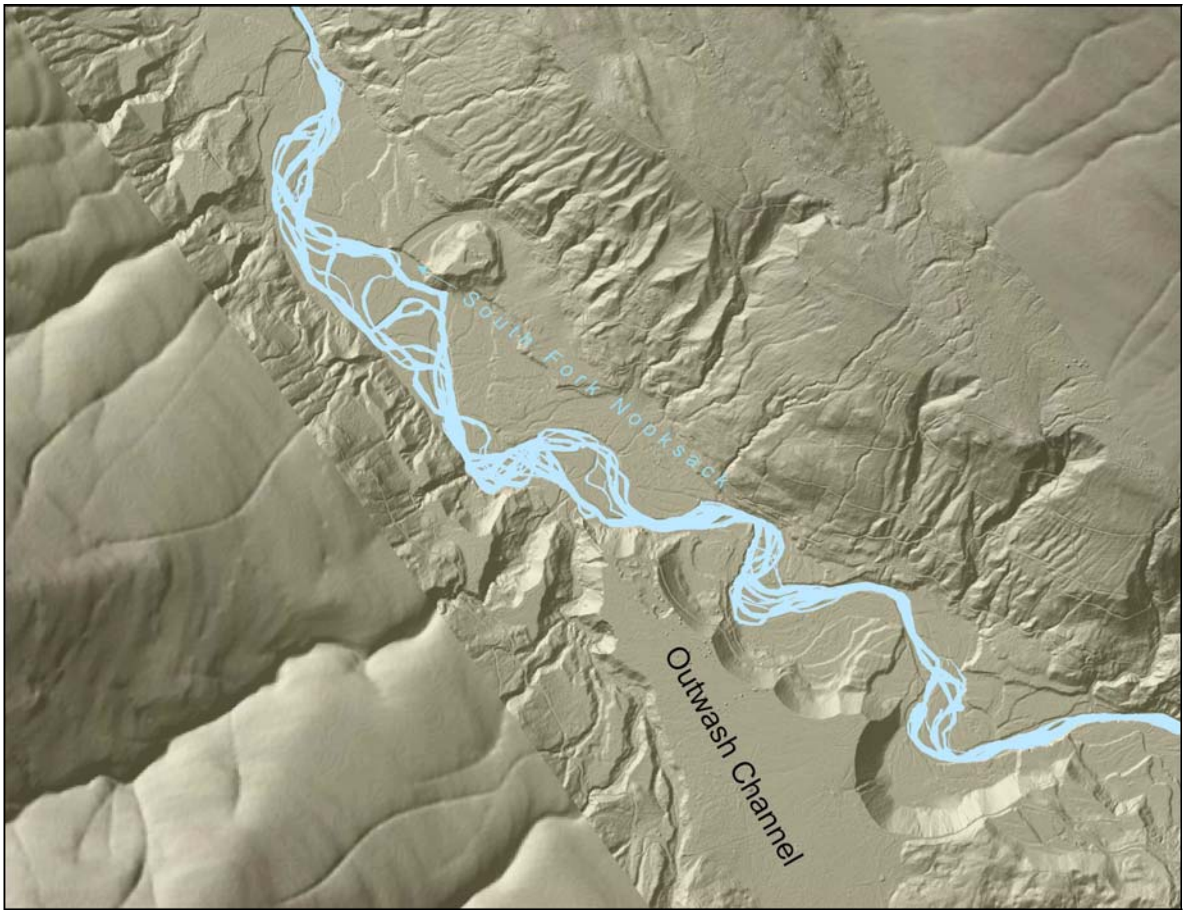


**Figure 24. Active channel migration downstream of outwash channel between 1940-2005 (RM 18-20).**

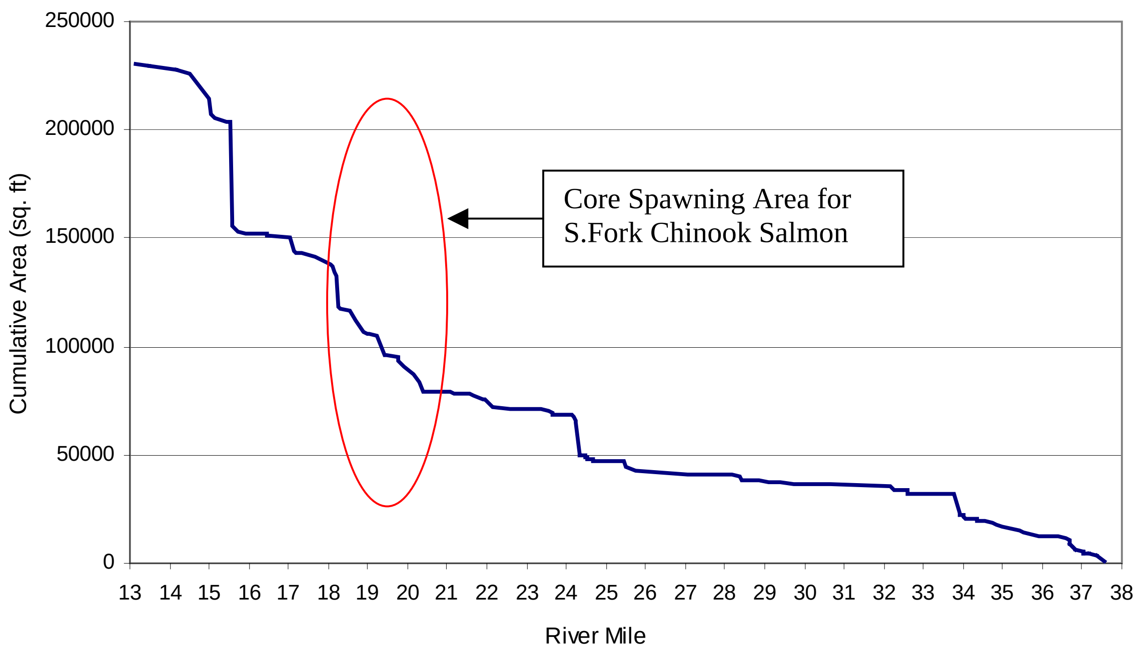


**Figure 25. Distribution of spawning-sized gravel in the upper South Fork Nooksack.**

While much of the channel has not changed position or size substantially, some reaches have shown changes in length and average width over time. The most significant increases occurred between the 1940 and 1956 photo years, where the length increased by nearly half of a mile and the average unvegetated width (calculated as the area divided by the length) increased by 40 feet (Figure 26). This corresponds to the time when early road construction methods were visibly impacting stream channels (Zander 1996). This rapid increase in channel width and sinuosity (channel length relative to valley length) also follows a period (1946-1952) where 5 of 6 years experienced above average annual peak flows. This combination of larger floods, harvest practices and poorly constructed roads likely led to the increase in unvegetated channel width and sinuosity. The other peak in both width and length occurred in 1991, which followed back-to-back floods of record in the 1990 and 1991 water years; although even these two extreme floods did not yield the channel increase in width and length that the 1956 photos did. It is likely that the conditions seen in the portion of the watershed downstream of Howard Creek in the 1940 aerial photo were affected by earlier forest activities, such as railroad logging, and do not represent completely undisturbed conditions.

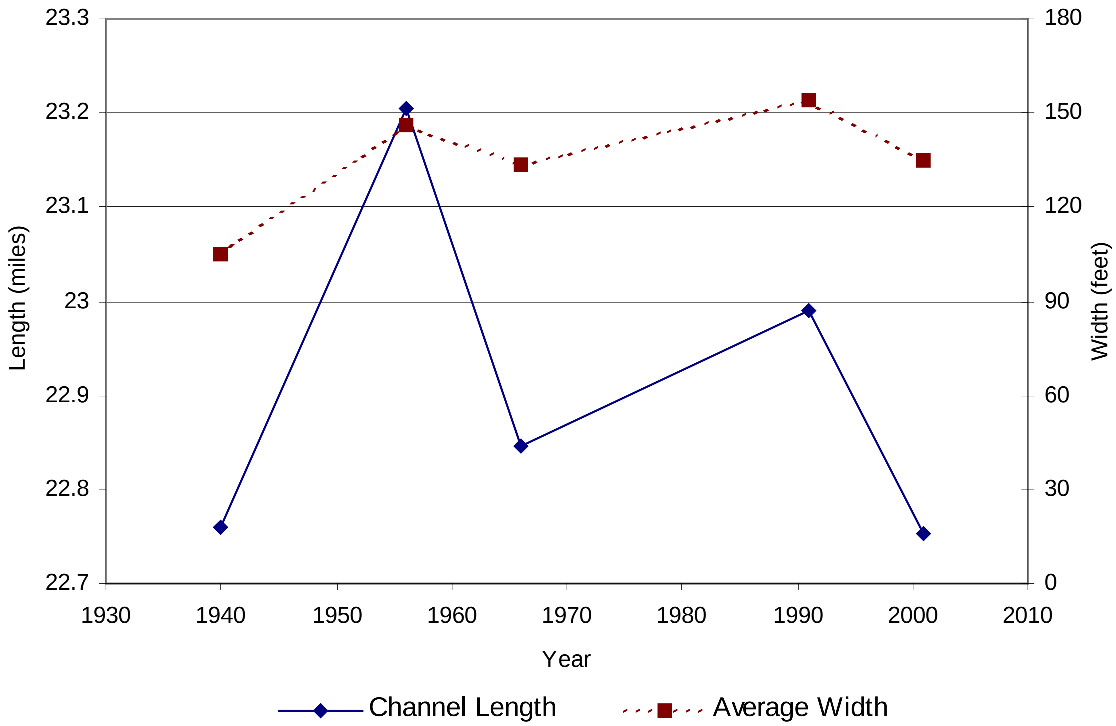


**Figure 26. South Fork channel length and average unvegetated channel width from 1940-2005.**

The channel widening of the 1950s is also associated with an increase in the development of vegetated islands within the active channel (Table 6). The count of vegetated islands nearly double between 1940 and 1956, although the mean area of the islands decreased to their lowest historic level because so much of the active channel area was comprised of gravel bars. Following 1956, it appears that the islands increased in size as the unvegetated channel narrowed and vegetation colonized the exposed gravel bars. Generally, it appears that the sediment deposited into the channel seen in the 1956 photos caused bed aggradation and then subsequent incision into the deposit, leaving islands where the vegetation had colonized the gravel bars.

**Table 6. Vegetated island area and count 1940-2001.**

| Year | Channel Area (acres) | Island Area (acres) | Island Count | Mean Island Area (acres) |
|---|---|---|---|---|
| 1940 | 250 | 16 | 12 | 1.3 |
| 1956 | 410 | 19 | 23 | 0.8 |
| 1966 | 370 | 38 | 29 | 1.3 |
| 1991 | 430 | 57 | 30 | 1.9 |
| 2001 | 370 | 55 | 23 | 2.4 |

The formation and maintenance of forested islands can be important for creating side-channel habitat areas used for spawning and rearing of fish. These areas are often better protected from the effects of large floods than main channel areas (Hyatt and Rabang 2003). In the case of the South Fork Nooksack during the photo record, the bulk of the islands were created between 1940 and 1956, likely as a result of the sediment deposition (reflected in the active channel widening and lengthening) in the channel during that period. These bars then began to stabilize, revegetate and develop over time. In many areas, the main channel continued to incise, side channels narrowed, and islands were rapidly incorporated into the floodplain forest along the channel. During subsequent floods, deposition on the floodplain continued to build the islands and provide organic debris for forest development.

While much of the upper South Fork Nooksack shows a long history of incision and only shallow alluvial deposits, there are several natural depositional sites. An extreme example lies immediately upstream of the narrow constriction at Sylvester's Canyon (near RM 25). Tree cores collected from a floodplain stand of Sitka spruce (*Picea sitchensis*) exhibiting multiple rooting levels and red alder (*Alnus rubra*) trees established on several different terraces revealed a history of burial and erosion at this site (Figure 27). The depths of rooting planes below the uppermost root plane were 5.5-feet, 6.4-feet, and 8.2-feet, with each rooting plane representing a stable floodplain surface. The deepest rooting plane was the best developed (largest roots) of the identified planes. The buried spruce stand had been exposed by channel migration through the floodplain, where close to ten stumps were displaying multiple rooting horizons at similar elevations to each other. Two cores were taken on several competent spruce snags: one above the uppermost rooting level and one midway between the two most prominent rooting planes, which established approximately 4 feet apart. From the cores, it was evident that the bole between the rooting planes stopped growing abruptly around 1967, while the upper bole continued to grow until 2005, when the channel exhumed the tree. The stand was subsequently buried under roughly three feet of sediment; as a result, an alder stand established here in 1991. The combined cores showed several episodes of burial, totaling over 11 feet of deposition between the mid-1880s and 2005.

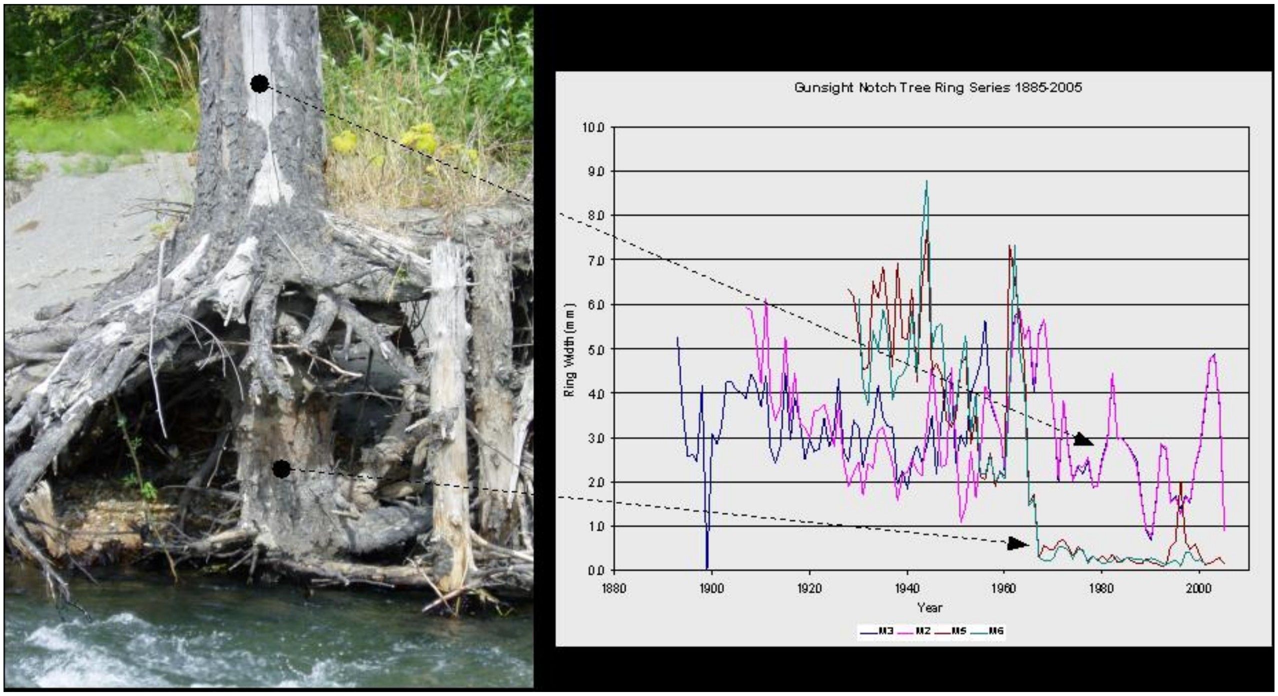


**Figure 27. Adventitious roots on a floodplain spruce tree, showing episodic burial and re-rooting.**

The channel characteristics in the upper South Fork vary considerably by reach and geologic history, from actively migrating channels near a large glacial outwash channel to a steep, confined channel where the channel follows the fault along the southern flank of the Twin Sisters. These characteristics control the dominant habitat-forming processes in the reaches and have a strong impact on the productivity of the instream habitat for salmon species. Channel responses, such as lateral migration or bed elevation changes, to climate and land use changes within the various reaches during the historic period also vary with the underlying geology and distribution of disturbances, leading to marked changes in how salmon species use the watershed. In extreme cases, channel changes have led to the formation of passage barriers that limit access by anadromous salmon to large portions of the basin.

## Sediment

Natural processes and human activities affect the volume, distribution and frequency of sediment delivery to stream channels. In general, erosion rates in forested mountain watersheds are highly variable and depend on differences in slopes, soils, geology, vegetation, and climate (Rice et al. 1972). 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. As the sediment supply increases, the ability to transport sediment through the channel decreases and channel responses such as aggradation, channel widening, substrate fining, pool filling and channel braiding can occur. Conversely, a reduction in sediment load can lead to channel incision and bedload coarsening. Either of these changes can negatively affect the quality of instream habitat. Attributing these changes in the channel to changes in sediment delivery is difficult, because many variables influence channel transport capacity, including wood loading, hydrology, riparian vegetation changes and channel type. Local effects such as bank hardening for erosion control, or channel alteration can further complicate the picture.

Three general types of bedrock mantled with thick glacial deposits characterize the bedrock geology of the upper South Fork Nooksack' watershed (Figure 19, Channel Conditions Section). Metamorphosed sedimentary deposits underlie the portion of the watershed west of the Twin Sisters (phyllite and schist of the Shuksan nappe, Darrington, and Mt. Josephine formations). The rocks of the Darrington and Mt. Josephine formations are mechanically weak and very large landslides, likely related to failures of glacially eroded and over-steepened slopes, have formed on hillsides composed of these two formations (Watts 1995). Bordering the meta-sedimentary rocks to the east are formations comprised of dunite and other ultramafic (very low silica, high magnesium and iron content) rocks. While the dunite is considered mechanically strong, several large deep-seated landslides are associated with the fault zones that bound the Twin Sisters (Figure 28). The easternmost reaches of the South Fork lie predominantly in metamorphosed volcanic and sedimentary rocks (Cultus Group and Chilliwack Formation). These different bedrock types have strong implications for slope stability and sediment generation for the watershed.

Glacial deposits overly the bedrock through much of the watershed. These deposits vary in composition from thinly bedded clay, silt and sand to boulder-laden glacial till. The deposits show a history of ice damming in the valley with thick lakebed deposits, glacial river deposits, and till material deposited in association with the ice in the valley. These glacial lake deposits line much of the valley and are exposed in the channel for several miles. These deposits are also largely associated with the numerous stream-adjacent failures that line the South Fork Nooksack (Figure 29). A large outwash channel is also present draining from the South Fork valley to the Skagit valley through Lyman Pass (Heller 1978, Kirtland 1995). This thick deposit of sand and gravel is associated with the most heavily used spawning reach in the entire South Fork for spring chinook salmon.

Slope failures in the upper South Fork watershed are related to the natural instability of the bedrock and glacial fill in the watershed as well as the land use activities that have occurred in association with these deposits and slope forms. The South Fork watershed contains both deep-seated and shallow-rapid failures. Large-scale deep-seated failures occur in the phyllite of the Shuksan nappe rocks; entire mountain slopes appear hummocky with convex slope profiles (Thorsen 1989). Most of these large, deep-seated Quaternary failures appear to be inactive based on stable forested conditions. However, some of the deposits may be locally reactivated, particularly where the Nooksack River and its tributaries undercut and de-stabilize the slides. This has occurred historically in the Howard Creek drainage, where a tributary undercuts a large dunite earthflow from the Twin Sisters.

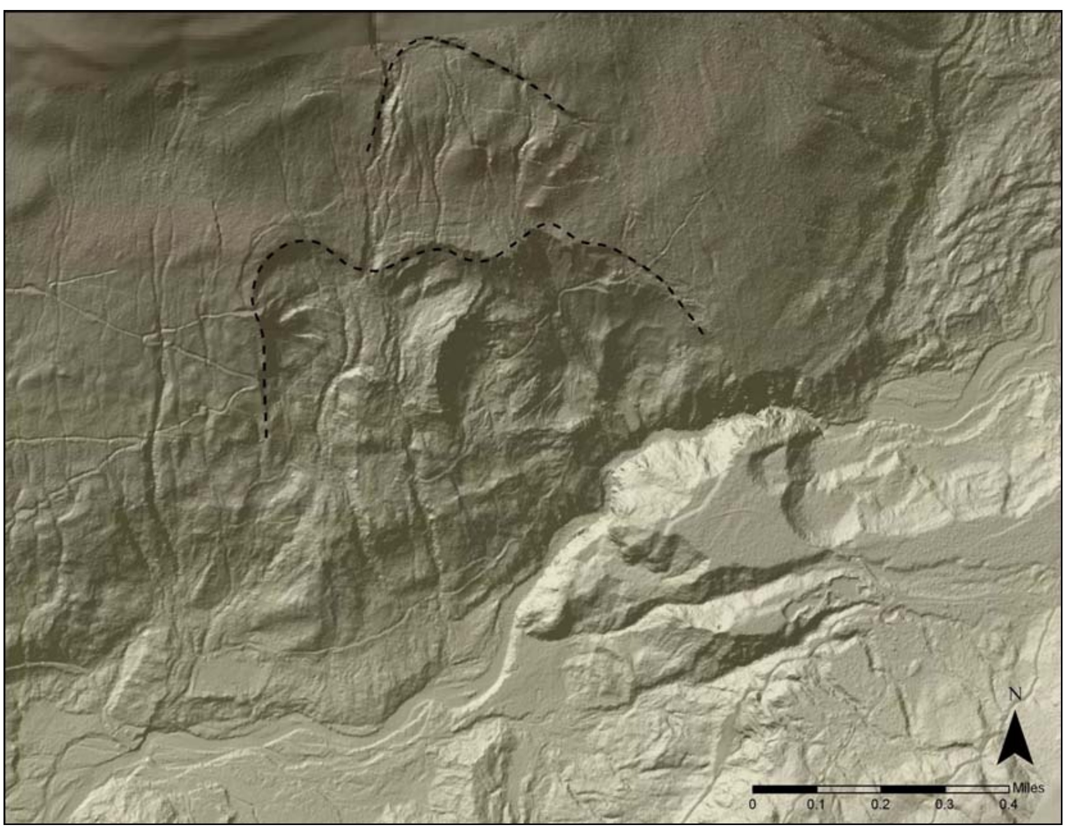


**Figure 28. Headscarps for the South Twin dunite landslides at RM 31.**

**Figure 29. Slope failure in glacial lake deposit (1160-ft long by 160-ft high) at RM 26.7; active since the earliest aerial photos in 1940.**

Other deep-seated failures are active, including actively moving glacial deposits along the South Fork Nooksack (Figure 30). These stream-adjacent landslides were mapped in 1986, 1995, and 2005 (Lummi Natural Resources 2005, Osbaldiston 1995, Lummi Natural Resources 1986). While the area estimates of the landslides likely varied between the surveys, the distribution and relative size of the features shows reaches with persistently unstable slopes (Figure 31). The deep-seated South Twin dunite landslide (~RM 31) shows-up as the largest feature present in all three surveys. This slide was also noted on the General Land Office (GLO) surveys conducted in the 1890s, so it has likely had a long history of contributing sediment to the river.

**Figure 30. Unvegetated head scarp of stream-adjacent deep-seated failure in glacial lake deposit showing ~20 feet of recent movement (nearly 2- feet of movement over one week).**

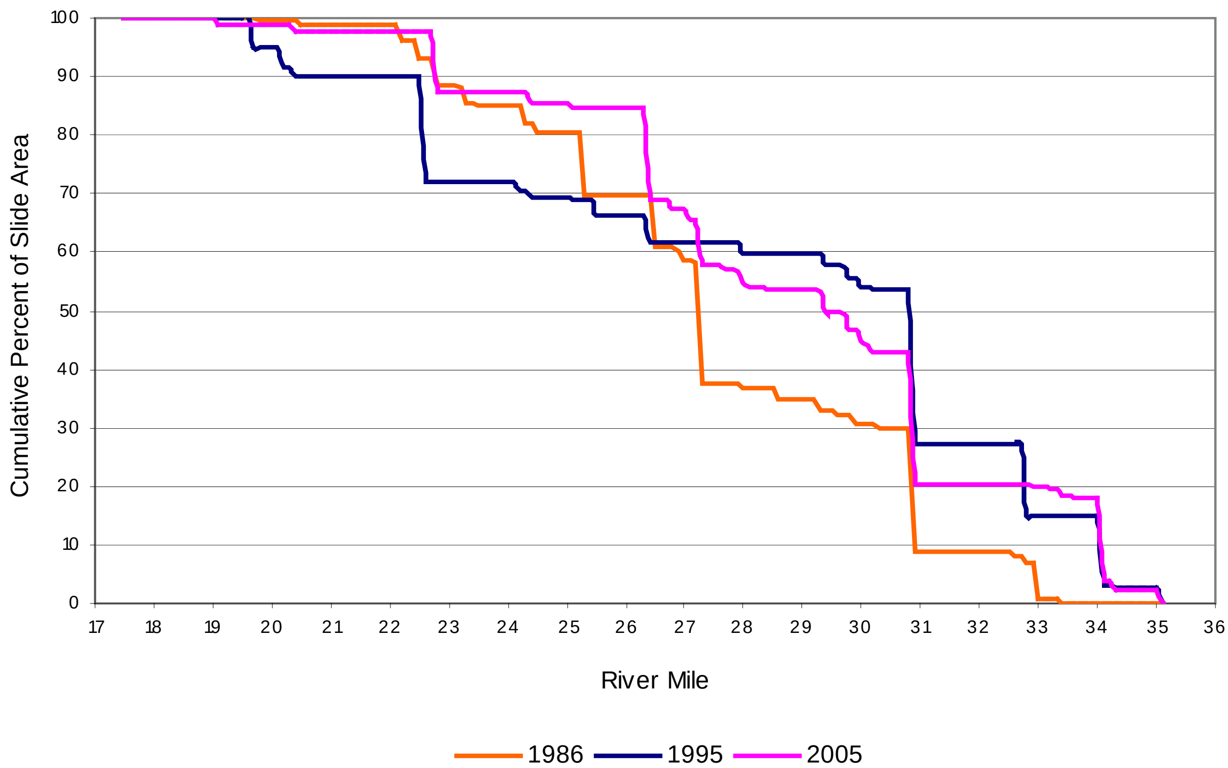


**Figure 31. Cumulative percent of landslide area in the upper South Fork watershed.**

At other locations, landslides appear to develop large slope failures, which then rapidly revegetate and can appear stable within the decade or so before the next survey. For example, the large landslide in glacial lake deposits present near RM 27 in 1986 had mostly revegetated by 1995, and appears to be active again in 2005. The landslide near RM 33 appeared to grow in size between 1986 and 1995, but was revegetated by 2005. Another interesting note is that over the 20 years represented in Figure 31, few sections of the river did not experience a slope failure. This would indicate that the distribution and size of stream-adjacent landslides through the river appear to change as the channel migrates into the unstable glacial deposits. Currently, seventeen landslides accounting for approximately 40% of the stream-adjacent landslide area lie between RM 25 and 30, which is also the reach of the river with the greatest increase in turbidity (Figure 69, Water Quality Section).

While these landslides likely have a large impact on fine sediment delivery to the channel, it is also likely that these slides are a result of a long history of the river evacuating glacial fill from the valley and are a natural source of sediment to the channel (Figure 32). Since the end of the last glacial period, the river has been eroding the glacial deposits and transporting them out of the valley. Periods of channel incision, floodplain development and lateral migration into unstable slopes are preserved in terraces that line much of the valley (Figure 33). These terraces are commonly composed of 1-2 meters of river gravel and glacial deposits, indicating that the channel has not been aggrading, but rather rapidly incising into its bed leaving only a shallow veneer of river deposits on the terrace. It is likely that these large stream-adjacent failures will continue to form and revegetate as the river continues to incise and migrate laterally into the unstable glacial deposits and will likely continue to be a source of sediment to the channel.

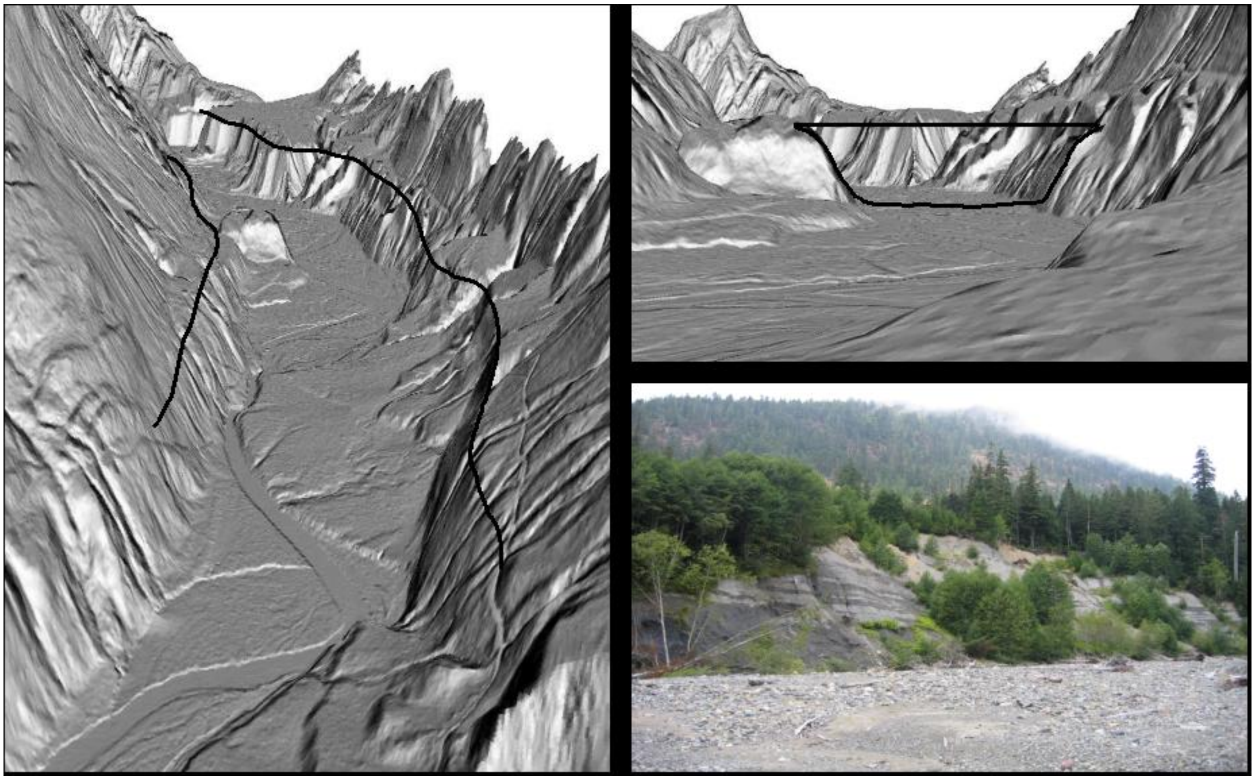

Figure 32. Upper South Fork valley showing remnant glacial lake deposits mantling the valley walls.

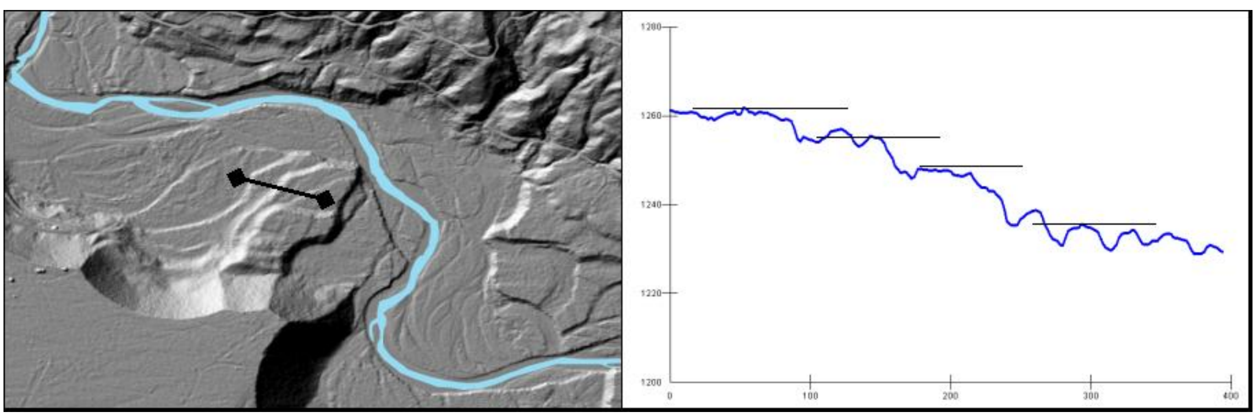


Figure 33. Pre-historic terraces showing history of channel incision and floodplain development in the South Fork valley.

In addition to the large deep-seated failures in the basin, there are many shallow-rapid failures. These failures are of particular interest because of the high percentage that is related to land use activities and the high percentage that deliver sediment directly to fish-bearing streams (Watts 1996). Using aerial photos (1940-1995), there have been 875 shallow-rapid landslides mapped in the upper South Fork watershed over the 55-year photo record (Figure 34). Of the characterized landslides, 62% (483 of 779) were associated with land use activities and 80% (465 of 580) delivered sediment to a stream. The most common land use associated with shallow rapid failures was recent timber harvest (Table 7). The failure rate associated with an individual timber harvest will often decrease with time because bared areas are quickly invaded by pioneer species and initially high sediment production rates decline rapidly as the sites revegetate (Rice et al. 1972). Although, the cutting of trees by itself does not significantly increase erosion, the timber harvest on steep unstable slopes appears to lead to increased mass erosion, partially attributable to the loss of root strength. Since the majority of shallow-rapid landsides are related to land-use activities, efforts to minimize or avoid activities on inherently unstable areas during forest practices (harvest and road construction) are important to recovering high quality instream habitat and water quality.

The road systems constructed to support timber harvesting generally overshadow logging or fire as causes of accelerated erosion. Roads increase surface erosion by baring soil and concentrating runoff, and they may trigger landslides more frequently than any other human disturbance (Rice et al. 1972). In the upper South Fork Nooksack, the conversion from railroad logging to truck logging began around 1940 (Zander 1996). Extensive road building was conducted from the mid-1950s to the early 1980s, and large portions of the non-Federal portions of these road systems have not been used for timber management purposes since the Forest Practices Act was passed in 1974, and therefore they predate state forest practice rules. While it is likely that many of these older roads have already failed, many of these "orphan roads" may still represent a potential source for shallow-rapid landslides. Areas identified in the upper SF watershed at a high risk of failure due to roads are: the region bounded by the South Fork Nooksack River on the west and drainage divide and Goat Mountain on the east; Deer, Plumbago, and Roaring Creek Watersheds; the upper reaches of Howard, Cavanaugh, and Skookum Creek watersheds; and the east-facing hillside above Howard Creek (Zander 1996). These areas have been targeted for road drainage improvement or abandonment projects to reduce the potential for road failure and sediment delivery to the stream network (Nooksack Recovery Team 2005).

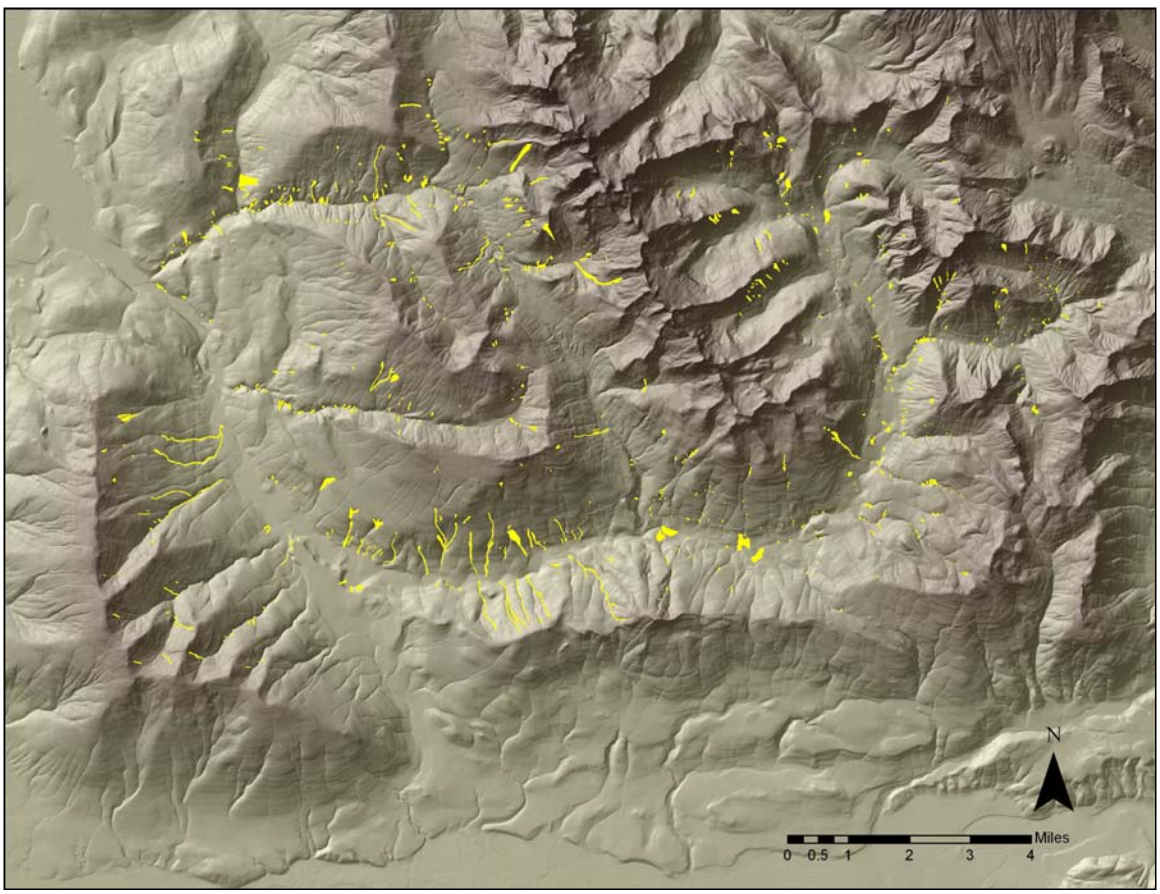


**Figure 34. Shallow-rapid landslides in the upper South Fork watershed 1940-1995 (Watts 1996, Kirtland 1995, Cascade Environmental Services 1993, Peak Northwest 1986).**

**Table 7. Landslide count by associated land use (Watts 1996, Kirtland 1995, Cascade Environmental Services 1993, Peak Northwest 1986).**

| Land Use | Count of Landslides Characterized |
|---|---|
| Natural | 296 |
| Recent Harvest | 266 |
| Roads | 170 |
| Older Harvest (>20 Years) | 15 |
| Landings | 8 |

The trigger for shallow-rapid landslides is often related to slope form. Using the results of a model that analyzes slope curvature and slope, the Department of Natural Resources (DNR) slope stability GIS layer classifies 10-meter cells into high, medium and low potential for instability (DNR 2000). The results were summarized by watershed for the upper South Fork (Figure 35). The highest potential for slope instability lies in the Bell, Elbow Lake, and Wanlick watersheds, so land use activities occurring on these potentially unstable slopes should be avoided, if possible, or carefully planned to avoid disturbing the triggering mechanisms for unstable landforms. All of the areas identified as a high risk for road failures lie within portions of the watershed with high potential instability based on slope form.

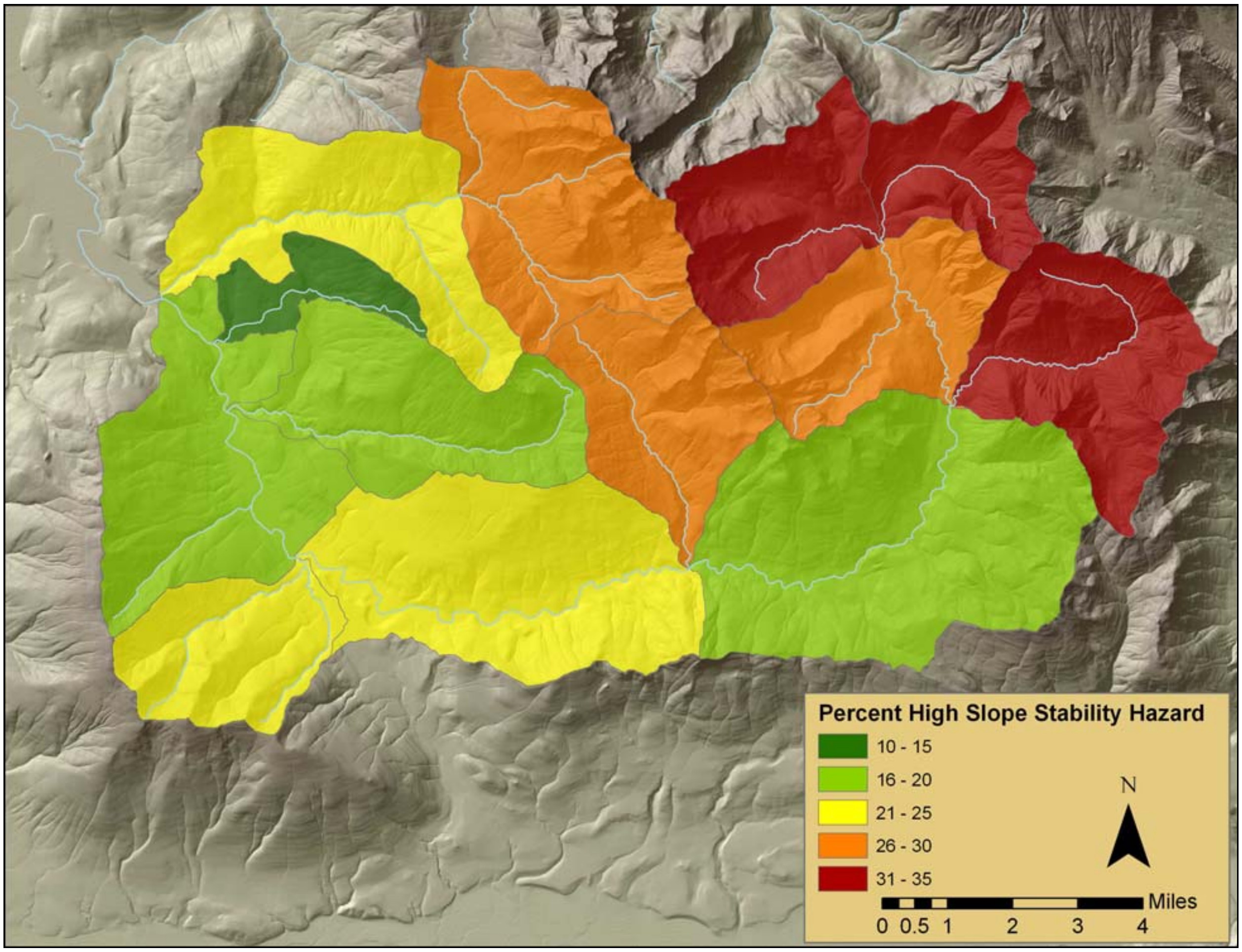


**Figure 35. Percent high slope stability hazard (DNR 2000).**

Watts (1996) assessed the slope form of shallow-rapid landslides through much of the upper South Fork assessment area and divided the results into the mainstem and the tributary watersheds assessed for comparison (Table 8). The results of the analysis show a strong relationship between gully/ inner gorge landforms and landslides, which are consistent with the kind of landforms identified as high hazards in the DNR slope stability layer (Figure 36). A combination of unstable landforms and aggressive land management has likely contributed to increased mass wasting and elevated sediment delivery to the South Fork Nooksack.

**Table 8. Landslide count by landform classification.**

| Watershed | Landform Class | | |
|---|---|---|---|
| | Gully | Inner Gorge | Open Slope |
| South Fork Nooksack | 65 | 72 | 11 |
| Hutchinson Creek | 8 | 26 | 5 |
| Howard Creek | 0 | 9 | 0 |

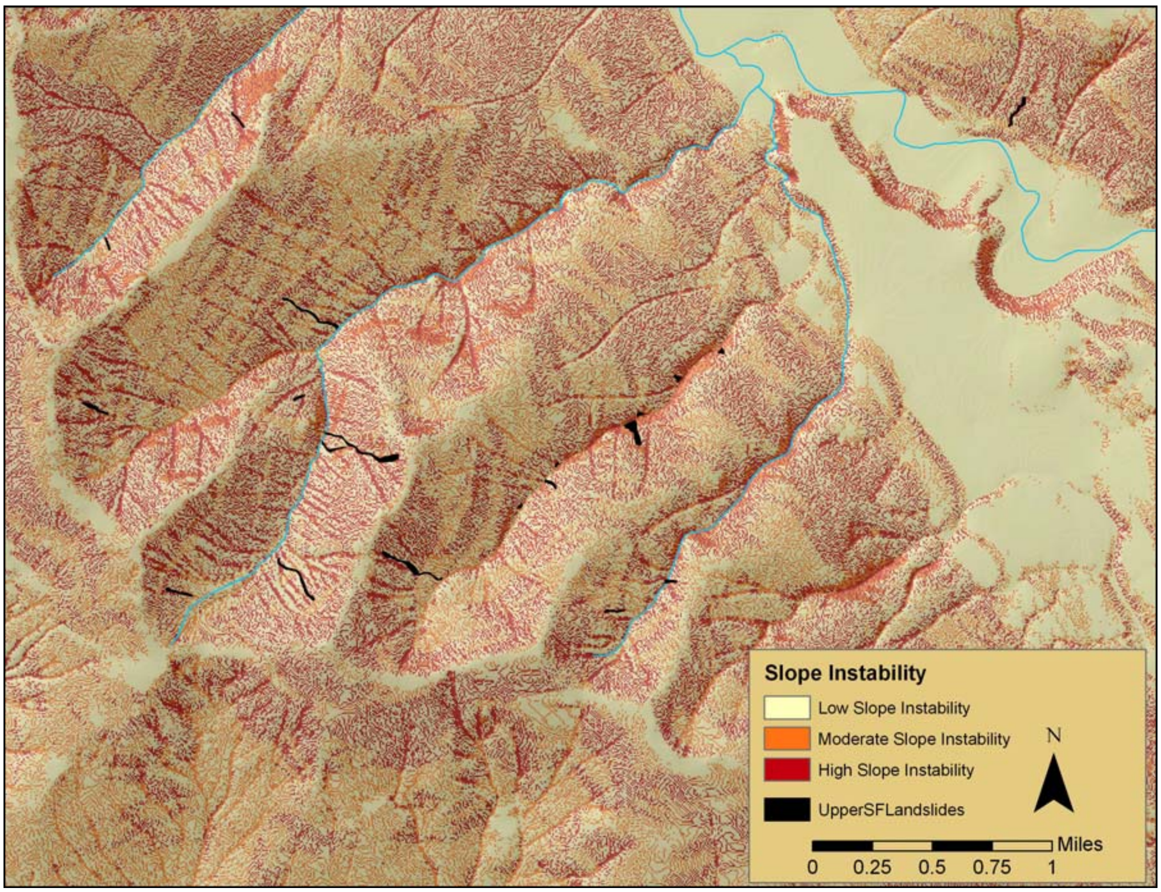


**Figure 36. Sample of mapped landslides and predicted slope instability showing the consistency of the two.**

Although it is likely that increased mass wasting has increased sediment delivery to the channel, sediment samples collected from the South Fork Nooksack since the mid-1980s within the assessment area have consistently shown a relatively low level of fine sediment in spawning gravel (Schuett-Hames and Schuett-Hames 1984, LNR 2001, Hyatt and Rabang 2003). While percent fine sediment is only one aspect of characterizing substrate, it has been associated with reduced survival of incubating salmonid eggs. Samples collected in the upper South Fork and its tributaries were analyzed for percent fine sediment (<0.85mm diameter) in 1982 and 1983 ranged between 8.8 and 12.3% were generally less than the 11% fine sediment indicated for a negative impact on incubation success (Spence et al. 1996). More recent sediment samples collected from the South Fork Nooksack near RM 20 in support of a restoration project showed fine sediment levels ranged between 6 and 11% (LNR 2001). Later samples collected in the same reach showed similar results, although results were locally impacted by construction of instream habitat structures during 2001 (Hyatt and Rabang 2003).

Comparing spawning gravel composition through time, Hyatt and Rabang (2003) found that there was no detectable difference in spawning gravel size distribution between 1982 and 2002. Further, the authors found that fine sediment levels have remained stable through time (1982-2002) in the upper Nooksack watershed. Looking at the South Fork mainstem channel, Hyatt and Rabang (2003) found an increase in percent fine sediment (from 12% to 16%) between RM 24 and the confluence of the river with the mainstem Nooksack. The longitudinal comparison was made difficult by the wide scatter at some sampling locations in the watershed. Other variables that increase with watershed area, such as total road miles, clearcut area, landslide area, and discharge, did not correspond to an increase in fine sediment in spawning gravel samples. These results would suggest that, while fine sediment sources are abundant in the watershed and negatively affect water quality, the direct impact of fine sediment accumulation in spawning gravel in the upper South Fork Nooksack is likely a low threat. However, it is likely that the sediment generated in the upper watershed does negatively affect spawning gravel quality in the lower twelve miles of the river, where percent fine sediment levels in the substrate often exceed the level where reduced survival of incubating eggs has been documented.

Various forms of mass wasting, including shallow rapid slides and deep-seated failures, occur throughout the upper South Fork watershed. Observations from the photo record suggest that many of the slope failures occurred following periods of intense timber harvest and varied both geographically and by intensity of land use (Watts 1996). Most land-use related mass wasting occurred in the first ten years following harvest or road construction, with less frequent failures occurring as the forest canopy matured. In addition to the apparent link between land use and mass wasting, there was also a link between mass wasting and unstable landforms. While the focus of watershed protection should remain on recent land use activities and the protection of unstable landforms, assessing the legacy affects of earlier forest practices, such as orphaned roads, should also be conducted to determine their potential impact on instream habitat.

## Large Woody Debris

The large woody debris (LWD) portion of this assessment was undertaken to gain a better understanding of the abundance and distribution of both large pieces and accumulations of wood in the larger (>65 ft wide bankfull) channels of the South Fork Nooksack Basin. The objective of this portion of the assessment is to provide a quantitative characterization of instream wood distribution, abundance, and function. The current wood distribution will be compared to wood recruitment potential from the riparian zones, as well as the channel characteristics, such as gradient and confinement, of the South Fork Nooksack. The assessment includes wood data collected throughout the length of the mainstem channel to show the downstream affects of wood recruitment and transport, and to provide context for collected upper South Fork data.

Wood measurements were collected for all 130 large pieces mapped in the South Fork Nooksack. The average "key-sized" piece volume was measured at 535 $ft^3$, with a range between 125 and 2,830 $ft^3$. Thirty-seven of the 130 measured pieces were actually less than the 318 $ft^3$ threshold for inclusion as a "key-sized" piece in channels wider than 60 feet, but were included in the analysis (Washington Forest Practices Board 1998). No assessment of single piece function was conducted, so the term "key-sized" refers only to the volume of the piece and not its inherent stability in the channel. The average length of measured pieces was 77.4 ft and the average diameter was 2.9 ft. Most pieces (73%) still had roots attached to the bole; the diameter of the rootwad ranged between 2.6 and 35.1 feet.

Piece size appeared to have little to do with logjam stability (Figure 37). Each piece was classified as key, racked or loose, with only the key pieces characterized as stable. Ninety-six of the pieces (73%) were considered stable. The average volume of stable pieces was slightly larger than unstable pieces (574 $ft^3$ compared to 427 $ft^3$ for unstable pieces), but the ranges largely overlapped and the difference is not statistically different when analyzed with a Wilcoxon Rank Sum Test. All pieces larger than 1,200 $ft^3$ were found to be stable, and this may better represent the volume of a key piece in a river the size of the South Fork Nooksack than the 318 $ft^3$ used as a guideline in the assessment.

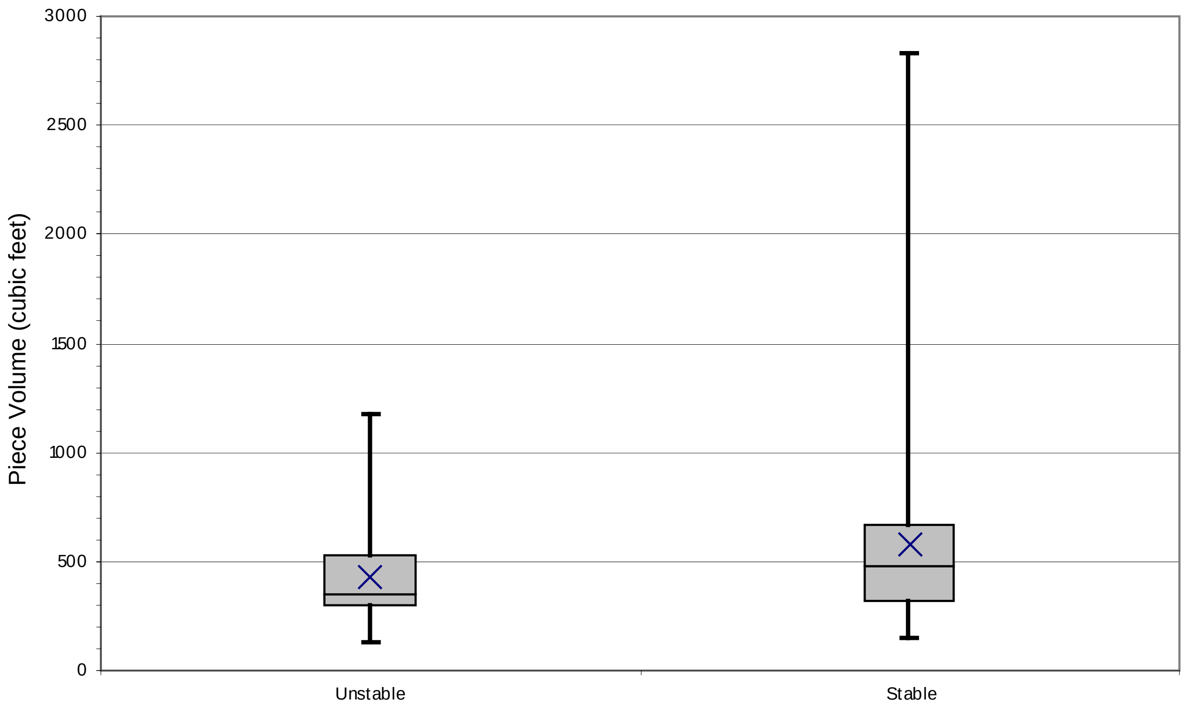


**Figure 37. Box plot (max, Q3, med, Q1, min, mean [X]) of piece volume for stable and unstable pieces.**

For surveys in the South Fork, instream wood was identified by species, when possible, and as conifer or deciduous where it was not possible to identify the species (Figure 38). For the species data, a comparison of mapped instream wood with estimates of the historical streamside and valley-bottom forest composition from GLO records shows that the two species that provided the largest wood to the channel in the 1880s, western red cedar and Douglas fir, still provide most of the large wood to the channel today (Collins and Sheikh 2002). These two species account for nearly 70% of the wood identified by species in the South Fork Nooksack.

The stand type of the South Fork riparian forest today is consistent with the species composition of the forest recreated from GLO surveys (Collins and Sheikh 2002). Approximately 60% of the South Fork Nooksack riparian area is hardwood dominated, compared to 18% mixed species and 13.5% conifer dominated (Duck Creek Associates 2000), although hardwood species only comprised 9% of the large wood located in the bank-full channel (Figure 38). This is likely due to the dominance of red alder in the riparian zones, which rarely reaches the volume of the pieces mapped in the channel. Black cottonwood was the only deciduous tree that contributed large wood to the channel. The abundance of red alder and large deciduous pieces of black cottonwood in the streamside forest are consistent with conditions depicted in the 1880s GLO surveys. This further shows that the relatively sparse conifers in the riparian zone play a critical role in providing the largest wood to the channel.

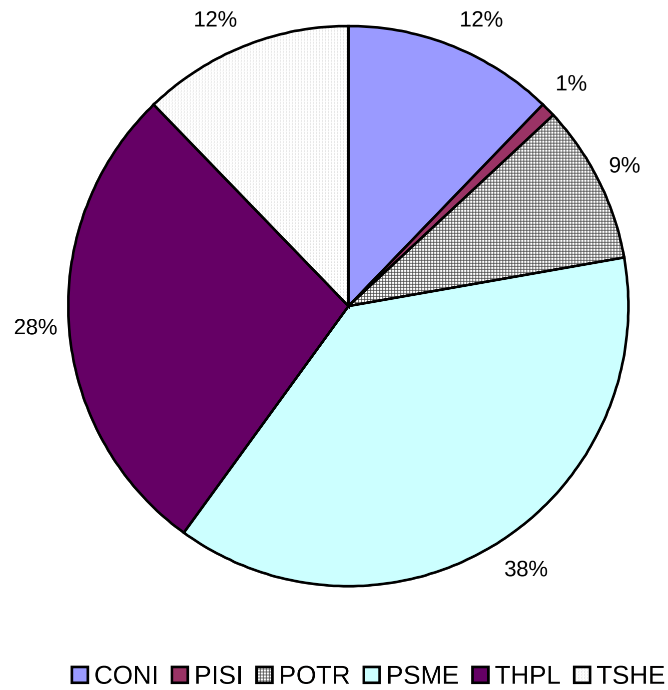


**Figure 38. Species distribution of key-sized pieces in the South Fork Nooksack. (CONI= unknown conifer, PISI= Sitka spruce, POTR= Black cottonwood, PSME= Douglas fir, THPL= Western red cedar, TSHE= Western hemlock).**

The abundance of wood in the channel is affected by both low recruitment rates from the riparian zone and rapid depletion from the channel due to removal, transport and decay. This is reflected in the decay class for the wood mapped in the South Fork Nooksack (Figure 39). Most of the wood mapped (81%) was in the moderate or old categories of decay; very few pieces were either freshly recruited (12%) or showed signs of advanced decay (7%). Based on wood decay and transport studies on other rivers displaying very rapid depletion of in-channel wood, even those pieces classified as “old” are likely less than 20-years old (Hyatt and Naiman 2001). Since these decay classes do not directly reflect the age of the recruited wood, it is difficult to tie the distribution across classes to temporal changes in land use, although extensive riparian timber harvest in the upper South Fork undoubtedly removed large streamside trees, interrupting the process of natural wood recruitment to the channel. Active removal of wood from the channel also interrupted the transport and storage of wood in the river. It will likely take many decades for the riparian zones to recover and begin to provide a significant amount of fresh large wood the channel.

The distribution of the decay classes through the river is not uniform; “young” pieces were identified in two specific locations. Most (11 of 16 pieces) of the recently recruited wood was located in a 3.4-mile reach of the South Fork Nooksack downstream of Wanlick Creek (RM 34). The remaining five pieces were located downstream of the assessment area in the Acme Valley (between RM 4-12) in reaches where no bank protection was present. The eleven pieces located in the upper reach were conifers, while the remaining five pieces were black cottonwood logs. This distinction between conifer logs in the upper watershed and deciduous logs in the lower reaches reflects the current local riparian conditions in the watershed and further suggests the importance of large trees in local riparian stands for instream wood.

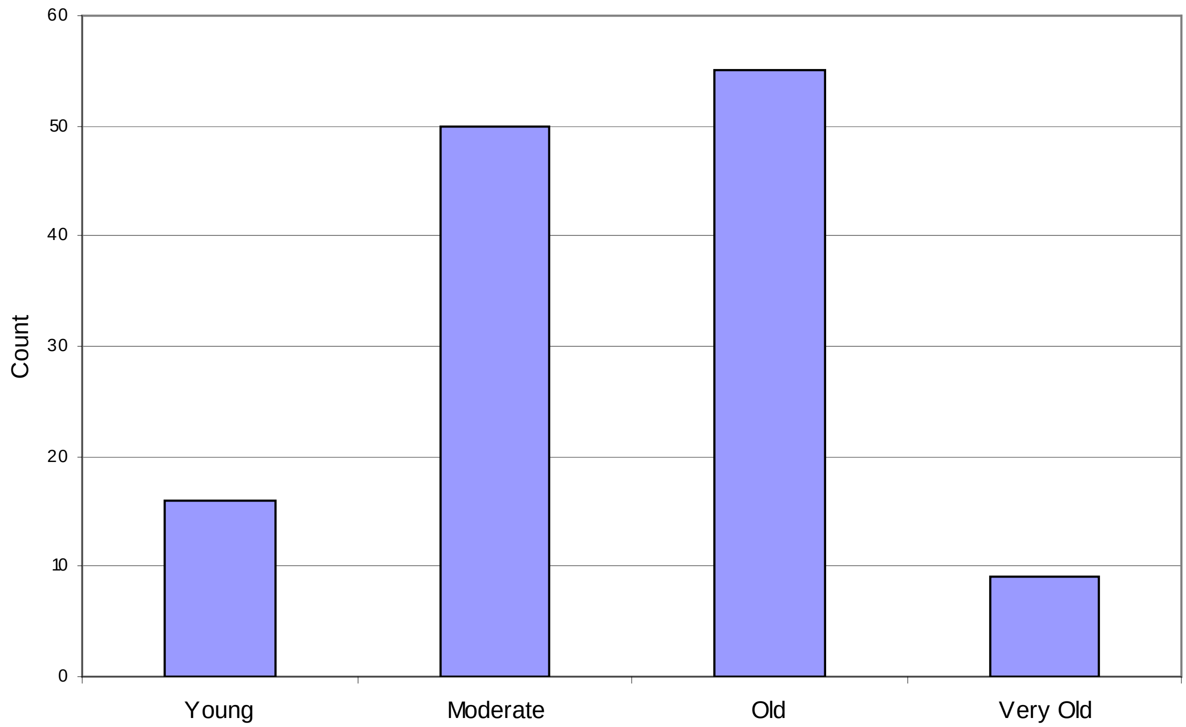


**Figure 39. Decay classes for South Fork Nooksack River instream wood; *n* = 130.**

While the current riparian stand species composition and instream wood species seem to mirror the historic riparian conditions in the South Fork Nooksack, land-use activities have disrupted the recruitment of wood and reduced the size and amount of wood delivered to the channel. Activities such as artificial bank armoring (rip rap), riparian harvest, and bank clearing for agriculture, railroad and road development, and stream cleaning have all played a part in reducing instream wood levels from the conditions described in the late 1800s. Many of these actions also leave a smaller area of mature riparian stands able to provide the large wood to the channel, resulting in less wood delivered to the channel and a reduced role for wood to play in habitat formation.

**Table 9. Key-sized piece counts and percent by channel location.**

| **Channel Location** | **Geographic Area** | | | | **Total** |
|---|---|---|---|---|---|
| | **South Fork** | **Middle Fork** | **North Fork** | **Upper Mainstem** | |
| Banks | 15 | 4 | 16 | 2 | *37* |
| Center of Low Flow | 12 | 1 | 0 | 0 | *13* |
| Edge of Low Flow | 67 (52%) | 7 | 36 | 3 | *113* |
| Lateral Bar | 16 | 50 (72%) | 178 (69%) | 10 (67%) | *254* |
| Mid-channel Bar | 6 | 4 | 25 | 0 | *35* |
| Over-hanging | 14 | 3 | 3 | 0 | *20* |
| *Total* | *130* | *69* | *258* | *15* | *472* |

The channel location of the wood deposition varied between the South Fork and the other forks of the Nooksack River (Table 9 and Table 10), with a much larger proportion of wood in the low-flow channel in the South Fork Nooksack. In the South Fork, the majority of large pieces (52%) and logjams (51%) were located along the edge of the low-flow channel. In the other forks and upper mainstem of the Nooksack River, the majority of pieces (67 to 72%) and logjams (45 to 57%) were located on lateral bars. This difference likely reflects the difference in channel types between the South Fork and the other forks. Much of the channel length of the South Fork is a single-thread, sinuous channel, while the other forks and upper mainstem are dominated by braided and anastomosing channel patterns, with a much greater bar area in the active channel area.

**Table 10. Logjam counts and percent by channel location.**

| **Channel Location** | **Geographic Area** | | | | **Total** |
|---|---|---|---|---|---|
| | **South Fork** | **Middle Fork** | **North Fork** | **Upper Mainstem** | |
| Banks | 18 | 1 | 8 | 5 | *32* |
| Center of Low Flow | 23 | 0 | 0 | 0 | *23* |
| Edge of Low Flow | 94 (51%) | 8 | 27 | 13 | *142* |
| Lateral Bar | 38 | 13 (45%) | 60 (57%) | 17 (49%) | *158* |
| Mid-channel Bar | 10 | 7 | 10 | 0 | *27* |
| *Total* | *183* | *29* | *105* | *35* | *352* |

Wood mapping in the South Fork Nooksack basin found 130 large pieces of wood and 184 logjams through the 37-mile assessment area (Table 11). This equates to a spacing of approximately one large piece every 1,480 feet of channel. Logjams are spaced slightly closer, with one logjam along every 1,050 feet of channel. The South Fork is also unique in the relatively high count of logjams compared to the number of large pieces of wood. In both the North and Middle forks, large wood piece counts outnumbered logjams, while on the South Fork and Mainstem logjams outnumbered large pieces. The mainstem channel between Everson (RM 24) and Marine Drive (RM 2), a reach where historically much of the instream wood moving down the Nooksack River once accumulated, contained no logjams or large pieces.

**Table 11. Comparison of South Fork piece and logjam counts to other geographic areas in the Nooksack basin.**

| **Count** | **Geographic Area** | | | | |
|---|---|---|---|---|---|
| | **South Fork** | **Middle Fork** | **North Fork** | **Upper Mainstem** | **Lower Mainstem** |
| Logjams | 184 (5.0 per mile) | 29 (4.1 per mile) | 107 (3.8 per mile) | 35 (2.9 per mile) | 0 |
| Large Pieces | 130 (3.5 per mile) | 69 (9.9 per mile) | 221 (7.9 per mile) | 23 (1.9 per mile) | 0 |

The presence of large pieces in the logjams did correspond with an indication of greater stability, based on geomorphic effects of wood on the channel or the presence of vegetation on the logjam (Table 12). Most (64%) of the logjams mapped and characterized exhibit some indication of stability. Of the 32 logjams containing "key-sized" pieces, 78% were considered stable, while only 61% of the 152 logjams that did not contain key-sized pieces were stable. It is likely that the presence of large pieces increased the probability that a logjam would persist, although the majority exhibited some geomorphic effect on the channel regardless of the presence of key-sized pieces.

**Table 12. Large piece presence and logjam stability**

| Presence of Large Pieces | Indications of Stability | |
|---|---|---|
| | **Yes** | **No** |
| **Yes** | 25 | 7 |
| **No** | 93 | 59 |

The distribution of logjams and individual large pieces in the South Fork was plotted as the cumulative count per length of channel (Figure 40). From the plot, it appears that the distribution of logjams per mile is linear, while the distribution of large pieces of wood is logarithmic. The different shape in these curves implies that there is little relationship between large pieces and logjams, although there are slightly more logjams per mile in the upper reaches where more key-sized pieces are present (RM 37 to 25). Rather than large pieces initiating logjams, it appears that logjams are uniformly distributed through the river, while the bulk of large pieces are present in the upper reaches of the river.

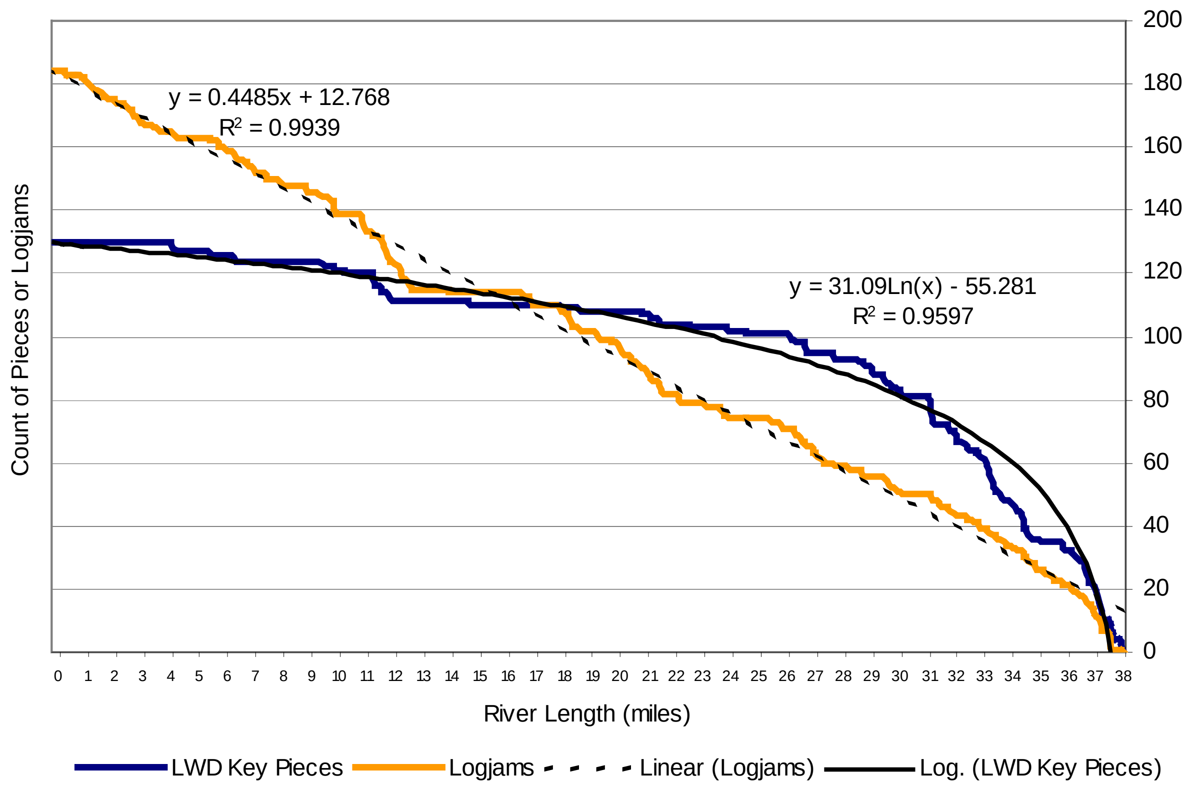


**Figure 40. Cumulative wood distribution in the South Fork Nooksack.**

In the South Fork Nooksack, the longitudinal distribution shows that 62% of key-sized pieces are above the partial barrier at RM 32 and 78% are above the partial barrier at RM 25. This implies that many of the habitat functions provided by large pieces of wood that directly affect salmon habitat (pools, hiding cover, gravel sorting) do not benefit many of the fish that cannot pass these barriers. Below RM 37, logjam frequency appears to be relatively constant. The exceptions are Dyes Canyon (between RM 12.4 and RM 16.8) where logjam frequency drops, and the unconfined portion below Saxon Bridge (between RM 10.6 and RM 12.4) where it increases sharply. Downstream of RM 25, the distribution of key-sized pieces appears related to channel confinement and gradient. Between RM 11.8 and RM 25, only 8% of the key pieces were found. Six-percent of the large pieces is located where the channel widens out between RM 11.2 and RM 11.8. This demonstrates the response of wood distribution to channel confinement and gradient.

The distribution of large pieces in the South Fork likely reflect the combination of larger trees adjacent to the channel in the upper watershed and the rapid break-up and decay of these pieces as they move down the river, while the distribution of logjams likely reflects channel characteristics, such as gradient and confinement. Therefore, piece distribution is probably more related to erosional stream processes and logjam distribution related more to depositional stream processes in the Nooksack Basin.

The habitat functions provided by logjams were described as they were mapped. The majority of logjams in the South Fork Nooksack are providing local effects (scour, cover, sediment deposition), rather than reach-scale effects (channel avulsions, channel deflection, or split flow) (Table 13). The most common reach-scale effect that is currently occurring is splitting the bank-full flow, which is important for side channel development and stability. The combination of these local effects would provide direct benefits to salmon species for a variety of life-stages, including adult holding and juvenile rearing, where the logjams are present.

**Table 13. Logjam counts and percent by the habitat functions provided (total of 184 logjams mapped).**

| Habitat Function | Count (percent) of All Logjams Providing the Function |
|---|---|
| Split Low Flow | 35 (19%) |
| Split Bank-full Flow | 69 (38) |
| Deflect Channel | 32 (17) |
| Channel Avulsion | 1 (0.5) |
| Sediment Deposition | 97 (52) |
| Local Scour | 98 (53) |
| Instream Cover | 117 (64) |

The channel-spanning habitat units associated with the logjams was described for 60 of the 184 South Fork logjams located in the upper South Fork Nooksack, where recent habitat mapping of the channel has been conducted (Table 14). The logjams were most commonly associated with riffle habitats, which are the most common habitat unit in the area. However, only 7% of logjams were associated with channel-spanning pools, a relatively common habitat type in the mapped area. Logjams were common (29%) in rapids habitat, which was relatively uncommon.

**Table 14. Logjams and associated main channel habitat units.**

| Habitat Type | Count of Logjams (%) | Percent of Habitat Area |
|---|---|---|
| Pool | 4 (7) | 17 |
| Run | 14 (24) | 18 |
| Riffle | 24 (41) | 51 |
| Rapid | 17 (29) | 8 |
| Cascade/Falls | 0 | 6 |

In addition to the relationship between river mile and wood, there was also a relationship between the degree of channel confinement and wood abundance. A strong relationship exists between areas that are naturally unconfined and the amount of wood in the channel in the South Fork Nooksack (Table 16). This holds for natural confinement as well as artificial confinement, such as bank protection. Stream gradient shows a relationship with both logjam volume and large pieces in the South Fork Nooksack (Table 15, Figure 41). In the case of logjam volume, there is an increase in volume with decreasing stream gradient; individual pieces are more prevalent in higher gradient sections.

**Table 15. Channel confinement and wood distribution in the South Fork of the Nooksack River (CW= channel width and VW=valley width).**

| Confinement | LWD/mile | Logjams/mile |
|---|---|---|
| Low (VW > 4CW) | 30 | 37 |
| Low with artificial confinement | 2 | 5 |
| Medium (2CW<VW<4CW) | 5 | 3 |
| High (VW< 2CW) | 3 | 3 |

**Table 16. Channel gradient and wood distribution in the South Fork Nooksack.**

| Gradient | Length (mile) | LWD | LWD/mi | Logjams | Logjams/mi |
|---|---|---|---|---|---|
| <1% | 22.9 | 55 | 2.4 | 107 | 4.7 |
| 1-2% | 9.8 | 42 | 4.3 | 40 | 4.1 |
| 2-4% | 2.9 | 16 | 5.5 | 10 | 3.4 |
| 4-8% | 1.0 | 8 | 8.0 | 3 | 3.0 |
| 8-20% | 0.2 | 0 | 0 | 0 | 0 |

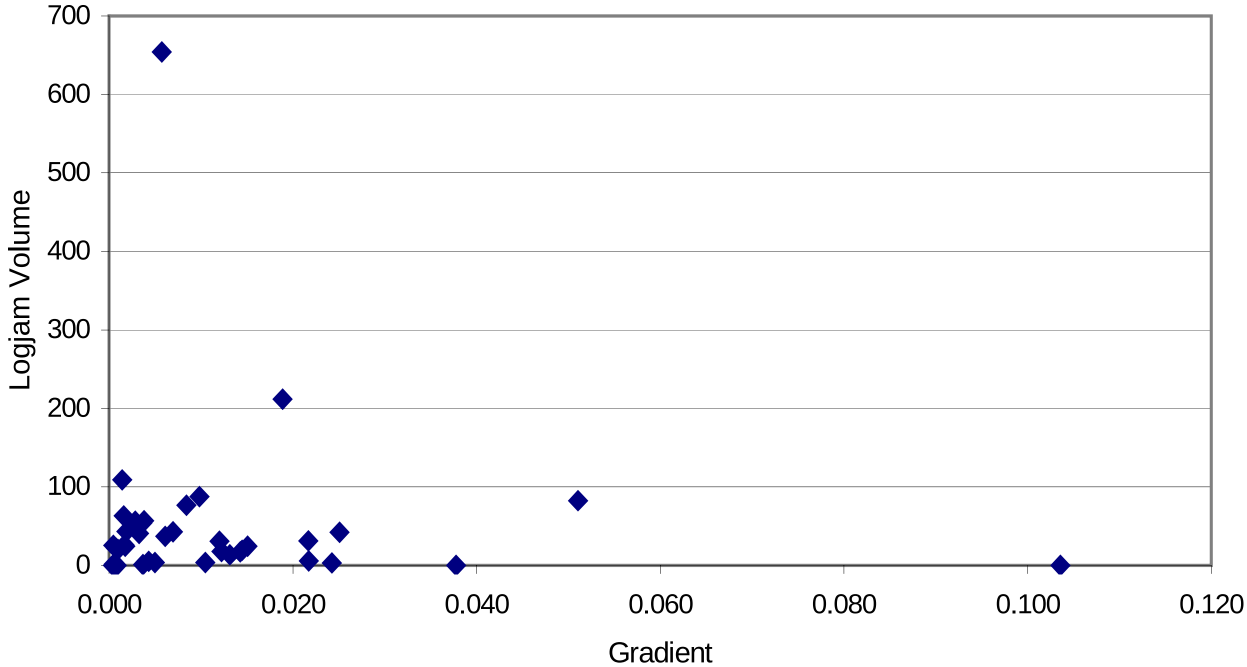


**Figure 41. Logjam volume and channel gradient in the South Fork Nooksack.**

The current relationship of logjams with gradient is consistent with the historic descriptions of massive logjams in the more downstream areas of the assessment reach, although this relationship differs for large pieces of wood (Sedell and Luchessa 1982). The current relationship between higher gradient and more instream wood may be because of the relationship between higher gradient and more large riparian trees, both occurring in the upper portion of the watershed, while historically, recruitment of large trees occurred through out the watershed.

Instream woody debris was compared to a Large Woody Debris Recruitment Potential rating for riparian stands along the mainstem South Fork channel (Duck Creek Associates 2000). The recruitment potential was defined according to stand characteristics, such as stand type, size, and density (WFPB 1997). Stands were classified as a 100-foot buffer on either side of the active channel or the channel migration zone where defined.

Based on these classifications, the mainstem of the South Fork Nooksack had the most degraded riparian conditions of the three forks, although it was in better condition than the mainstem Nooksack River (Table 17). In the South Fork Nooksack, the wood recruitment potential decreased from the headwaters to the mouth of the channel. For instance, no riparian areas with high recruitment potential were found along the mainstem South Fork below Saxon Bridge (RM 13) (Coe 2001). Conversely, most of the stand area classified as high occurred along the mainstem above the 200 Road Bridge (RM 24.8) (Coe 2001).

**Table 17. Comparison of percent of riparian stands adjacent to the main channel by wood recruitment potential class.**

| Wood Recruitment Potential | Geographic Area | | | | |
|---|---|---|---|---|---|
| | North Fork Nooksack | Middle Fork Nooksack | South Fork Nooksack | Upper Mainstem | Lower Mainstem |
| High | 50% | 37% | 25% | 0% | 0% |
| Moderate | 28% | 30% | 33% | 49% | 14% |
| Low | 22% | 33% | 42% | 51% | 86% |

Using a chi-squared goodness of fit test, it was determined that there is a relationship between recruitment potential and instream LWD in the South Fork, but no relationship between logjams and recruitment potential (Table 18 and Table 19).

**Table 18. Wood recruitment potential and *large pieces* in the South Fork Nooksack.**

| Recruitment Potential for Each Bank | South Fork Pieces/ Mile |
|---|---|
| High/ High | 8.89 |
| High/ Medium | 5.59 |
| High/ Low | 3.91 |
| Medium/ Medium | 1.71 |
| Medium/ Low | 1.40 |
| Low/ Low | 1.93 |

**Table 19. Wood recruitment potential and *logjams* in the South Fork Nooksack.**

| Recruitment Potential for Each Bank | South Fork Logjams/ Mile |
|---|---|
| High/ High | 4.99 |
| High/ Medium | 3.90 |
| High/ Low | 3.77 |
| Medium/ Medium | 3.22 |
| Medium/ Low | 4.93 |
| Low/ Low | 6.12 |

High resolution LiDAR aided in mapping and delineating mature trees for the portion of the South Fork Nooksack basin above Saxon Bridge (RM 12.8), where all of the high recruitment potential stands are located. Mature trees are defined by the 100-year site index from the Whatcom County Soil Survey (U.S. Department of Agriculture 1985). This index for Douglas fir indicates a 100-year-old tree would be approximately 150 feet tall. Based on this designation, less than 1% of the riparian management area along the mainstem of the South Fork above Skookum Creek is comprised of mature trees. In spite of this, 47% of the key-sized pieces in the area covered by LiDAR in the assessment area are within one average bankfull channel width (150 feet) of these larger trees. Key-sized logs in the channel appear closely related to the riparian and bank conditions immediately adjacent to their location and likely reflect local recruits from the mature riparian forest.

The high resolution DEM was also used to identify stands occupying areas that were likely to contribute wood to the channel. These areas were defined based on their elevation relative to the channel (less than 6 feet), their proximity to the channel and the lack of any impediments to channel migration (Figure 42). The 6-foot threshold was based on field mapping of the depth of easily eroded alluvium (commonly <2 meters) overlying the erosion-resistant glacial lake material that comprises the terraces. The results showed only 25 stands, ranging from 0.8 to 46 acres, likely contributing LWD to the channel. The total area of the likely stands was 181 acres, of which conifer trees dominated less than 10 acres, and no stands were composed of mature trees (Duck Creek Associates 2000).

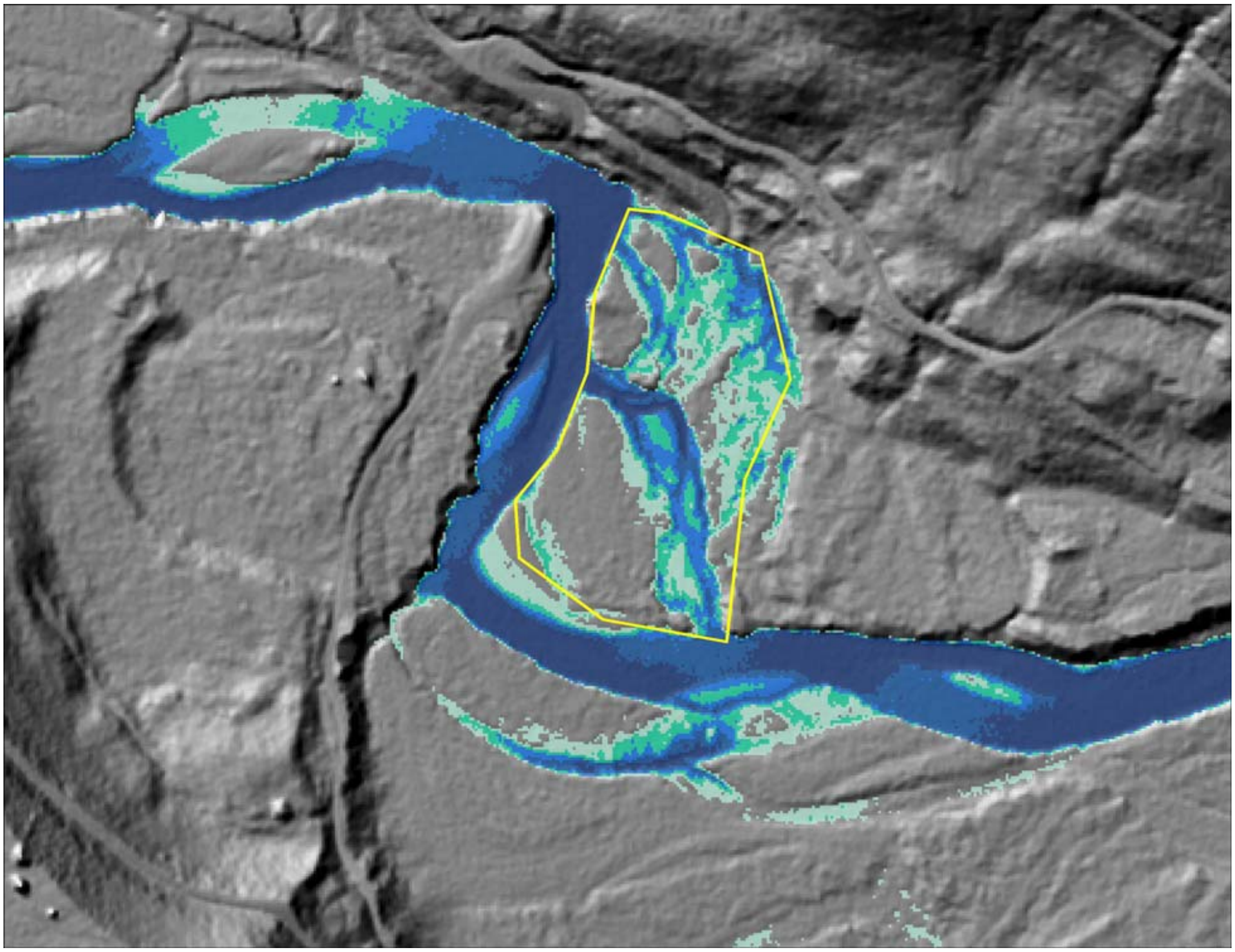

**Figure 42. Sample high priority wood recruitment stand based on elevation relative to the channel (darker blue is lower elevation).**

There appears to be a strong relationship between the recruitment potential of the riparian stands and the amount of large pieces in the channel adjacent to those stands. This implies that the presence of single large pieces of wood in the channel is more related to riparian and bank conditions than channel characteristics, such as confinement or gradient. Where recruitment potential is high and bank erosion not impaired by resistant native material, such as bedrock and landslide lag deposits, or bank protection, there are more large pieces in the channel.

In the South Fork Nooksack, the longitudinal distribution shows that 62% of key-sized pieces are above the partial anadromous barrier at RM 32 and 78% are above the partial barrier near RM 25. This implies that many of the habitat benefits created by large pieces of wood (pools, hiding cover, gravel sorting) are not realized by many of the anadromous species that live in the river. The abundance of wood in the channel is affected by both low recruitment rates from the riparian zone and rapid depletion from the channel due to transport and decay. Most of the recently recruited wood (all of the recently recruited large coniferous wood) was located in a 3.4-mile reach of the South Fork Nooksack downstream of Wanlick Creek. It is possible that the relative scarcity of large pieces means that logjams do not persist as long as they would with an abundance of large pieces in the channel. Most of the logjams mapped and characterized exhibit some indication of stability, although a higher percentage of those with large pieces appeared stable. It is likely that the presence of key-sized pieces increased the probability that a logjam would persist, although the majority appears to be stable regardless of the presence of key-sized pieces. These results suggest the need to protect wood recruitment areas from timber harvest (including unstable hillslopes adjacent to the channel), maximize the growth of riparian trees, and remove barriers to wood recruitment such as bank protection and stream-adjacent infrastructure.

## Water Quality

### *Temperature*

Water temperature is a critical element of salmon and trout habitat in WRIA-1. Salmonids, particularly those listed as threatened under the Endangered Species Act, need cold water to survive. Nooksack River chinook salmon, steelhead trout, and bull trout are listed as Threatened under the ESA. Of particular concern is the early chinook salmon in the Nooksack River's South Fork, as this population is included within the Puget Sound/Georgia Strait Evolutionary Significant Unit, and essential to the recovery of Puget Sound chinook. Recent spring chinook escapement has been extremely low; in 2005, 120 adult chinook returned to spawning grounds in the South Fork. Near lethal water temperatures in the summer are thought to be a limiting habitat factor to chinook and other salmonid species production. Criteria set forth by state water quality standards provide a standard to be met to assist us in restoring viable populations of endangered and threatened species (Table 20).

**Table 20. The higher end of the threshold temperature range beyond which mortality increases. *Denotes values based on 7-DAM.**

| *USEPA 2003* | | | | | |
|---|---|---|---|---|---|
| Species | Incubation | Emergence | Rearing | Adult Migration | Holding-Spawning |
| Salmon | 12.0 | 12.0 | 18.0 | 15.0 | 13.0 |
| Bull Trout | 9.0 | 9.0 | 12.0 | NA | 7.0 |
| Steelhead Trout | 12.0 | 12.0 | 12.0 | 19.0 | NA |
| | | | | | |
| *Hicks 2000** | | | | | |
| Species | Incubation | Emergence | Rearing | Adult Migration | Holding-Spawning |
| Chinook Salmon | 12.0 | 12.0 | 16.8 | 16.8 | 15.6 |
| Bull Trout | 6.5 | 6.5 | 12.0 | 17.0 | NA |
| | | | | | |
| *Bjornn & Reiser 1991* | | | | | |
| Species | Incubation | Emergence | Rearing | Adult Migration | Holding-Spawning |
| Spring Chinook Salmon | 14.4 | 14.4 | 15.6 | NA | 13.9 |
| Steelhead Trout | NA | NA | NA | NA | 9.4 |

Water temperature is a dynamic characteristic that varies temporally in the upper South Fork reach. Surface temperatures may differ from benthic temperatures in stream channels, as UV radiation can heat the upper layers of a water body, and groundwater discharge into the streambed can maintain cooler, lower layers.

Daily fluctuations of water temperature in the South Fork are common, as they correspond to changes in UV exposure and the natural rise and fall of ambient temperatures. The ability of the stream to buffer these changes depends on its location in the watershed, as well as surface area exposed to sunlight and watershed activities that may be impacting natural processes.

Temperature is limiting to salmonid production in the South Fork during the hot, low-flow summer and early fall months, primarily July through October (Mobrand 2003). This period coincides with the presence of adult chinook migrating up and holding in the river until ready to spawn, actively spawning adults, and the incubating egg life stages. Optimum temperatures for salmonids vary among species and life stages (Table 20). The reach between Skookum Creek (RM 14.1) and the 200-Road Bridge (RM 25.2) is where the South Fork chinook population is most severely impacted by high water temperatures because this is where most of the population spawns, holds and incubates.

Likely the largest impact to water temperature in the upper South Fork was the historic harvest of the riparian zone. Analysis of the current riparian stand conditions showed less than 1% of the remaining trees were mature based on the local soil site class. These mature trees were often located in the inaccessible bedrock canyons where topography provides the bulk of the shading to the channel. Improved management should allow for the natural recovery of the riparian system, although poor site conditions limit the growth of conifers in large portions of the watershed. In the uppermost reaches of the watershed, unharvested riparian trees often have a diameter less than 40" and height less than 150 feet.

Shade modeling of the current conditions through the upper South Fork showed that during the middle of the day the active channel was only 15-25% shaded (Figure 43). The current conditions were then compared to the percent of the channel shaded under mature riparian conditions. For the projected sun angle and azimuth for August 21st, the results showed a striking difference between the current shade level and the shade provided by a mature riparian ecosystem (Figure 44). By comparing the area of the active channel shaded under each scenario, it is possible to identify the reaches that have been most heavily impacted by riparian harvest and identify priority stands for riparian improvement opportunities.

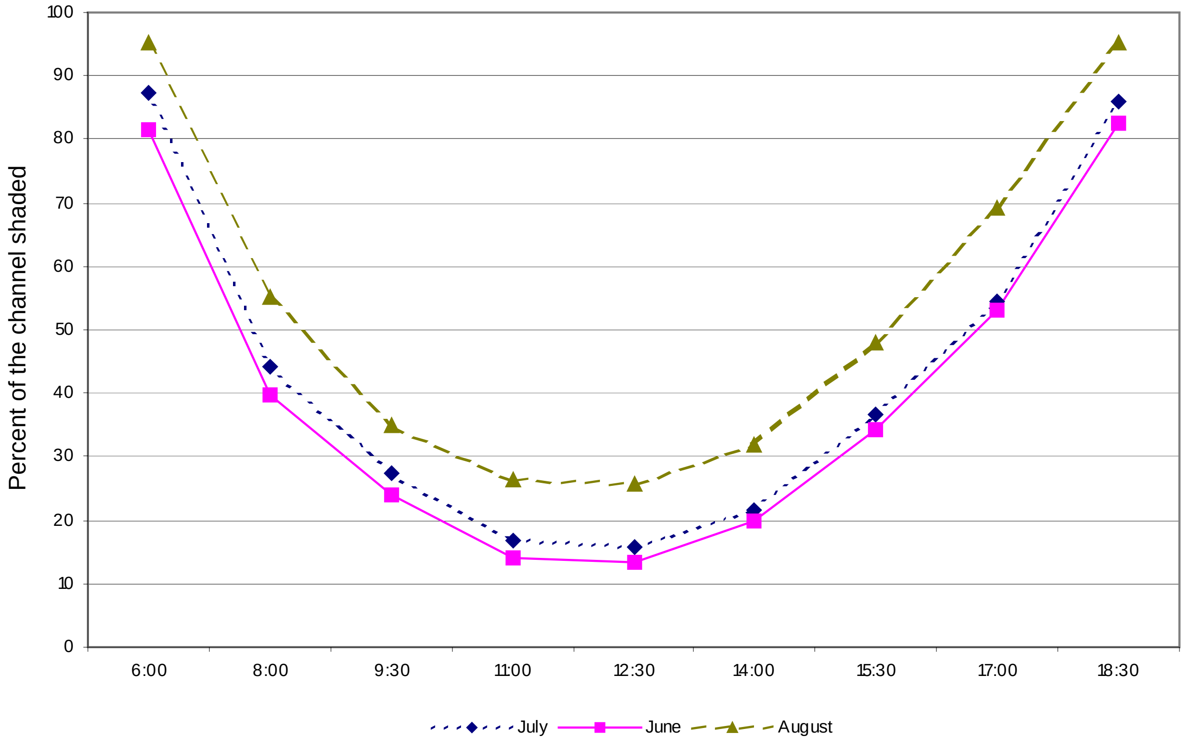


**Figure 43: Shade modeling of the current riparian conditions in the upper South Fork watershed.**

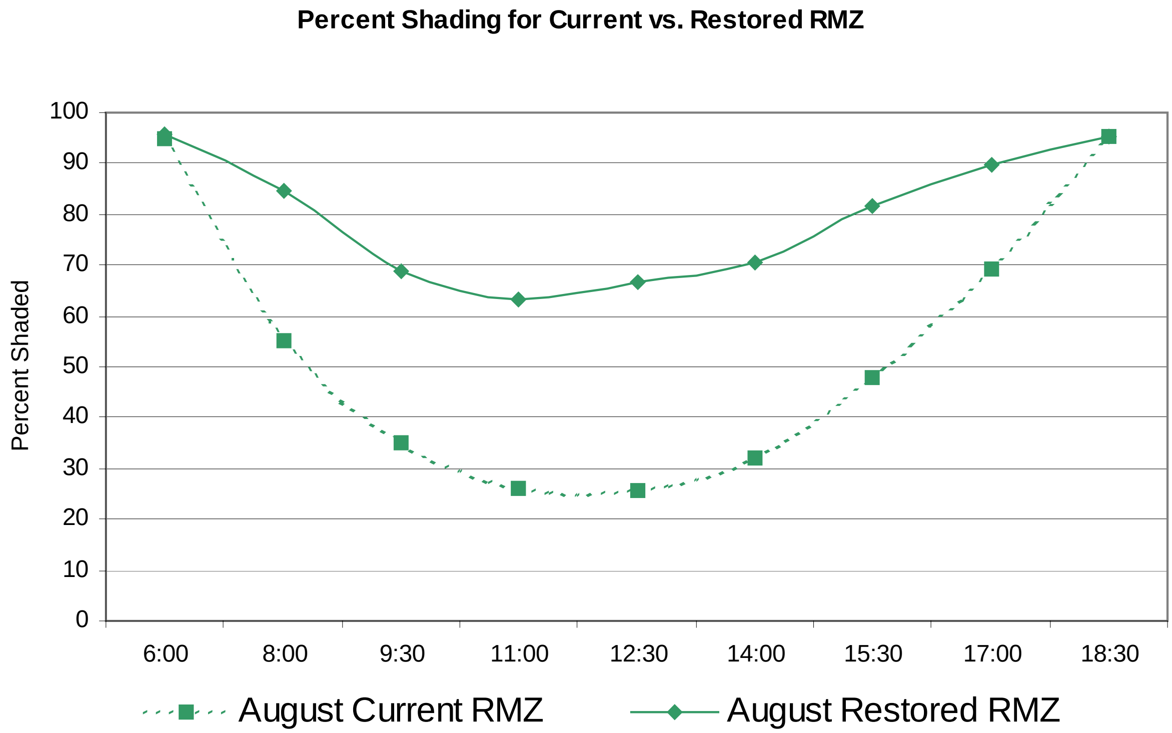


**Figure 44: South Fork channel shading under current and mature riparian forest conditions.**

The increase in stream heating likely associated with the loss of shade is probably exacerbated by the lack of cooler water inflow to the channel. Due to the long history of channel incision and sediment evacuation from the valley, the South Fork Nooksack upstream of RM 20 lacks deep alluvial fill that interacts with the channel and can store water and provide cooler water discharge to the channel during low flow periods. Summer stream flow commonly drops below 100 cfs in the South Fork during the summer months reflecting the lack of water storage in the basin. The thin depth of alluvium in the active channel reduces the opportunity for groundwater- surface water interaction and likely reduces the cooling effect on the channel that this interaction can provide.

Elevated temperatures can adversely affect salmonid development and survival in many ways. Since salmon are poikilotherms, they do best in habitat that maintains cool, stable temperature regimes. The preferred temperature range for spring chinook growth and development is 10 – 19.1°C (McCullough 1999). Extreme temperatures on either end of salmonid temperature ranges impart negative impacts on development and survival. Growth is reduced at low temperatures, due to the slowing of metabolic processes. Salmonid development ceases at high temperatures because food must be used for maintenance rather than maturation (Bjornn and Reiser 1991). Compromised by temperature extremes, salmonids are more susceptible to predation and disease, and may alter metabolism, maturation, feeding, and other natural behaviors in their effort to survive (Spence et al. 1996).

High temperatures can delay or prevent migration upstream, which can affect spatial structure of the spawning grounds by disrupting distributional patterns of redds. High temperatures can also stress holding and spawning fish, which may increase their vulnerability to disease and pre-spawn mortality. In addition, increased temperatures are known to disrupt riverine food web processes, which can affect the diet of rearing salmonids that is highly dependent on invertebrate production. McCullough (1999) found that temperatures of 21.0°C must be avoided because they represent thermal blockages (Figure 45) and are near the adult upper incipient lethal temperature, described as 26.2°C for chinook salmon by Brett (1952), and as 25.0°C by Torgersen (et al. 1998).

The effects temperature can have on gamete maturation in returning adult salmon and on embryo development and survival rates are well documented in literature. Studies show that when adult fish are exposed to constant or average temperatures above 13 – 15°C during the final leg of upstream migration or during holding prior to spawning, there is a detrimental effect on the size, number, and viability of eggs held by females (Hicks 2002; EPA 2001, in NOAA 2003). It is preferable for spring chinook adults to enter their natal streams when water temperatures are between 3.3-13.3°C (Figure 45). Temperatures lower than 16.0°C at the time of egg maturation in holding females are essential for maximum egg viability and the initiation of spawning activities (McCullough 1999).

Eggs are the most temperature-sensitive salmonid life stage (Hicks 2000). The upper temperature limit for 50% egg mortality in most salmonids is 16.0°C (Alderice and Velsen 1978, cited in Healey 1991). Prolonged high autumn temperatures or early spring warming can result in early emergence, and therefore, mortality. Reduced egg survival may result in earlier fry emergence and an amplified exposure of fry (for the early spawning species including spring chinook, sockeye, and pink salmon), to larger floods that tend to occur during their emergence periods. Early emergence may lead to involuntary downstream displacement from natal habitats, and reduce growth rates if fry emergence is desynchronized from insect hatches that support rapid fish growth in spring and early summer (Spence et al. 1996).

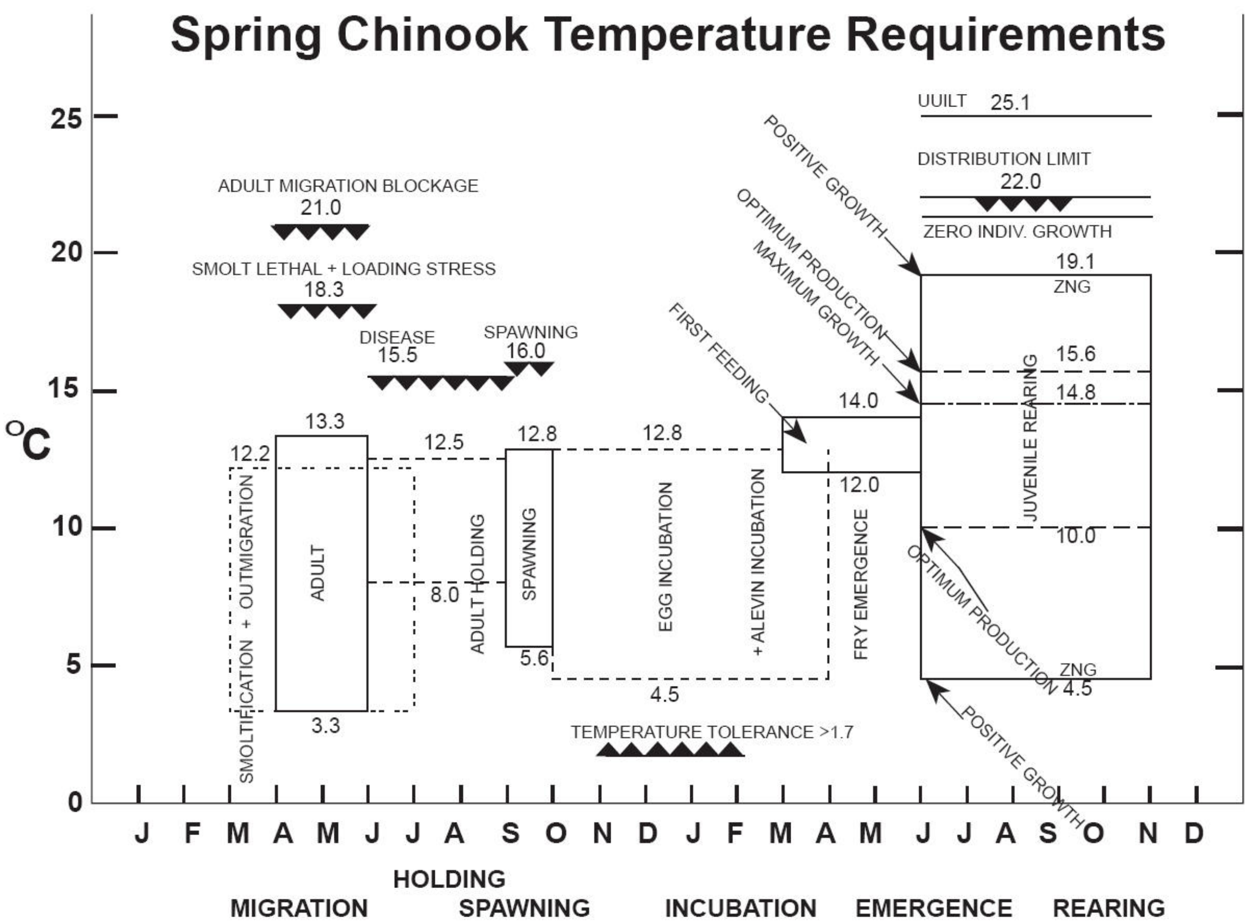


**Figure 45. Spring chinook life stage temperature requirements from McCullough (1999).**

Temperature data in this assessment are expressed as daily average maximums averaged over seven-day periods. The 7-day average maximum (7-DAM) [in contrast to the daily maximum (1-DM)] is the water quality standard unit used for temperature analysis of fish habitat that best reflects the potential for fish to respond to changes in water temperature. For example, fish can often endure one day of 24°C water temperatures by eating more or moving into zones of cooler water. However, if the water temperature peaks at 24°C for a week, these survival strategies become less effective (Runyon et al. 2003).

The upper end of the optimal temperature range for migrating adult chinook salmon ranges between 14.2 – 16.8°C; for bull trout it ranges between 14.0 – 17.0°C (Table 20). The 7-DAM's upper end of the optimal temperature range for egg incubation for chinook falls between 11.0 – 12.0°C; bull trout egg incubation requires temperatures at or below 6.5°C (Hicks 2000). Bull trout have among the lowest upper thermal limits and growth optima of North American salmonids (Selong et al. 2001). Considering these limits and the life stage requirements of spring chinook described in Figure 45, NOAA (2003) proposed to lower the temperature standard set for surface water quality in Washington State for spawning and rearing salmon, steelhead, and trout from 16°C to 13°C. The Washington State water quality standards now reflect this 13°C minimum for geographic areas used by salmon or steelhead for spawning or incubation during the summer months when a reduction of water quality occurs.

High water temperature in the South Fork is more commonly limiting to salmon production than low water temperature. Water temperature in the upper South Fork regularly exceeds the optimal range for life stages present during the summer season (Figure 46). High temperature decreases the maximum amount of oxygen that can be dissolved in the water. This can lead to oxygen stress if the water is receiving high loads of organic matter or aeration of water is insufficient. Water temperature fluctuations in streams may be further exacerbated by reduced shade and by increased absorption of heat due to elevated water turbidity.

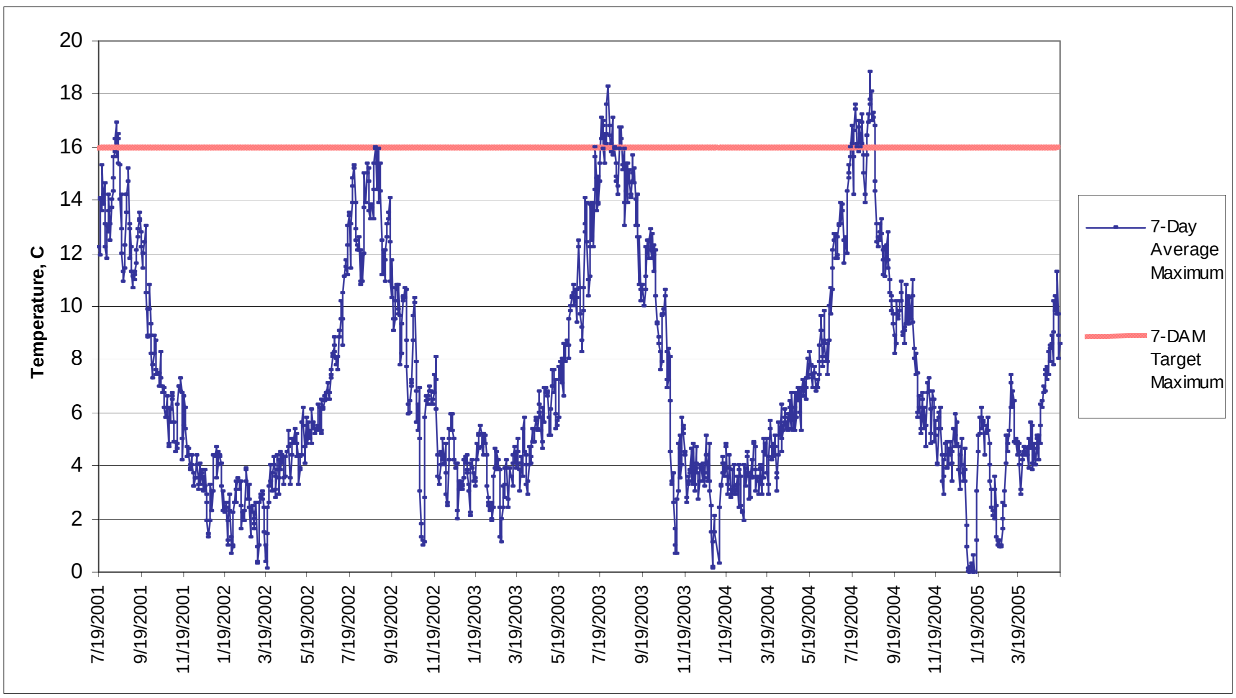


**Figure 46. Temperatures recorded at the USGS –12209000 gage (RM 14.8) between 2001-2005. The 7-DAM target maximum temperature for adult chinook holding and spawning as determined by Hicks (2000) and McCullough (1999).**

The period between late June and early October presents the most stressful water quality conditions for salmonids in the South Fork (Figure 46). Unfortunately, the species most at risk in the South Fork reside here during this period. It is the season where chinook sub-zero age fish, sub-yearlings preparing to reside over summer, and yearling juveniles rearing to smolt are present, as well as adults attempting to migrate, hold, and spawn where they can find suitable habitat. Most early-timed chinook redds are built near the end of September, as temperatures begin to decrease.

The long period of elevated water temperature during key life history phases for ESA-listed chinook, steelhead, and bull trout has lead to a strategy of identifying where cooler water refuge areas are located for the fish use to avoid stress and possible diseases associated with warm water.  Once located, the refugia may be developed to accommodate more fish or improve existing water conditions when possible. Refuge areas in the upper South Fork are usually tied to the mixing zones of cold tributaries and the main channel; groundwater seeps, or reaches with decreasing water temperatures (Figure 47).

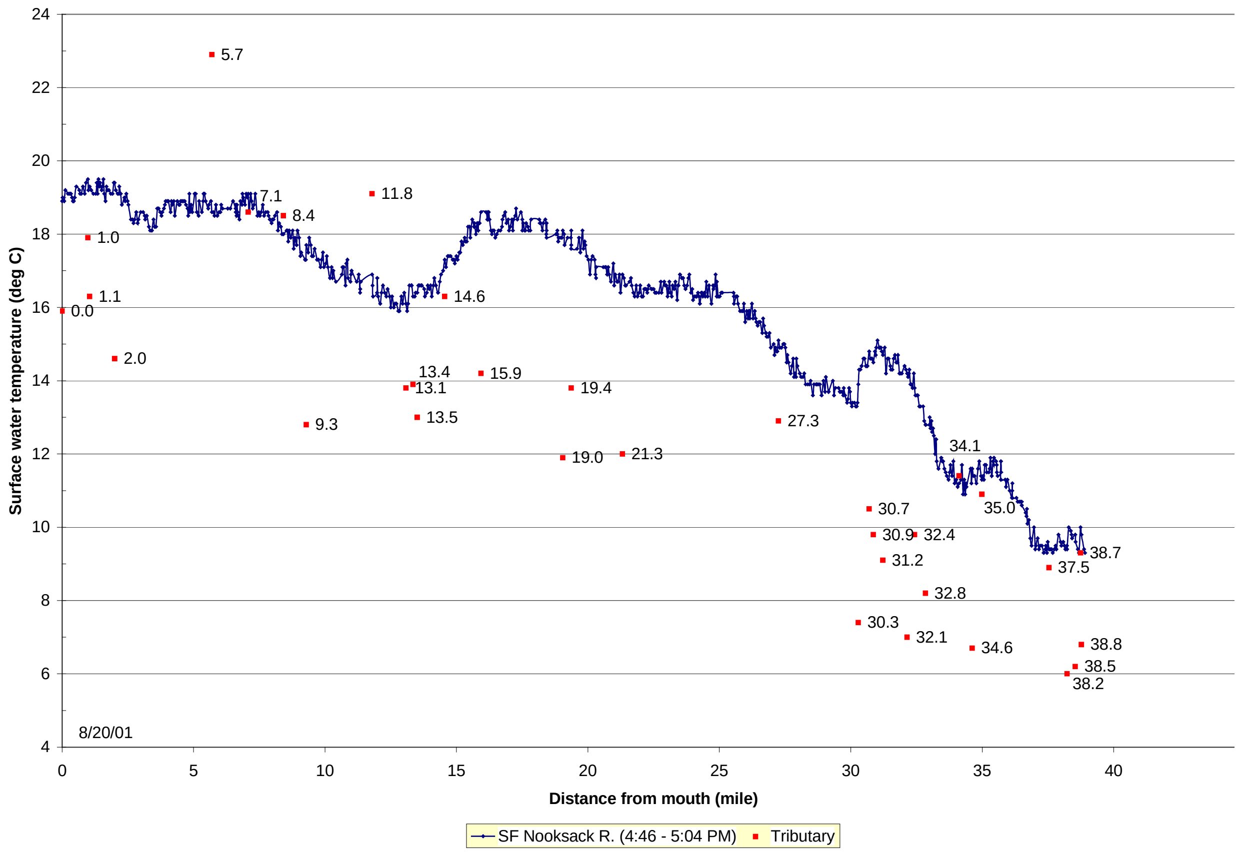


**Figure 47: Longitudinal surface water temperature profile of the South Fork Nooksack showing river mile of cooler water tributaries entering the channel.**

**Table 21.  The percent of summer days between August 1 and Oct 1 over 12.5°C (7-DAM) at USGS–12209000 gage (RM 14.8)*.**

| | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
|---|---|---|---|---|---|---|
| *Percent Days over Ideal Chinook Holding Temperature (McCullough 1999)* | 96.7 | 96.7 | 88.5 | 78.7 | 95.1 | 95.1* |

*Verified by USGS.

### Potential Temperature Refuges Sampled

Longitudinal profiles of summer water temperatures in the South Fork were created from surface temperature data obtained from an aerial flight on August 20, 2001, around 5:00pm, just before the summertime daily maximum temperature was recorded at the USGS-12209000 gage. A thermal forward-looking infrared (FLIR) sensor captured thermal conditions. Representations of surface water temperatures were delineated by color ramping, revealing variation in temperature along the channel in low-flow conditions. The images were converted to raster files and entered into a GIS database. Analysis of the images in GIS identified the location of areas that apparently maintained temperatures significantly cooler than the main channel flow.

FLIR analysis revealed that the South Fork channel exhibits a diversity of surface water temperatures throughout the upper and lower reaches, cooling, warming, and cooling again as flow is distributed downstream. From the hundreds of snapshots FLIR produced from surface temperature data, we identified more than twenty areas in the upper South Fork channel that had potential to provide salmonids relief from high summer temperatures. We narrowed our scope to six sampling sites (Figure 48) for field verification under the premise that they would maintain cooler temperatures and less daily fluctuation during chinook holding and spawning windows.

Our hypothesis was that benthic temperatures in these specific refuge areas would remain cool over the summer. Using continuous temperature monitors, we found potential thermal refuges in several of our sampling sites that maintained temperatures at or below the upper end (12.5°C) of the optimal temperature range for chinook in the holding life stage (McCullough 1999). However, these refuges were often located at the confluence of spring-fed, disconnected side channels or tributaries with the river, in areas with little or no cover for adult life stage salmonids. These cool areas, referred to as temperature refuges, were ranked based on: 1) observed surface temperature described by FLIR data; 2) distance from known spawning activity; 3) habitat type of suspected refuge; 4) feasibility of restoration project development in the area and 5) accessibility to the site, for frequent monitoring of equipment and downloading of data. This information, along with historical geospatial chinook spawning records, determined priority sites for finer-scale data collection. Descriptions and important data analyses for each site are described below.

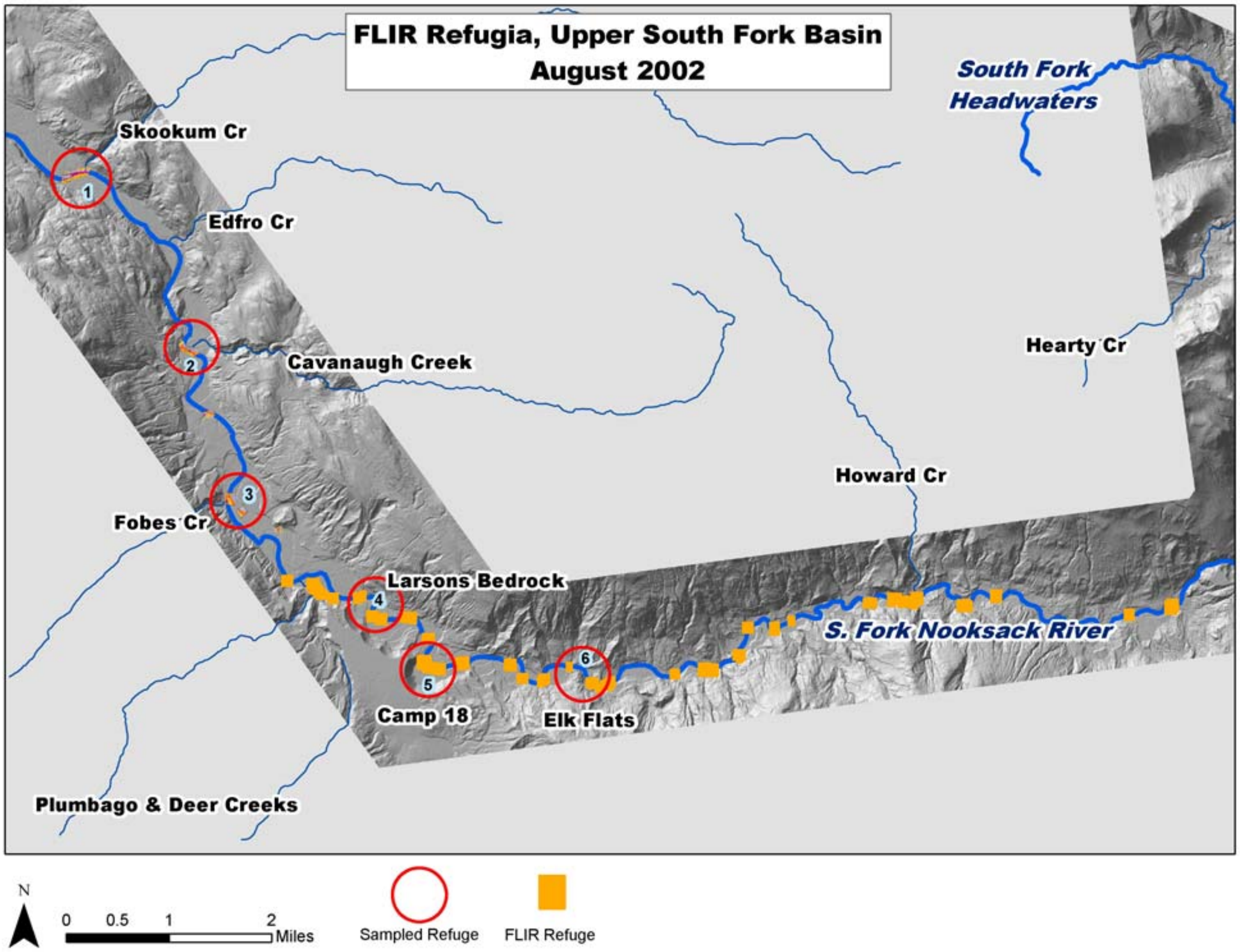


**Figure 48. Potential cold water refugia identified by FLIR data analysis, and the six sites selected for the paired-probe temperature study.**

**Skookum Creek**
Skookum Creek flows are known to be significantly cooler than the river in the summer, creating a temperature refuge for fish not only in the creek itself, but also in its mixing zones with the river. Three water temperature data loggers were deployed at this site. Since this was the most downstream site of our assessment, an air temperature logger was also deployed here.

The control data logger that was recording the temperature in the main channel was located about 400 feet above the confluence of Skookum Creek and the South Fork channel (Figure 49). One logger was deployed in the mixing zone (plume) of Skookum Creek with the South Fork, on the right bank of the river. The Lummi Nation operates a salmon hatchery along the river at Skookum Creek. Water diverted from Skookum Creek flows into the hatchery and out into the South Fork through a culvert that enters the river on the right bank. The third logger was deployed on the right bank in the mixing zone of the Skookum Creek Hatchery outfall with the South Fork.

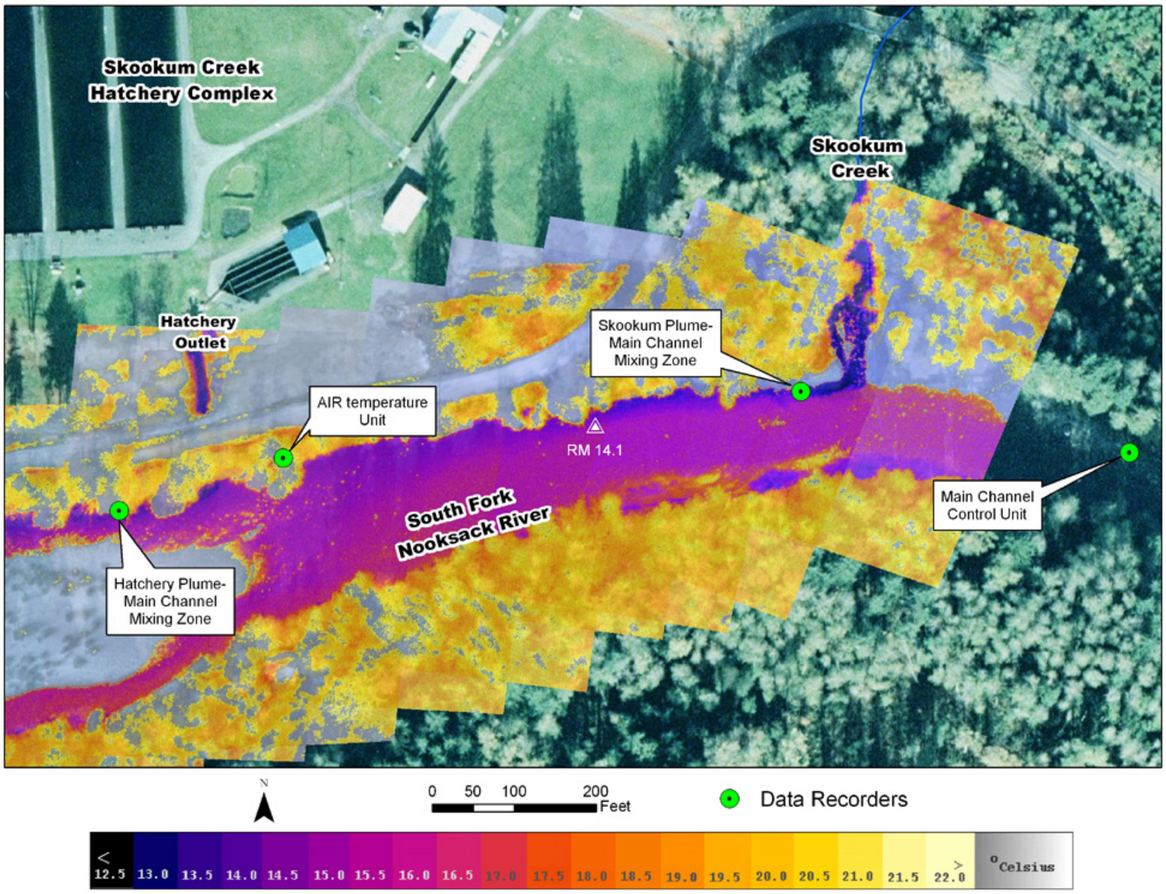


**Figure 49. The Skookum Creek study site, with surface temperatures delineated by FLIR, and the locations of paired temperature data loggers.**

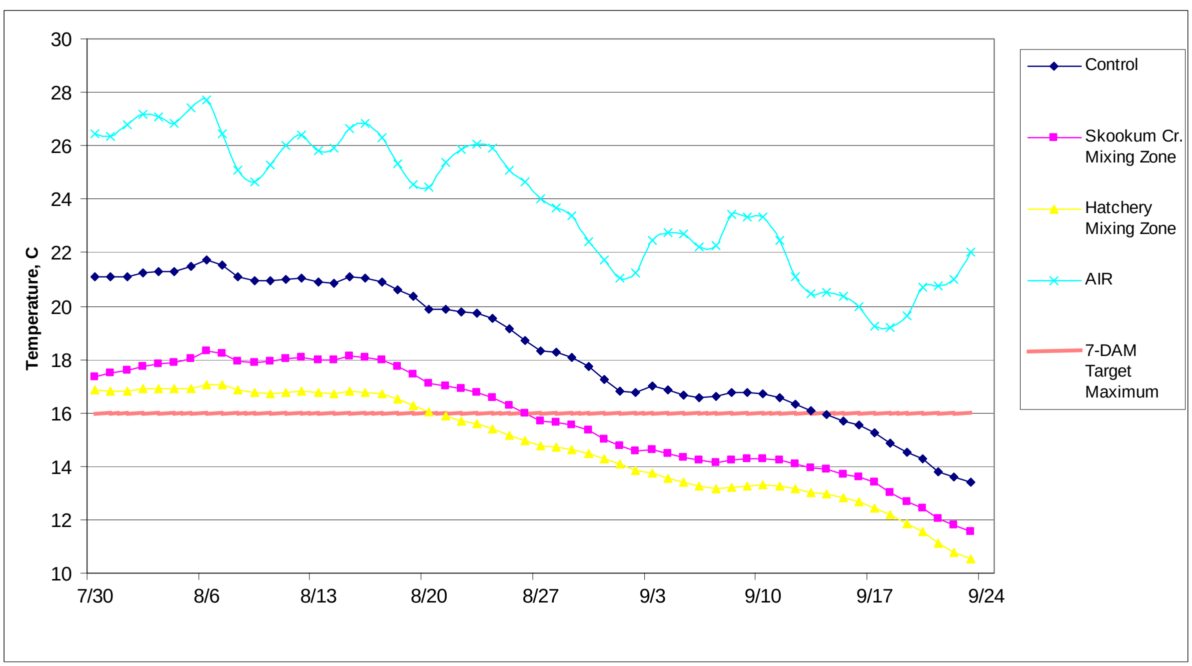


**Figure 50. 7-DAM data from the Skookum Creek monitoring sites in 2005. The 7-DAM target maximum temperature for adult chinook holding and spawning as determined by Hicks (2000) and McCullough (1999).**

The contribution of Skookum Creek and the Skookum Creek Hatchery outfall flows to the South Fork Nooksack River create areas along the right bank where temperatures are consistently cooler than those in the main channel (Figure 50). The 7-DAM of the mixing zones (plumes) climbs above the upper optimum range for holding adult chinook, yet stays lower than the main channel temperature. The temperatures recorded in the plume mixing zones were consistently between 1.8 and 4.7°C lower than those recorded in the main channel by the control probes. The plumes in this reach provided fish lower stress environments than the main channel did.

The statistics for the Skookum Creek site data loggers indicate that cool temperatures are maintained in the mixing zones of both the stream and the hatchery outfall toward the end of early-timed chinook migration and spawning period. Stream temperatures in the Skookum Creek reach followed a trend of cooling after early August. Water temperatures reflected changes in ambient temperature, until mid-September, when the two groups diverged; water continued to decrease as air warmed several degrees. Early September marked the start of ideal holding life stage water quality in both mixing zone areas, creating a month-long window near this site for spring chinook spawning activity. Decreases in temperature may be attributed to shorter day lengths and lower sun angles projecting onto the river's surface.

**Cavanaugh Creek**

Summer flows in the South Fork's tributary streams are considerably cooler than waters in the main channel; Cavanaugh Creek is no exception. FLIR analysis placed this stream and the immediate area downstream of its confluence with the main channel into one of the cooler temperature refuge groups. Four data loggers were launched at this site: one control unit upstream of the tributary, one directly in the tributary-main channel mixing zone, one opposite the mixing zone, and one downstream to investigate a possible seep that showed up in the FLIR data (Figure 51).

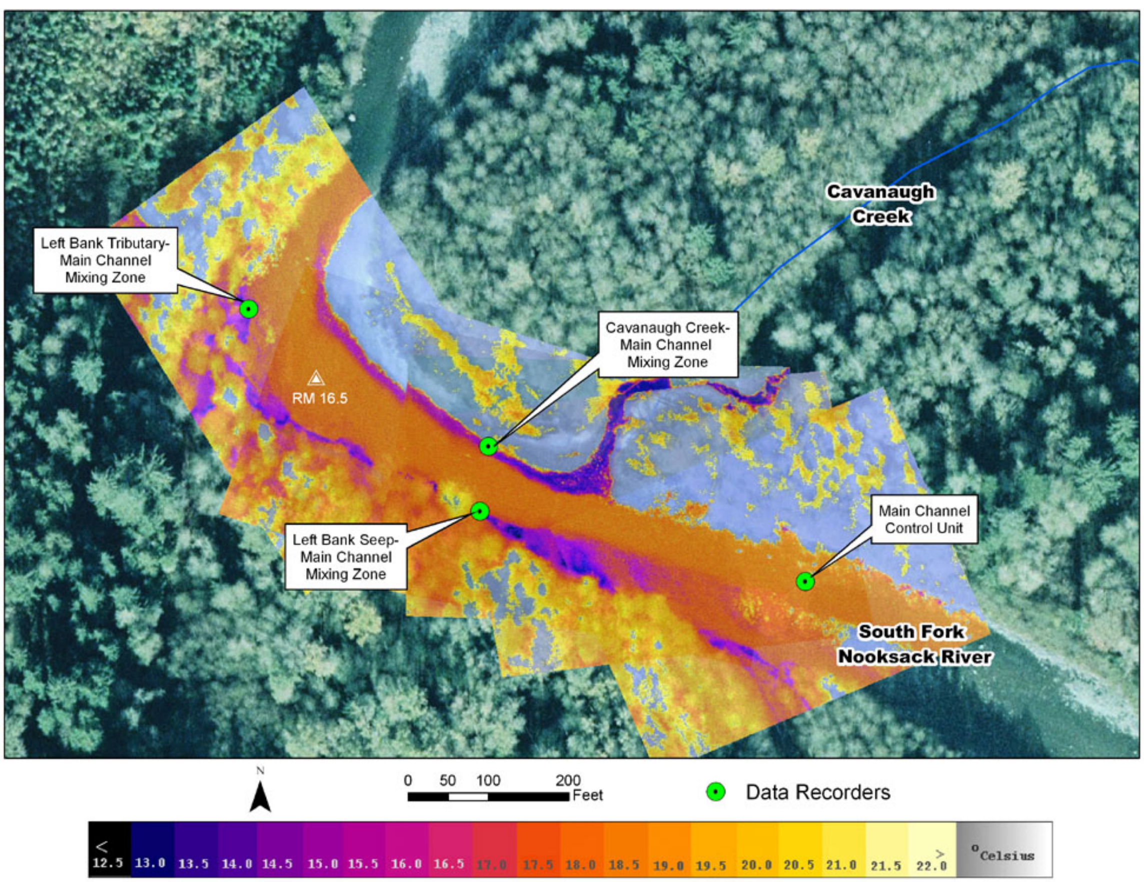


**Figure 51. Paired temperature data recorders and the FLIR surface water temperature profile at the Cavanaugh Creek site.**

The area near the confluence of Cavanaugh Creek and the main river channel was the coolest area of the three tested at this site (Figure 52). Although historic temperature data collected in the tributary stream itself describe ideal conditions for chinook production, current data indicate that the monitored sites did not sustain cold water habitat throughout the summer.

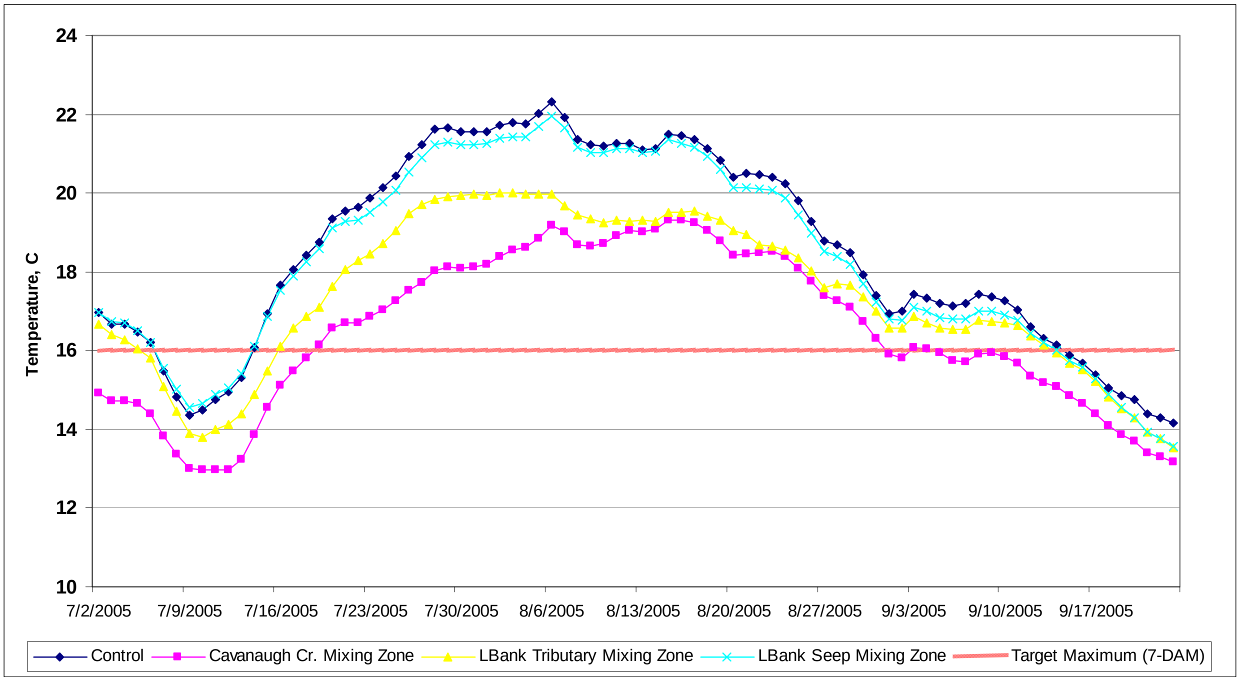


**Figure 52. 7-DAM data from the Cavanaugh Creek area monitoring sites in 2005. The 7-DAM target maximum temperature for adult chinook holding and spawning as determined by Hicks (2000) and McCullough (1999).**

## Fobes Creek

The mixing zone of Fobes Creek with the South Fork main channel kept edge habitat ideally cool during most of the summer (Figure 54). A two-week period of increased temperature in the plume occurred, but values did not exceed 18°C, and refuge was most likely possible in the tributary itself during this time.

FLIR analysis revealed that Fobes Creek may serve salmonids in need of cooler water during the summer (Figure 53). In the FLIR images, the mouth of Fobes Creek displayed temperatures in the 11-12°C range, mixing with main channel temperatures that were in the 18-19°C range. The duration of cool water temperatures in the Fobes Creek mixing zone may provide potential restoration opportunities to improve thermal refuge. This area of the South Fork holds potential for habitat development for summertime rearing and migrating salmonids, and is ranked near the top of all sites studied for project design possibilities.

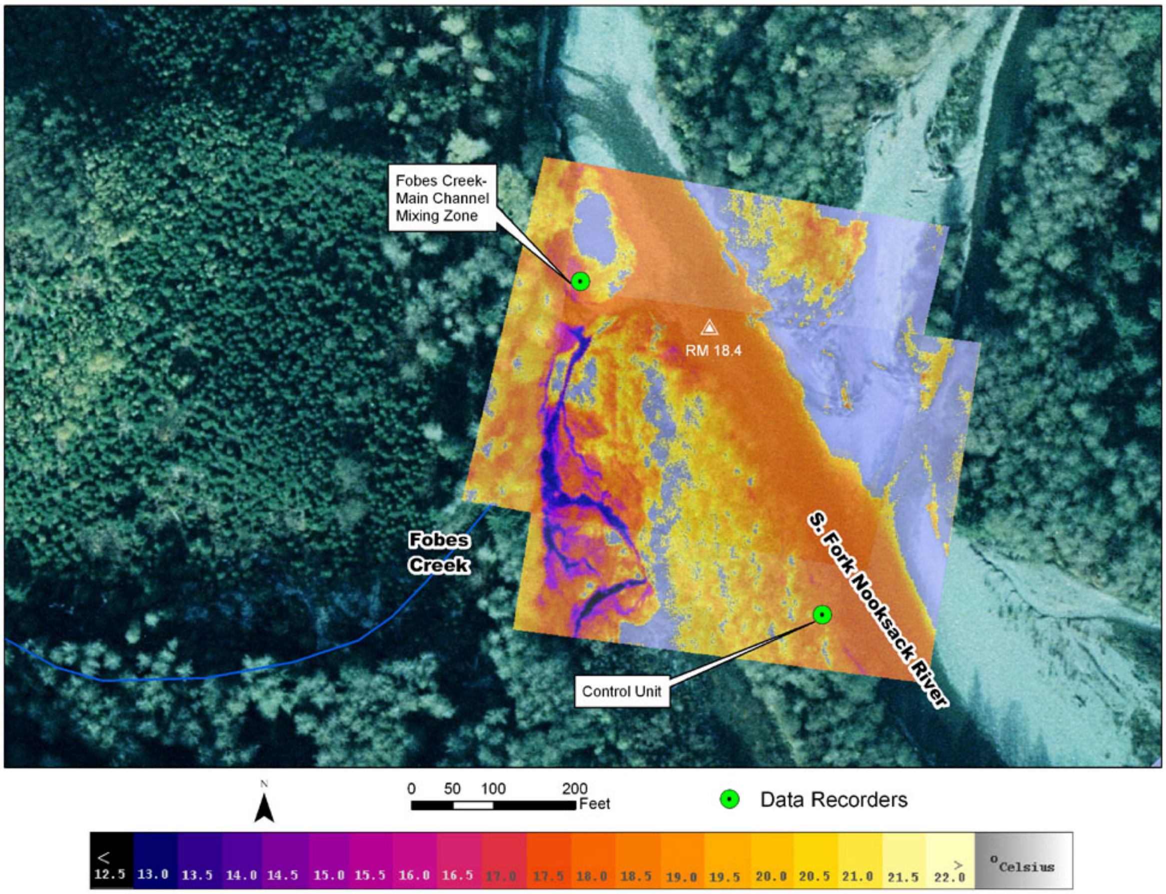


**Figure 53. Paired temperature data recorder locations and the FLIR surface water temperature profile at the Fobes Creek site.**

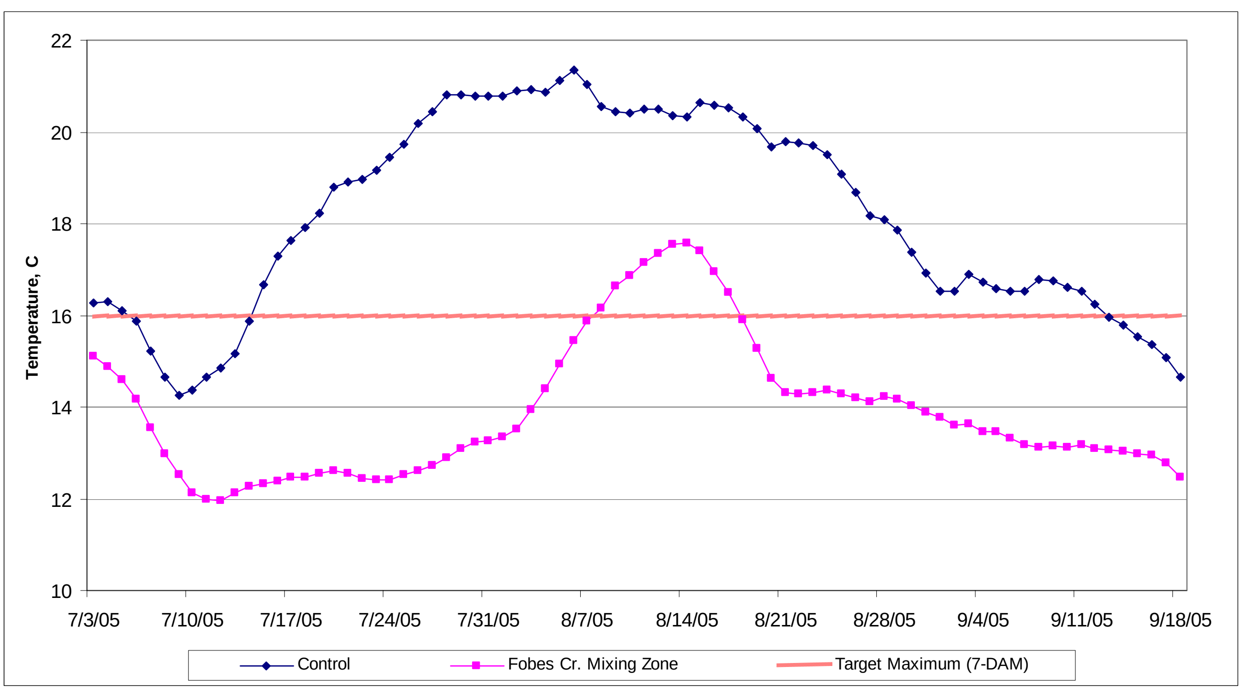


**Figure 54. 7-DAM data from the Fobes Creek area monitoring sites. The 7-DAM target maximum temperature for adult chinook holding and spawning as determined by Hicks (2000) and McCullough (1999).**

**Larson's Bridge Bedrock**

The Larson's Bridge temperature testing site is immediately upstream of both a large, engineered logjam built as a key member in a 2002 habitat restoration project, and significant historic chinook spawning grounds. In addition to the control unit, three data loggers were launched at this site. FLIR analysis detected the presence of cold water in a side channel off of the left bank, so we placed a logger there, anticipating year-round submersion and temperature relief (Figure 55). Additionally, loggers were placed in a possible seep on the left bank, and at the mouth of a tributary where it mixes with the main channel. Overhanging bedrock provides cover for salmon directly downstream from the sampling site, although near bank temperatures here rise with those observed in the main channel. The idea of a project to enhance holding habitat in and around the area prompted us to select this site for monitoring.

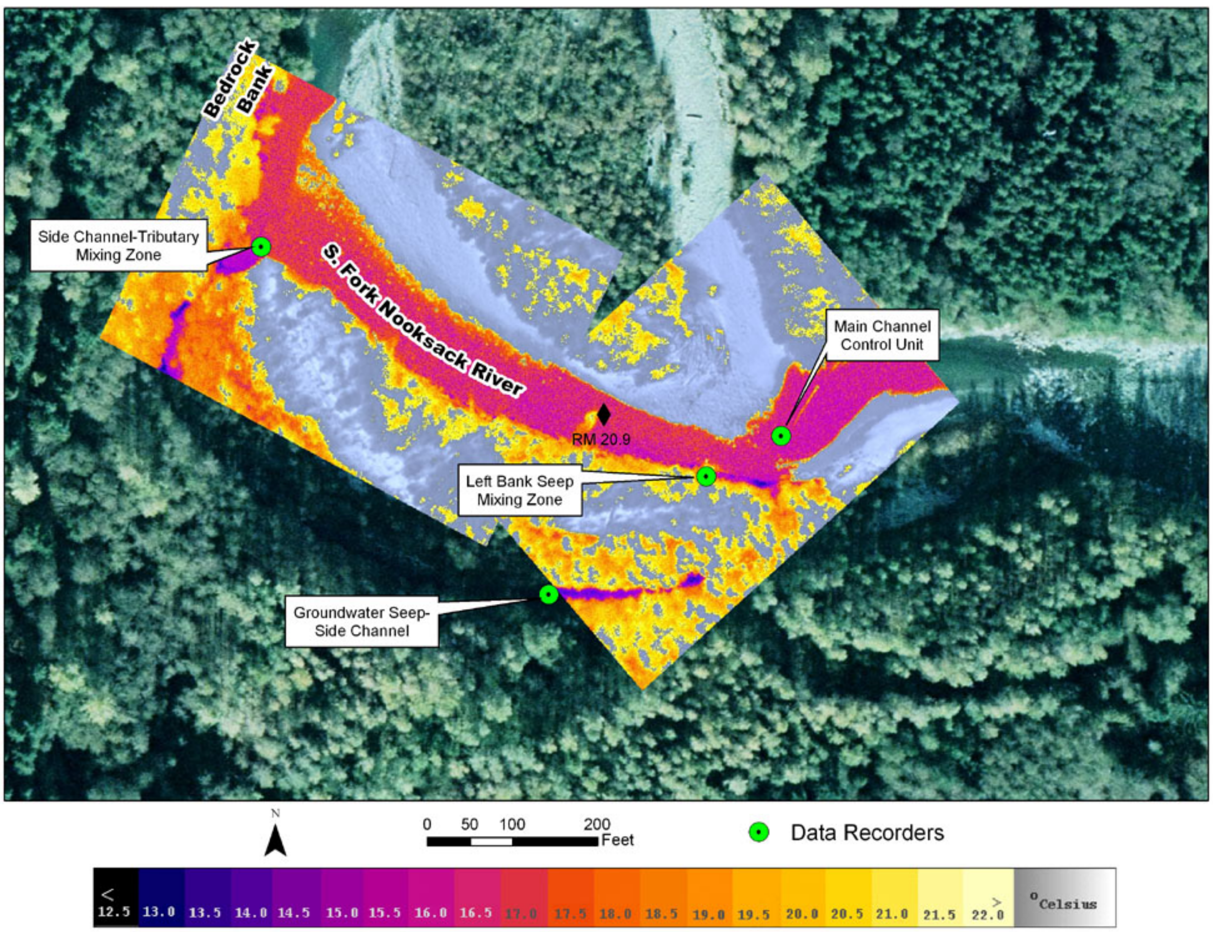


**Figure 55. Paired temperature data recorder locations and the FLIR surface water temperature profile at the Larson's Bedrock site.**

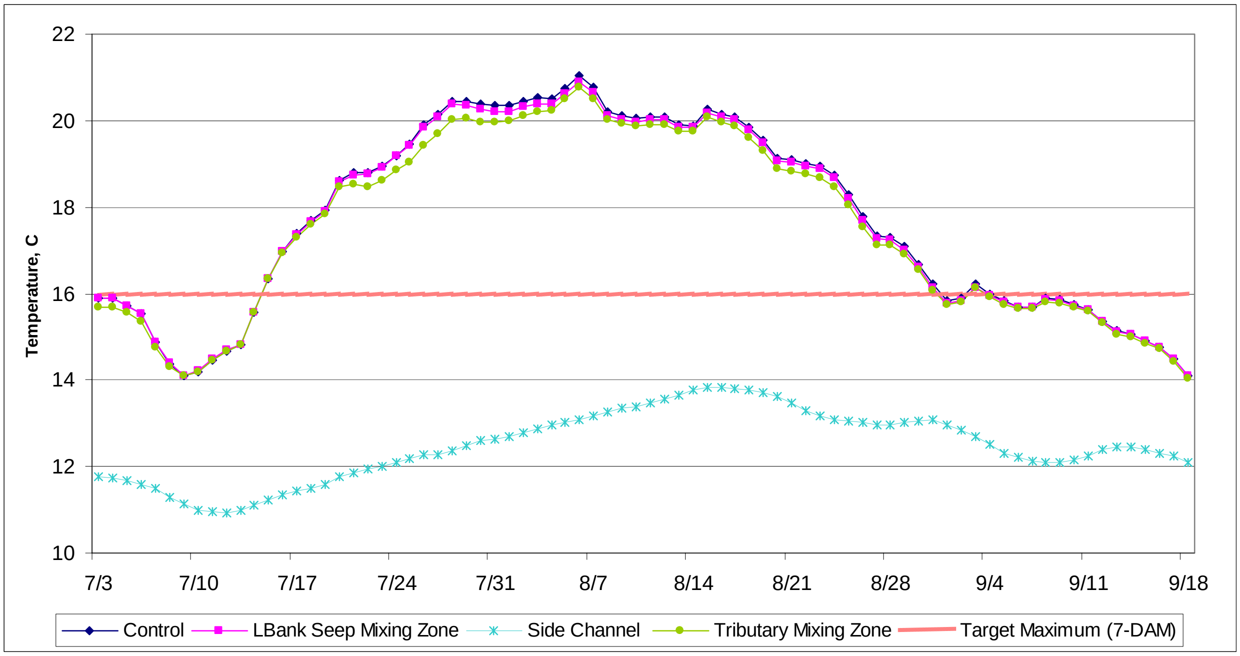


**Figure 56. 7-DAM data from the Larson's area monitoring sites. The 7-DAM target maximum temperature for adult chinook holding and spawning as determined by Hicks (2000) and McCullough (1999).**

Data collected at the Larson's Bedrock site revealed that temperatures in the side channel remained below 14°C for most of the summer (Figure 56). This is within the optimum range for adult chinook holding and spawning. The two test sites located in the mixing zones of the main channel with a left bank seep and a left bank tributary followed the temperature pattern of the main channel very closely. Less than 0.2°C separated the average 7-DAM temperatures of the two left bank sites from the main channel site. Conversely, the side channel habitat studied at the Larson's Bedrock site maintains favorable summertime temperatures for chinook salmon in all life stages. Data at this site averaged 5.2°C lower than temperatures recorded in the main channel at the control site. The side channel habitat monitored at this site features good riparian cover for shading.

**Camp 18**

This site is located just upstream of the Larson's site and is named after the old railroad logging camp that sits above it. FLIR detected cold water areas along the left bank of the main channel, indicating the presence of possible seeps entering the channel that may lower temperatures in the South Fork. Upon further investigation, we found a tributary channel draining side channel floodplain that feeds cold water into the South Fork. Data loggers were placed in the seep just downstream from the control logger and at the mouth of the tributary channel, in the main channel-tributary mixing zone (Figure 57).

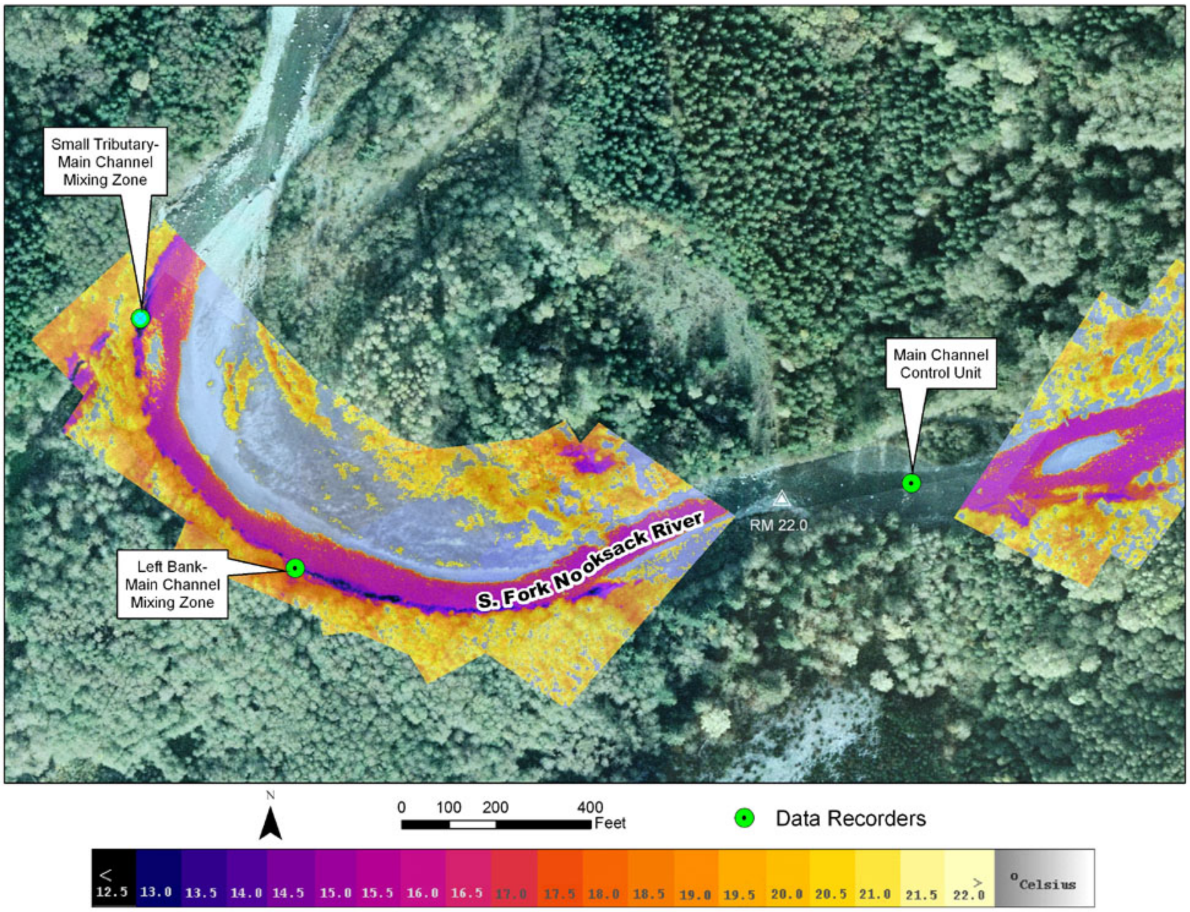


**Figure 57. Paired temperature data recorder locations and the FLIR surface water temperature profile at the Camp 18 study site.**

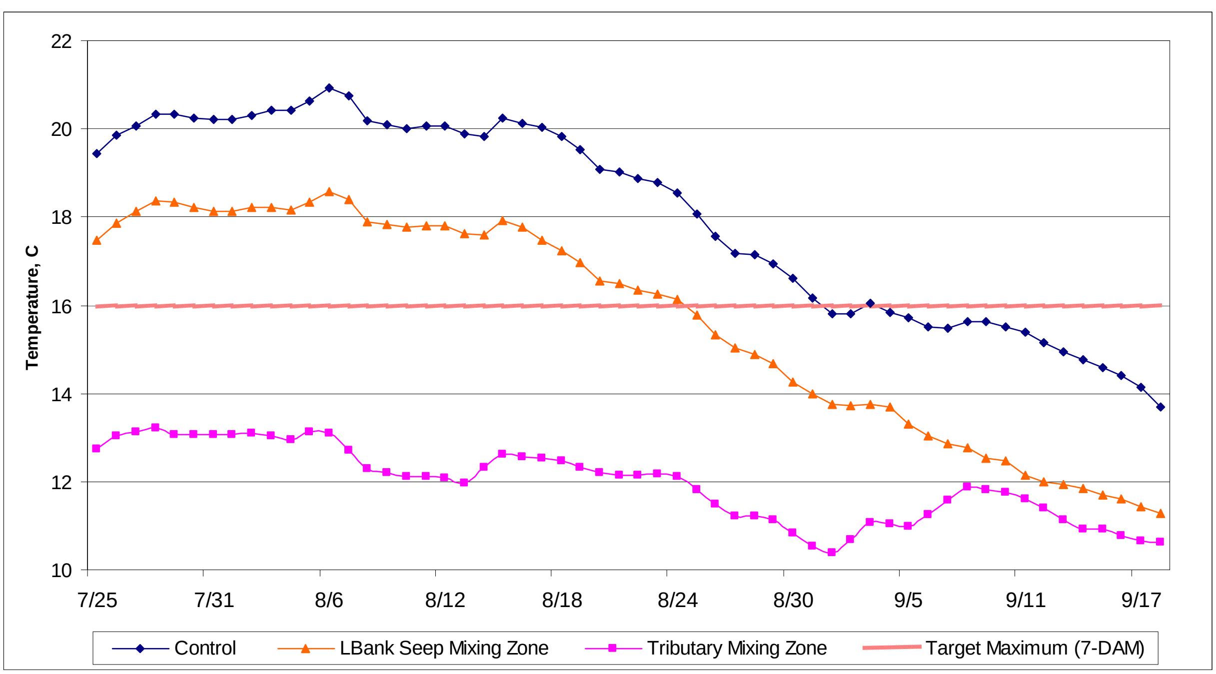


**Figure 58. 7-DAM data from the Camp 18 monitoring sites. The 7-DAM target maximum temperature for adult chinook holding and spawning as determined by Hicks (2000) and McCullough (1999).**

Data collected at the Camp 18 site tended to support our hypothesis that the conditions described in the selected FLIR images are representative of temperature refugia for fish. They describe channel conditions in the bank seep and tributary plumes as being cooler than nearby main channel temperatures recorded there (Figure 58). Though temperatures recorded in the left bank seep held above the ideal chinook holding temperature of 14.3°C for most of the migration period, they were, on average, 2.4°C cooler than temperatures recorded in the main channel. The tributary flowing into the main channel from the left bank just downstream from the seep maintained nearly ideal cold water conditions throughout the summer. On average, temperatures recorded in the mixing zone of the tributary with the main channel were over 6.0°C colder than those recorded by the control data logger.

**Elk Flats**

The Elk Flats area includes many stream habitat types, including riffles, a boulder cascade, and a large, deep pool. Overhanging vegetation and gravel contributions from a large landslide complements it. FLIR analysis detected cold flows along the left bank, thought to be a seep feeding groundwater into the main channel. A data logger was placed in the channel at the base of the seep, downstream from the control unit, to monitor water temperatures in the area throughout the summer.

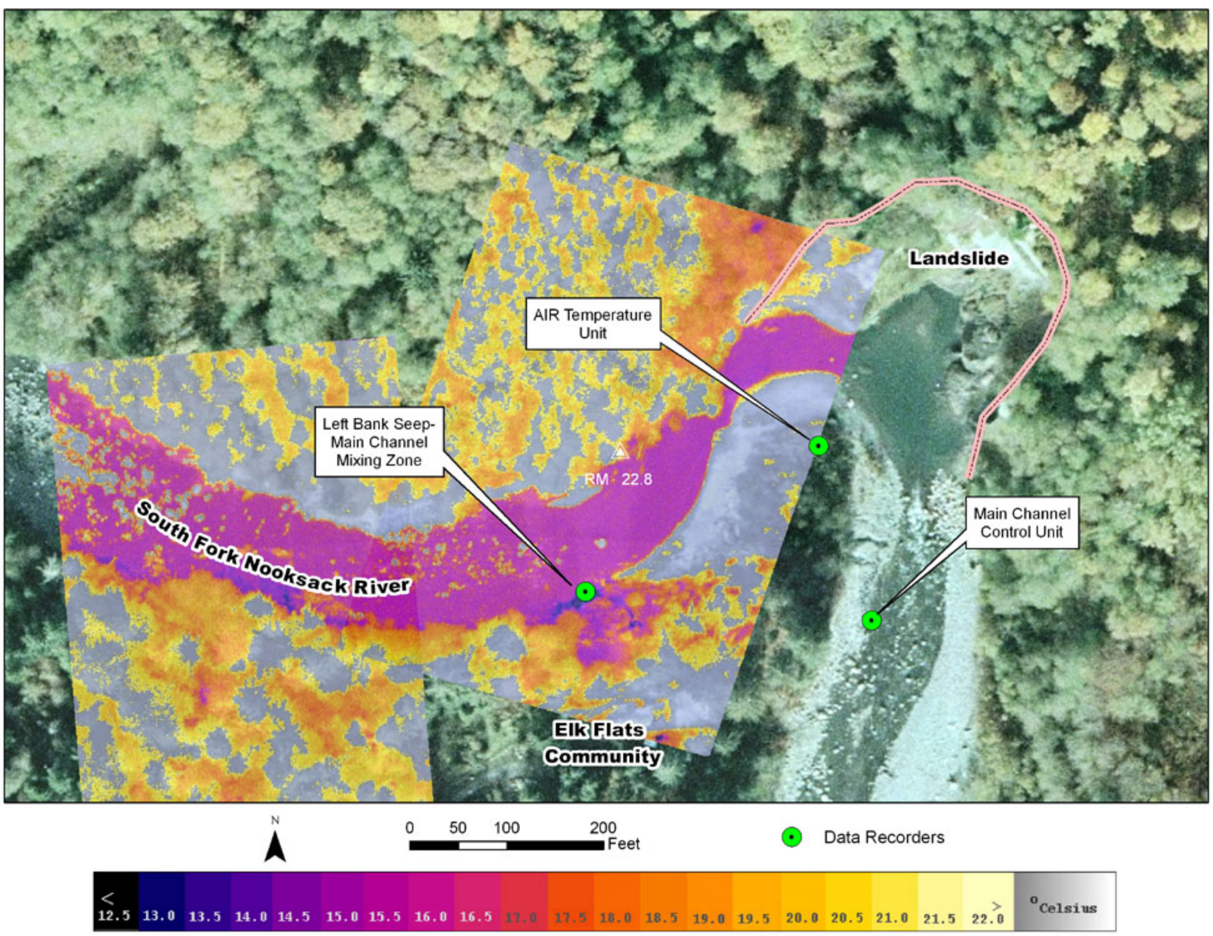


**Figure 59. Paired temperature data recorder locations and the FLIR surface water temperature profile at the Elk Flats study site.**

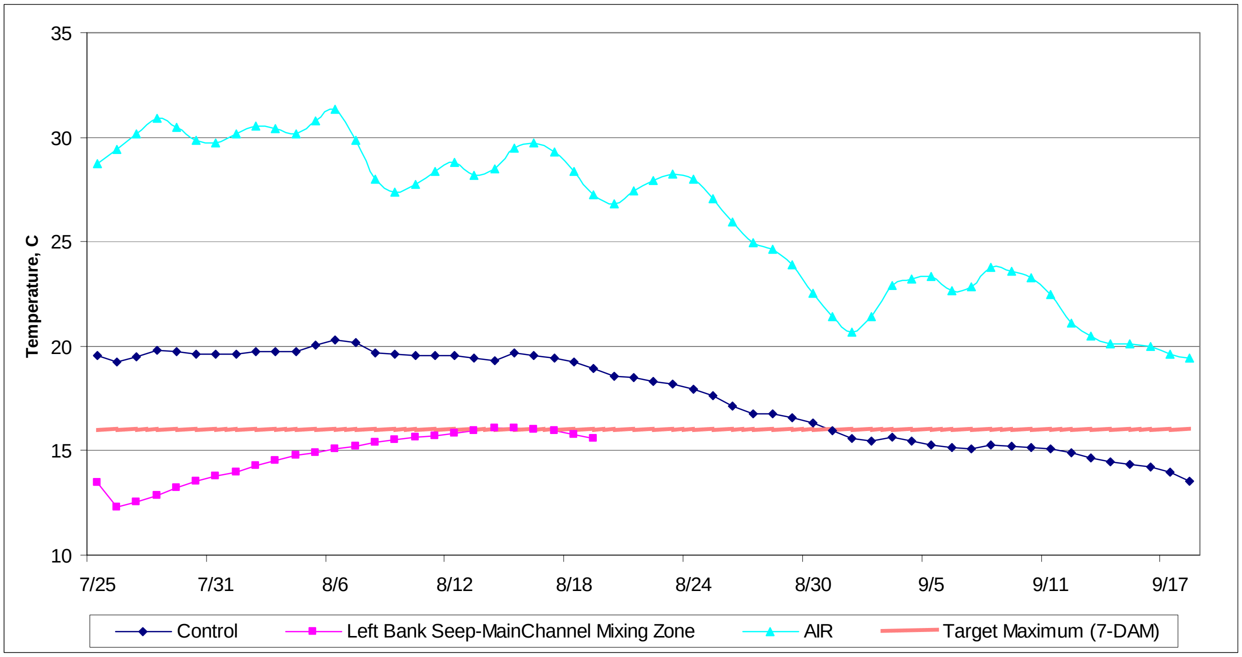


**Figure 60. 7-DAM data from the Elk Flats monitoring sites. The 7-DAM target maximum temperature for adult chinook holding and spawning as determined by Hicks (2000) and McCullough (1999).**

Data collection at the seep site was halted in mid-August when the probe was discovered to be dry. The seep it had been monitoring had dissipated to a level below the logger's channel position; however, the logger remained within its undercut bank location, recording temperatures. Environmental conditions recorded at the left bank site were consistently cool. Temperatures did not fluctuate daily like the air temperatures did at this site (Figure 60). The main channel temperatures recorded at the Elk Flats site proved to be the lowest of all control sites within the study reach (Figure 61). These results were to be expected, as the Elk Flats site is furthest upstream.

### *Summary*

This study's summer temperature refuge monitoring objective consisted of locating and prioritizing sites in the study area with potential for habitat enhancement for the benefit of South Fork salmonids. The areas sampled for this study varied in the degree to which they maintained cold water habitat through the summer. All main channel 7-Day Average Maximum temperatures recorded by the control units monitoring conditions in the main channel near refuge sites exceeded both the 12.8°C maximum (for ideal spawning conditions) limit (McCullough 1999) and the 13.0°C Water Quality Standard (DOE 2005) for the upper South Fork chinook holding and spawning window (Figure 61). Chinook in their emergence and rearing life stages during this time are affected by these elevated temperatures as well, as optimum production requirements for them range between 10.0 – 15.6°C (McCullough 1999). Water temperatures increased moving downstream.

Temperature conditions below the 13°C Department of Ecology water quality standard assigned to the upper South Fork were maintained at several refuge sites. However, conditions required for chinook and other salmonids using the river during the summer were deficient (Figure 62, Figure 63). Adult chinook need temperatures between 8.0 – 12.5°C during their holding and spawning life stages. Egg incubation temperature requirements for spring chinook range between 4.5 – 12.8°C, and rearing juveniles exhibit optimum growth when temperatures are between 10.0 – 15.6°C. The refuge candidate sites that maintained temperatures most closely to these requirements were the Camp 18 tributary plume, the Larson's Bedrock side channel, the Elk Flats left bank seep, and the Skookum Creek plumes created by both tributary flow and the hatchery outfall (Figure 64).

Water temperatures at the Elk Flats site depict the coldest main channel conditions, but were not cold enough to qualify the site as acceptable for optimum chinook production. Additionally, main channel temperature regression at Elk Flats was not significantly different from that recorded by the ambient temperature logger. Main channel temperatures increased downstream, and were highest just above the Cavanaugh Creek confluence at RM 16.5. Water temperatures decreased again below Cavanaugh and Skookum Creeks. Ambient temperature recorded at the Skookum Creek site exhibited daily and seasonal fluctuation that likely influenced main channel temperatures. However, Adams and Sullivan (1989, in Cross 2002) assert that ambient air temperature is but one of four factors that influence stream heating and cooling. The others are solar radiation, relative humidity, and groundwater influx. The channel at Skookum Creek is likely more influenced by the latter three due to a narrow, but tall canopy cover on the north bank of the river, and the cold tributary stream (Skookum Creek) flowing into the area. A significant divergence between the two temperatures occurred in mid-September, as the water temperature began a sharp decline and the air temperature remained elevated.

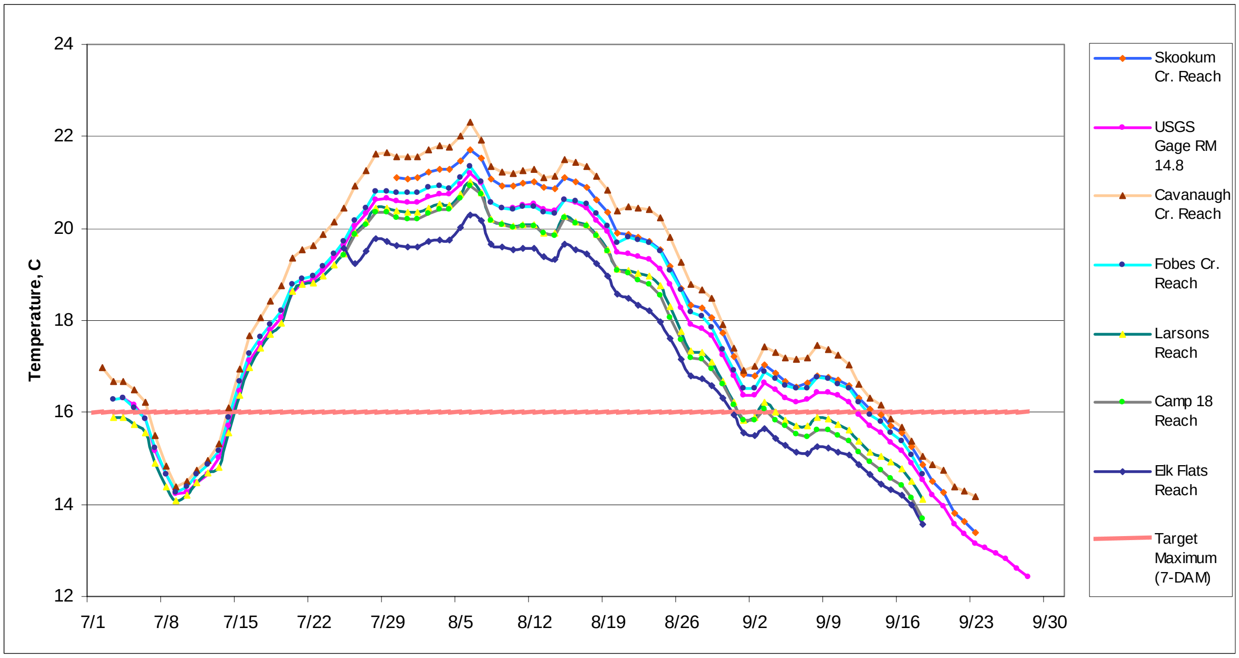


**Figure 61. 7-DAM temperatures recorded by the main channel control data loggers. The 7-DAM target maximum temperature for adult chinook holding and spawning as determined by Hicks (2000) and McCullough (1999).**

Temperatures collected in the plume at the confluence of a tributary at the Camp 18 and the main channel did not increase above 14°C. Temperatures collected in the small, spring-fed side channel at the Larson's site also did not rise above 14°C. The left bank seep at Elk Flats, though short lived due to low flow conditions in late August, reached 16°C at its 7-DAM peak in mid-August. The site of the plume created by the Skookum Creek Hatchery hovered between 16 and 18°C at its peak temperature (Figure 62), and the plume created by Skookum Creek itself peaked near 18°C for a two-week period starting August 3 (Figure 63). Of the twelve potential refuge sites sampled, these five exhibited the greatest potential for physical habitat improvements for salmonid habitat targets.

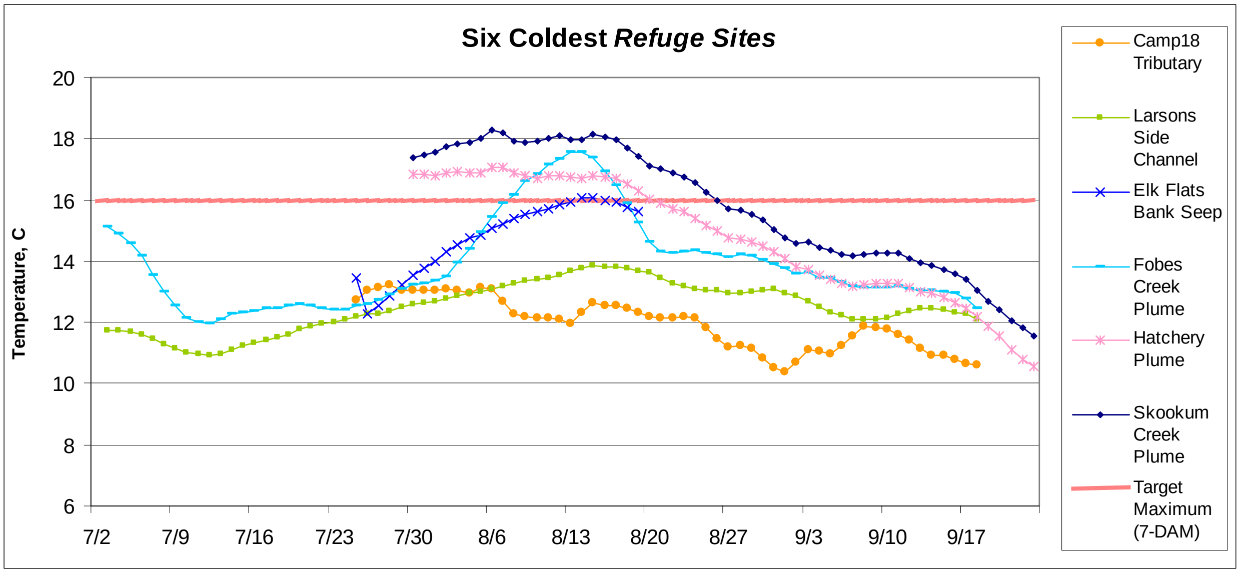


**Figure 62. 7-DAM temperature patterns from the six coldest refuge sites sampled in 2005. The 7-DAM target maximum temperature for adult chinook holding and spawning as determined by Hicks (2000) and McCullough (1999).**

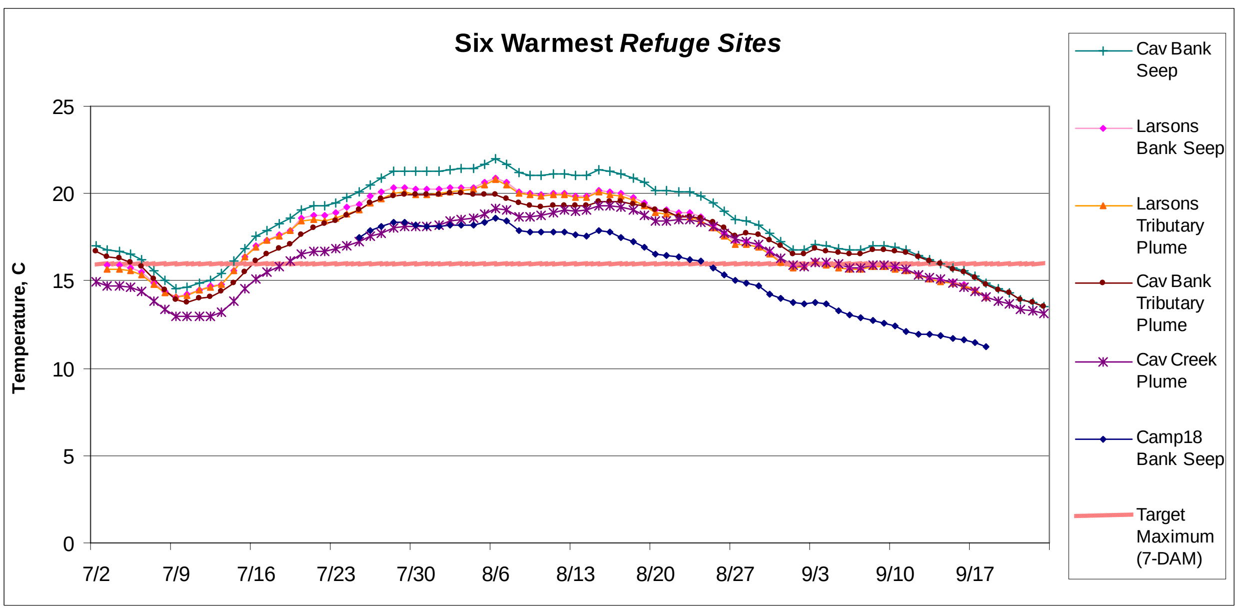


**Figure 63. 7-DAM temperature patterns from the six warmest refuge sites sampled in 2005. The 7-DAM target maximum temperature for adult chinook holding and spawning as determined by Hicks (2000) and McCullough (1999).**

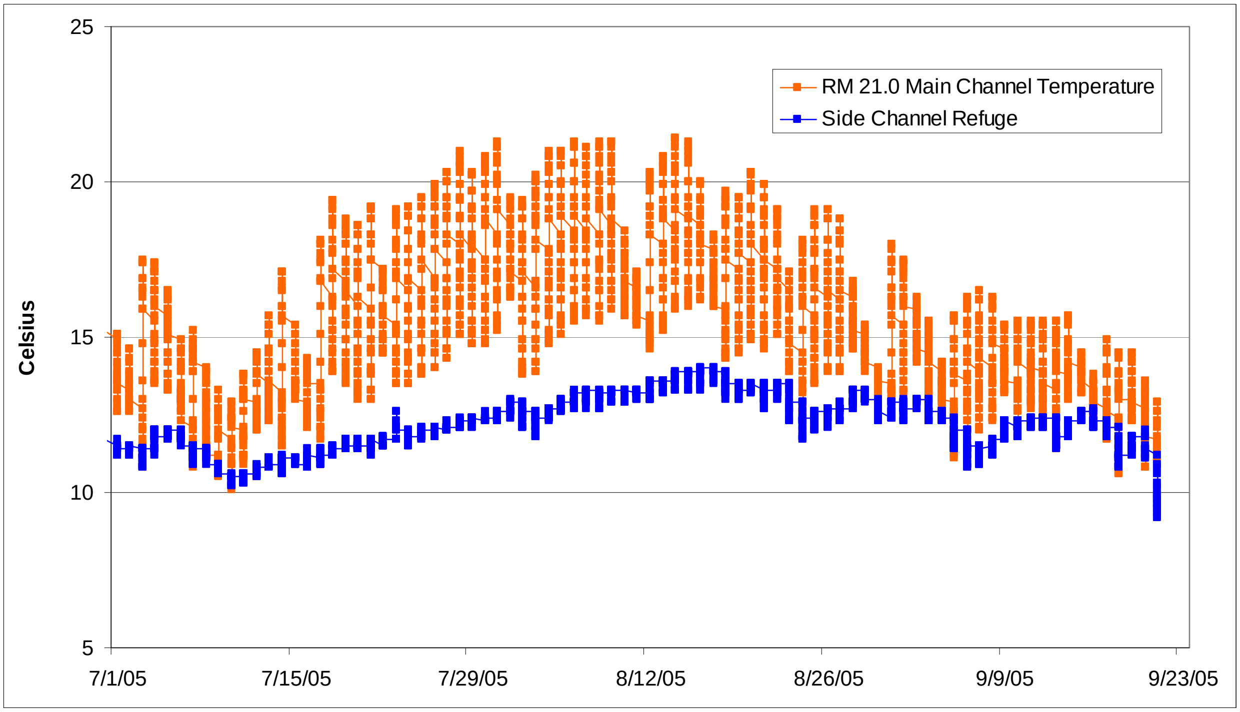


**Figure 64. Daily temperature ranges for the main channel at RM 21.0, and for a nearby side channel.**

### *Turbidity*

Turbidity is an index used to represent the amount of sediment and other suspended particles within the water column. Turbidity characterizes water quality by clarity, measured by the degree to which light is scattered across suspended particulate material. The greater the amount of total suspended solids (TSS) in the water, the murkier it appears and the higher the measured turbidity. Turbidity is measured in Nephelometric Turbidity Units (NTUs). The Washington State Department of Ecology classifies the South Fork Nooksack River as core salmonid waters, expected to exhibit the highest standards for all water quality parameters. The standard for acceptable turbidity values in core salmonid waters is 5 NTU over background values, if background values are 50 NTU or less. If background values are more than 50 NTU, the acceptable standard is 10-percent over background. The effects of turbidity and suspended solids on salmonids are varied; physiology, behavior, and habitat are all impacted.

**Physiological effects**:

1. Gill Trauma: sediment accumulating in gill filaments causing fish to excessively open and close their gills to expunge silt. If irritation continues, mucus is produced to protect the gill surface that may obstruct water circulation over gills and interfere with respiration (Berg 1982 in Bash et al. 2001).
2. Osmoregulation: salmonids undergoing the smolt transformation process have an increased sensitivity to total suspended solids. Noggle (1978 in Bash et al. 2001) found that smolts suffer an impairment in their osmoregulatory processes when exposed to pulses of increased sediment.

**Behavioral effects:**

1. Avoidance: juvenile salmon exhibit a lower threshold for avoidance of increasingly turbid waters. Lab studies by Sigler (et al. 1984 in Bash et al. 2001) found that turbidities between 25-50 NTU reduced growth and caused more young salmon and trout to emigrate from these streams than did those in clear water. Berg (1982, in Bash et al. 2001) found that juvenile salmon exposed to a short-term pulse of 60 NTU left the water column and congregated at the bottom of

an experimental tank. When the turbidity was reduced to 20 NTU, the fish returned to the water column.

2. Territoriality: increases in turbidity appear to disturb normal social behavior and alter the nature of aggressive interactions. Bash et al. (2001) suggests that the loss of territoriality and the breakdown of social structure can lead to secondary effects. Berg and Northcote (1985) found that feeding behaviors and territory structure are disrupted during high turbidity events. For example, a dominant fish positioned upstream would consume the majority of prey in that territory. During turbid phases, territories and social organization broke down, and subordinate fish captured a greater proportion of the prey.
3. Foraging and Predation: the reduction in visibility has the largest impact on feeding ability. Alterations in feeding ability are important because fish, juvenile salmonids particularly, must meet energy demands to compete with other fishes for resources and to avoid predators. A reduction in foraging has been linked to a decrease in growth and overall health (Gardner 1981 in Bash et al. 2001). Bash (et al. 2001) presents two major themes on the effect of turbidity on foraging. As visual feeders, the effectiveness of salmonids collecting prey is reduced by turbidity as low as 20 NTU (Berg 1982). Other researchers indicate that some species of salmonids (juvenile coho, chinook, and steelhead) appear to prefer slightly to moderately turbid water for foraging (Sigler et al. 1984, Gregory 1988). Perhaps this represents a trade-off between predation risk and bioenergetic demand and the benefits of increased growth. While ability to forage in turbid water may be reduced, the reduction in predation risk may make it worthwhile to occupy partially turbid areas (Gregory and Northcote 1993 in Bash et al. 2001).
4. Primary Production: suspended materials reduce the amount of light available to illuminate submerged objects and provide energy for plant photosynthesis. Reduction of water column penetrating light may also alter oxygen balances, resulting in decreased secondary production and decreased efficiency of some fish management practices (Lloyd 1987 in Bash et al. 2001).
5. Abundance and Diversity of Prey: the presence of fine sediment can affect secondary production by impacting algal growth, biomass, and benthic species community structure, density, and diversity. Sediment can clog feeding structures, reducing the efficiency and growth rates of filter feeders. Benthic invertebrates are subject to scouring which can damage respiratory organs and expose organisms to predation through uprooting and drifting (Newcombe and MacDonald 1991 in Bash et al. 2001). Field studies conducted in watersheds affected by forest practices found a decrease in benthic invertebrate abundance and distribution; one sampling station positioned above the logged watershed produced 25.5 organisms per square foot of benthic surface, while the station below the watershed produced 7.3 organisms per square foot (Tebo 1955 in Bash et al. 2001).
6. Homing and Migration: migrating salmonids avoid waters with high silt loads, or cease migration altogether when such loads are unavoidable (Cordone and Kelly 1961 in Bash et al. 2001). Timing of arrival at spawning grounds that migrate upstream during snowmelt runoff can vary by a month or more, depending on suspended solid concentrations in natal streams (Bjornn 1968 in Bash et al. 2001).

**Habitat effects:**

1. Increased Embeddedness: intragravel survival of salmonid embryos is dependent on benthic structure that facilitates oxygen exchange and waste product removal. High levels of fines in or on spawning gravels can reduce oxygen permeability for egg incubation, as well as create emergence barriers for newly hatched fry.
2. Reduced Complexity: pool habitat volumes decrease as a result of sediment loading, resulting in a loss of rearing habitat for juveniles and holding habitat for migrating adults (USFWS 1998 in Bash et al. 2001). Elevated sediment loads also increase the frequency of channel scour and fill events, increasing channel widths through aggradation (Spence et al. 1996 in Bash et al. 2001).
3. Refugia: aquatic habitat is created and maintained by watershed processes. Subsequently, salmon production is affected by the creation and maintenance of this habitat. Watershed processes altered by land use activities and pollution is known to result in a loss of channel structure; the heterogeneity of which provides refugia against turbidity pulses and other water quality extremes (Bash et al. 2001). As suspended solids progressively change geomorphic

channel structure, suitable habitat may become marginalized and unusable (Poole and Berman 2001 in Bash et al. 2001).

4. Hyporrheic Inputs: upwelling areas where groundwater contributes cold, clear water to streams may be compromised by increased sedimentation. They are critical to proper water exchange in salmonid redds; bull trout have been observed selecting redd sites that correlate to areas of hyporrheic exchange (Baxter and Hauer 2000 in Bash et al. 2001). Increased sediment loads can also clog coarser streambed materials with fines, in turn decreasing streambed connectivity and reducing the exchange of ground to surface water across the streambed. These fine sediments may alter the dynamics of heating, cooling, and temperature buffering. This two-way exchange between the channel and hyporrheic zone is one of the most important buffers to high stream temperatures (Poole and Berman 2001 in Bash et al. 2001).

Burns (1972 in Bash et al. 2001) linked sedimentation of streams with higher water temperatures and low dissolved oxygen. The use of bulldozers on steep slopes caused excessive sedimentation in drainages and tributary streams. During heavy rainfall after hill slope construction activities in the South Fork River in Idaho, erosion and road failures caused extremely high turbidities and the deposition of as much as 0.6m of sediment in lower gradient streams. Brown and Krygier (1971 in Bash et al. 2001) found that sediment production doubled after road construction but before logging in one watershed, and tripled after burning and clearcutting in another watershed. Of course, all watersheds vary in their species composition, land-use activity levels, slope, etc., and these results may not represent conditions observed in South Fork Nooksack streams. However, these examples clearly define the degree to which land clearing and road building have detrimental effects on water quality. An illustration of the linear relationship between increased turbidity and the impacts on fresh water fish is described in Figure 65.

Excess fine sediment has been identified as a limiting factor for salmon recovery in the South Fork Nooksack River (SRFB 2005, Mobrand 2003). Bull trout in particular are highly susceptible to sediment inputs and related bedload movement. They require the lowest turbidity and suspended sediment levels of all salmoinds for spawning, incubation, and juvenile rearing (USFWS 1998 in Bash et al. 2001). Bull trout are strongly associated with cover, including interstitial spaces in gravels. They also show a strong preference for stream bottoms and deep pools of cold water. This association makes them susceptible to forest practices and floodplain development that directly or indirectly changes substrate composition (USFWS 1998 in Bash et al. 2001).

The most common source of suspended particulates in the South Fork is likely clay and silt from stream adjacent landslides. Turbidity sources in the South Fork differ from those in the river’s Middle and North Forks. The headwaters of the South Fork are not augmented by perennial glacial melt, but rather by seasonal rainfall and yearly snowpack melt from the Twin Sisters Mountains and surrounding areas. The perennial, suspended silt characteristic to the North and Middle Fork flows is not common in the South Fork, hence, summertime turbidity values are often low after the mountain snowpack melts. Particulates common in the upper South Fork include clay, silt, and fine (in)organic matter commonly derived from upland runnoff, plankton, and microscopic organisms. Late fall and spring flows augmented by rain events usually produce the highest turbidity values in the South Fork. Turbidity monitoring in the lower South Fork during and after storm events have recorded readings of over 1,000 NTUs, the maximum reading possible by the turbidimeter that was used (Soicher 2000).

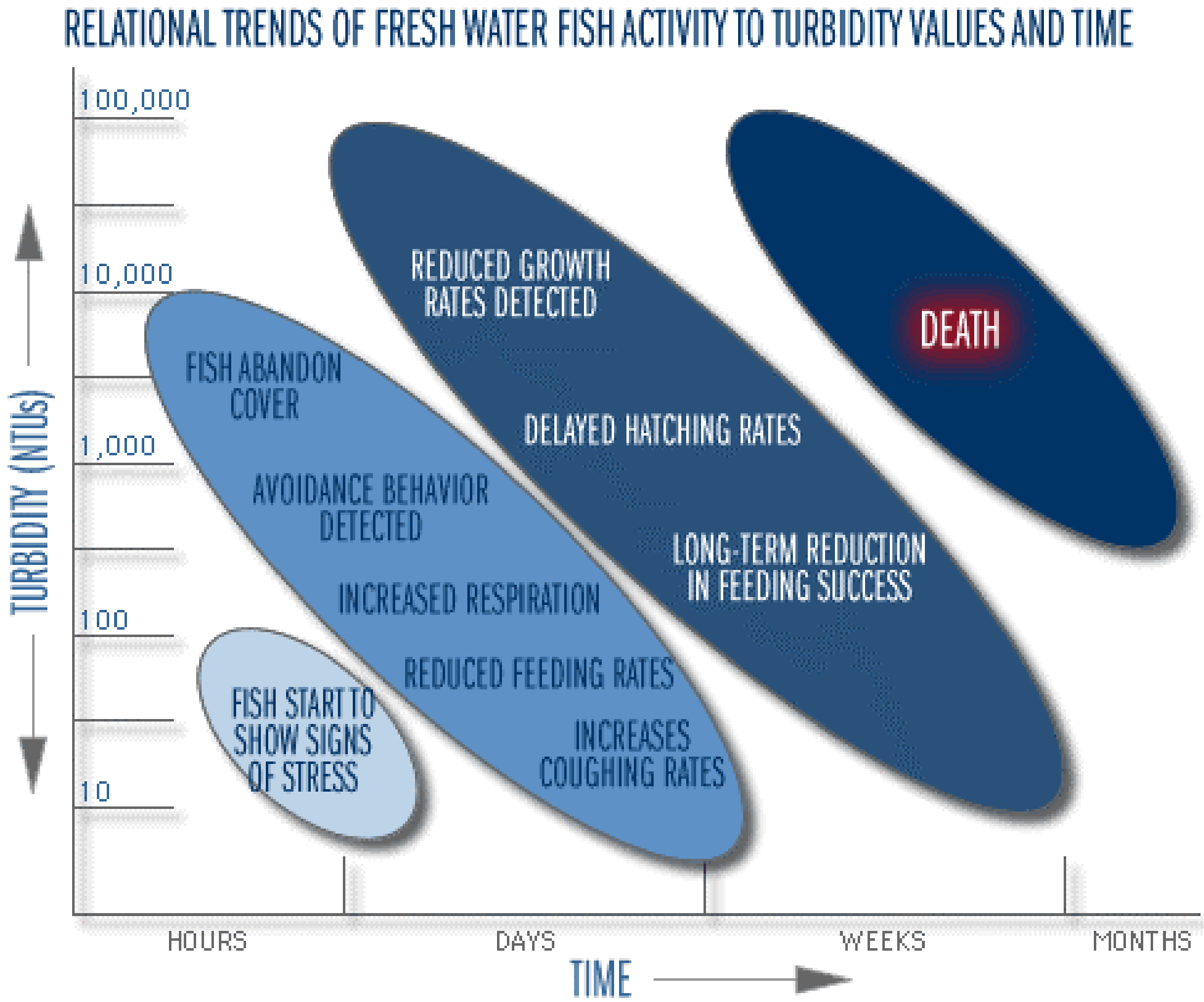


**Figure 65. Turbidity values and resulting effects on fresh water fish development (Newcombe and Jensen, 1996).**

### Turbidity Monitoring Stations

Turbidity levels were measured from samples collected at eight sites throughout the assessment reach (Figure 66), between the USFS 1260 Road Bridge (RM 37.7) and the Saxon Bridge (12.8). Data collection at these eight sites was spotty, limited to intermittent access to the sites. We collected baseline data after a string of fair, sunny days, when the river was reasonably clear. Additional sampling was designed around rain events to capture conditions in the river during high runoff activity.

As expected, turbidity values increased during in periods following rain events. In addition, turbidity values increased as the river moved through its channel downstream. There was a particularly significant increase in turbidity values between the 330-Road bridge and the 200-road bridge. In some cases, turbidity values increased five-fold between these two sites, located five river miles apart. Because of this, additional sampling of sites both above and below Howard Creek, the only large tributary between these two bridges, was added to the design. The Howard Creek watershed is steep, unstable, and landslide-prone, and contributes significant amounts of sediment to the South Fork Nooksack River. There are also many chronic mass wasting sites along the river in this reach (Lummi Natural Resources data 2005, Osbaldiston 1995, Lummi Natural Resources data 1986). It is likely that these active sediment sources together decrease the clarity of the river during increased precipitation and runoff. Conditions allowed these additional sites at Howard Creek to be sampled only twice, both times following rain events and increased discharge through the system. Although the turbidity values measured at these sites were not markedly different, we detected an increase between the upstream and the downstream sites, resulting in the conclusion that Howard Creek discharge has a negative impact on the water quality of the South Fork main channel.

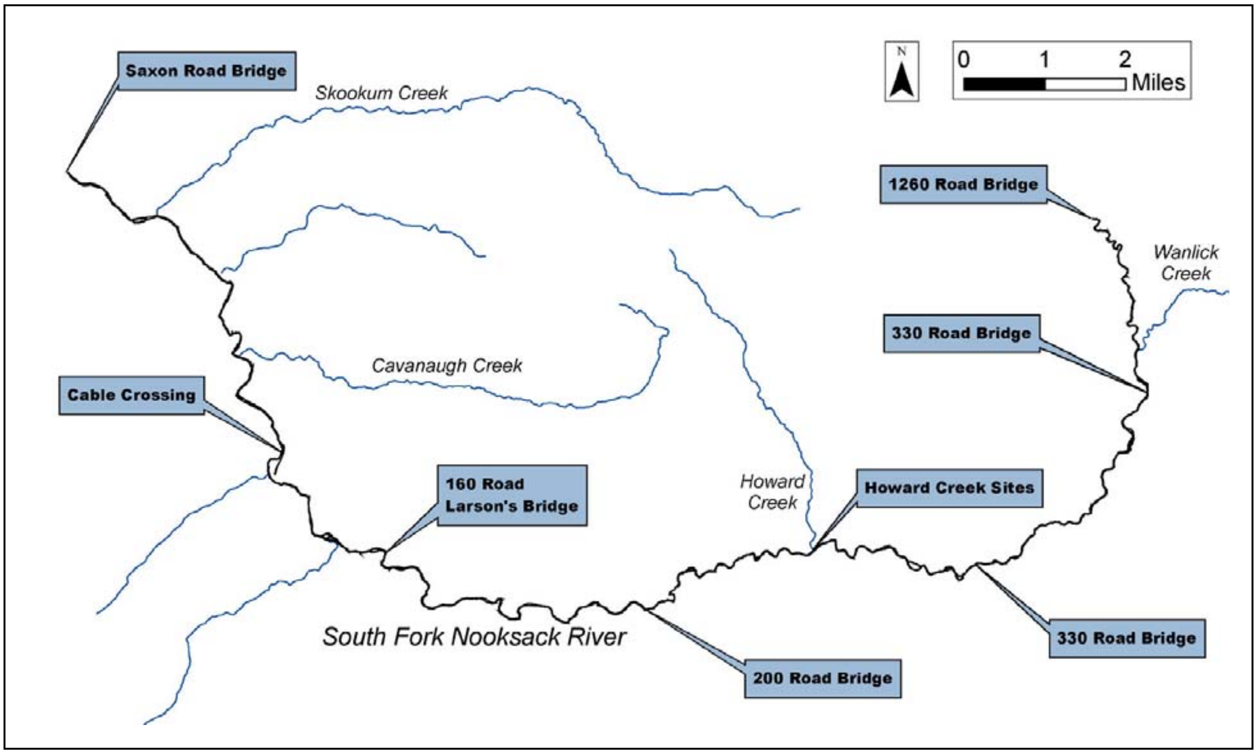


**Figure 66. South Fork turbidity monitoring site locations.**

The baseline measurement at each site, measured in late September after a period of nearly a month without precipitation, was 1-NTU. The next round of sampling was conducted after fall rains appeared and the river began taking runoff again. Turbidity values increased with precipitation, and then declined during a cold period that brought precipitation in the form of snow. Warmer temperatures and heavy precipitation during January raised the turbidity; the values fell again with decreased discharge.

Turbidity data collected over the fall and winter of 2005-06 reflect trends that correlate to rainfall and discharge (Figure 67 and Figure 68). When turbidity sampling occurred after a rain event of any magnitude, elevated turbidity values were measured. We found that even a small increase in discharge often produced a large increase in turbidity. If sampling did not coincide with a rain event or was conducted well after one, turbidity values were relatively low. The graph in Figure 67 describes a period of low discharge between September 1$^{st}$ and October 1$^{st}$, and a recorded maximum turbidity value of 1-NTU. After two early-October rain events that resulted in discharges of 1,580 and 1,120 cfs, the maximum turbidity value increased nearly 100-fold. This trend continued with the discharge increase on October 16$^{th}$, and again on the 31$^{st}$.

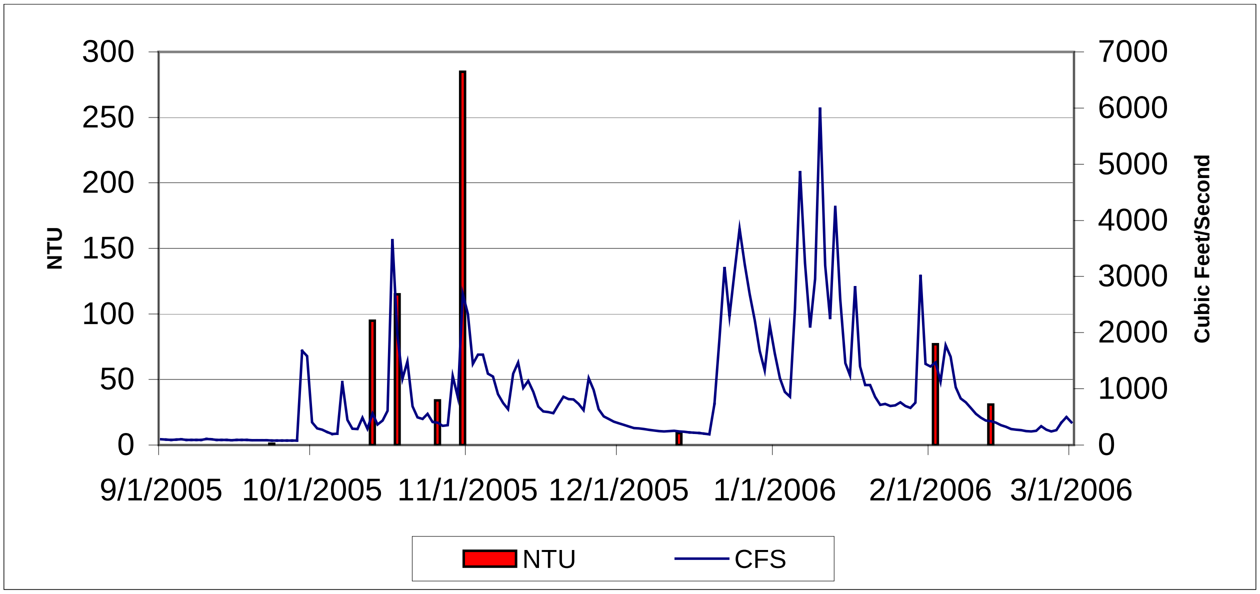


**Figure 67. Maximum turbidity values and local discharge conditions.**

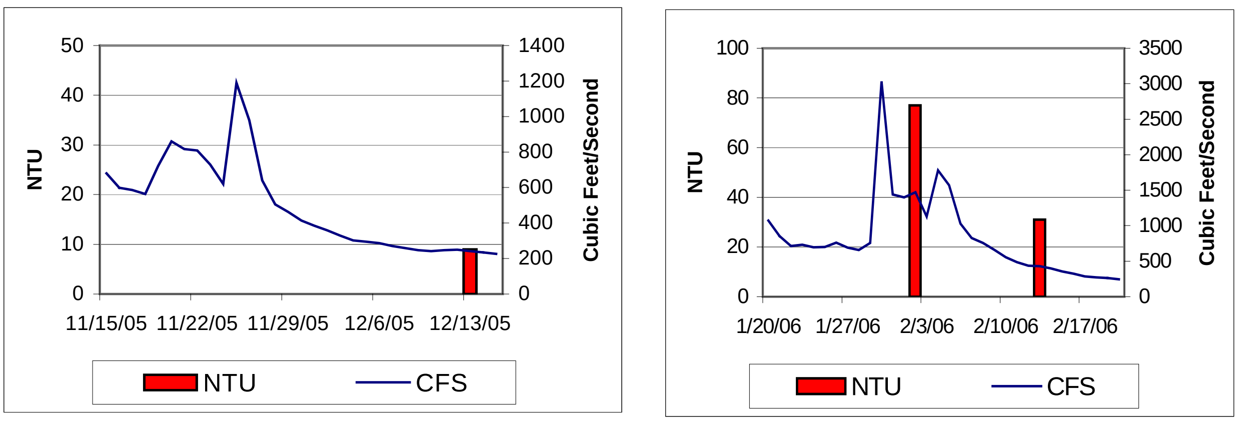


**Figure 68. Reach-scale daily maximum turbidity values and mean discharge data plots.**

Turbidity values increased as sampling advanced downstream (Figure 69 and Figure 70). The upper-most sampling site in the watershed (RM 37.7) was always the least turbid. Values measured at this site were never greater than 10-NTU. Alternatively, turbidity measured at the fifth site downstream (RM 17.9) was the highest, with a maximum reading of 285-NTU. However, the distribution of turbidity data presented in a quartile format (Figure 70) describes the highest mean turbidity produced at the most downstream site, inferring that this site was most consistent in presenting high turbidity values.

Data collected on October 31, 2005 describe conditions that exceed the Washington State WQS for turbidity (Figure 69). The background value measured near RM 38 was 1-NTU. Turbidity measured at the most upstream site (RM 37.7) was also 1-NTU. Peak discharge measured at the USGS gage more than tripled from 848 cfs the previous day to 2,690 cfs. Turbidity values increased as the river moved through the valley and picked up surface runoff and tributary flows. Conditions at the 160 Bridge (RM 20.6), the gravel reach where a significant proportion of South Fork chinook build their redds, was nearly 250 times the background value. It neared 300-NTU at the Cable Crossing, and fell slightly before the Saxon Bridge at the downstream end of the study reach. These data support the suggestion that turbidity values elevate both as a result of high flow events and downstream migration. Interestingly, the most upstream site at RM 37.7 maintains a significantly low turbidity of 1-NTU. This suggests that turbidity conditions at this site are not affected by rain events, and that surface runoff contribution to turbidity upstream of this site is negligible.

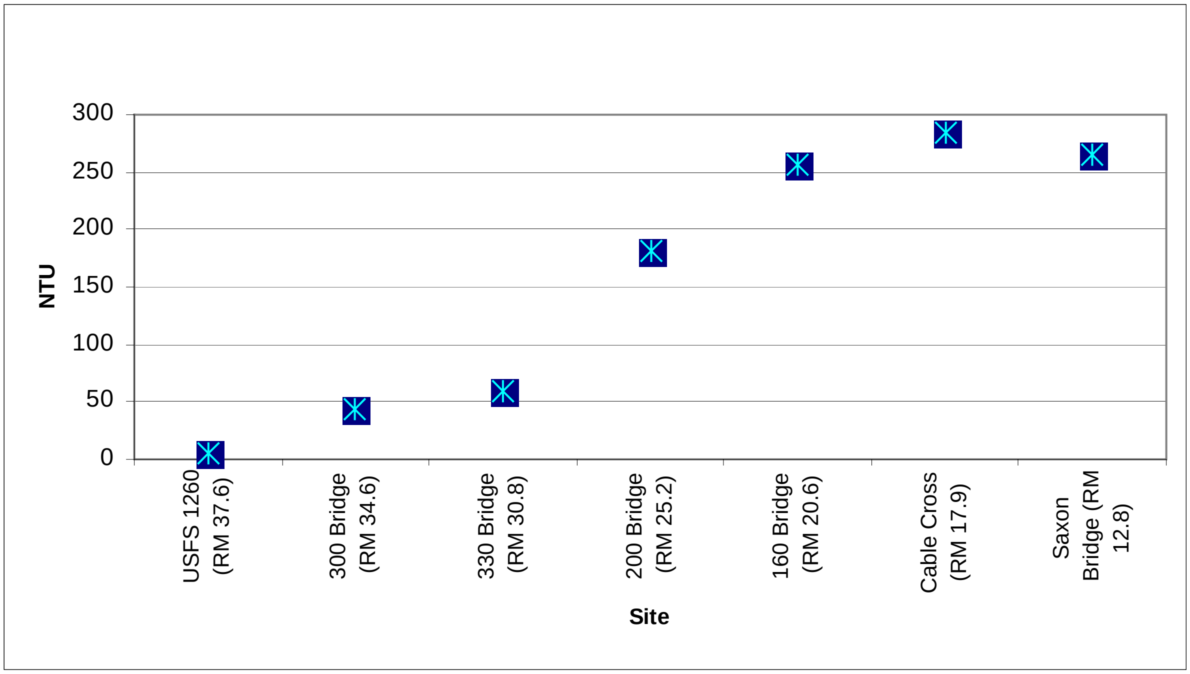


**Figure 69. Mean turbidity values measured on October 31, 2005.**

Descriptive statistics for all turbidity data collected are described in the logarithmic-scale box plot below (Figure 70). Minimum values were 1-NTU at all sampling sites, recorded during periods of low, stable flows. Maximum values reflect the trend seen in the October 31, 2005 chart (Figure 69). The mean values increase downstream following the trend seen with the site maximums. This analysis also supports the suggestion that turbidity values are influenced by discharge and surface runoff.

The highest water quality for turbidity was consistently documented at the USFS 1260-Road Bridge (RM 37.7) site. The mean value at this site was more than 10-times lower than the next best water quality site at the 330-Road Bridge (RM 30.8). Additionally, the range of values between the lowest $25^{th}$ and greatest $75^{th}$ percentiles for this site is small, and falls very close to the minimum. The lowest water quality, represented by the highest and most frequently high turbidity, was observed at the Saxon Bridge (RM 12.8). The mean turbidity value analyzed from data collected at this bridge was very near the highest 75-percent of the data collected here. The range of values between the $25^{th}$ and $75^{th}$ percentiles was nearer the maximum value than its minimum value.

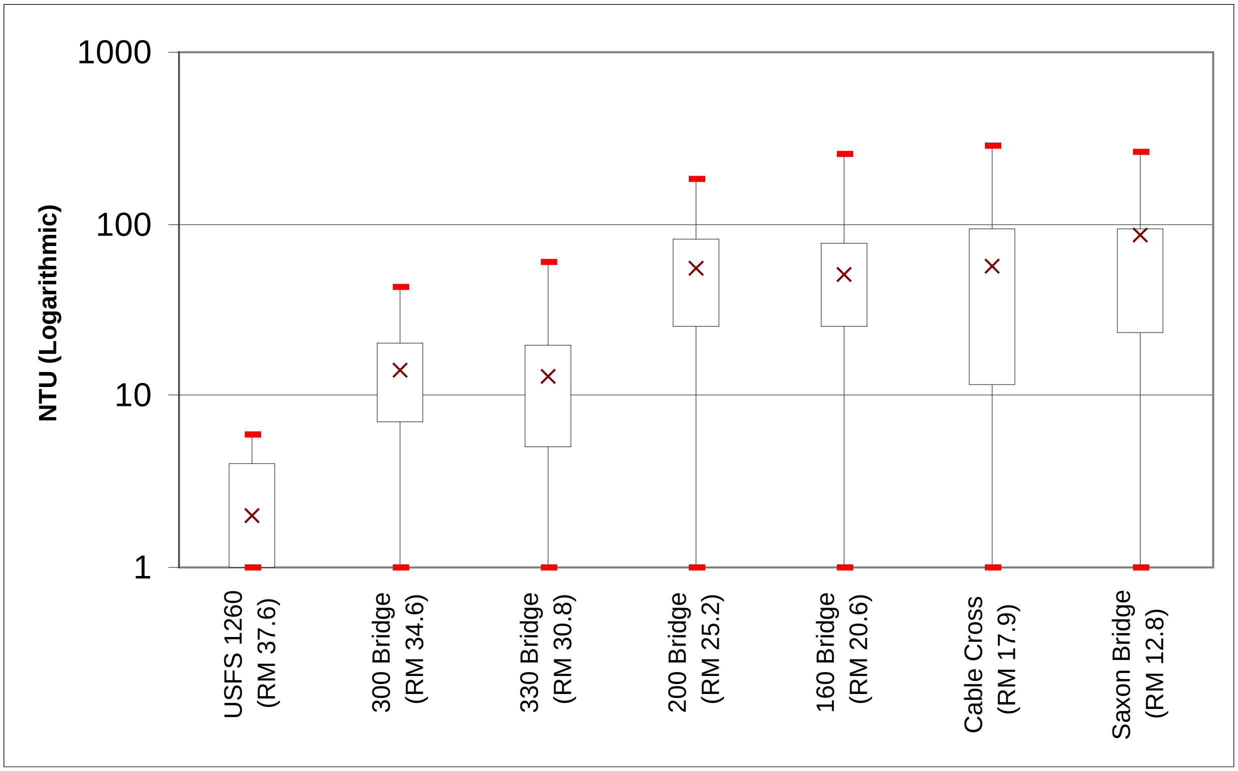


**Figure 70. Quartile distribution of turbidity values collected throughout the 2005-06 sampling season.**

Overall, turbidity represents a decline in water quality that worsens as the river flows downstream. The values recorded at the most upstream site were regularly low, making it a candidate reference site. Turbidity increased ten-fold between the USFS 1260-Road Bridge and the next sampling site downstream at the 300-Road Bridge. The presence of several large landslides between the two landmarks, as well as the river flowing over and incising into silty glacial deposits may explain this increase. An interesting thing happens in this vicinity, however. Turbidity values hold fairly steady between this site and the following site at the Seattle City Light-owned 330-Road Bridge. The mean values between the two sites are nearly equal, and there was little difference between the 75$^{th}$ percentile of the data sets or the maximum recorded value. The next significant increase in turbidity appears between the 330-Road Bridge and the 200-Road Bridge. This is the largest increase in turbidity values and it appears to hold reasonably steady through the remaining sampling sites downstream, increasing slightly between each one. This information may be used to prioritize projects that work to restore salmon recovery in the South Fork Nooksack River, focusing on identifying sources that input suspended materials to the river between the 330-Road Bridge and the 200-Road Bridge where the greatest degree of difference in turbidity values is observed during rain events.

## Salmonids in the South Fork

The Nooksack watershed has supported numerous species of anadromous and resident salmon and trout for thousands of years. The salmonid species that use the upper South Fork reach include early (spring) chinook, late (fall) chinook, coho, pink, chum and sockeye salmon, summer- and winter-run steelhead, bull trout, cutthroat, rainbow trout, and Dolly Varden trout. Winter steelhead, coho, early and late-timed chinook, pink, sockeye and chum salmon use the reach for spawning, rearing, migration, and holding. Steelhead, coho, some chinook, and sockeye juveniles also rear in the reach year-round. Anadromous bull trout and summer-run steelhead are considered the anadromous species that utilize the low gradient habitat upstream from the partial passage barrier at RM 32 (USFWS 2004). Resident or fluvial sea-run cutthroat and rainbow trout also occupy headwater reaches, and Dolly Varden trout have been confirmed in Wanlick Creek (RM 35.2) and in Bell Creek (RM 39.0) upstream of falls or very steep cascades (USFWS 2004). Spring chinook are recorded most often, but not in all years, between the partial passage barriers at RM 25 and RM 32, while the other anadromous species and life-history types are considered to use portion of the reach downstream from Sylvester Falls at RM 25. Both early and late-timed chinook salmon stocks consistently build redds in the main channel, although many salmon species spawn in tributary streams. During years when discharge permits, spring chinook sometimes spawn in the lower reaches of larger tributaries, while fall chinook will also enter a few additional tributaries including since discharges are generally higher later in the fall. Winter-run steelhead spawn in the mainstem some tributaries. The variety of fish species that use the Saxon to Headwaters reach indicates the need for diverse stream habitat and the restoration of the natural processes that create and maintain produce habitat.

There is a bull trout population in the Nooksack River watershed that includes anadromous, fluvial, and possibly resident life-history phases. Adult bull trout have been documented in the South Fork, incidental to spring chinook surveys; however, little is known about this species' production. Bear Creek is one tributary where spawning has been recorded (USFWS 2004). In 1999, Puget Sound bull trout (*S. confluentus*) received federal protection as a Threatened species under the ESA by the USFWS. The Coastal-Puget Sound Distinct Population Segment (DPS) supports the only known anadromous form of bull trout within the coterminous United States (USFWS, 2004). The Nooksack River supports one of eight local populations in the Puget Sound DPS. There are also at least two isolated resident populations of Dolly Varden (*Salvelinus*) in the upper watershed, but again, these have not been studied as extensively as some salmon species in the river, and little biological information has been collected (Currence, pers comm. 2007).

In 1999, the Nooksack River chinook salmon (*O. tshawytscha*) ESU was listed as a threatened species under the federal regulations of the ESA by the National Marine Fisheries Service (NMFS). The South Fork early (spring) chinook population has fallen to critically low levels and faces extinction (Koenings 2004).

Beginning in 1999, the co-managing surveyors agreed to establish reliable protocols that would result in more accurate representations of adult activities in this reach. Flagging was tied to streambanks at recorded sites, and labeled with biological information so subsequent surveys did not count previously recorded redd data. Viewing conditions, based on turbidity and water depth and ranging from poor to good, and were recorded along with other field data. The data recorded post-1999 were used to create more reliable assessments of conditions and predictions of outmigration.

### Chinook Salmon (*Oncorhynchus tshawytscha*)

In WRIA-1, the early South Fork chinook are most at risk for extinction simply because they are not replacing themselves. The Nooksack River spring chinook is a species of great value to the genetic diversity of the Puget Sound chinook population as a whole and is listed as the species most at risk of extinction by the Puget Sound Technical Recovery Team (PSTRT 2006, 2002). Several factors have been identified as causal mechanisms that intensify this problem (WRIA-1 SRB 2005). Two significant factors include unsupportive habitat conditions such as high summer temperatures that can lower egg viability and trigger diseases like Columnaris, and a lack of habitat diversity that provides good spawning and rearing areas and adult holding cover. Resource managers in this watershed agree that addressing these issues through habitat restoration is key to increasing chinook production in the South Fork.

Early-timed (spring) chinook enter the Nooksack basin between February and August, and spawn between July and October. Late-timed (fall) chinook begin their upstream migration around June, and spawn between September and December (SRFB 2005). Spawning maturity for South Fork spring chinook occurs at three to six years of age, with four years being the most common in the upper South Fork, and six year olds being very uncommon (Currence pers. comm. 2007). Adults are semelparous, dying shortly after spawning.

Generally, chinook seek waters between 5.6-12.8°C during the spawning life stage (McCullough 1999). This biological requirement proves difficult for early chinook spawning in the South Fork of the Nooksack River, as temperatures in the upper South Fork reach peak in early August, persisting at or around 20°C until mid-September. After September, however, water temperatures fall quickly and eggs begin incubating within the optimal range. Early chinook redds built later in the summer season may fare a better chance of egg-to-fry survival by missing the window of warmer temperatures altogether. Fall chinook spawn in this reach immediately after the early chinook. There is known overlap between the two runs (Hawkins pers. comm 2007); however, redds built before October 1 are characterized as early, and those after October 1 are considered late-run nests.

Upon emergence from the streambed, chinook fry feed off of a protein-rich yolk sac attached to the ventral surface. Increased size and the full absorption of the yolk sac create the demand for other food sources. Fry forage for macroinvertebrates, and as they mature into larger fingerlings, they add small fish to their diet. Soon thereafter, young chinook of both the early and late varieties begin their downstream migration as one of two types. Stream type chinook will migrate up and down river foraging for up to a year before entering the estuary and ocean environments as yearling smolts. Ocean type chinook outmigrate to the estuary quickly or after rearing as long as several months. These fish often reach estuarine habitat early in the calendar year to feed and develop for an indeterminant time before beginning their ocean migration. The majority of juvenile chinook found in estuary and nearshore habitats of the Nooksack River are predominately ocean type fish (LNR, 2005). Fingerling chinook smolts (stream type) recovered in these areas are less common. Scale analysis of wild adults indicated an average of 38% of wild South Fork spring chinook spawners outmigrated as stream-type (PSTRT 2002).

Spawning surveys conducted in the upper South Fork above RM 13.0 date back to 1946. Data collection methods and visibility have varied over the years; therefore the records kept between the 1940s-1960s are spotty. As salmon populations began their steep decline in the 1970s, and with the initiation of co-management following the 1974 Boldt Decision, these surveys became a priority for resource managers needing to estimate stock abundances, outmigrants, and potential future escapement. The surveys became more frequent and more thorough, resulting in more reliable analysis; therefore, the decades between the 1970s and 2000s serve as the foundation for this study’s results.

Although early spawning records provide insight into the geographic locations of activity over the years, the associated chinook population data have to be analyzed with an understanding of the limitations of the data. Prior to 1999, many attributes that now characterize the database were not collected in the field. Compromised visibility is an important limiting factor when surveying spawning activity, yet viewing conditions were not consistently recorded. That begs the question of whether years with low redd numbers are a result of low visibility/low detection resulting in false negatives, or high visibility/low detection resulting in true negatives. Compromised visibility is an important factor to consider when surveying spawning activity. Low visibility conditions could possibly result in redds being counted more than once if reaches were revisited in a single season, or not at all when they are, in fact, there. Therefore, data collected after 1999 are a bit more reliable. More descriptive attributes are recorded in the field, coordination between co-managers has improved, and survey sessions are more abundant and reliable as survey protocol is understood, agreed upon, and adhered to (Currence pers. comm, 2007).

Spawning habitat available to early chinook in the South Fork has been estimated to have had the capacity to support 13,000 fish annually (Mobrand 2003). Since 1984, detailed records of escapement into the upper reach have been kept; the reliability of which increases substantially in 1999 as a result of improved field methods and organization of efforts. Early escapement to the South Fork spawning grounds dropped from 608 fish in 1989 to 120 in 2005.

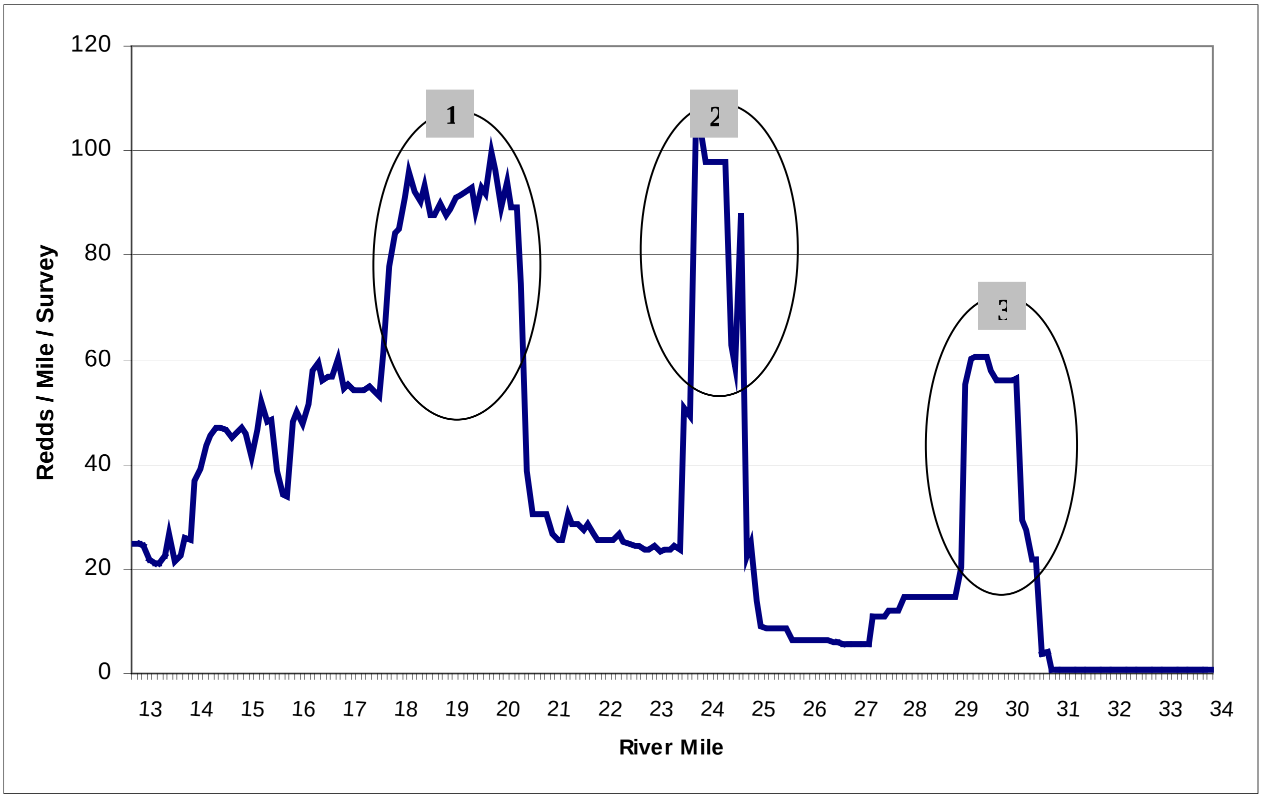


**Figure 71. Cumulative South Fork Nooksack spring chinook redd abundance by river mile between 1947 – 2006, highlighting the three most productive spawning reaches.**

Figure 71 above identifies the locations of three principal spawning centers in the upper South Fork reach and the distribution of summer temperature refuge areas that were identified by FLIR data collected in August, 2001. It is evident through comparative analysis that these three areas have historically been, and continue to be, consistent spawning activity foundations. The three primary geographic areas of spawning by early chinook were identified as, 1) RM 18.0 – 20.5; 2) RM 24.0 – 25.0; and 3) RM 29.0 – 30.5 (Figure 71).

Factors that shape the redd location and distribution line (Figure 71) are likely instream habitat quality- or availability-based. Habitat quality and availability in the upper South Fork are influenced by water quality, flow regime, sediment load, and channel stability. Channel substrate is mobile throughout the study area, and local scour does move gravel around. The uppermost area of high spawning activity (3) is found immediately downstream from habitat that is impassible to chinook and most other salmoinds year-round. The resulting lack of upstream passage may force fish to spawn in the vicinity if they are ready. It is believed that much of the spawning that occurs here is a result of fish meeting the end of accessible habitat. The spawning activity center located at RM 25 may also be the result of limited passage through a steep, narrow canyon known as Sylvester's Canyon. Documented fish passage blockages in Sylvester's Canyon are not common; however, they have constitute several theories that attempt to explain low redd counts upstream. Although habitat (in)accessibility may affect redd production here, the increase is most likely due to high spawning habitat quality here. Gravels, although lower in distribution that at other reaches of the river, are cleaner. Water quality also tends to be better, characterized by lower temperatures and higher dissolved oxygen.

The productive reach between RM 18-20 (Number 1 in Figure 71, above) is a natural sink for spawning-sized gravel for chinook, and has served early chinook as reliable spawning habitat in the upper South Fork. This lower section's concentration of chinook redds may be attributed to good habitat and its certain availability, whereas the upper two areas may exhibit concentrations of redds as a result of the necessity to spawn at the end of navigable habitat and lower quantity of gravel available for spawning in the wetted channel.

Flow records from the USGS Wickersham (USGS 12209000) gage at RM 14.8 were plotted against the redd data from the three high-production reaches to examine how high and low flows may influence escapement to the spawning grounds, as well as redd building and future escapement. The flood of record that occurred in 1990 and other near-record floods (1955, 1989, 1995 and 2003) is suspected to have had an adverse effect on egg-to-fry survival, subsequent juvenile outmigration, and future adult returns.

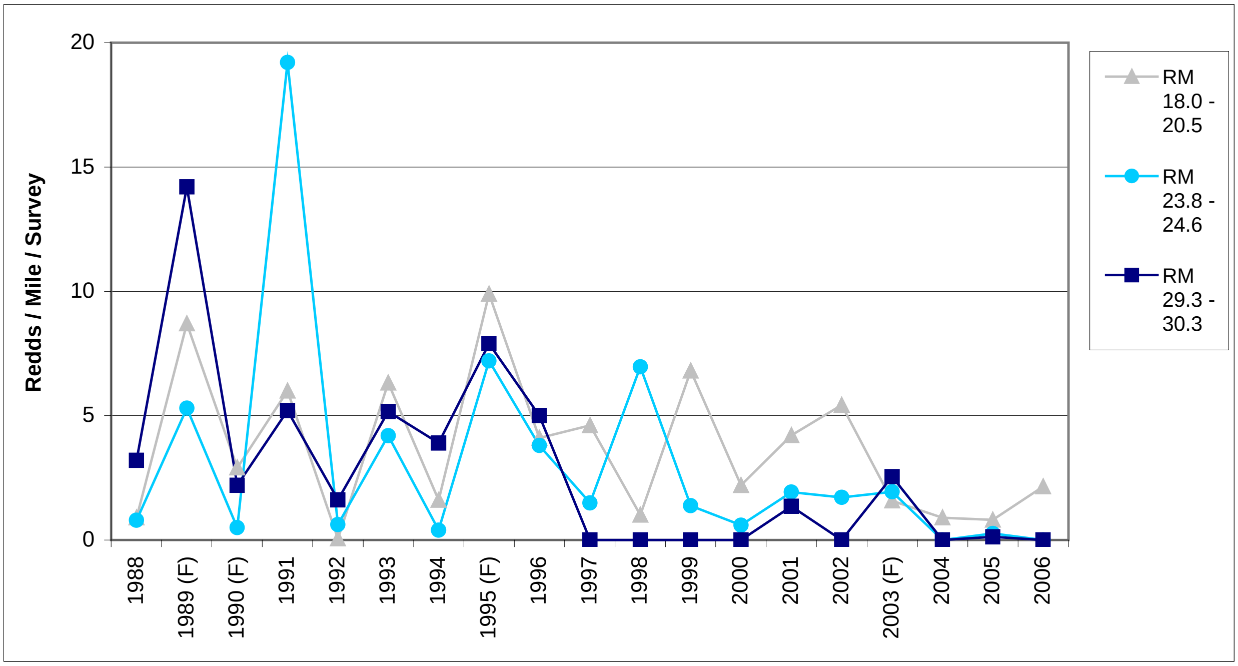


**Figure 72. Recent trends in redd abundance per river mile per survey by reach. (F) denotes a flood year; 1990 is the flood of record.**

Several environmental and biological factors that may affect trends in the data limits the degree to which solid conclusions can be drawn from it. However these data were used for the purpose of trend analysis between spawning, escapement, and hydrology. Low survival would likely reflect low escapement and redds surveyed between three and five years later, when the majority of chinook adults return to spawn (Healey 1991). Visibility through the water column to the bed where redds are built often deters surveyors from observing new redds. Additionally, high flows may limit access to spawning grounds by on-the-ground surveyors.

One trend that became obvious was the annual variability in redd production and escapement over time (Figure 72, Figure 73). The high on-the-ground escapement estimate and redd counts observed in 1991and the peak in spawning activity documented four years later describes the classic pattern used to predict future returns. However, high redd abundances in 1995 and 1999-2000 did not fit the pattern. It is important to consider other factors that influence the pattern of adults returning to their spawning grounds, most notably ocean conditions and harvest restrictions.

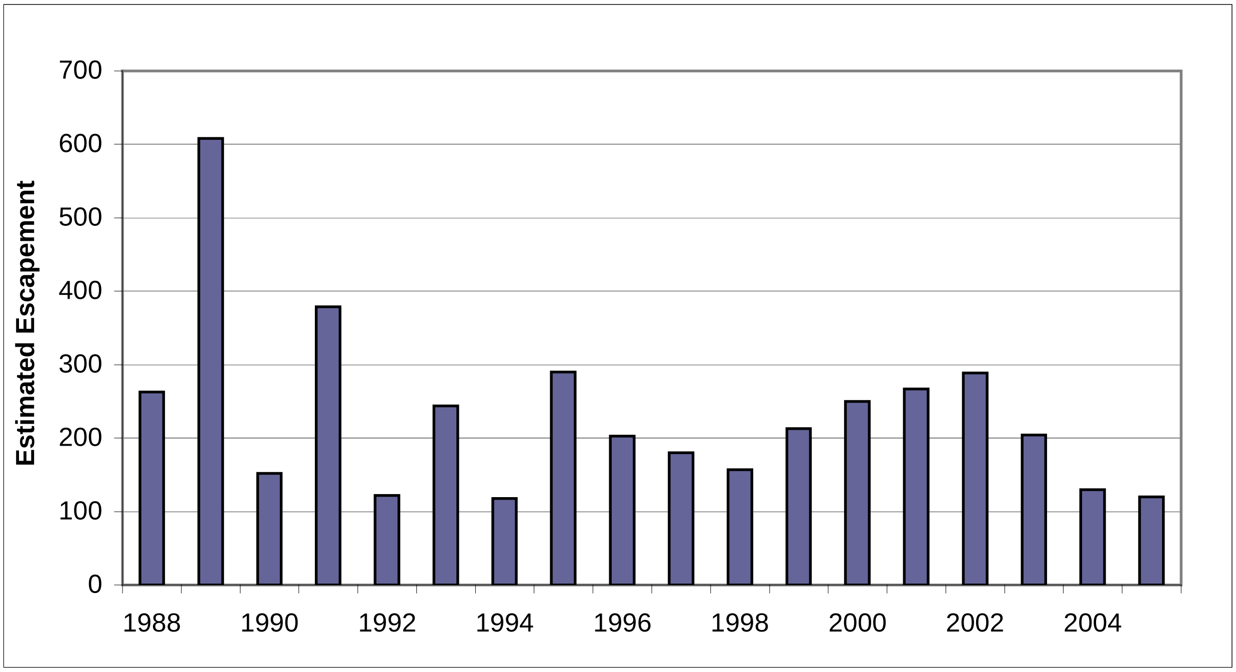


**Figure 73. Estimated escapement for early chinook in the South Fork Nooksack River.**

Figure 74-Figure 77 describe changes in documented redd abundance calculated as number of redds-per-tenth river mile-per-survey between the Saxon Bridge and the anadromous passage barrier at RM 31.8. Yearly figures were compiled for each decade and divided by the number of years in that decade, usually ten. For the 2000 decade, summed data was divided by six, as only data for years 2000-2005 were available at the time of analysis. For each figure, the early decade's values were subtracted from the later decade's values to achieve net values between decades.

Progressive improvements have been made in the efforts to collect survey data. Spawning survey methods became standardized among the resource managers responsible for monitoring conditions. To track changes in activity throughout the reach, survey data were grouped by decade along each tenth-river mile. By assembling data by decade, outliers that represent a particularly good or bad year's escapement and spawning activity are eliminated, and longer-term trends can be analyzed. The decadal data in Figure 74-Figure 77 explain where spawning activity occurs, and how active spawning reaches remain in place or have moved throughout the upper South Fork reach over time.

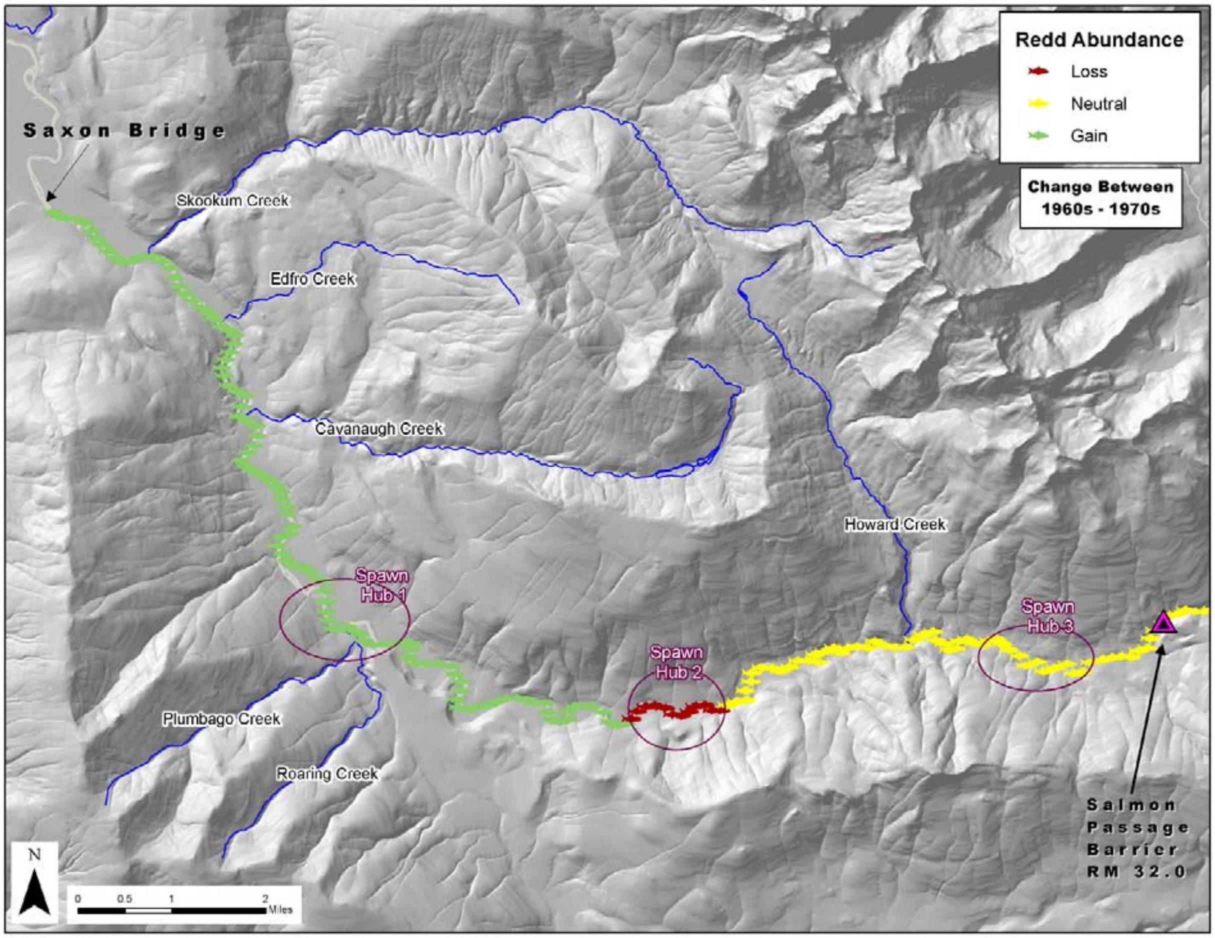


**Figure 74. Decadal changes in early chinook redd abundance between the 1960's and the 1970's.**

Shifts in redd abundances between the 1960 and 1970 decades were positive or neutral through much of the spawning reach, with the exception of the area between river mile 24-25 (Figure 74). The loss in redd abundance in the middle reach cannot be explained with a high degree of certainty. Mean discharge and peak flow data collected during this period do not suggest the falls at river mile 25 would have posed a barrier to fish passage during early migration, as may be the case when flows are too high or too low to accommodate fish above the falls.

Between the 1970s and 1980s, several small reaches below Sylvester's Canyon experienced a net loss (marked in red in Figure 75 above) in redds built; however, there were overall gains in redd abundance in the study reach. This trend reversed in the next period analyzed; between 1980-90, there was a positive shift in redd abundance (Figure 76). In fact, the areas that had declined between 1970-80 regained their positive status, and declines detected during the period between 1980-90 were located in areas that had not previously been negative. Redd numbers declined in the channel between spawning areas 2 and 3, enhancing the development of these areas. The overall trend in the 1980-90 analysis is positive, although there is decrease distinguished just downstream the RM 32 falls barrier. There are several mechanisms that may have caused this decline. Early chinook may have been forced to spawn there during the 1980s, and not in the 1990s, causing the decline, or the number of fish that regularly spawn there did not make it that far in the latter decade. The former explanation is more likely, due to the positive aspects the miles of habitat between the RM 32 barrier and the RM 25 falls afford to fish. It is evident that fish were passing the RM 25 falls, so passage through here was not likely a factor.

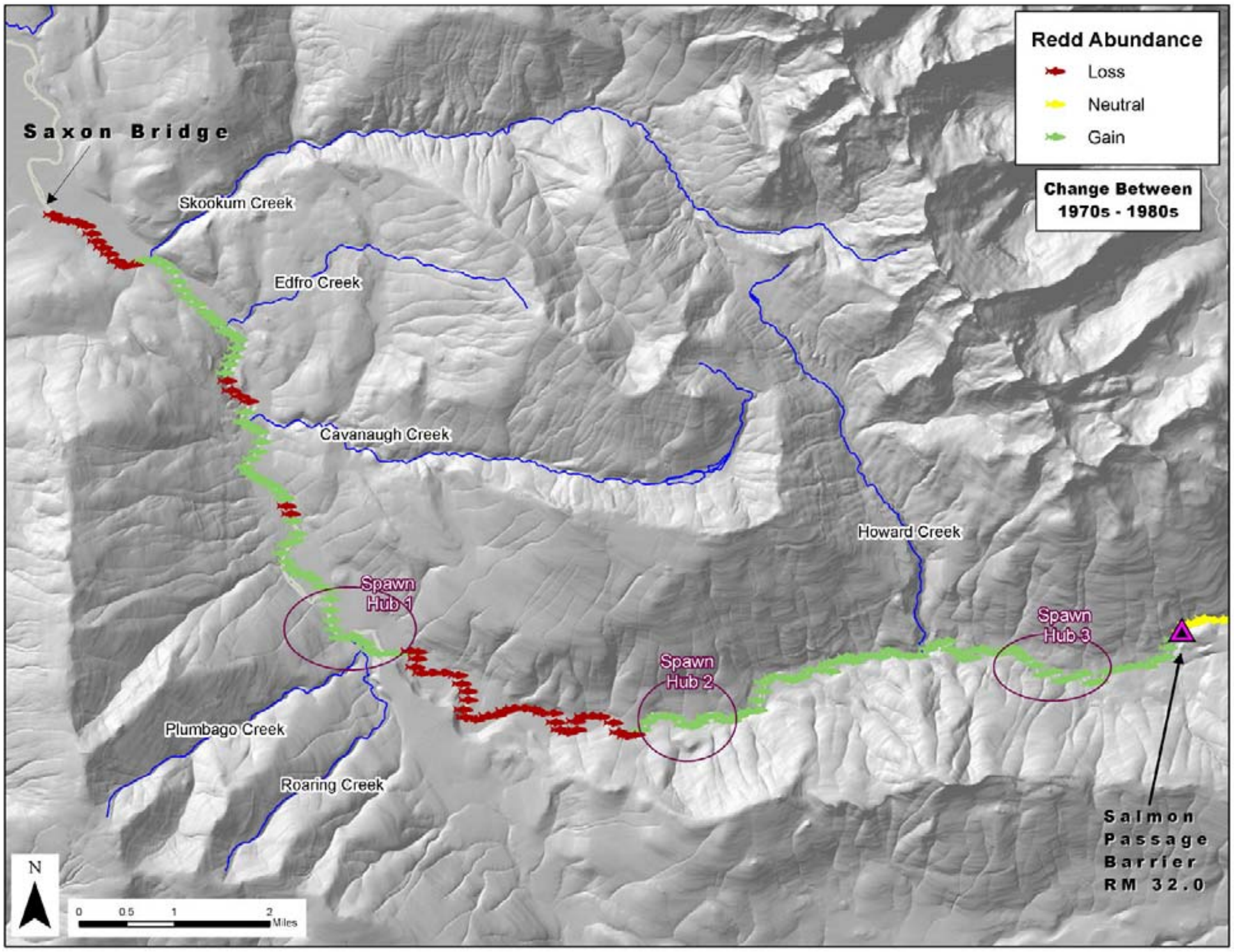


**Figure 75. Decadal changes in early chinook redd abundance between the 1970's and the 1980's.**

The most significant change identified in the redd abundance analysis occurred between the 1990s and 2005. With the exception of a 1.4-mile stretch just upstream of Larson's Bridge (RM 20.6), redd abundance decreased between the 1990s surveys and those performed between 2000-05. Bed visibility during surveys taken between 2000-05 can be ruled out as a factor in this decline. Although survey conditions in 2004 were described as poor (Figure 78, Figure 79), surveyors rated visibility as either good or fair in all other years of the decade. The decline seen between the 1990s and 2000s is troubling. It culminated in the exceptionally low escapement to the spawning grounds seen in 2005 (n=120). In fact, the escapement recorded in 2005 was the second lowest of the past 22 years; only 1994 was lower (n=118).

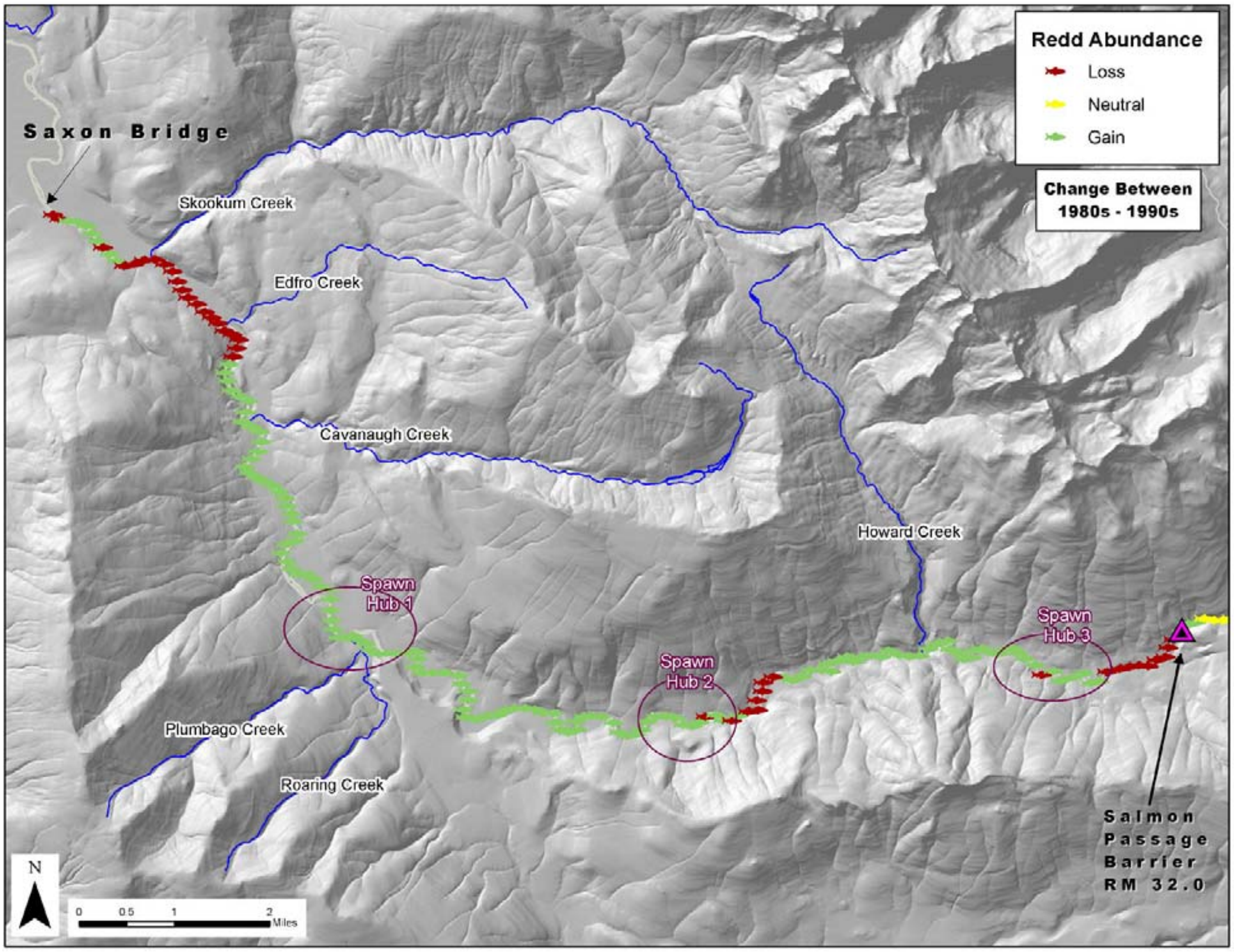


**Figure 76. Decadal changes in early chinook redd abundance between the 1980's and the 1990's.**

Further analysis of the most recent redd count data confirms the trend of declining spawning activity in the upper South Fork. Figure 78 and Figure 79 below describe both early and late-timed chinook spawning activity by annual redd cumulation. Early chinook spawning activity below Larson's Bridge decreases from 101 redds surveyed in 2001 to 30 surveyed in 2005. Survey data collected here in 2006 (n=94) is promising, and may be a sign of trend reversal. Early chinook spawn survey data for the channel upstream of Larson's Bridge did not yield a statistically significant change during the same period.

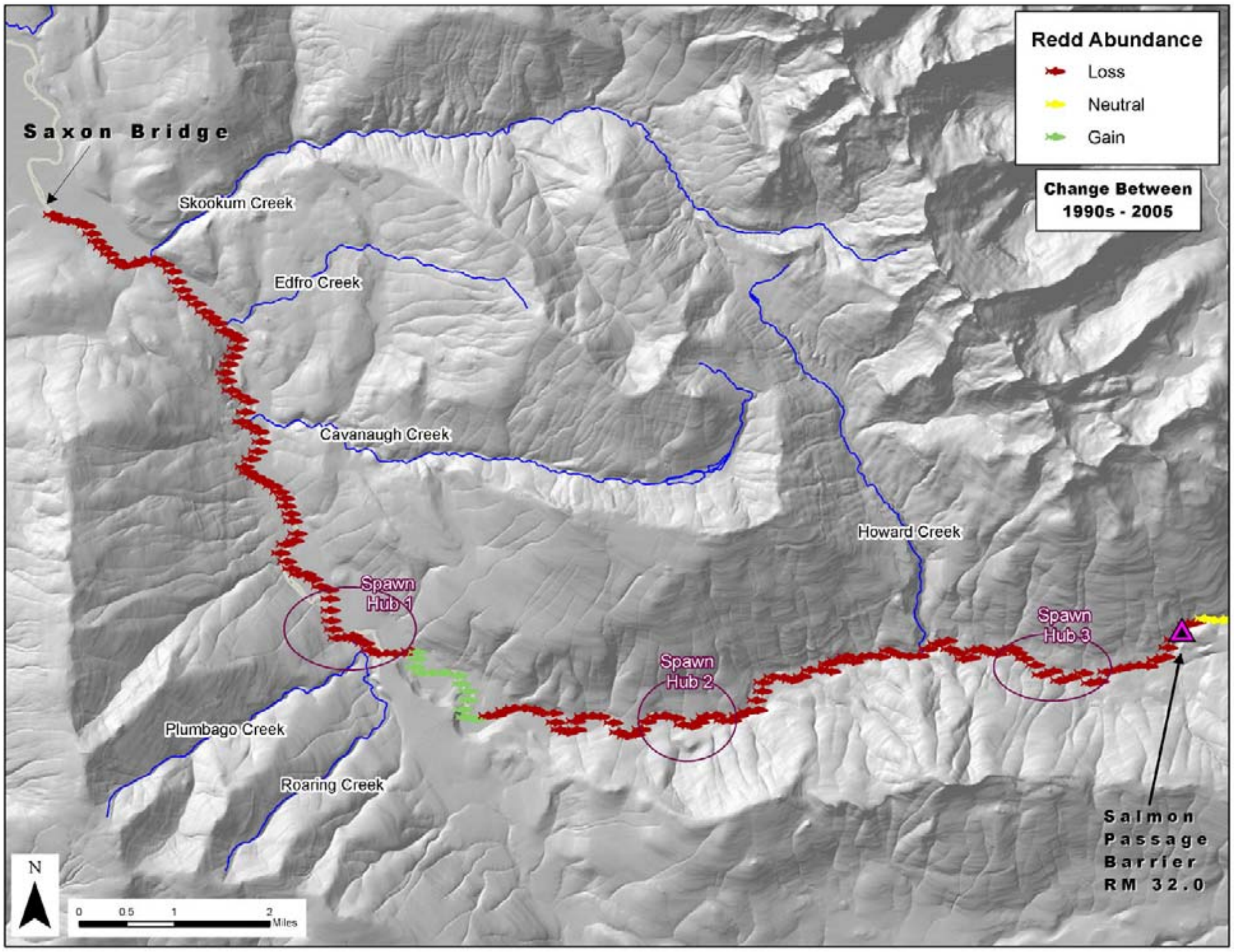


**Figure 77. Decadal changes in early chinook redd abundance between the 1990's and 2005.**

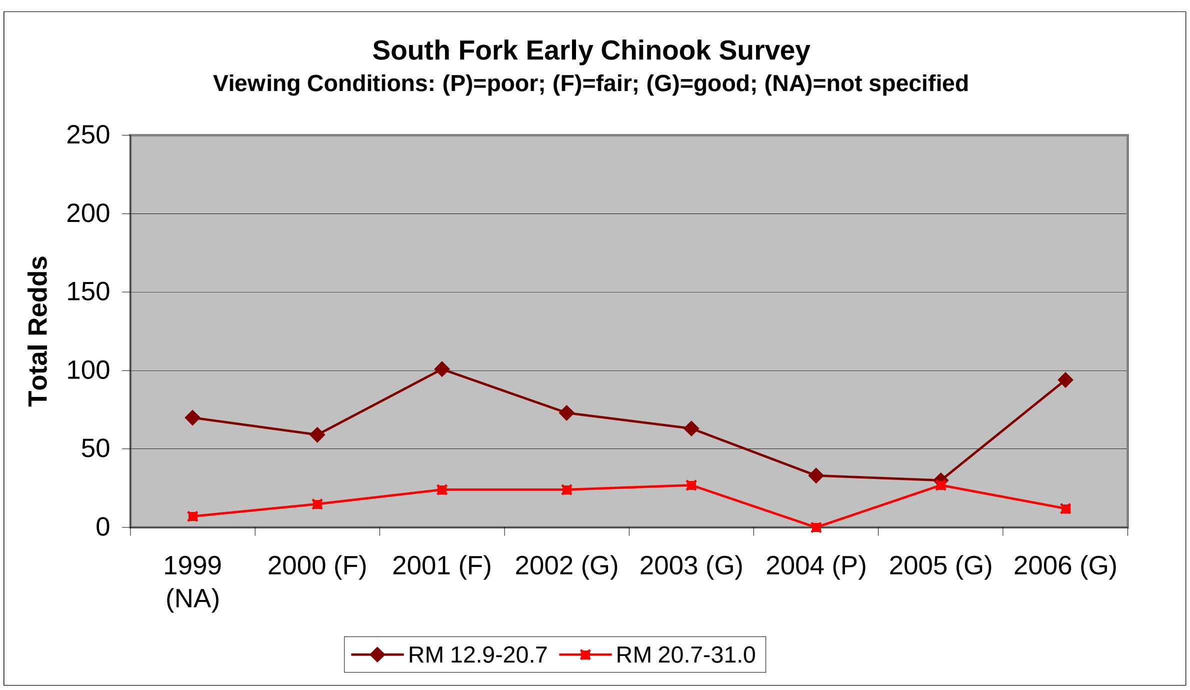


**Figure 78. Spawner survey results for early (pre-October 1) chinook in the upper South Fork.**

In general, early chinook are more active on the spawning grounds lower in the study area, between the Saxon Bridge and Larson's Bridge, than higher up above Larson's Bridge to the passage barrier. This may be explained by the larger quantity of spawning gravel available to chinook in the lower areas of the river. Channel habitat above Larson's Bridge is steeper and less likely to retain large areas of gravel and cobble suited to chinook for nest building.

Spawn data for the late-timed chinook spawning above Larson's Bridge describe a pattern similar to those from the early chinook. The number of redds built in 2001 (n=241) is impressive in this field, but the activity returns to the consistently low standard in the following four years. Surveys after October 1 above Larson's Bridge did not produce great numbers, partly due to a decreased effort by the WDFW there. These data lack substantial statistical power and were not used in detailed analysis.

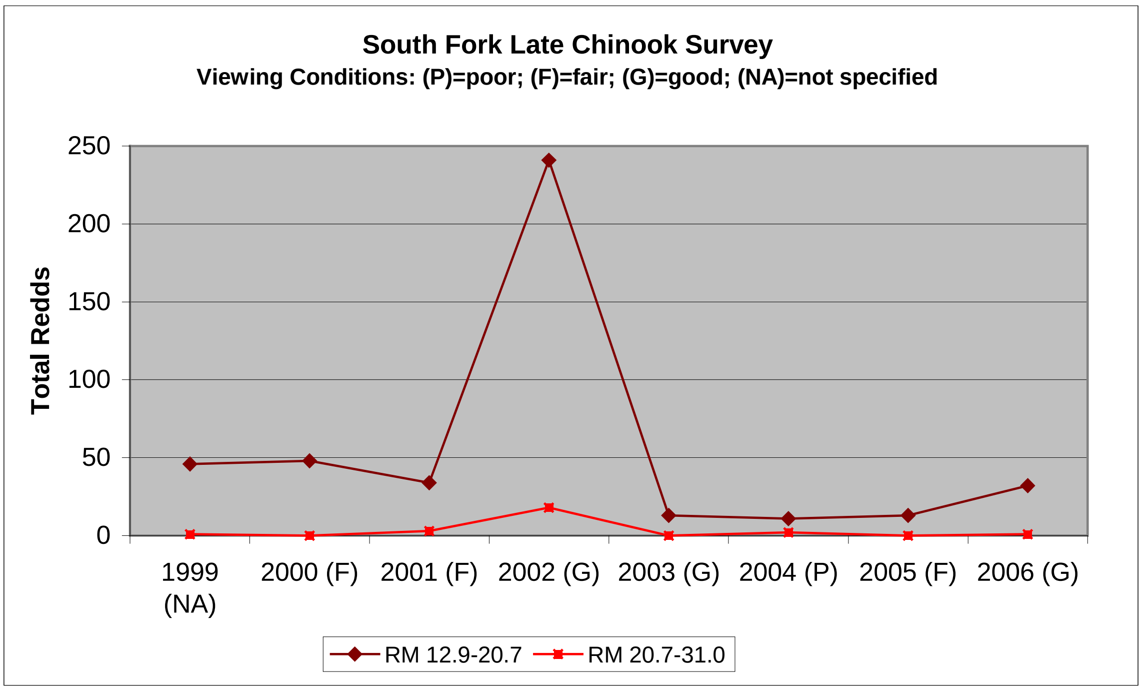


**Figure 79. Spawner survey results for late (post-October 1) chinook in the upper South Fork.**

## Native Char (*Salvelinus*, spp.)

The char subgroup of the family Salmonidae in WRIA-1 includes bull trout (*S. confluentus*) and Dolly Varden (*S. malma*). They are the only char native to Washington State (Whatcom County 2006, USFWS 2004). Compared to other salmonids, bull trout have more specific habitat requirements, including cold water temperatures, particularly for spawning and rearing, and the presence of complex forms of cover for life history stages. Complex cover required by bull trout includes large woody debris, undercut banks, boulders, and pools (USFWS 2004).

The Coastal-Puget Sound Distinct Population Segment (DPS) of bull trout includes all Puget Sound drainages, including the Nooksack River. The Nooksack population is significant to the species as a whole, because it is one of only seven spawning river systems in Puget Sound The Coastal-Puget Sound DPS supports all life history forms of the species, including the only known anadromous forms in the

United States (USFWS 2004). The Nooksack River is home to ten sub-populations of bull trout, including three in the South Fork; one specific to Wanlick Creek at RM 35.2; one in the accessible tributaries upstream of Wanlick Creek; and one in the accessible tributaries downstream of Wanlick Creek to, and including Hutchinson Creek. Bull trout have been in decline as a result of both historical and current land use activities, including dams and flow diversions, forest management practices, fisheries management, agricultural practices, road construction and maintenance, and residential and urban development (USFWS 2004). As a result, the bull trout was listed as Threatened in the Coastal-Puget Sound Distinct Population Segment on November 1, 1999.

The final rule designates the South Fork Nooksack River and the lower Nooksack River downstream of approximately RM 24, as well as all nearshore habitat within Bellingham and Lummi Bays, and north to the Canadian Border as critical habitat in the recovery of bull trout in Unit 28-Puget Sound of Washington State. Federal and some state-managed lands, such as Forest Service and DNR coverages, are excluded from critical habitat designation. The recovery and delisting of bull trout will depend on the achievement of recovery goals and criteria described in the USFWS (2004) recovery plan. Details specific to the recovery of bull trout include the protection, restoration, and maintenance of suitable habitat conditions for bull trout, not only within their local population spawning and rearing areas, but also in their migration corridors and foraging areas. Others include the prevention and reduction of negative effects of non-native fishes and other taxa on bull trout; the characterization, conservation, and monitoring of genetic diversity and gene flow among local populations of bull trout; the use of all available conservation programs and regulations to protect and conserve bull trout and bull trout habitat; and the assessment of the implementation of bull trout recovery actions and the revision of management plans based on these assessments (USFWS 2004).

Some bull trout populations are migratory, spending portions of their life cycle in larger rivers or lakes before returning to smaller streams to spawn, while others complete their entire life cycle in the same stream. In the Nooksack watershed, the resident native char genetically tested to date have described only Dolly Varden. Microsatellite DNA testing of several individual native char in waters accessible to migratory fish in the upper South Fork described them as bull trout (USFWS 2004). Although bull trout and Dolly Varden are genetically distinct, their similar phenotypes make it difficult to distinguish them in the field. However, previous DNA analysis has progressed local population surveys and concludes that both species inhabit the Nooksack watershed (USFWS 2004). These char have anadromous or freshwater life histories; however, it is assumed that the population above the South Fork Nooksack migratory barrier are primarily resident Dolly Varden, and those found below the barrier are primarily bull trout (anadromous) (NNR 2005, Hart 1980).

Spawning maturity for bull trout is commonly reached in the fourth year of age (USFWS 2004, Hart 1980). Unlike salmon, adult bull trout are iteroparous and can spawn every two or three years. Nooksack bull trout adults begin upstream migration in May and usually complete spawning in November. Bull trout spawn higher in the watershed than their salmon counterparts, in tributary streams and side channels after water temperatures fall below 9°C. Eggs incubate optimally between 2-4°C for a long period of time, and hatch in the spring. Fry swim up from the gravel around May. Juveniles outmigrate in spring, but may move between fresh and salt water environments throughout the year. They may overwinter in freshwater Puget Sound habitats and head to saltwater for foraging opportunities. Their run timing puts them in the estuary at an opportune time, as most juvenile salmonids are rearing in estuarine habitats in the spring.

Spawner survey data for char in the South Fork watershed is limited. Few surveys occur in the remote areas they occupy; their spawning areas are often located upstream from other species more heavily surveyed, like chinook. Additionally, these fish prove to be elusive, and viewing conditions during fall and early winter, when rainfall decreases water clarity, can be poor. The WRIA-1 spawner database's fires char survey (described as bull trout-Dolly Varden) in the upper South Fork Nooksack was recorded on October 21, 2002. To date, five spawner surveys have been completed in the South Fork mainstem and recorded into the database. In addition to these main channel surveys, five others have been conducted in upper South Fork tributaries. Ecotrust (2003) surveys describe the presence of adult bull trout in Wanlick Creek (confluence at RM 35.2).

## Coho Salmon (*O. kisutch*)

Coho salmon in the Nooksack River Basin are not listed under the ESA. However, there are concerns about the fitness of the native population, found in the North Fork above RM 61. Non-native hatchery-origin coho from the Kalama, Samish, May Creek, Skagit, Clark Creek, and Skykomish systems were released from the Skookum Creek Hatchery into the South Fork between 1974 and 1995 (WDFW 2002). Although the South Fork coho are not protected under federal law, their production is highly important to other salmonid species as part of the river ecosystem. They serve as both predators and prey in the South Fork food web. Commercial, ceremonial, subsistence, and sport fisheries depend on healthy runs of coho as well, as they are of high economic and cultural value to local tribes and fishermen.

Coho salmon return to natal rivers for upstream migration early in the fall to commence October through January spawning. In the Nooksack River, adult coho have been observed as early as mid-July (Williams et al. 1975). They commonly spawn in the tributary streams. Upon emergence in March, coho juveniles establish territory near their natal nest to feed on insects. From Central British Columbia, Canada, they typically rear in freshwater habitat a year or a bit longer after emergence, and spend about eighteen months in marine waters before returning as age-three adults (Weitkamp et al. 1995). The primary exception to this pattern is the return of “jack” coho; sexually mature males that return to natal rivers after only 5-7 months in marine waters.

With moderate water temperatures and an abundant food supply, coho fry will grow from 30 mm at emergence to 60 – 70 mm by September, to 80 – 95 mm by March of their second year, and to 100 – 130 mm by May (Rounsefell and Kelez 1940; Sandercock 1998). Water temperatures between 12° - 14°C are optimum for maximum growth efficiency (Brett 1952). Coho may stay two, three, or even four years in fresh water before outmigrating; however, most Nooksack River migrants leave the river during their second year (Pfundt, pers. comm.).

The size of fish, flow conditions, water temperature, dissolved oxygen conditions, day length, and food availability all affect the exact time of migration (Shapovalov and Taft, 1954). In a single river system, there are year-to-year variations in the timing of coho smolt migration, related to environmental factors. Smolt trapping efforts at the mouth of the Nooksack River by Lummi Natural Resources staff between 1994 and 2003 reveal a consistent pattern of coho migration down into the estuary between the first week of April and the last week of July (LNR 2000, 2004, unpublished data.). The return of coho to the South Fork of the Nooksack River begins not long after the first autumn rains bring in adults waiting in Puget Sound. Coho are present by mid-October, but holding and waiting to spawn.

Coho redds are counted during infrequent winter surveys in November and December. Between 1999 – 2004, one redd was recorded in the main channel above RM 12.8, during seven surveys completed. Typically, suspended sediment loads do not permit sufficient visibility during this time, and tributary streams prove to be more suitable for coho spawning. The WDFW uses index reaches to estimate coho escapements, and the only South Fork stream that is surveyed annually as an index is lower Hutchinson Creek. Consequently, coho surveys have not been consistently conducted in any streams in the study area, though some survey data is available. Between 1999 – 2004, thirty-seven redds were recorded over twenty-five surveys. One mid-November 2002 survey conducted in Edfro Creek (confluence at RM 15.1) yielded nineteen redds. Assuming that redd counts from surveys conducted only once per year are considered to be fairly reliable because multiple counting of one redd is unlikely, pre-1999 survey data were analyzed. The results from these surveys describe random patterns for coho salmon building redds. Of the one-day surveys conducted in select tributary streams running back to the mid-1970s, all surveys but two yielded less than five redds. The two exceptions are from surveys conducted in Edfro Creek; one in 1984 that yielded 44 redds, and another one in 1986 that yielded 17. It is recognized that Edfro Creek is an important spawning ground for coho salmon. Cavanaugh Creek and small wetland areas that drain into the river around RM 15 are also of known importance to coho.

### Pink Salmon (*O. gorbuscha*)

Nooksack River pink salmon are considered a unique genetic diversity unit (GDU) because they are genetically unique and exhibit earlier river entry timing and spawn activity than other Puget Sound pink salmon stocks (Maudlin et al. 2002). This early entry and spawn time results in early emergence and outmigration, observed consistently by LNR staff at the lower Nooksack River (RM 4.8) smolt trap every odd-numbered year. The smallest of the Pacific salmon species, pink adults begin their freshwater migration to spawning grounds throughout the main channels and forks of the Nooksack during the summer months. In the Nooksack basin, pink salmon tend to build nests in the forks and mainstem reaches of the river, as well as in tributaries high in the accessible areas. There is record of pink salmon reaching RM 25 of the South Fork, and spawning in the following tributaries downstream: Hutchinson, Skookum, Cavanaugh, Deer, and Plumbago Creek (WDFW et al 1993, cited in WRIA-1 Recovery Plan). Being early spawners, access to streams can be discharge-dependent. After emergence, pink salmon fry migrate quickly downstream, spending less time, on average, in fresh water than other *Oncorhynchus* species that commonly migrate to sea after months or even years in fresh water. Migration duration has been documented between 53 to 72 days post-hatch, depending on stream length (Heard 1998).

Between February and May, outmigrant pink fry arrive at the lower river smolt trap. Throughout its Pacific range, the mean size of migrant pink fry varies from about 28mm to 35mm in fork length (Heard 1998). Nooksack River pink salmon fry are no different; fry observed at the trap have been observed to be as small as 22mm, but average about 35mm in fork length (LNR 2000), indicating short freshwater residency periods. It is not uncommon to see outmigrants at the lower river trap with remnants of their egg sack intact. These small-sized outmigrating pink salmon play an integral part in the riverine and estuarine food webs, as they provide a valuable food source for larger piscivores, a group that commonly includes chinook, coho, and trout in the Nooksack River and its estuary.

Snorkel surveys of pink (as well as chum) salmon are limited by the timing of their presence coinciding with elevated turbidity and cold waters in the fall and winter months. Pink salmon outmigration observed at the lower river trap appears to peak in March and April, diminishing sharply in May. Dewberry (2003) noted that their absence from summer snorkel surveys in the South Fork of the Nooksack River may be explained by their aforementioned direct migration to the estuary or marine environments.

### Chum Salmon (*O. keta*)

Nooksack River chum salmon are recognized as part of the Puget Sound/Strait of Georgia Evolutionarily Significant Unit (ESU), one of four throughout Washington, Oregon, and California (NMFS 2006). Although the Hood Canal summer chum and Columbia River ESUs are listed as Threatened, listing of the Puget Sound/Strait of Georgia ESU was not warranted as of June 8, 2007.

Nooksack River adult chum salmon begin their freshwater migrations in late summer and begin entering natal drainages around mid-September (Williams et al. 1975). Chum salmon spawn in the lower reaches of rivers and streams, typically within 60 miles of the ocean. Spawning sites are often near springs. As one of the Pacific salmon species that can and frequently does spawn near river outlets, chum fry do not usually require a lengthy freshwater rearing period. They hatch in the early spring and many proceed immediately to the sea, arriving at the mouth of the river as early as February (LNR 2000, Salo 1998). Nonetheless, others rear in freshwater and in the estuary to increase their size before entering nearshore environments. This early life history strategy, which chum salmon generally share with pink salmon, reduces the mortality associated with the variable freshwater rearing environment, but makes chum more dependent on estuarine and marine habitats for development and ocean preparation than other species of salmonids (WDFW 2005).

Nooksack River chum salmon adults have been observed migrating through the upper reaches of the South Fork; however, the extent of their spawning activity has not been precisely monitored here. Spawning survey data collected by state co-managers describe eight surveys conducted in South Fork tributaries between 2001–2002. These surveys did not produce records of live adult fish, dead carcasses, or redds built. Small numbers of chum utilize the river downstream of Saxon Bridge, and small numbers also rear in lower South Fork tributaries, including McCarty and Todd Creeks. Visibility and flow conditions prevent accurate counts, but the absence of large numbers of carcasses at these locations indicates that chum salmon in the South Fork are not abundant. Chum surveys in the project area are infrequent, although these fish have been observed as far upstream as the Lummi Nation logjam project at Larson's Bridge (RM 20.6). Spawning records for other reaches of the Nooksack River note that the bulk of chum salmon redds are recorded between late November through December, tapering off in early January. Spawning records for chum date back as far as 1944. The surveys logged between 1944 and the early 1970's recorded hundreds of live and dead adult fish; however, the first chum redd recorded into the database came from RM 45 of the mainstem on November 27, 1974.

Not unlike the pink salmon, young chum begin actively feeding immediately after emergence from their spawning beds, preparing for a comparatively early outmigration to the estuary and nearshore environments. It is well known that chum fry both migrate and feed at night, consequently, they predominately prey on items available this time of day (Salo 1998). Their basic diet consists of chironomid, mayfly, stonefly, and dragonfly larvae, chironomids being the most abundant of these benthic invertebrates (Salo 1998). Insects at adult and larval stages comprise most of their diet.

### Sockeye Salmon (*O. nerka*)

Sockeye salmon have long been regarded as the most commercially valuable of Pacific salmon in Canadian waters; however, regularly low escapement in the Nooksack system has not afforded this species an economically critical standing among local harvesters. The Nooksack River sockeye is a distinct run that spawns in larger tributaries, the upper reaches of the North, sporadically throughout the South Fork, and occasionally in the Middle Fork (Currence, pers. comm.). Riverine sockeye populations commonly include sea-type and river-type life history strategies, although Puget Sound wild riverine sockeye scales that have been analyzed indicate most leave as yearlings (river-type) (John Sneva, via Currence, pers. comm.). Due to their wide geographic distribution but low abundance, it is difficult to estimate sockeye salmon escapements in the Nooksack River system. Maudlin et al. (2002) states that while no escapement estimates have been produced in the Nooksack drainage, the South Fork reach consistently supports sockeye spawning; they are among the earliest spawners in the South Fork.

The typical life cycle of the sockeye salmon includes a stage of juvenile lacustrine (lake) rearing after migration from riverbed redds. However, the Nooksack River sockeye stock is a purely riverine stock, one that lacks a lake nursery in its life cycle. The Nooksack sockeye, along with its Skagit River counterpart, is not considered to be a formal stock, although recent genetic analysis of adult spawners indicates they are more closely related to river-type populations in British Columbia and Alaska than to lake-rearing populations nearby (Maudlin et al. 2002).

State spawning records for sockeye salmon in the Nooksack watershed begin in 1943 with an adult spotted at the mouth of Canyon Creek (North Fork tributary stream at RM 55) in September. Surveys conducted through 1960 did not yield live or dead fish, nor redds. During the 1961 survey season, dozens of live adults were recorded in the upper main stem channel; six dead adult carcasses were also recorded in the main stem. The first sockeye redd recorded was found near the mouth of a North Fork tributary on August 29, 1985. In 1986, sockeye built 27 redds at RM 12 in the South Fork, and 35 more were recorded between RM 18 – 19. Ten years passed with few redds recorded; the last significant years that bore sockeye redds were 1994 and 1996, with 12 and 10, respectively, seen near RM 62 in the main stem.

Upon hatching, river-type sockeye juveniles commonly use side-channel stream habitat to rear for up to two years. Downstream migration begins when temperatures rise above 7°C, and may last as little as one week, as sockeye juveniles are known to have traveled up to 25 miles a day (Hart 1980). Young sockeye reach the Nooksack River estuary smolt trap at age-0 and age-1, though the numbers for both age classes are very low.

Upon reaching salt water, sockeye salmon are usually between 60 and 95mm in fork-length, but records show sockeye smolts in large Canadian rivers measuring up to 130mm (Burgner 1998, Hart 1980). During the early part of the summer they appear to remain inshore, within the influence of their natal river

(Hart 1980). While here, they feed heavily in the estuary, focusing on prey found in the nearshore and brackish environments, rarely straying back up into freshwater tidal habitats.

Sockeye juveniles rear in either lake or stream nurseries, and feed mainly on insects and their larvae. They spend up to two years feeding in freshwater, growing up to 130 mm FL in size at age-2 (Hart 1980). Downstream migration to the sea takes relatively little time. Once in the estuary, their larger body size affords them the opportunity to feed on a variety of larger-sized prey items. Food at this stage includes crustaceans such as copepods, amphipods, decapods, barnacle larvae, ostracods, and euphausiids; insects; larval and juvenile fishes such as sand lance, rockfish, eulachon, starry flounder (*Platichthys stellatus*), herring, stickleback, hake; and the larvacean *Oikopleura* (Hart 1980).

Sockeye juveniles are known to be heavily preyed upon by Dolly Varden, arctic char (*Salvelinus alpinus*), squawfish (*Ptychocheilus oregonensis*), rainbow trout (*O. mykiss*), coho salmon, and prickly sculpin (*Cottidae* spp.) in estuary and nearshore habitats (Hart 1980). As adults, sockeye are regularly preyed upon in the estuary by seals, gulls, eagles, vultures, and humans. During their ocean phase, piscivorous mammals such as toothed whales as well as commercial fishing nets compose the largest group of sockeye takers.

## Steelhead Trout (*O. mykiss*)

Steelhead trout, the anadromous form of rainbow trout, inhabits the mainstem, all three forks of the Nooksack River, and numerous Nooksack River tributaries. They spawn in mainstem, side channel, and tributary habitats, and produce fry that rear in freshwater for extended periods, but typically one to three years prior to outmigrating, and typically spend from one to three years at sea before spawning (Currence, pers. comm). Some populations actually return to freshwater after their first season in the ocean, but rarely spawn, and then return to the sea after one winter season in freshwater (NMFS 2006). Timing of return to the ocean can vary, and the Nooksack River supports both “summer-run” steelhead that enter the river in summer or early fall, and a more numerous “winter-run” steelhead that enter the river late fall through early spring. The winter-run steelhead are known to hold for shorter periods before spawning (Currence, pers. comm.). Steelhead are unusual in that they are not semelparous and often return to spawn in their natal stream for a second or third time (Hart, 1980).

Both summer-run and winter-run Nooksack stocks are native, but have unknown stock status in the watershed as a whole (Maudlin et al. 2002). The South Fork steelhead runs, both winter and summer, are classified as depressed due to flooding and habitat instability by the Washington Department of Fish and Wildlife (et al. 1994). The Puget Sound Distinct Population Segment (DPS) was proposed for ESA listing in February 1994; on May 7, 2007, the National Marine Fisheries Service officially listed it as Threatened. This DPS includes all naturally spawned anadromous winter-run and summer-run steelhead populations in streams in the river basins of the Strait of Juan de Fuca, Puget Sound, and Hood Canal, Washington, bounded to the north by the Nooksack River and Dakota Creek (NMFS 2006).

In the Nooksack Basin, winter-run adults usually return between November and May, spawning from January to June (Maudlin et al. 2002). They are more common than their summer-run counterparts in this system, but do not usually access upper reaches of the Nooksack, perhaps due to lower metabolisms in colder water (Maudlin et al. 2002). In the South Fork, winter-run steelhead spawn in the river primarily between RM 8 and RM 25; the cascade/falls at Sylvester’s Canyon often block upstream migration (Currence, pers. comm.). Summer-run steelhead enter the Nooksack River from May to October, and spawn between February and April. No official escapement is estimated for these fish in the Nooksack, although they do not appear to be numerous. Escapement in the Nooksack River varies between 20 and 400 adults. In contrast, this system once supported one of the largest winter runs in Washington State, pre-1950 (Maudlin et al. 2002).

Relatively consistent surveys for winter-run steelhead did not begin in selected tributaries until the winter of 1983-84. Between March and June of this year, 392 steelhead redds were recorded; few sightings of live and dead fish were confirmed, but several dozen redds were recorded in the north and middle forks. Surveys for steelhead continued, but it wasn’t until 2004 when redds were counted in significant numbers again. Dozens of redds were documented in late spring in the South Fork main stem, the north fork, and near the mouths of a few upper watershed tributaries. Again, few accounts of live and/or dead fish were made. Instream rearing by steelhead has been observed in many different habitat types; however, they exhibited a preference for woody debris cover and deep pool microhabitat as age-1+ fish (Ecotrust 2003, James et al. 1999).

Catch records at the lower river smolt trap between 1994 and 1999 indicate that Nooksack River steelhead juveniles outmigrate during all months of the trap's operation, with a peak in April (LNR 2000). Due to the variable spawn timing and migration patterns of steelhead in the Nooksack basin, the sizes of individuals, either young smolts or adult kelts arriving at the lower river trap, range from 70mm to 700mm (LNR 2000). It is also difficult to distinguish winter from summer-run steelhead juveniles, as both stocks tend to leave the river year-round. Once in the estuary, trout may stay here for up to a year, feeding heavily on other fishes such as coho salmon, stickleback, rockfish, sculpin, and flatfishes. Smaller individuals regularly eat Crustacea and both freshwater and terrestrial insects (Hart 1980). Rearing juveniles provide a consistent food source to larger piscivores, and also serve as food fish for common predators of chinook and coho salmon.

## Cutthroat Trout (*O. clarkii*)

Nooksack River coastal cutthroat trout are of native, mixed-stock origin (Maudlin et al. 2002). There are few spawning surveys recorded to date, but abundances appear to be low at the South Fork outmigration trap (Currence, pers. comm.). Snorkel surveys of juveniles record the presence and abundances of trout by age (0-, 1-, and 2+ year), however, due to the difficulty of distinguishing cutthroat from steelhead trout at these ages, and from a distance in the water column, they are counted as trout and not their specific species (Dewberry 2003).

Predators of salmonid fry and juveniles throughout the river, young coastal cutthroat serve as an important food source to those same prey species. This predator-prey interaction is always size-specific; the larger fish will prey on smaller fish. Cutthroat trout occur as both anadromous fish and as fluvial or resident trout in lakes and streams throughout the Nooksack Basin. The anadromous cutthroat trout spawn between January through July; resident cutthroat spawn from January through June. Cutthroat prefer to spawn in small tributaries and rear in ponds, side channels and wetland areas (Whatcom County 2006).

## Mountain Whitefish (*Prosopium williamsoni*)

Mountain whitefish is a salmonid species commonly found in the Nooksack's South Fork habitats that are known to support juvenile salmon rearing. It occurs in both lakes and streams; however, limited lacustrine rearing opportunities in the Nooksack watershed restrict whitefish populations to a riverine life cycle.

The mountain whitefish is a Nooksack River salmonid that is unique in that it does not build a nest for egg incubation. Between October and February, adults seek out areas of coarse gravel or cobble with depths up to one meter. Like most fish, female fecundity is a function of body size. McPhail and Troffe (1998) found that mountain whitefish fecundity in British Columbia, Canada, ranged from 4,000 to 17,000 eggs. In the absence of a nest built to incubate eggs, spawning adults drop fertilized eggs into the substrate below, where they settle into interstitial spaces and develop over the winter. Fry emerge in the spring or early summer, very small in size, and drift downstream before moving into shallow, low velocity river margins (McPhail and Troffe 1998). Newly emerged fry often serve as a food source for larger salmonids, such as resident trout or rearing anadromous salmon. James (et al. 1999) found that age-0 mountain whitefish exhibited a preference for bedrock substrate, using turbulence for cover.

Snorkel survey data collected in the Acme (RM 8.5) to Saxon (RM 12.8) reach during July 2003 (Ecotrust 2003) documented whitefish use of stream habitat in conjunction with several salmon species. Although adult salmonids and suckers were counted in this reach, the majority of individuals recorded were in their juvenile (rearing) life stage. Whitefish were documented in eleven habitat units; three riffles, four runs, and four pools.  Within these eleven habitats, 46 whitefish were present, compared to 3,940 coho salmon, 7,125 steelhead trout, and 232 chinook salmon.

## Sucker (*Catostomus* spp.)

Suckers are largely present in pool habitats in the South Fork.  There are several species native to freshwater habitats in the Pacific Northwest, most commonly the largescale sucker (*C. macrocheilus*), the bridgelip sucker (*C. columbianus*), the longnose sucker (*C. catostomus*) and its closely related, but increasingly rare cousin, the Salish sucker (*C. catostomus*).  The bridgelip sucker is one *Catostomus* species in particular that is observed regularly during monitoring activities in the South Fork (Dunphy, pers. comm.).

Adult bridgelip suckers average a fork length of 12 inches, the record being 15.5 inches from the Yakima River (Wydoski and Whitney, 1979).  Like the mountain whitefish, suckers do not bury their eggs in nests for incubation.  They deposit their eggs, which can number up to 60,000, over deep gravel beds and into interstitial spaces.  Eggs incubate for up to two weeks in the late spring, upon which fry emerge and migrate to edge habitats to rear.  Sucker fry feed primarily on zooplankton when they are feeding at the surface or in mid-water column.  After they become bottom dwellers, they may change their diet to aquatic insect larvae and diatoms, as well as plant material and detritus scraped from rocks.  In addition to plant material, larger suckers feed on a variety of benthic organisms such as amphipods, clam, caddisfly, and snail larvae (Wydoski and Whitney, 1979).  Suckers may compete for food with local salmon and trout species, but fry may serve as forage for larger piscivorous species.

## Biotic Interactions

### *Competition*

Fish of comparable size are perpetually in competition with each other for aquatic resources.  Although species of like size sometimes vary in age, life cycle, biotic variability, and resources they prioritize, they share the common requirements for food and refuge from predators and refuge from high flows.

The competition indices for Yakima/Klickitat River spring chinook were examined by James (et al. 1999).  This research found that food competition among juvenile species was greatest between stream-type chinook juveniles and mountain whitefish, followed by rainbow/steelhead trout, and redside shiner (*Richardsonius balteatus*).  Similar results for competition between spring chinook and redside shiner were observed by Hillman (1989), as the shiner effectively displaced chinook from preferred habitat in the Wenatchee River complex.  Competition for space was high between spring chinook and the trout and shiner species, but the whitefish did not exhibit similar behavior.  Among potential competitors, age 1+ rainbow/steelhead trout exhibited the greatest degree of microhabitat overlap with spring chinook salmon (James et al. 1999).

Snorkel surveys done in the Yakima River (James et al. 1999) concluded that age-0 spring chinook salmon were found in a relatively small portion of the available habitat and exhibited a preference for specific microhabitat conditions.  These conditions included cobble/gravel as the dominant/subdominant substrate in run/glide-habitat type.  James (et al. 1999) describes woody debris as the most common instream cover type associated with age-0 spring chinook during low flow periods.  Age-1+ spring chinook exhibited similar preferences of habitat as their age-0 counterparts.  Competition for these habitats with other fish species is usually high, with the exception of age-0 whitefish showing a preference for bedrock over gravel/cobble substrate.  The majority of freshwater, riverine fish species sized similarly to age-0 and –1 salmon tend to rear in the gravel/cobble-woody debris-run/glide habitat type (James et al. 1999), although snorkel surveys in the South Fork reveal a notable presence of young salmonids utilizing pools with a woody cover component (Dewberry 2003).  Based on this information, the quantity of these highly sought-after habitats in a given system may have an influence on carrying capacities.  An increase in the extent to which these habitats are available to salmonids may positively impact the populations of species that are struggling to reach their carrying capacity and limited by the decrease of available rearing habitat through watershed modification and development.

Although the principal food sources of fresh water-rearing chinook appear to be insects in the larval and adult stages, piscivory is fairly common in salmonids (Schabetsberger 2003, James et al. 1999, Healey 1998, Hart 1980). The importance of insects in the diet of young chinook suggests an opportunistic survival trait, one that is similarly seen in coho, steelhead, and other stream-dwelling salmonids. Competition for the same resources is presumably reduced as the timing of life-stage development and the resulting habitat segregation among species is common (Healey 1998).

### *Disease*

The presence of disease in all life stages of Pacific salmon species is not uncommon. Run timing and high temperatures appear to be factors that facilitate conditions favoring the spread of disease in species that return to spawn in the summer and early fall months (Burgner 1998). Disease seems to be more evident in hatchery-produced fish, but is seen in wild-produced individuals (Healey 1998). Disease and pathogens occur naturally in aquatic ecosystems, but due to the difficulty of monitoring wild fish populations, little is known about the interactions and risks associated between wild and cultured (hatchery) stocks. Hatcheries are often blamed for what ails wild fish, even though few documented cases exist where hatchery fish have transmitted diseases to wild fish (Harris 1997). In fact, it frequently thought that although hatcheries can amplify the rates of disease due to crowding, diseases inflicting these fish are naturally occurring and passed from wild fish.

Monitoring pathogen occurrence in wild South Fork fish is not common, but spawn surveyors do attempt to have pre-spawn chinook mortalities evaluated by a co-manager pathologist. Tissue sample extractions are required for laboratory examination of diseases such as Bacterial Kidney Disease (BKD) and Columnaris; these fungal diseases are evident from examination of gill tissue. Saprolegnia, a fungus, is detectable with the naked eye. Chinook are susceptible to BKD and Columnaris, the latter of which has been responsible for pink and chinook salmon adult mortalities in the South Fork.

Evidence of warm temperatures and run timing as catalysts for the occurrence of disease is described in Harris (1997). Reduced water quality and a reduction of instream flows by dams on the Elwah River have created ideal conditions for the parasite Dermocystidium to thrive. Consequently, this parasite has particularly affected chinook in this North Olympic Peninsula River in Washington state, decimating summer runs on a somewhat regular basis.

## Habitat Characterization

All species of Nooksack River salmonids require cold, clean water and a complex, connected habitat structure to thrive. The habitat requirement specifics vary with species and life stage but they encompass two important attributes: food and shelter. Primary riverine food resources for salmon include small fish and aquatic invertebrates. In the upper reaches of the river, shelter from poor water quality, predators, and/or UV radiation is established in places ranging in size from the interstitial spaces between gravels, to large woody debris and rootwads, to the bottom of deep, scoured pools. Compared to other Pacific salmon, chinook in their spawning life stage need habitat that provides larger and deeper streams and pools, and larger-sized gravel for nest building. Concurrently, spawning bull trout require habitat provided by upwelling, cold-water streams that maintain loose, clean gravel between 1-2 inches in size (Baxter and Hauer, 2000).

Habitat diversity is a term used in assessments to describe habitat types and the complexity of their attributes in relation to the ability of these attributes to provide an environment that sustains production of a species. Habitat is rated by how accessible and functional these attributes are to resident and/or part-time dwellers. Highly diverse and complex river habitat is created from a mosaic of habitat types such as pools, braids, side channels, sloughs, backwaters, and edge habitats (WRIA-1, 2005a). Salmonid habitat types surveyed for this assessment include pools, riffles, cascades, runs, and rapids. Finer scale habitat types observed during summer snorkel surveys include cover along edge habitat, and in pool habitats with rock, large wood, and overhanging vegetation. Cover types are habitat attributes that contribute to habitat diversity. The relative importance of various cover types to salmon and char vary among species throughout the salmonid life stages. Most importantly, cover provides hiding protection from predators and resting areas away from high flows.

Watershed development that began in the late-1800s has heavily compromised the habitat diversity of the South Fork Nooksack River. Natural logjams, thought to pose a hazardous threat to downstream structures and property, known to impede steamboat travel, and interfering with commercial transport of logs downstream, were intentionally pulled apart and removed from the channel as early as 1860 in the lower Nooksack River (USFWS 2004).

As development expanded into the upper watershed, so did the impacts on fish habitat. In the 1960's large wood was systematically cleared from the upper South Fork by Washington State Department of Fish and Wildlife contractors in a tragically misguided effort to improve fish passage upstream (USFWS 2004). Overall Nooksack River in-stream complexity has been reduced or lost due to human activities such as removal of large woody debris; channel encroachments (including bank hardening), dredging, relocation and realignment; loss of side channel, off-channel and floodway connectivity (diking, channel aggregation, flood gates), conversion of free-flowing reaches to impoundments; burial of streams in culverts to facilitate development; and the installation of road crossing structures. Wood loading in the South Fork channel declined as the clearing of upslope and floodplain forests gradually reduced the supply of wood available for river recruitment. Land and channel clearing, continuing for more than a century, has affected the biotic integrity of the mainstem channel of the Nooksack and its three forks.

As South Fork settlers realized success from their flood control efforts, development moved upstream and levee building became extensive throughout the lower valley. The resulting network of artificial bank protection structures has produced unintended consequences for fish habitat. Habitat diversity that develops from natural flood and ebb processes has decreased significantly, evident by the simplification of bank conditions (cover removal) and reduced channel sinuosity (length) through bank hardening and channelization. Levees built along the river's lower 13-miles have effectively reduced the river's natural floodplain scour and deposition processes, as well as opportunities for wood recruitment and wood stability. Other hydro-modifications such as bridges, culverts, and roads, and the resulting disconnect between the river's channel and its floodplain have also impacted habitat diversity.

Removing wood to clear channels, cutting floodplain and riparian forests to clear land, building roads and railroads for access to these cleared lands, and forcing the river to maintain a fixed channel position through the hardening of embankments over many decades have influenced native fish production. Studies conducted in western Washington rivers and streams have analyzed these adverse effects on fish habitat. Ralph (et al. 1994) found that timber harvest often results in a shift in location of large instream wood to channel margins, outside of the low-flow wetted width. By comparing rivers with intact, old growth timber to those with intensively harvested drainages, they found that timber harvesting also simplified channel habitat by increasing riffle area and reducing pool area and depth. The effects of development on stream habitat include reduced large wood habitat and amplified flow velocities. These are causal mechanisms for increased bedload scour and fill of salmon nests, and the replacement of spawning gravels by coarser large sediment. The legacy effects of these watershed development practices have created a cascade of change that finds native fish populations struggling to overcome it.

In the upper South Fork geographic area, the EDT (Mobrand 2003) model was used to estimate the degree that the loss of salmon habitat quality has impacted spring chinook production. The reach from Plumbago Creek (RM 18.5) to the falls at RM 32.0 bears high to extreme negative impacts on fry colonization and zero-age life stages. Incubating eggs and alevins are most vulnerable to reduced habitat diversity during fall and spring months, when channel volume and velocities are high, and adults are most negatively impacted during the summer and early fall months, when stream temperatures are at or near lethal highs, and well above temperatures that reduce fecundity of holding individuals. Additionally, pool habitats are compromised by lack of depth and cover, as well as low flows.

### *Pools*

Pools are the result of scour or impoundment created by river water during high flows over or around streambank or instream structures, where the bed is deformable. They can be areas of deposition for fine sediment at low flows. The removal of the obstruction, or pool forming feature, will also compromise the function of the pool, and infilling often results (Chamberlin et al. 1991). The size of substrate found in pools varies with hydrologic regime. Pool substrates range from silt and sand to large cobble and boulders.

The hydraulic transition zone between pools and riffles collects gravels left behind by the deposition of bed scour from which sand and finer materials have been removed and transported downstream (Chamberlin et al. 1991). Pools are preferred habitats by many salmon and trout species and life stages. The wide array of habitat features provided to salmon and trout by pools makes them a highly significant habitat class. Because of this, it is an important objective to re-establishing pool habitats over the riffles and runs that dominate many impaired Pacific Northwest streams.

Pool habitats differ in their importance to the various species in the Pacific salmon group. For instance, chum and pink salmon enter their natal river generally ready to spawn. They tend to hold for fairly brief periods only. Chinook, summer-run steelhead, and bull trout, however, may hold for several months before the onset of spawning. Eggs mature in their skeins during the holding period, and the importance of holding habitat to these fish is notable. Whether adult salmon migrate upstream to their spawning in a matter of days or months, they are in constant need of habitat that will offer them cover from predators and good water quality.

Increasing the pool count (frequency) in salmon streams is a common goal described in habitat restoration prescriptions because pools build improve the function of habitat for salmonids. Scour pools are often deep, and during summer months may maintain a striated thermocline with cooler, more oxygen-rich water on the bottom, if there is not appreciable mixing. The scouring of the channel bed often increases the river channel's opportunity to connect with cold-water seeps or other hyporrheic veins that contribute additional cold water.

Deep pools may also provide salmonids with cover from potential terrestrial or surface-feeding predators. Wood and rock are common pool-forming elements in streams the size of the Nooksack River and its tributaries. Large rock tends to form pools in somewhat steeper gradients, while large wood (LWD) often has more influence on pool formation in low gradient reaches. Where large rock is missing, LWD naturally forms a high percentage of pools. Large rock and LWD are often reliable sources of cover for both adult and juvenile salmon and trout. Wood creates a visibility barrier in the water column by reducing sight distances, both vertically and laterally, that fish may use for cover. Wood in the form of single large logs, rootwads, jam assemblages, or debris piles supports aquatic invertebrates that use it for rearing substrate and its detrital food source. Invertebrates serve as an important food source for juvenile salmonids, constructing up to 100% of their diet until their size affords them the opportunity to forage on small fish (Healey 1991, Hart 1980). Pools formed by rock can also provide important habitat for fish. Bedrock channel beds may form a type of pool that provides cover for fish if the channel has scoured deep enough. The naturally smooth, hard feature exhibited by bedrock does not easily retain wood, especially since bedrock channels are often steep or confined, or both. Consequently, bedrock pools may not retain the degree of cover that wood-formed pools do, but the stability of these pools is great. Banks artificially hardened with large rock often create long shallow pools that may attract single logs or suspended sediment that builds up to support bank vegetation, but the degree of cover in these shallow pools is usually low. The rocks themselves provide a degree of protective cover for juveniles, as the interstitial spaces between boulders and rip-rap provide functional habitat that is difficult for larger predators to access (Dewberry 2003), but complexity within the uniform structure is most often low. Juvenile densities along armored banks are generally lower than along natural bank.

Pools formed by wood, either by rootwads, debris piles, or single logs indicate high quality fish habitat attributable to greater residual pool depths, increased cover, and possibly lower water temperatures in the summer. The presence of instream wood often correlates to high quality fish habitat (Harvey and Stewart 1991), and is classified as an attribute that will provide habitat function during its tenure in the channel.

### *Riffles*

Riffles are bars that collect the first sediment material deposited after high flow events, most commonly gravel, cobble, and boulders (Chamberlin et al. 1991). Riffles are characterized by shallow, relatively fast-moving water. As fish habitat, they are less preferred and support lower densities than pools. Substrate in riffle units is sometimes used as cover; however, if pool habitats shift to riffles, salmon productivity may decrease (Currence, pers. comm.).

Cover types found in riffle habitats usually pertain to benthic substrates that include rocks with interstitial spaces large enough to protect fish from predators or ultraviolet radiation. Other cover types in riffle habitats include overhanging bank and riparian vegetation, and turbulence in the water. In addition, riffle substrates commonly serve as rearing habitat for many species of freshwater invertebrates. Common riffle dwellers in northwest rivers include small sculpin (*Cottidae* spp.) and the larvae of the caddisfly (Trichoptera), dragonfly (Odonata), and mayfly (Ephemeroptera). Macroinvertebrate communities between pools and riffles differ significantly. Logan and Brooker (1983) found that Ephemeroptera abundances in upland North American rivers accounted for a higher proportion of the total density in riffles than in pools. Black fly larvae (diptera) covered a higher proportion in pools than in riffles. Ephemeroptera represented the only taxa to show significant differences in density between the two habitats, riffles supporting higher densities than pools. Both of these insects comprise a significant part of the diets of young fish. Low gradient riffles deliver these insects to the water column for use as food by fish. The riffle turbulence created by swift, shallow water flowing over substrate provides cover from predators and increases dissolved oxygen.

### *Runs*

Runs are sometimes referred to as glides, although glides usually describe stream sections with slower moving water. Runs are similar in function to riffles, but their depths and velocities are usually lower. The velocity in a run is swift, but does not agitate the water's surface. Low channel gradient is a common feature of run habitat, hence the non-turbulent surface condition. Gravel and cobble are often the dominant substrate types retained in run habitat. This flat water habitat is often representative of cumulative watershed management effects, where pools have been lost due to a reduction of LWD, and percent substrate embeddedness is high (McCain et al.1990), and cover for salmonids is generally low.

### *Cascades*

Cascades are stream segments with a stepped series of drops distinguished by exposed boulder and large cobble substrates. These units are also characterized by greater channel gradient and high turbulence (Chamberlin et al. 1991). The open spaces often observed in the steps between boulders within the cascade unit may serve as resting areas for salmon migrating through the channel, but due to their turbulence and short length, they do not qualify as pool habitats but as attributes of the cascade unit. As the channel bed becomes less steep, a plunge-scour pool is often found at the downstream end of a cascade.

### *Rapids*

Rapids are steep, boulder-dominated channels with considerable surface agitation. These units are similar to cascades, but lack the resting places and velocity refugia that afford migrating salmon and trout passage upstream against high flows. Swift currents and drops in bed elevation of up to one meter are also characteristic of rapids (Chamberlin et al. 1991). Dissolved oxygen levels near saturation are common in rapids; however, these habitats are usually transitory for fish as they are deficient in food resources or resting opportunities.

### *Falls*

Falls are tall, steep units commonly formed by a "pinch" or obstruction in channel form that results in an abrupt drop in bed elevation. During high flows and/or low flows, these units may become impassable to some species of salmon and trout during upstream migration. The immediate drop in elevation often creates plunge pool habitat just downstream, serving migrating salmon by providing a "springboard" from which to launch their attempt to clear the obstacle and continue upstream. The falls themselves are poor habitat for fish, but the drop in elevation aerates the stream, increasing dissolved oxygen concentrations.

## Habitat Distribution and Abundance

South Fork salmon habitat was surveyed within the context of presumed limiting factors to document baseline conditions to develop restoration prescriptions and provide restoration project baseline monitoring data. The results will inform and guide restoration projects designed to restore natural processes to the area so that the river may again support healthy salmon runs. Aerial photos, archival maps, and various anecdotal accounts and of the watershed were used to assess how habitat has changed over the past century. Where the documentation of past habitat conditions is not available, this report will use the properly functioning conditions analysis generated by the EDT model as a substitute upon which to base it's recommendations.

### *Methods*

The study area was divided into sections that would facilitate a day's survey and data collection by two separate groups, each starting at a section end and working up or downstream to the other end. One group surveyed bank conditions and spawning gravel distribution, and the other surveyed channel habitat through unit measurements. The annual average flow between 2000-2005 in the upper South Fork measured 724 cfs. Observations and data collection for this assessment took place during the late summer months of August and September 2005, when flows during this period (August and September) averaged 234 cfs at the USGS Wickersham gage (RM 14.8). Stream flows in the South Fork are usually low this time of year, as the channel is not glacially fed, and hydrology is controlled primarily by groundwater discharge, as rain events are infrequent. Stream flows during the 2005 sampling year were lower than average; hovering around 100 cfs during the period.

**Table 22. South Fork landmarks and their updated river mile designations.**

| Landmark | River Mile | | Landmark | River Mile |
|---|---|---|---|---|
| Saxon Bridge | 12.8 | | Elk Flats | 22.8 |
| Hatchery Outfall | 14.0 | | 200 Road Bridge | 25.2 |
| Skookum Confluence | 14.1 | | Sylvester Canyon | 25.6 |
| USGS Gage | 14.8 | | Howard Confluence | 28.1 |
| Edfro Confluence | 15.1 | | McGinnis Confluence | 28.4 |
| Cavanaugh Confluence | 16.5 | | 330 Road Bridge | 30.8 |
| Fobes Confluence | 17.5 | | Anadromous Barrier | 32.0 |
| Plumbago Confluence | 18.5 | | 300 Road Bridge | 34.6 |
| Deer-Roaring Confluence | 20.1 | | Wanlick Creek | 35.2 |
| ELJ #5 | 20.2 | | 1260 Road Bridge | 37.7 |
| Larson's Bridge | 20.6 | | Bell Creek | 39.0 |

River mile designations within the upper South Fork study area were re-assigned for this assessment. The river has changed course significantly since the last river mile designations were made in the latest version of the WRIA-1 stream catalog (Williams et al. 1975). The Saxon Road Bridge, mapped as RM 12.8 in the catalog served as the downstream end of the assessment reach, as well as the anchoring river mile. River miles were updated using a line representation of the river's thalweg that was mapped for this assessment in 2005. This line was spliced into 1/10-mile sections using GIS, and river mile tenths on the map were re-numbered accordingly. Therefore, all river miles used to describe points of interest in this document correspond to the new points. Common landmarks and their new river mile designations that are referenced in this report are listed below in Table 22.

Habitat units were measured using the Washington State Timber, Fish, and Wildlife (Pleus et al. 1999) habitat unit survey manual as a reference. These methods were used to collect information on the frequency and distribution of riffle, run, cascade, falls and pool units for the characterization of current conditions and the monitoring of these conditions over time. The individual units were further described by cover types exhibited in their environs. Cover types provided to salmon and trout in the upper South Fork include deep water, turbulence and turbidity; wood aggregations, single logs, and rootwads; undercut banks; riprap, large cobble or boulder substrates; and overhanging vegetation. Monitoring criteria were based on changes in the size or frequency of the units in response to changing inputs of sediment, discharge, and large woody debris. These changes were associated with natural or management-driven disturbances. Wetted channel area was measured, rather than the bankfull channel area, since wetted area is representative of summertime low-flow conditions that early chinook encounter upon arrival to their upper-watershed spawning grounds. Also, low-flow conditions make the channel units more accessible for on-the-ground surveys, making data collection methods more reliably repeatable for future efforts.

**Table 23. Habitat unit classifications used for the upper South Fork Nooksack River assessment.**

| Habitat Level 1 | Habitat Level 2 | Habitat Level 3 | Habitat Level 4 | Cover Types | Pool-Forming Features |
|---|---|---|---|---|---|
| Main Channel | Fast Water: | Turbulent: | Falls | Boulder | Boulder |
| Braided Channel | | | Cascade | Bedrock | Bedrock |
| Side Channel | | | Rapid | Cobble | Free-Formed |
| | | | Riffle | Deep Water | Resistant Bank |
| | | | Chute | Vegetation | Artificial Bank |
| | | Non-Turbulent: | Sheet | Plants | Beaver Dam |
| | | | Run | Pilings | Bank Roots |
| | Slow Water: | Scour Pool: | Eddy | Riprap | Debris Pile |
| | | | Trench | Rubble | Single Log |
| | | | Mid-Channel | Undercut Bank | Remnant Channel |
| | | | Convergence | Brush | Rootwad |
| | | | Lateral | Branch | |
| | | | Plunge | Bank Roots | |
| | | | Deposition | Debris Pile | |
| | | Dammed Pool: | Debris | Single Log | |
| | | | Beaver | Rootwad | |
| | | | Landslide | | |
| | | | Backwater | | |
| | | | Abandoned | | |

Residual pool depth (RPD), the measure of the difference between maximum pool depth and pool tailout depth, is another indicator of pool habitat quality. Habitat restoration projects often identify increased RPD as a deliverable outcome because this measure may represent better habitat quality due to increased depths, complex cover, slower velocity within the pool itself, and possibly cooler summertime water quality. The target for average RPD in the assessment reach is three feet.

In 1996, The National Marine Fisheries Service established pool frequency standards for fish habitat in Western Washington rivers as an indicator of habitat in Properly Functioning Condition (PFC). These standards are outlined below in Table 24. They are assumed to be consistent with a template that represents 80% of historic conditions, and are referenced in salmonid habitat recovery plans throughout Puget Sound.

Habitat quality in each sub-reach is ranked by the following attributes:

- Pool frequency by the number of pools mapped per river mile,
- Percent pools with wood as a pool-forming function,
- RPD greater than 3.0-feet (WSFWC 1997, Brown et al. 1994),
- Pool: riffle ratios closest to one (1),
- Percent of pools by length in a reach at or above 30% (WSFWC 1997),
- Surface water temperatures of Class AA lower than 14.0 (USEPA 2003),
- Turbidity values less than 5 NTU over background turbidity if background is 50 NTU or less; or less than a 10% increase when background is more than 50 NTU.

**Table 24. Pool frequency standards for Western Washington rivers (NMFS 1996), and results from the South Fork.**

| Wetted Width | | NMFS (1996) PFC Standard | | | South Fork Sub-Reach | Wetted Width PFC | 2005 Pools/Mile | Pools/Mile Disparity |
|---|---|---|---|---|---|---|---|---|
| Width | 5' | 184 | pools/mile | | 1 | 25 | 13.5 | *-11.5* |
| Width | 10' | 96 | pools/mile | | 2 | 27 | 15.1 | *-11.9* |
| Width | 15' | 70 | pools/mile | | 3 | 25 | 14.3 | *-10.7* |
| Width | 20' | 56 | pools/mile | | 4 | 24 | 15.6 | *-8.4* |
| Width | 50' | 26 | pools/mile | | 5 | 26 | 19.5 | *-6.5* |
| Width | 75' | 23 | pools/mile | | 6 | 32 | 22.4 | *-9.6* |
| Width | 100' | 18 | pools/mile | | 7 | 47 | 39.3 | *-7.7* |

The ratio of pool to riffle habitat is another assessment tool used to describe habitat quality through channel diversity. This tool measures the ratio of the surface area or length of pools to the surface area or length of riffles in a given stream reach, frequently expressed as the relative percentage of each category. An equal amount of each habitat type in a reach, or a 1:1 ratio, is optimum for salmonid rearing. For this assessment, the percent of total lengths for pools and riffles/rapids was used to calculate ratios. Taking a cue from Pleus (et al. 1999), units classified as rapids were included with the riffle formula, representing turbulent water in the reach; therefore, the calculated ratio represents slow-water units to fast-water units.

## Results

Riffle habitat, as measured by area, dominated all other habitat types by more than 3-times throughout the study reach, followed by runs, pools, rapids, and cascades (Figure 80). The disparity between riffle and pool habitat coverage produces poor quality instream habitat quality for salmonids (NMFS 1996). The data describe a nearly 1:3 pool to riffle ratio across the entire reach, and between the upper and lower reaches as well.

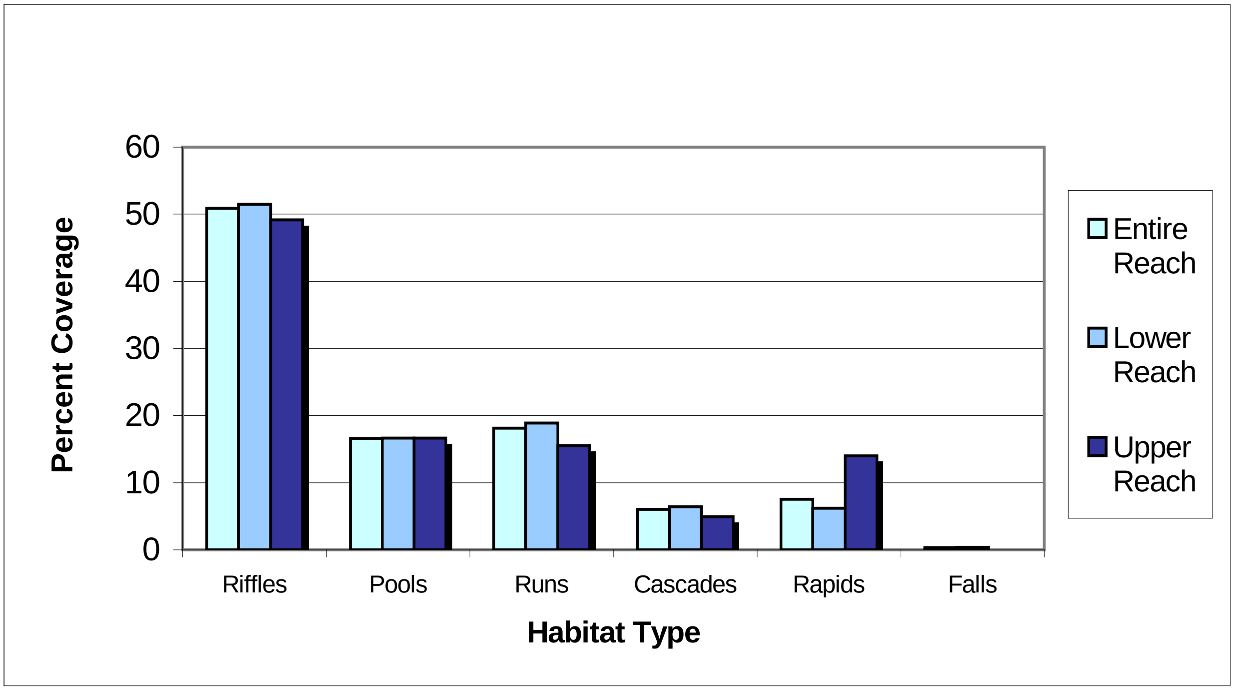


**Figure 80. Distribution of fine-scale habitat units in the South Fork, 2005. Lower reach (RM 12.8-32.0), upper reach (RM 32.0-37.7).**

Seven-percent (*n*=15) of the units classified as riffles below the RM 32.0 barrier displayed chinook spawning gravel-sized substrate as the primary cover type, and 30-percent (*n*=60) displayed cobble-sized substrate as the primary cover type. Similarly, 60-percent of riffles exhibited boulder-sized substrate as the primary cover type. Units classified as falls did not account for a large component of the habitat mapped in 2005, as they are usually found in steep terrain, and they themselves being steep, do not cover much distance longitudinally. The number of units categorized as rapids was significantly higher in the upper half (sub-reaches 6 and 7) than in both the lower half (sub-reaches 1-5), as well as the entire reach by percent coverage. A steeper riverbed in the upper watershed that shallows as the river flows downstream can explain this. Both of the latter habitat unit types characteristically exhibited boulders as the primary substrate cover type. Primary cover types found in pools were dominated by substrates of boulders, cobbles, and gravel (70%), followed by bedrock (22%), and wood (2%).

Pool habitat in the upper South Fork represents 16.6% of the total habitat in the reach by wetted area. The upper South Fork channel as a whole averaged 18.8 pools per river mile, with a low frequency of 13.5 (sub-reach 1) and a high of 39.3 (sub-reach 7). As noted above, the pools-per-mile attribute is often used as an indicator of habitat quality. The extent to which this attribute may describe habitat quality is largely dependent on the channel's width. Figure 83 below describes how the pools-per-mile standard representing a stream's PFC decreases with wetted stream width. It also represents wetted width conditions mapped in 2005, and the quotient of pools per mile needed to meet PFC standards.

The percent of total pools formed by wood (Figure 81) is higher in the reach above the barrier at RM 32. Over 40-percent of all pools above the barrier are formed by wood. Less than 25-percent of all pools in the reach below the barrier, where most south fork anadromous salmonids spawn and rear, are formed by wood. In contrast, nearly 70-percent off pools in the lower reach are formed by rock or resistant bank. Seventeen-percent of pools in the reach above the barrier are formed by rock: six by bedrock, and one by boulders. Remaining pools in the upper reaches were formed freely as trench, plunge or backwater types.

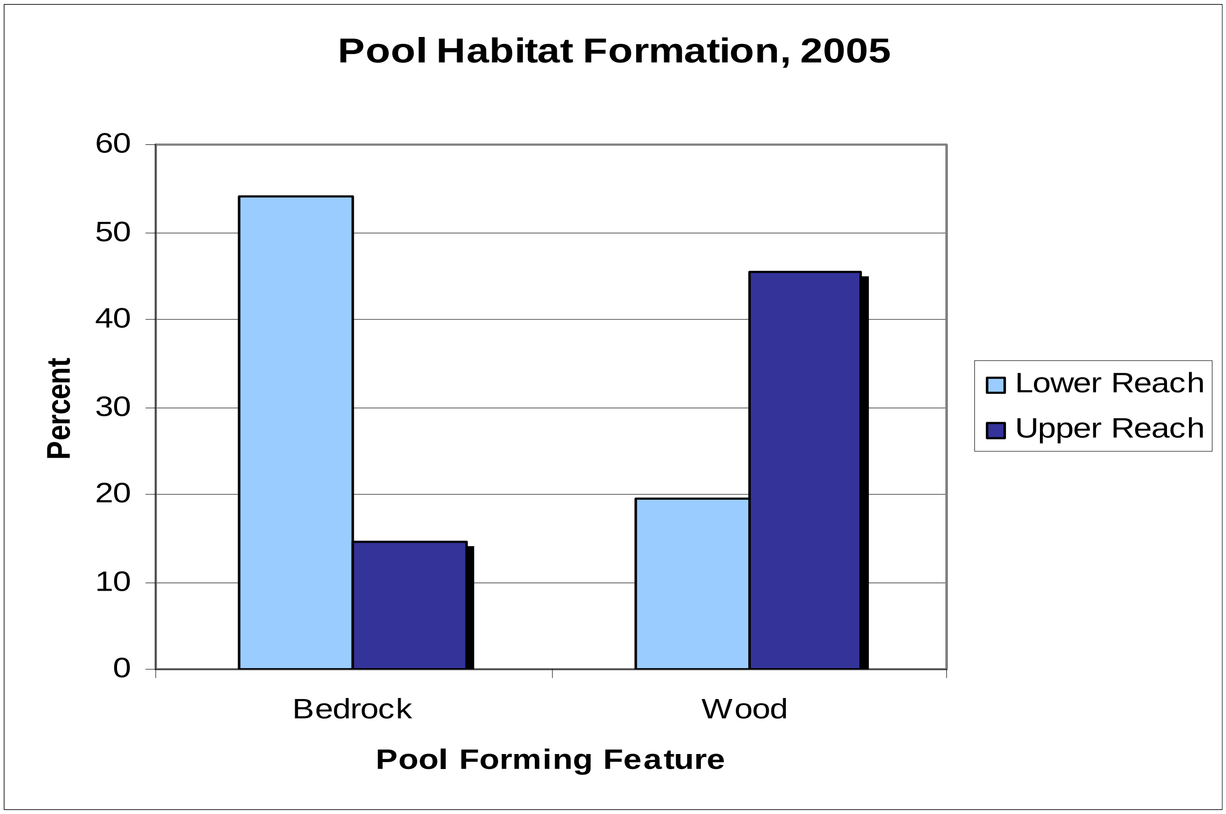


**Figure 81. Pool-forming feature comparison between reaches below (lower) and above (upper) the barrier at RM 32.0.**

The mean residual pool depth (RPD) calculated for the study reach is 6.3 feet. The habitat performance standard for minimum pool depths defined by the WSFWC (1997) is three-feet; however, chinook prefer pools much deeper than that. Sub-reach 6 contains three pools that skew the mean depth statistics for this sub-reach, as well as the averages for the entire study reach. One of the three pools measured in sub-reach 6 yields a maximum depth of 36.6-feet, one is 30.0-feet, and one has a depth of 28.2-feet. These pools are found in the trenched channel just upstream of the falls at RM 32, and are inaccessible to most anadromous salmonids. Although they supply exceptionally deep habitat, they are not representative of desired pool habitat due to the extremely high velocities surveyed within. For statistical analysis, the three pools were removed as outliers. The residual pool depth by mean, $25^{th}$, and $75^{th}$ percentile statistics, as well as the minimum and maximum RPD calculated in each reach is represented in Figure 82.

Sub-reach 7 has both the deepest maximum and shallowest minimum residual pool depths. Sub-reach 6, even with the three outliers removed from analysis, sustains deep pool habitat as well. Even with the removal of the three outliers, the mean RPD in this sub-reach yields the highest values, consistent with the trend of increasing pool depths with river mile. Sub-reach three produced both the lowest mean RPD and the least variance between the mean, maximum and minimum RPD values. The depth of pools in sub-reach 3 was consistently greatest. Over 80-percent of pools in the study reach have RPDs of 3.0 or more feet. Ninety-two percent of pools in the reach above the barrier yield an RPD of more than three feet. In the reach below the barrier, between RM 32.0 and RM 12.8, 84-percent of pools meet or exceed the three-foot depth standard.

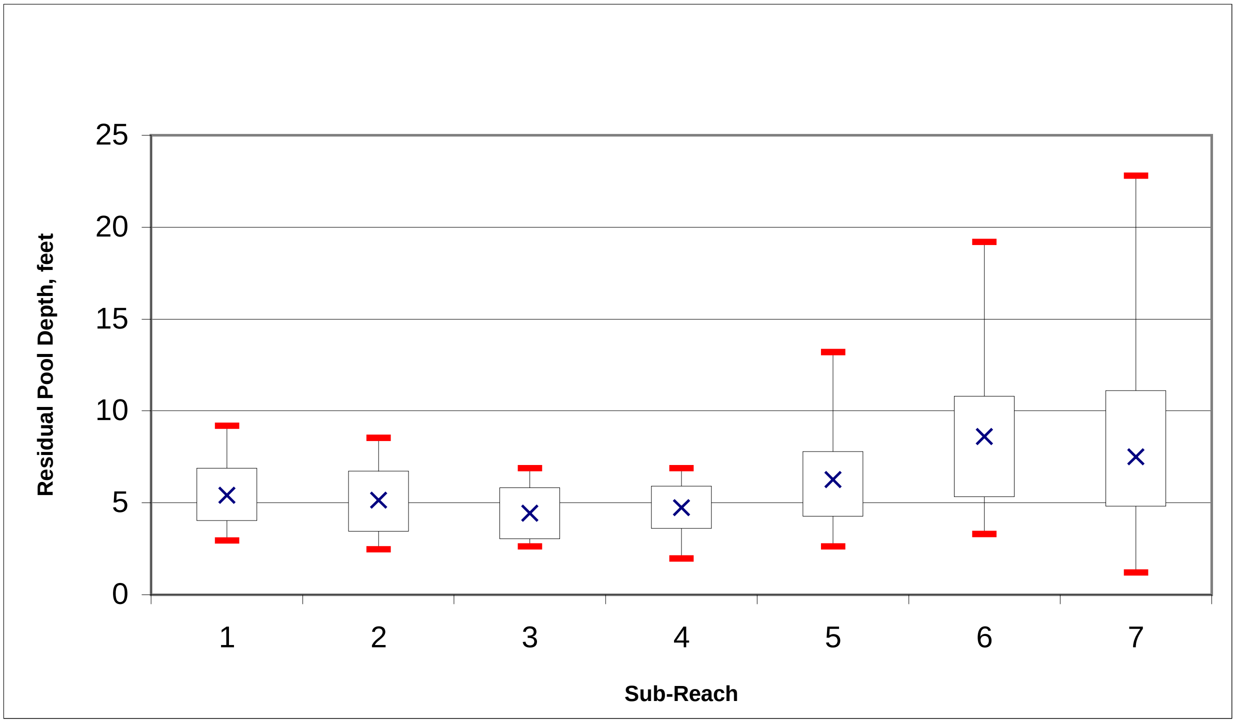


**Figure 82. Residual pool depth statistics by sub-reach in the upper South Fork. Maximum, mean, minimum, and the 25th and 75th-percentiles are displayed.**

Although residual pool depths measured in the South Fork during summer months are at or deeper than the properly functioning target value for juvenile salmonid rearing, the pools deep enough to provide holding habitat for adults are sparsely located throughout the reach. The proximity of these pools to patches of spawning gravel is less than desirable as well. The mean distance mapped between pools is 850 feet, with a minimum distance of zero feet, and a maximum distance of 4,484 feet. The mean proximity of holding pool habitat to spawning gravel patches was 546 feet. This may in part reflect the impaired pool frequencies. Twenty-five percent of holding pools throughout the entire reach were within one channel width (100-feet) of spawning gravel; thirty-six percent of pools were within two channel widths. There were twenty-two pools that contained spawning gravel in their substrate, thereby their distance from spawning gravel patches was zero; the maximum distance measured between a holding pool and its nearest patch of gravel was 3,610 feet.

Percent pool habitat in all seven sub-reaches was deficient according to the SSHIAP standards set by gradient (Table 25). This deficiency is more pronounced in the reaches below the falls barrier. The gradient was considerably lower in these downstream reaches; therefore, the pool performance standard was higher as more pools would be expected, resulting in larger discrepancies between the observed values and the standards. The average insufficiency of pool habitat below the falls barrier was just above 30%; above the falls barrier, where gradients are steeper, the average pool frequency was deficient 16%.

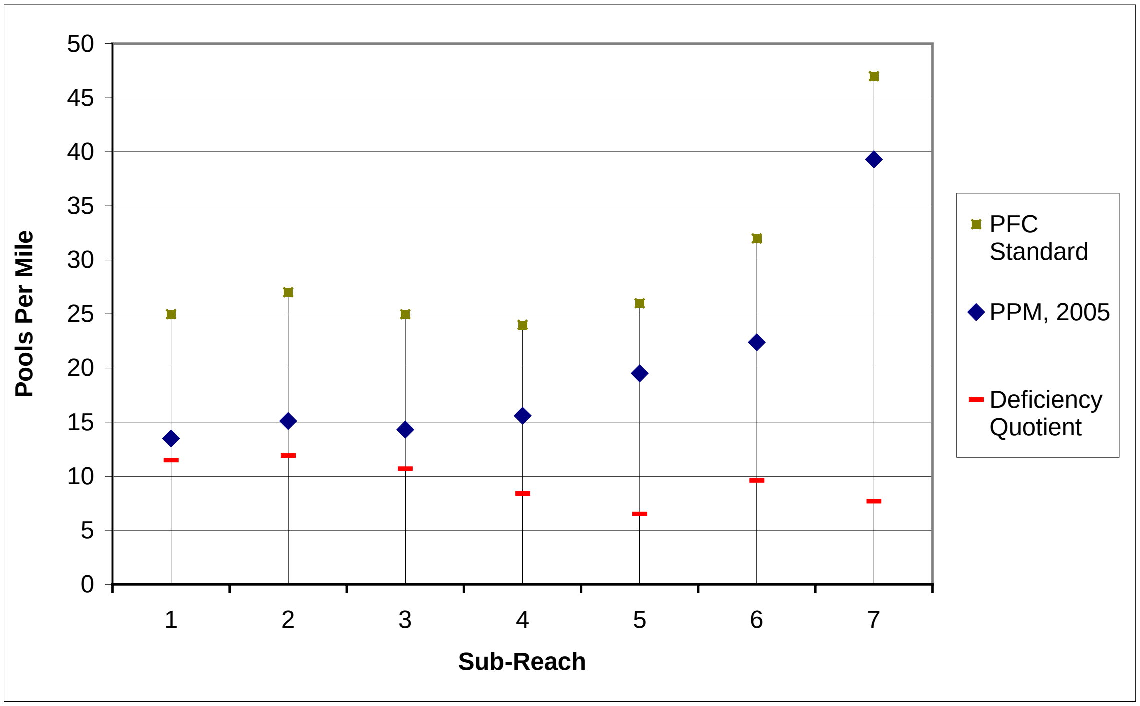


**Figure 83. PFC values based on wetted widths measured in 2005, actual S. Fork pool frequency in pools-per-mile, and the disparity between.**

**Table 25. Sub-reach pool performance calculation, based on observed gradients and percent pools by unit length.**

| Sub-Reach | Dominant Gradient Class* | Pool Performance Measure** | % Pools Observed | % Deficient |
|---|---|---|---|---|
| | | | | |
| 1 | <1% | 55% + | 13.6 | 41.4 |
| 2 | <1% | 55% + | 27.9 | 27.1 |
| 3 | <1% | 55% + | 15.9 | 39.1 |
| 4 | 2 - 4% | 40% + | 21.6 | 18.4 |
| 5 | 2 - 4% | 40% + | 11.7 | 28.3 |
| 6 | 4 - 8% | 30% + | 14.3 | 15.7 |
| 7 | 2 - 4% | 40% + | 22.9 | 17.1 |
| | * SSHIAP (2001) | ** WSFWC (1997) | | |

Pool: riffle ratios calculated in each sub-reach of the upper South Fork are described in Figure 84 below. The highest ratio was observed in sub-reach 5, and the lowest ratio (most desirable) was observed in sub-reach 2. The figure also describes the percent of reach length habitat by pool, riffle and rapid, and run/glide. The performance measures relative to percent pools in a reach are outlined in the Washington State Watershed Analysis Manual (WSFWC 1997). This manual breaks these measures into three groups based on channel gradient. For example, in streams of any gradient but less than 15 m wide, the frequency of pools should not occur at intervals less than one pool for every two channel widths. For streams less than 15 m wide, if the reach gradient is less than 2%, more than 55% of habitat should be pool. For streams with a reach gradient between 2-5%, more than 40% of habitat should classify as pool, and reach gradients greater than 5% should yield at least 30% pool habitat. The 30% target, or the lowest standard to meet in the South Fork channel, is added to Figure 84 below.

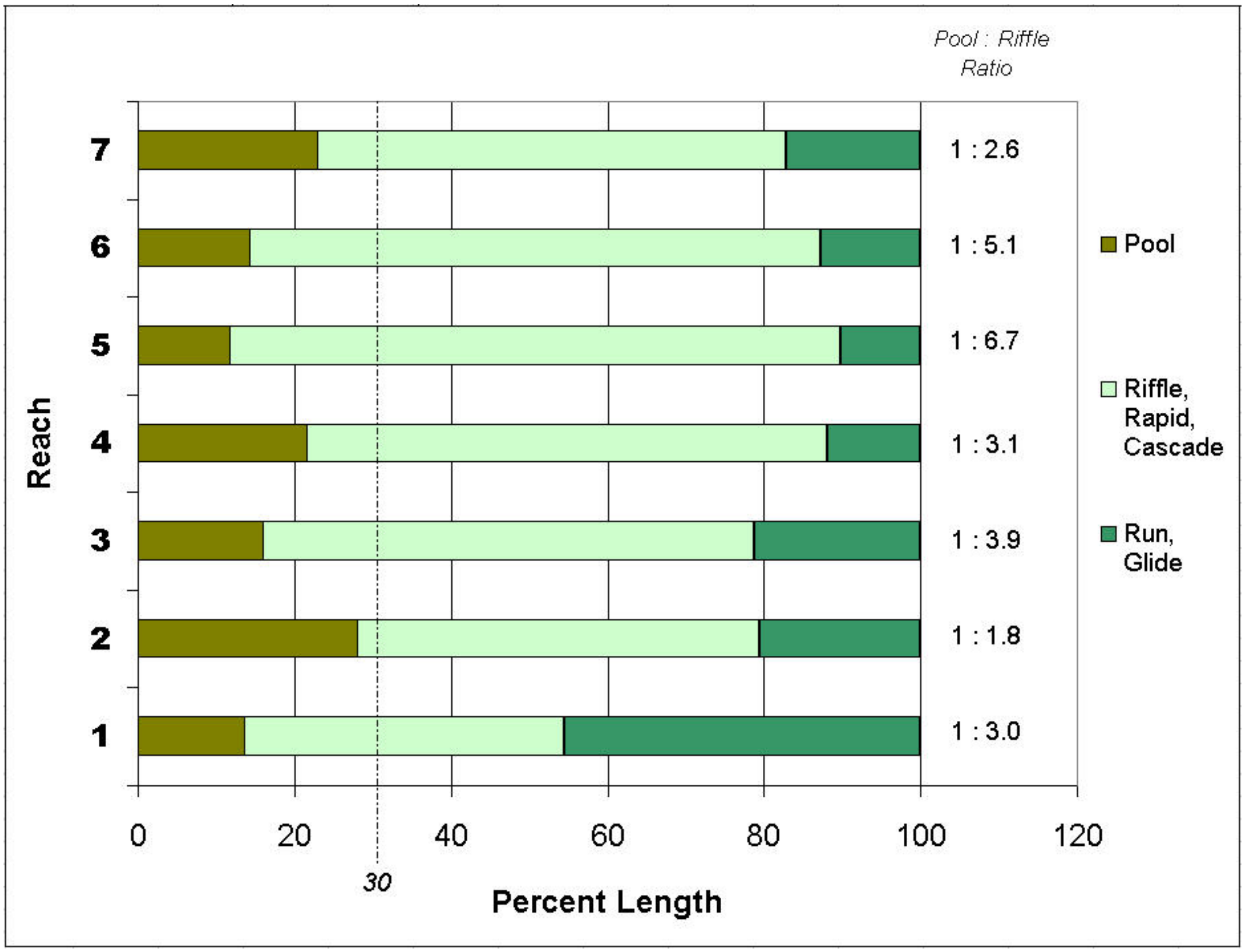


**Figure 84. Habitat percent length by stream sub-reach, and the pool: riffle ratios for each.**

## Summary

Many of the habitat analyses compare results between reaches above the upper (RM 32 barrier) and lower channel segments, under the hypothesis that the channel above the RM 32 barrier provides higher quality habitat to aquatic species. Forest practices (specifically road building and timber harvesting) are less extensive in the upper watershed, and private development is very limited. Supporting arguments are based on the premise that under less impacted conditions, the river may function more naturally for fish above the barrier. Data analysis supports this suggestion, particularly when describing cover types and function, pool attributes, and water quality.

There was a distinct difference in overall stream habitat quality between the sub-reaches below the RM 32.0 barrier and those above it. In general, habitats above the barrier provide higher quality habitat for fish in all life stages. These include, most importantly, lower summertime water temperatures, deeper and more frequent pools, and more large wood cover throughout the reach. Human activities impacted natural processes in the upper watershed to a lesser degree than more downstream areas. Most public access to upper watershed habitats is limited by private property boundaries, and lands most freely open to the public (primarily the headwaters draining the Mt. Baker Wilderness) are owned and managed by the US Forest Service.

Unfortunately, this high quality habitat is not frequently accessible to most South Fork anadromous salmonids, particularly chinook salmon. These fish are limited to river habitat below the RM 32.0 barrier, generally of lower quality. Some years they seem to be limited to habitat downstream of RM 25, and coho, pink, and sockeye salmon migrations are often blocked from making it to habitat above this partial barrier. Summer and early fall water temperatures in accessible stream segments are commonly limiting to chinook production (Mobrand 2003). They even exceed the lethal range (Hicks 2000) during the summer months when adult spring chinook are in their migrating, holding, spawning and incubating life stages. Bull trout and summer-run steelhead have been observed in habitats above the barrier, but the rate of passage of these anadromous fish to upper South Fork watersheds is poorly understood.

At a finer scale, we found measurable differences in habitat quality and abundance within and between channel sub-reaches. Analysis by water clarity and temperature resulted in an overall decline in quality with downstream progression. Furthermore, habitat types targeted by salmonids in the Nooksack River, primarily deep pools and clean, loose gravels, declined in similar fashion. High quality habitat units and types were noted and assessed within every sub-reach. However, the abundance and complexity of these units followed the declining trend along the South Fork's longitudinal profile as well.

Habitat types in the study reach were dominated by riffles, and within this unit type, large substrates dominated the cover type. Boulders were prevalent as cover for fish using riffle habitat throughout the upper South Fork channel, followed by cobble and spawning gravels. Woody debris was non-significant in South Fork riffles. The substantial distribution of riffle habitat in the upper South Fork has created a ratio to pool habitat that needs to be improved upon. Currently, the overall ratio is 1:3; habitat quality and complexity targets in rivers such as the South Fork are closer to a 1:1 pool to riffle ratio.

Guided by the properly functioning condition (PFC) standards set by NMFS, habitat in the upper South Fork is deficient in percent pool units; pool to riffle ratio; large wood available for cover and pool forming function; spawning gravel proximity to pool habitats; riparian stand maturity; elevated temperatures in the summer; and high turbidity during the wet seasons.

Habitat conditions in the upper two sub-reaches can be described as comparatively better than those in the lower sub-reaches in nearly all attributes that were analyzed. Overall, in reaches above the RM 32 barrier, summer water temperatures are lower, turbidity values during rain events are lower, LWD loads are higher, pools are deeper and more frequently formed by wood, and pool frequency is significantly higher. Although habitat conditions in the upper reaches are more desirable, they often did not meet or exceed PFC targets. The PFC targets (WRIA-1 2005, USEPA 2003, WSFWC 1997, NMFS 1996, Brown et al. 1994) should guide restoration in the South Fork.

# Conclusions and Recommendations for Management

The Endangered Species Act defines a species' status in terms of viability, characterized by four parameters (McIlhany et al. 2000, *in* Coe 2005). These parameters are: 1) abundance, or the number of individuals; 2) productivity, or population growth rate, (the ratio of abundance in the next generation to current abundance); 3) spatial structure, or how the abundance is distributed among available habitat types; and 4) diversity, the variety of life histories, sizes, and genetics. The objectives that guide habitat restoration targets for northern Puget Sound rivers focus on the improvement of natural habitat forming processes that are designed to improve these parameters. The WRIA-1 Salmonid Recovery Plan encourages the initiation, as quickly as possible, of actions that will lead to increased productivity and the recovery of the most critical salmonid stocks in the watershed: the South Fork Nooksack early chinook and the Coastal-Puget Sound bull trout (WRIA-1 Lead Entity 2005). Restoring habitat for populations of the recently listed Puget Sound steelhead trout adds to the challenge.

## Habitat-Limiting Factors

Resource managers have identified eight significant habitat factors that limit early chinook production in the Nooksack River: channel stability, sediment load, habitat diversity, key habitat quantity, obstructions, passage, flow, and water temperature (WRIA-1 Lead Entity 2005). These limitations vary in their severity and impact on chinook populations across the watershed. Three of these are particularly relevant to the upper South Fork: temperature, sediment load, and habitat diversity (Mobrand Biometrics 2003), and are the focus of habitat restoration projects prescribed in this report.

### *Elevated Water Temperature*

One of the most significant impacts water temperature in the upper South Fork remains to be the over-harvesting of the riparian zone. Analysis of current riparian stand conditions showed less than 1% of the trees in the riparian management zone are mature. Mature trees produce far-reaching shadows, and play an integral role in cooling streams. The removal of large trees from the river's riparian zone also removed an important shade element that blocked direct sunlight from much of the water surface. Improved management should allow for the natural recovery of the riparian system, although poor site conditions may limit the potential size of conifers in portions of the watershed.

The increase in stream heating likely associated with the loss of shade may be amplified by a lack of cold water supplementation to the channel. Due to the long history of channel incision and sediment evacuation from the valley, much of the South Fork Nooksack upstream of ~RM 20 lacks deep alluvial fill that interacts with the channel and can store water and provide cooler discharge to the channel during low flow periods. The thin depth of alluvium in the active channel reduces the opportunity for groundwater- surface water interaction and likely reduces the cooling effect on the channel that this interaction provides.

While the reach-scale effects of loss of riparian vegetation and shallow alluvium currently hamper stream cooling, thermal refuge areas are present at many sites along the South Fork Nooksack. These sites generally occur where a cooler water tributary, groundwater seep, or side channel enters the main channel. Measurements of water temperature in these areas showed that some refuge areas can maintain temperatures up to 8°C cooler than the main channel during the summer months.

**Table 26. Habitat restoration prescriptions and actions that address limiting habitat factors.**

| Limiting Factor | Prescription Target | Project Actions |
|---|---|---|
| High Water Temperature | Increase Channel Shading | • Riparian treatment to encourage large trees in priority shading areas<br>• Encourage stability of forested islands in active channel area<br>• Protect riparian and floodplain areas from development |
| | Improve Channel and Groundwater Connectivity | • Deepen pool habitats<br>• Decrease pool spacing by increasing wood pool-forming function<br>• Encourage LWD flow impedance in unconfined reaches |
| | Provide Thermal Refuge | • Improve habitat quality in known cool water areas (tributary confluence, floodplain channel confluence, groundwater seep). |
| Low Habitat Diversity | Increase Planform Diversity | • Increase stability of forested islands |
| | Increase Pool Frequency | • Increase pool-forming function of LWD to scour pool habitat (including construction of logjams)<br>• Riparian treatment to increase wood recruitment potential |
| | Improve Gravel Retention and Stability | • Restore LWD flow impedance in unconfined reaches<br>• Restore floodplain and floodplain channel connectivity for high flow |
| | Improve Instream Cover | • Add LWD structures for complex cover<br>• Riparian treatment to increase wood recruitment potential<br>• Remove artificial bank material, replace with wood or natural rock |
| Elevated Fine Sediment | Reduce Fine Sediment in Substrate | • Restore LWD flow impedance unconfined reaches<br>• Set-back stream-adjacent infrastructure and bank armoring to allow channel migration and floodplain development |
| | Reduce Sediment Sources | • Protect unstable landforms from disturbance<br>• Stabilize or buffer stream-adjacent landslides<br>• Improve existing forest road stability<br>• Assess orphan forest road stability |

Bedform variation (pools and riffles) could force greater interaction between ground and surface water. Water is generally cooler near the bottom of scour pools as a result. Currently, the pool counts documented in the upper South Fork reach fall below the guidelines for Properly Functioning Conditions (PFC).

Long stretches of channel that lack any channel-spanning pools are common. Approximately 17% of the total habitat area in the upper South Fork is defined as a pool; the remaining habitat represents faster moving water over a variety of gradients. The majority of pools identified in the assessment area are created and maintained by channel scour against bedrock, the dominant substrate type in the reach. Significantly fewer pools are formed by wood.

Elevated water temperature conditions experienced by chinook and coho salmon, as well as steelhead and bull trout in the South Fork impact several life-stages of these fish, and may initiate negative effects on the overall production of them. Life stages affected by high water temperature include early <u>spawning</u> (adults), July-August-September <u>egg incubation</u>, summer <u>rearing</u> (1+ and 2+-year juveniles), <u>migration</u> (fry; 0+, 1+, and 2+-year juveniles; and adults), and <u>holding</u> (fry to adult resting during migration). As water temperature rises, dissolved oxygen saturation decreases. The degradation of water quality is known to initiate stress in salmonids. Symptoms resulting from high temperature and low dissolved oxygen include increased respiration, reduced appetite, reduced energetics, and incidence of disease. Long-term exposure to high temperatures is known to reduce growth rates, reduce reproductive rates, and lead to stress-related mortality (McCullough 1999).

The strategy for improving water temperature in the upper South Fork will rely on developing high quality instream habitat in known cold water areas in the near-term, and riparian stand enhancement to improve shading in the long-term (Table 26). Another way to potentially lower water temperature is through increasing channel-groundwater interaction. Increasing bedform variation through a decrease in pool spacing could potentially increase the interaction between groundwater and surface water.

Associated project actions include:

- Improve habitat quality in thermal refuge areas (groundwater, tributaries and side-channels),
- Riparian treatment to improve shading,
- Improve stability of forested islands,
- Restore flow impedance in unconfined reaches,
- Improve bedform variation (decrease pool spacing) by encouraging more wood-formed pools
- Protect riparian and floodplain areas from development.

### *Sediment Load*

High levels of fine sediment (grain size < 0.85mm) in streambed substrates have been identified as a limiting factor of chinook production in the South Fork Nooksack River (WRIA-1 Lead Entity 2005, Mobrand Biometrics 2003). While sediment samples collected within the assessment area have generally shown "fair" to "good" fine sediment levels, the lower-gradient and unconfined reaches downstream of Saxon Bridge (RM 12.8) are routinely rated as "poor" for spawning gravel quality based on levels of fines.

Although turbidity values recorded at the most upstream sampling site (RM 37.7) were consistently low over the course of the sampling schedule, they increased an average of ten-fold between that site and the next sampling site downstream at the 300-Road Bridge (RM 34.6). The next significant increase in turbidity appears between the 330-Road Bridge (RM 30.8) and the 200-Road Bridge (RM 25.2), where the mean increases from ~20 NTU to ~90 NTU. This is the largest increase in turbidity values and the level appears to remain high as samples are collected downstream.

It is likely that sediment released in the upper reaches of the watershed affect spawning habitat quality in the lower reaches. Sediment sources include streamside slope failures, shallow-rapid landslides associated with forest practice activities, and channel incision into fine-grained glacial lake deposits. The stream-adjacent features appear to occur most commonly in the glacial lakebed deposits. These deposits are composed of thinly bedded sand, slit, and clay that enter as deep-seated slumps and debris slides. The features are often large slope failures that contribute sediment over a period of years. Comparative analysis of three landslide surveys conducted between 1986 and 2007 revealed that most sections of the river experienced a slope failure during the 20-year period. This would indicate that the distribution and size of stream-adjacent landslides through the river changes as the channel migrates into the unstable glacial deposits. These slides also appear to have a direct effect on turbidity in the river. Currently, seventeen landslides accounting for approximately 40% of the stream-adjacent landslide area were found between RM 25 and 30. Coincidently, this five-mile reach also produces a significant increase in turbidity values. It is likely that these slides are the result of the river's long history of evacuating glacial fill from its valley, contributing natural sources of sediment and wood to the channel. In reaches where the channel does not readily migrate, these landslides could be an important wood recruitment mechanism.

Periods of channel incision have exposed the glacial substance in the bed of the channel in several areas. The exposed silt and clays that characterize glacial materials are easily eroded and contribute to high turbidity during peak flow events. Terraces composed of these materials line much of the channel and are eroded as the channel migrates. It is possible that the loss of flow impedance (such as large wood) from the channel has hastened channel incision into the glacial deposits and resulted in degraded water quality.

A review of aerial photos flown between 1940-1995 showed that there have been 875 shallow-rapid landslides mapped in the upper South Fork watershed over the 55-year photo record. Of the characterized landslides, 62% were associated with land use activities and 80% delivered sediment to a stream. The most common land use associated with shallow rapid failures was recent timber harvest. Considering that most shallow-rapid landsides are related to land-use activities, efforts to minimize or avoid activities on inherently unstable areas during forest practices (harvest and road construction) are important to the recovery of naturally functioning instream habitat and good water quality.

Road failure is often a mechanism for landslide initiation and delivery of sediment to streams. Road density in the upper South Fork Nooksack varies by watershed, although it is generally greater than the standard three miles per square mile of watershed used as a "poor" quality standard in regional assessments, including the WRIA-1 Limiting Factors Report (Smith 2002). The mapped road density is likely under-representing the actual on-the-ground road network in the watershed because many of the older roads have become overgrown and lost from the managed road network. Many of these older roads and railroad grades predate forest practice rules, and the maintenance or abandonment of this type of infrastructure is not required by law. Within a narrow band of upper South Fork valley, there are over 27 miles of unmapped road and railroad grades visible on the high-resolution terrain model created from LiDAR imagery. The status of these roads is largely unknown, although a lack of maintenance or abandonment increases the likelihood that these roads are having a negative effect on hydrology and sediment delivery in the watershed.

Suspended particulate matter impacts fish production in several ways. Fine particulate material may damage sensitive salmonid gill structures, decrease fish resistance to disease, prevent proper egg and larval development, interfere with foraging activities, and possibly cause death. For example, being sight feeders, juvenile salmonids may experience a reduction in sight distance and increased problems finding food. Fine particulate matter can smother benthic habitats, impacting aquatic organisms in all life stages. As particles of silt, clay, and other organic materials settle to the bottom, they pose a threat to the food web by filling in spaces between rocks that aquatic organisms depend on for habitat. Cobble embeddedness also threatens salmonid productivity, as it may produce a substrate that cannot be moved around for nest building, may 'cement' eggs inside their nests and prevent them from breathing or hatching, or impair winter cover opportunities for juveniles during cold spells. Other negative effects on fish include prolonged, high concentrations of fine particulates in the water column. These fine particulates may also provide attachment sites for heavy metals such as cadmium, mercury, and lead, and toxic organic contaminants such as PCBs, PAHs, pesticides, herbicides, and other chemicals used in agriculture and industry (WOW 2004).

The recommended strategy for addressing elevated sediment in the upper South Fork focuses on source control and monitoring of land use activities in the watershed (Table 26). While direct measurements of sediment in the river have yielded relatively low fine sediment levels in spawning gravel, the instability of glacial deposits lining the channel and the nature of the material contributed to the channel from these deposits maintains the potential for fine sediment to affect incubating salmon eggs. Source control efforts should focus on forest road abandonment and drainage improvement work (for example, replacing failing culverts with properly sized ones), as well as buffering the channel from the effects of large stream-adjacent landslides where practical. Additional assessment activities should focus on characterizing any existing threats from orphaned forest roads and abandoned railroad grades.

Project actions include:

- Improve existing forest road stability,
- Assess orphaned road stability,
- Stabilize or buffer stream-adjacent landslides,
- Avoid forest practice activities on unstable landforms,
- Restore flow impedance to incising reaches.

### *Habitat Diversity*

The channel characteristics in the upper South Fork vary considerably by reach and geologic history, from actively migrating channels near a large glacial outwash channel to a steep, confined channel where the channel follows the fault along the southern flank of the Twin Sisters. These characteristics control the dominant habitat-forming processes in the reaches and have a strong impact on the productivity of the instream habitat for salmon species. Channel responses (lateral migration or bed elevation changes) to climate and land use changes during the historic period vary with the underlying geology and distribution of disturbances, leading to marked changes in how salmon species use the watershed.

Reduced habitat diversity by way of reduced riparian function, decreased size of instream wood, overall low instream wood residence time, channel straightening, channel encroachment, and floodplain-channel disconnection in the upper South Fork watershed has impacted the ability of both migrant and resident salmon and trout species to maximize production during rearing, holding and spawning life stages. With reduced habitat diversity come inadequate opportunities for predator avoidance, high velocity refuge (off-channel habitats such as ponds, backwaters, side channels, etc.), aquatic and terrestrial invertebrate foraging, and spawning habitat availability for all species.

Low habitat diversity in the upper South Fork watershed can be addressed by near-term restoration projects that add complexity to areas of the river that have become simplified through wood removal, riparian vegetation clearing, and the impedance of stream-adjacent infrastructure. Several habitat types should be represented throughout the general river mile. Variation between fast- and slow-moving water, or riffle/run and pool units is representative of properly functioning condition, and provides all fish life stages their specific habitat requirements within reasonable distance.

Increasing the area of perennial secondary channels will also improve conditions for a variety of salmonid life-history stages. Analysis of differential scour across channel types has indicated that secondary channel types are less susceptible to bed scour and can be important to improved egg-to-fry survival. Channel incision has contributed to the loss of secondary channels; only 1,480 feet (less than 1% of total channel length) of perennial side channels were mapped during low flow conditions. The loss of wood from the channel has also has reduced the complexity of cover in pools. Of 144 upper South Fork pools mapped in 2005, wood cover only dominated three of the pools.

There are several actions recommended to enhance habitat diversity (Table 26). Their temporal impacts on the stream will vary between long- and short-term; however, all are integral to habitat restoration for fish. Removing artificial barriers to wood recruitment, such as bank protection, and improving riparian conditions in important areas for wood recruitment by the stream are examples. Instream wood contributes greatly to the formation of scour pools that not only have the potential to improve water quality, they provide complex cover to fish from their predators. These wood recruitment areas include terraces within the expected channel migration zone of the river, river-adjacent unstable slopes, and the lower reaches of large tributaries that can provide adequately sized wood to the South Fork channel. The loss of mature riparian stands, coupled with relatively low channel migration rates, has led to a dramatic decline of large wood in the channel and a resulting lack of pools formed by scour and associated with stable wood accumulations.

Project actions that aim to increase habitat diversity include:

- Decrease pool spacing by increasing pool-forming function of wood,
- Increase planform diversity (secondary channels vs. mainstem channels) by increasing the stability of forested islands,
- Increase woody cover in rearing and holding habitats,
- Riparian treatment to improve wood recruitment,
- Increase flow impedance in unconfined reaches,
- Remove artificial barriers (infrastructure) to channel migration and floodplain function,
- Protect riparian and floodplain areas from development.

## Proposed Projects

The following restoration prescriptions address the goals and objectives developed by the WRIA-1 Salmon Recovery Board for habitat restoration projects in the upper South Fork. Figure 85 below describes the location of each proposed project in relation to the study reach. The prescriptions are focused on the instream habitat conditions for ESA-listed species: spring chinook, bull trout, or steelhead trout. In general, the restoration projects seek to first remove unnecessary infrastructure from the channel migration zone of the river, then restore habitat-forming processes that have been interrupted by harmful land use activities, and lastly to enhance habitat quality in key areas to provide important refuges while the habitat forming processes recover.

The prescribed projects will work to moderate elevated water temperatures, increase habitat diversity, and decrease fine sediment through the enhancement of the river's connection with cold groundwater, relict side channel, and floodplain wetland habitats; the creation of deep pools with abundant wood cover; and the stabilization of landslides and slope failures (Table 26).

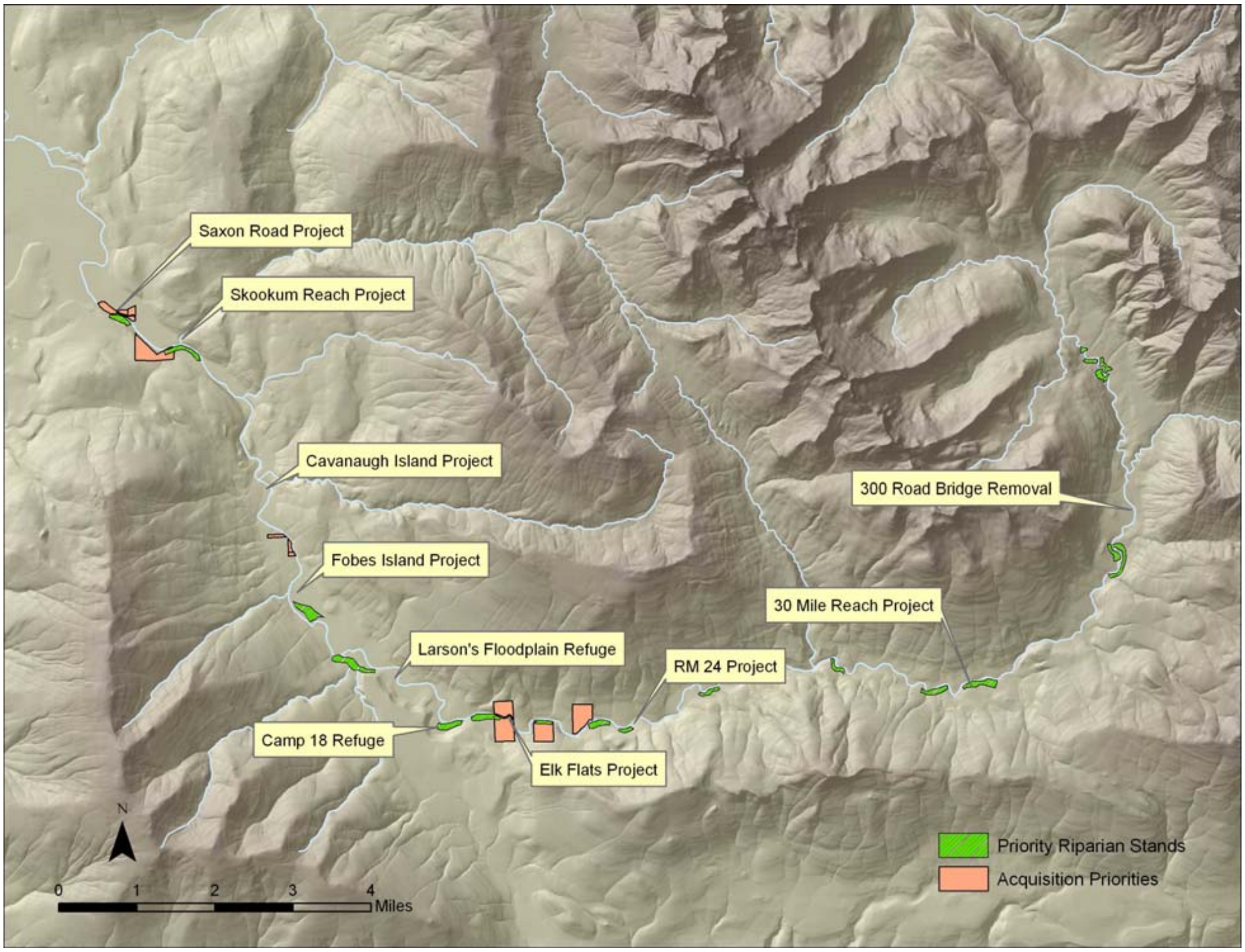


**Figure 85. Location of recommended restoration and acquisition projects.**

### *Saxon Road Project*

The Saxon Road Project is designed to improve river conditions between river miles 13.2-13.5 on the South Fork of the Nooksack River. Through this section of the channel, Saxon Road is located on the eastern bank of the river and protected with bank armoring. This reach of the river has low habitat diversity (dominated by riffle habitat) and lacks large pieces of wood or stable accumulations of woody debris that would increase diversity. The project includes the removal of bank armoring, installation of engineered logjams, set-back of a road and riparian buffer establishment (Figure 86). These actions will address both the longer-term habitat-forming processes of wood recruitment and channel migration as well as the near term habitat deficiencies in the reach.

The reach has been identified as a groundwater influence zone, where the South Fork surface water temperature is cooled by the interaction with groundwater. Local scour associated with instream structures would increase the groundwater-surface interaction by increasing the bedform variation in the reach. While the project includes riparian planting it will only slightly improve channel shading because it lies on the northern bank of the river. The project will have a greater impact on wood recruitment to the channel by removing bank protection and relocating Saxon Road to the extent of the historic migration zone and restoring the vegetation in the riparian zone. Removing the bank protection will allow the channel to migrate again and will widen the floodplain where it is currently confined by a riprapped terrace. Allowing floodplain creation will improve gravel stability in the main channel and allow for increased fine sediment storage on the floodplain. The construction of logjams will increase pool habitat and complex cover in the cooler reach of the South Fork, where spawning habitat is present, but largely unused.

The project is expected to have a positive impact on the productivity of Endangered species, particularly spring chinook. The project will improve habitat quality for holding, spawning, incubating, and rearing salmon. Spring chinook can hold for weeks during the warm summer months when water temperature can routinely exceed 20°C in the South Fork. Providing increase interaction between groundwater and surface water is expected to reduce the likelihood of disease and pre-spawn mortality on adults and thermal stress on rearing juveniles. Allowing channel migration should reduce the impact of floods on the channel, and may reduce the loss of incubating eggs to scour if the channel can widen enough to lower the velocity in the main channel and provide increased floodplain for fine sediment deposition.

The site is accessed along Saxon Road. The property is owned by three private landowners and the Whatcom Land Trust. These landowners would need to support the project before the project could go forward. Whatcom County Public Works is charged with maintaining the Saxon Road and would need to be a project partner in the road relocation to the edge of the historic migration zone. The road would need to be relocated prior to construction of the engineered logjams and removal of the bank protection.

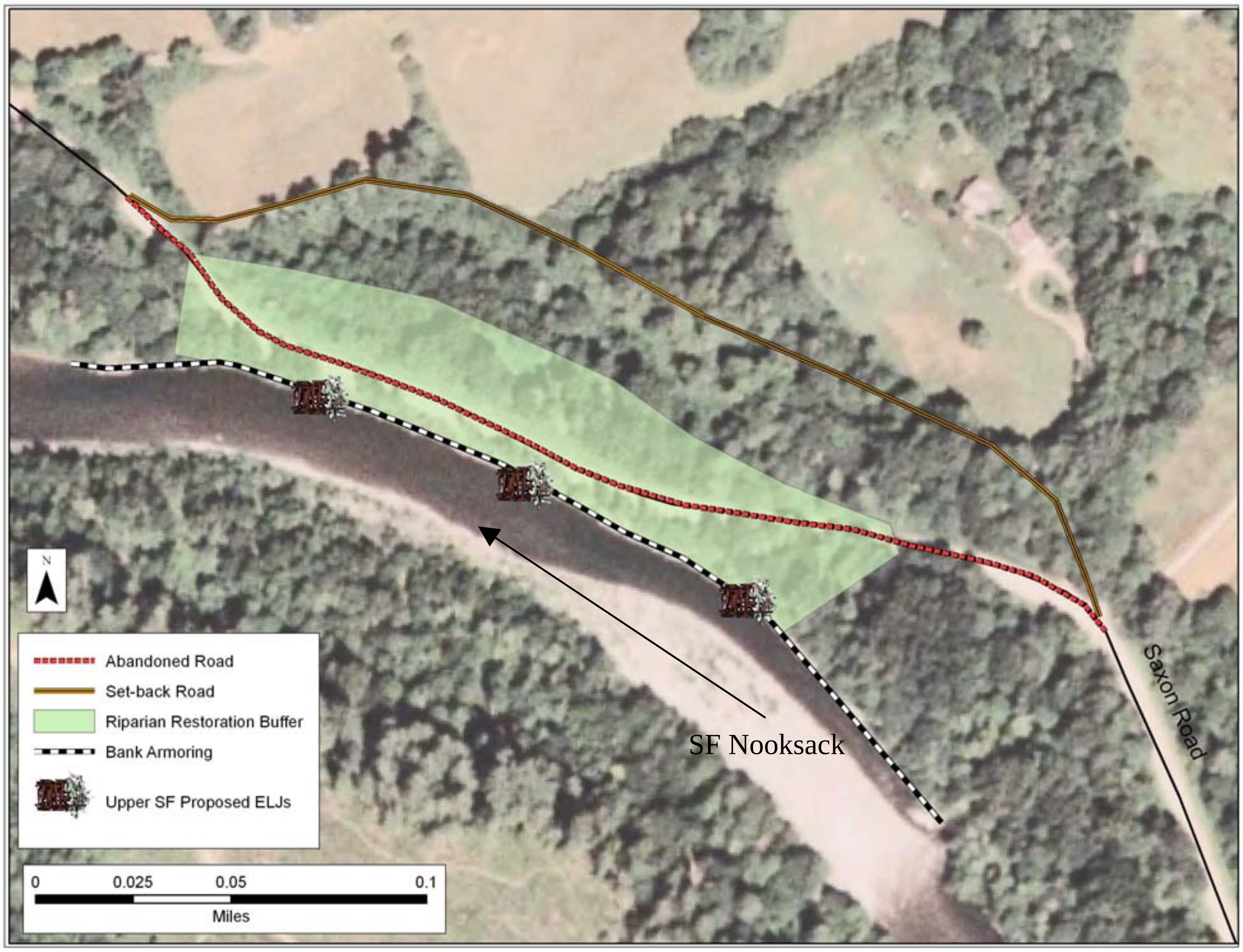


**Figure 86. Saxon Road project area at South Fork river mile 13.0.**

### *Skookum Reach Project*

The Skookum Reach Project lies between river miles 13.6-14.2. The South Fork Nooksack through this reach is characterized by riffle and as it flows along Saxon Road. The reach is devoid of pieces of large wood and has only one pool formed at the downstream The stream-adjacent road limits wood recruitment and shading of the channel and leads to increased harassment of fish near the hatchery. Both Skookum Creek and the Skookum hatchery outflow enter into the South Fork in the reach and provide cool water to the channel. The project is designed these limitations by constructing engineered logjams to create high quality habitat in the cool water refuge provided by Skookum Creek and relocating Saxon Road at least 200 feet to the edge of the riparian zone (Figure 87). The project is designed to improve the current habitat limitations by constructing habitat structures in a thermal refuge area and address habitat-forming processes.

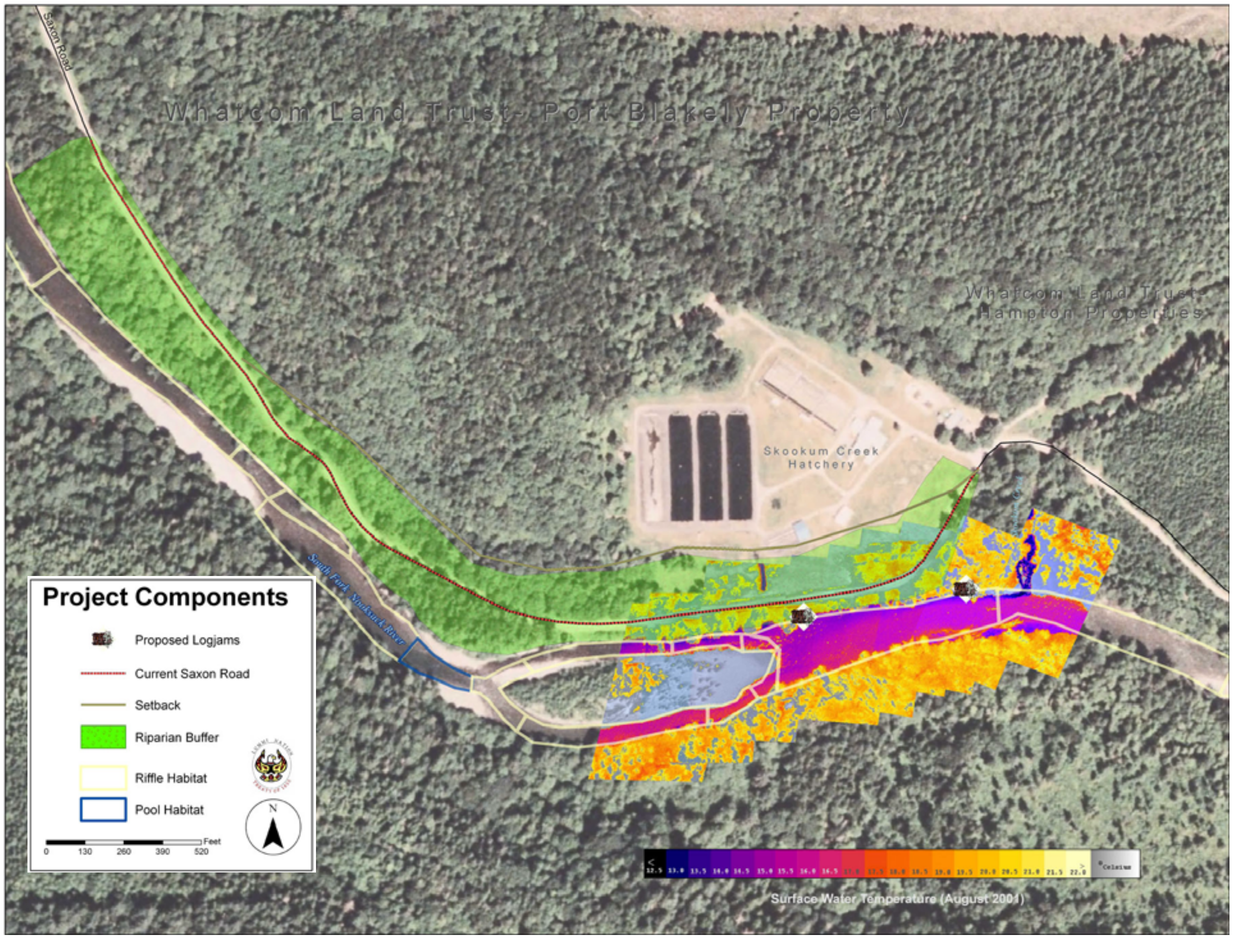


**Figure 87. Proposed restoration project outline for the Skookum Creek reach.**

The project lies in a groundwater influence zone of the South Fork and the engineered logjams are expected to create pools and increase bedform variation in cooler section of river. The project also will improve habitat quality in the largest and coolest thermal refuge area (Skookum Creek confluence) in the South Fork watershed. The project also includes riparian planting, but since the project area lies on the northern bank of the channel, the shading benefit is expected to be limited. The riparian planting will improve future wood recruitment to the channel. Setting-back Saxon Road will allow the channel to migrate again into the terrace where the road is located. Although this has been a very slow process historically, channel migration will widen the floodplain to allow for increased fine sediment storage and improved gravel stability in the main channel by reducing the confinement of the channel. The project will address the lack of habitat diversity and key habitat through increasing the amount of stable wood in the channel. The added wood, in the form of engineered logjams, is expected to increase the pool frequency in the reach by creating scour pools near the structures. Lastly, by relocating the road and allowing the channel to migrate into the terrace on the northern side of the channel, it should reduce the confinement of the channel.

The project is expected to have a positive impact on the productivity of Endangered species, particularly spring chinook. The project will improve habitat quality for holding, spawning, incubating, and rearing salmon. The project will allow improved holding conditions near the mouth of Skookum Creek, which is one of the few South Fork tributaries consistently used for spawning by chinook. The project will also improve access to the hatchery outfall (fish intake) for returning adult fish. Providing a thermal refuge is expected to reduce the likelihood of disease and pre-spawn mortality on adults and thermal stress on rearing juveniles. Allowing channel migration should reduce the impact of floods on the channel, and may reduce the loss of incubating eggs to scour if the channel can widen enough to lower the velocity in the main channel and provide increased floodplain for fine sediment deposition. It is expected that this would be a modest impact due to the low migration rate observed in the reach over the last 70 years.

Access to the site is along Saxon Road and property ownership is split between the Lummi Nation and the Whatcom Land Trust. Both property owners are supportive of the project concept. Project staging could occur on the Skookum Hatchery grounds. Whatcom County is responsible for maintaining Saxon Road and has been supportive of the concept of setting the road back from the channel to reduce future maintenance. The road would need to be relocated to enable construction of the engineered logjams in the current road prism.

### *Cavanaugh Island Project*

The Cavanaugh Island project is located in the South Fork between RM 16.6-17.0. The project reach includes the greatest length of side channel habitat in the South Fork watershed. The channel is separated from the main channel by an 11-acre island that is forested with deciduous trees and occasional young conifers. During the low flow period, the side channel is dry, but it receives enough water from the mainstem during high discharge events to maintain a 30-foot wide unvegetated, gravel-dominated bed. The project seeks to improve habitat diversity in the Cavanaugh Creek reach by maintaining year-round flow in the side channel (Figure 88). Flow will be encouraged into the channel by using wood accumulations to draw the thalweg of the main channel toward the head of the island. Riparian restoration on the island will increase the stability of the island, and large wood will be placed in the side channel to impede flow and provide instream cover for rearing juveniles. The project also includes placing wood structures in the thermal refuge areas associated with Cavanaugh Creek, located at the downstream end of the side channel. These structures will improve habitat quality in known cool water influence areas, including the plumes of two cooler water tributaries and a groundwater seep that enters the channel from terrace bordering the western side of the channel.

Encouraging the maturity of the vegetation on Cavanaugh Island site will improve shading and help address the thermal issues in the reach, while encouraging the maintenance of the side channel. In addition to riparian treatment of the island, the project includes the construction of wood habitat structures in known cool water areas to immediately provide refuge from warm summer water for Endangered species. The woody structures should also slightly increase bedform variation and groundwater interaction in the reach, although the reach does not appear to be strongly influenced by groundwater inflow. The engineered structures will greatly improve instream cover for holding and rearing salmon, in a reach that is annually used for spawning by Threatened spring chinook. The engineered structures will also increase pool frequency by local scour and should improve planform diversity by better connecting the side channel to the main channel during low flow conditions. Controlling access on the off-road vehicle trail will reduce harassment of holding and spawning fish.

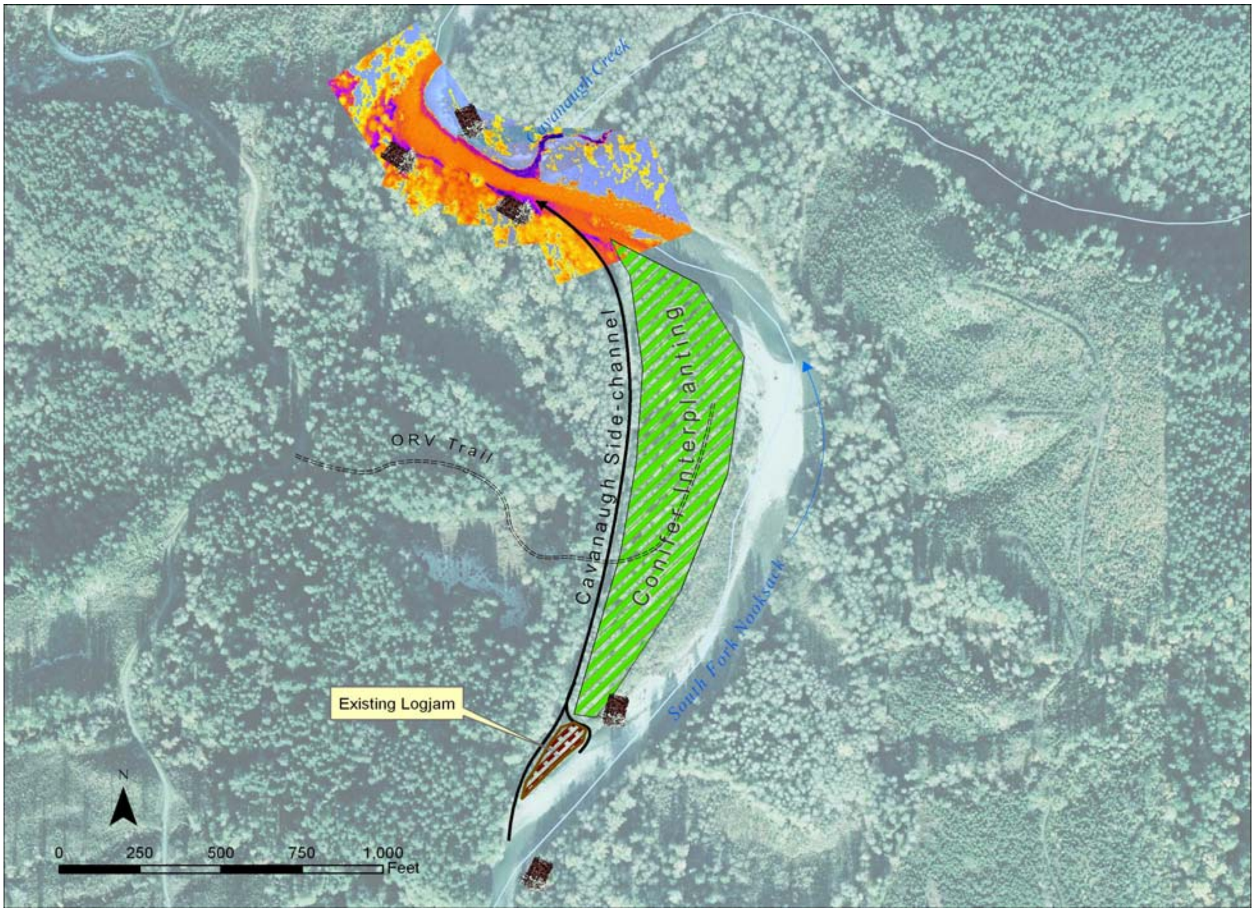


**Figure 88. Cavanaugh Island protection and restoration project.**

This project is expected to improve holding, spawning, incubation, and rearing habitat for Endangered species. The Cavanaugh Island side channel now functions well as overwinter juvenile rearing habitat and flood refuge. Enabling year-round flow through this side channel would benefit chinook by creating summer habitat for them in an area enhanced by mature, woody vegetation for overhanging and instream cover, as well as large, stable gravel required for successful spawning and egg-to-fry survival. The engineered wood structures would improve summer holding and rearing conditions in cooler water areas adjacent to consistently used spawning areas for spring chinook. The project is expected to reduce thermal stress and disease and reduce the loss of incubating eggs to scour.

The island and side channel features are accessible by off-road vehicle via DNR forest roads. To access the site, the ORV trail would need to be widened and straightened to accommodate construction equipment. Staging of material and equipment could occur in a large clearing just to the west of the project site. The project site is owned by the Department of Natural Resources and Sierra Pacific and a partnership would need to be developed before the project could go farther.

### *Fobes Creek Island Project*

The Fobes Creek Island project proposes to stabilize forested islands in the South Fork that are located between RM 18.2-18.5. The reach is one of the few areas where the South Fork Nooksack has historically migrated across its floodplain, resulting in many relict channels. These channels maintain connection during periods of high flow, which is critical for reducing scour in the main channel during floods. The reach contains abundant small pieces of wood that can be stabilized to increase the function of woody debris in the channel. The reach is heavily used for holding, spawning, and rearing by Threatened spring chinook and other species. The Fobes Creek Island Project seeks to improve the persistence of islands and maintain high flow connectivity with existing side channels, while improving habitat in the cool water refuge at the confluence of Fobes Creek (Figure 89). The project includes riparian treatment to increase the conifer content on the forested islands in the reach and the placement of large woody debris to improve habitat quality in the Fobes thermal refuge area. Instream wood will be placed throughout the channel to provide flow impedance and slow flow in the channel.

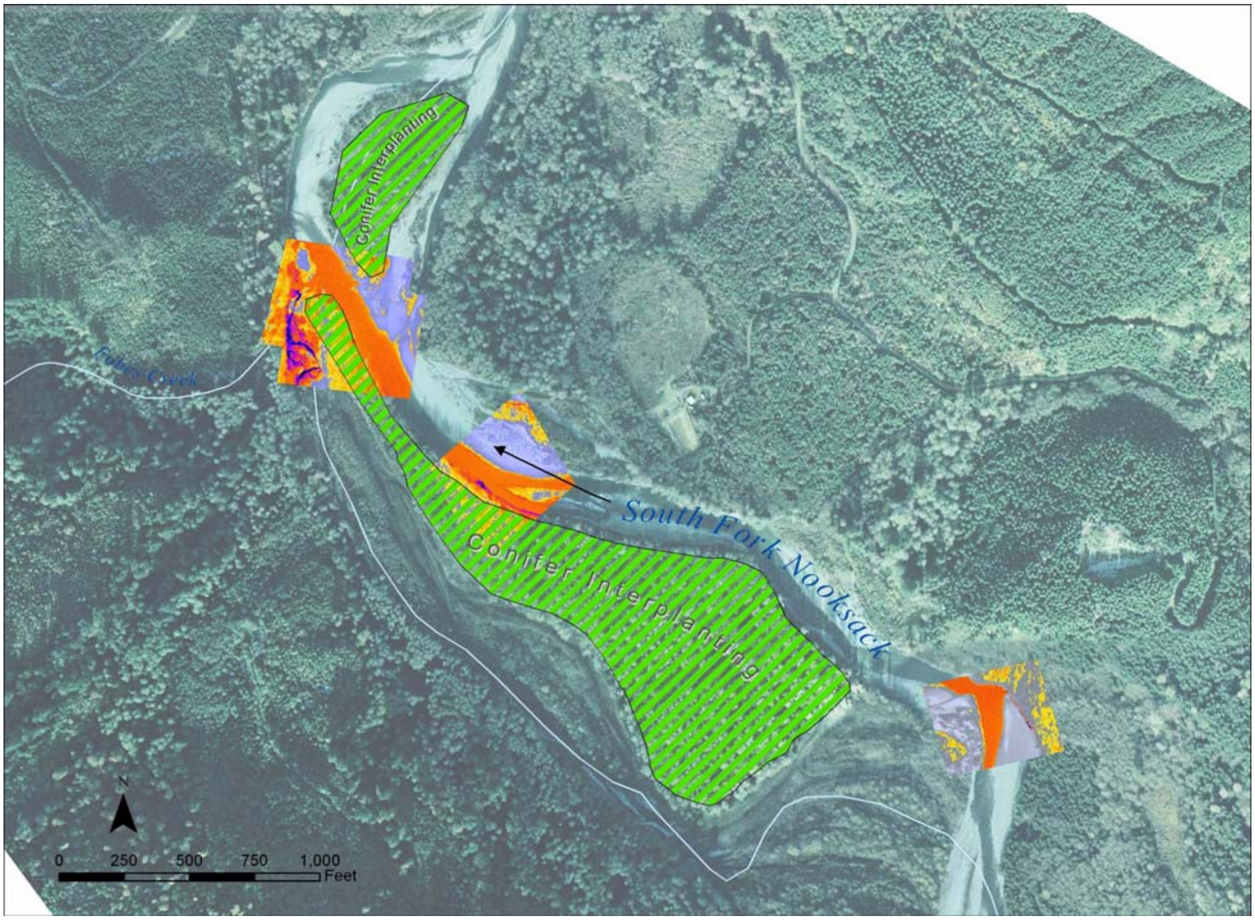


**Figure 89. Fobes Creek entering the channel on the left, and the forested islands slated for preservation and restoration.**

The project will improve habitat quality in a known thermal refuge area at the confluence of Fobes Creek. The wood placed will provide improved cover and local scour in the plume as well as increasing the bedform variation in a reach that is likely influenced by groundwater discharge to the channel. Riparian treatment of the islands will increase future shading of the channel and improve wood recruitment. By placing a large amount of wood in the channel and attempting to increase flow impedance, it is expected that better floodplain connectivity will result. The improved connectivity will allow for greater sediment deposition on the floodplain and improved gravel stability in the main channel areas. Protecting the islands with woody structures should also increase the perennial side-channel area and planform diversity of the reach. It is also expected that the increased wood load will lead to an increased pool frequency in the reach.

The project is expected to improve spawning and incubation conditions by encouraging high flow into secondary channels and reduce flow in the low-flow channels used for spawning in the reach. Holding and rearing habitat should be improved by the local scour associated with the wood placements. Habitat enhancement in the cold-water plume of Fobes Creek should reduce thermal stress and disease in pre-spawning adults and juveniles that rear in the freshwater during the warm summer months.

The project lies on property owned by Sierra Pacific and access is via their forest road system that reaches the river midway through the project reach. Staging for the project could be done in the clearing to the east of the project area. The landowner would need to be a project partner to provide access to the reach.

### *Larson's Area Floodplain Refuge Project*

This site is a series of groundwater-fed floodplain channels located just above the Larson's Bridge at RM 20.9. A relict South Fork channel, dating from the 1940s, runs through the forested floodplain and mixes with the main channel. Flows in the relict channel are low in the summer; however, temperatures (7-DAM) recorded in this channel averaged 12.5°C between July and October 2005. The best water quality

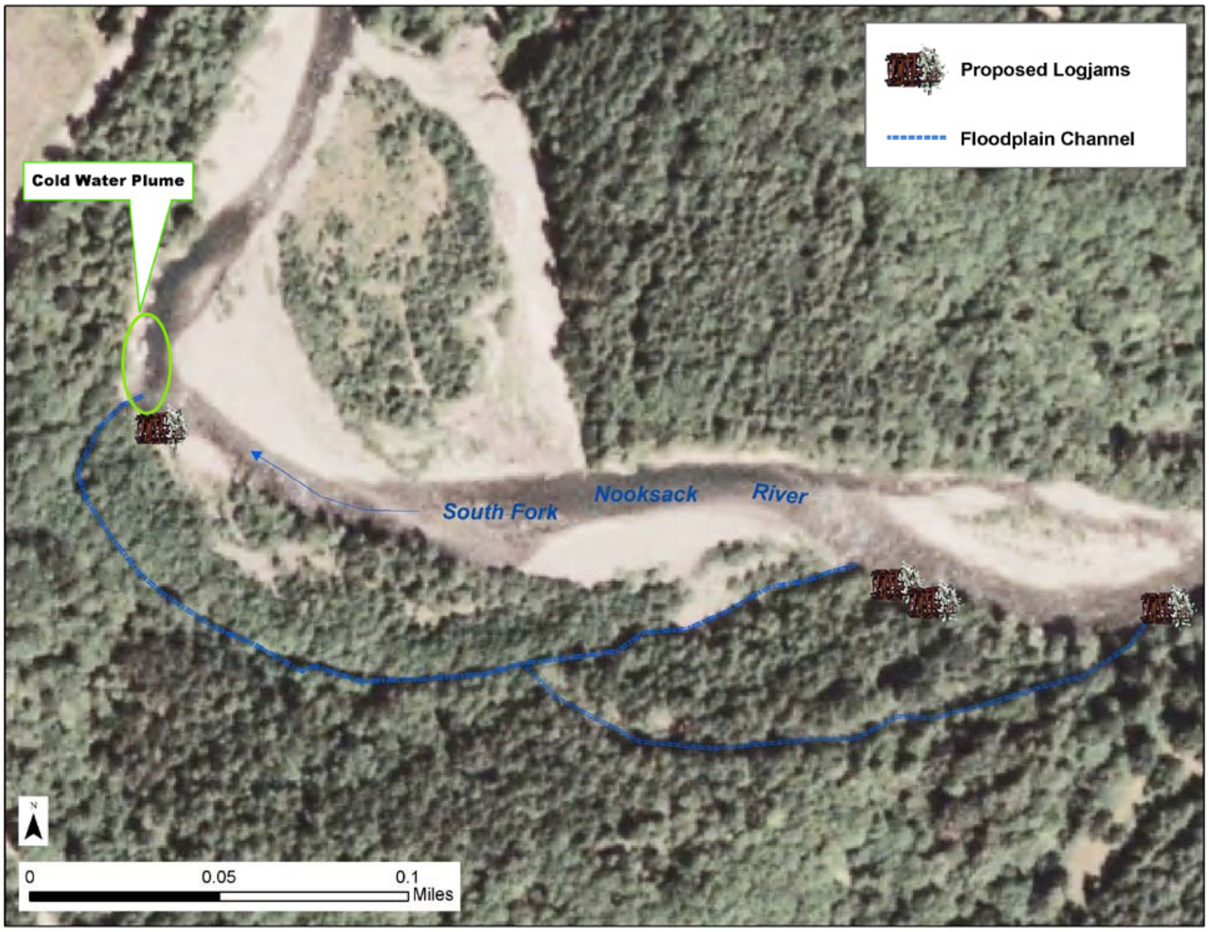


**Figure 90. Floodplain channels just above RM 20.6-Larson's Bridge**.

conditions of all stations sampled were observed at this site. Temperatures recorded in the coldwater plume also maintained low values, providing an instream refuge for fish in the area during warm periods. The project envisioned at this site is based on improving fish access to the coldwater floodplain channel, improving cover in the cooler plume of the channel and groundwater seeps from the terrace on the southern bank of the river (Figure 90). Currently, it takes a stage of approximately 4 feet to overtop the terrace and flow into the side channel. The elevation of the side channel itself is similar to the main channel, so channel migration through the high terrace that separates the channels will lower increase connectivity of the two channels.

The project will improve habitat quality in a known thermal refuge area at the confluence of the Larson's floodplain channel. The wood placed will provide improved cover and local scour in the plume as well as increasing the bedform variation in a reach that is likely influenced by groundwater discharge to the channel from the southern terrace. The placement of the woody structures should also encourage the connection of the floodplain channels during high flow, while providing improved woody cover to the reach. It is also expected that the increased wood load will lead to a modest increase in pool frequency in the reach.

The project is expected to improve summer rearing and holding conditions by the local scour associated with the wood placements in cool water locations. Habitat enhancement in the coldwater plume of the floodplain channel should reduce thermal stress and disease in prespawning adults and juveniles that rear in the freshwater during the warm summer months.

The project lies on property owned by Sierra Pacific and access is via an abandoned forest road that runs down onto the terrace where the project is located. Staging for the project could be done in a gravel pit just upslope from the site. The landowner would need to be a project partner to provide access to the reach.

### *Elk Flats Project*

The Elk Flats project is located at RM 22.6 on the South Fork of the Nooksack River. The project is designed to remove on-site infrastructure, including numerous structures and vehicles from the channel migration zone of the river (Figure 91). The property owners have also cleared 10-15 acres of land in the floodplain of the river for recreational use. Harassment and harvest of Threatened chinook has been documented at the site. The channel has actively migrated into the property and the landowners have responded by armoring sections of streambank to protect infrastructure. The site is immediately across from one of the largest stream-adjacent landslides in the South Fork watershed. Removing flow barriers along the streambank and allowing the channel to migrate through the Elk Flats property again will disperse energy across the floodplain, reducing impact to the landslide.

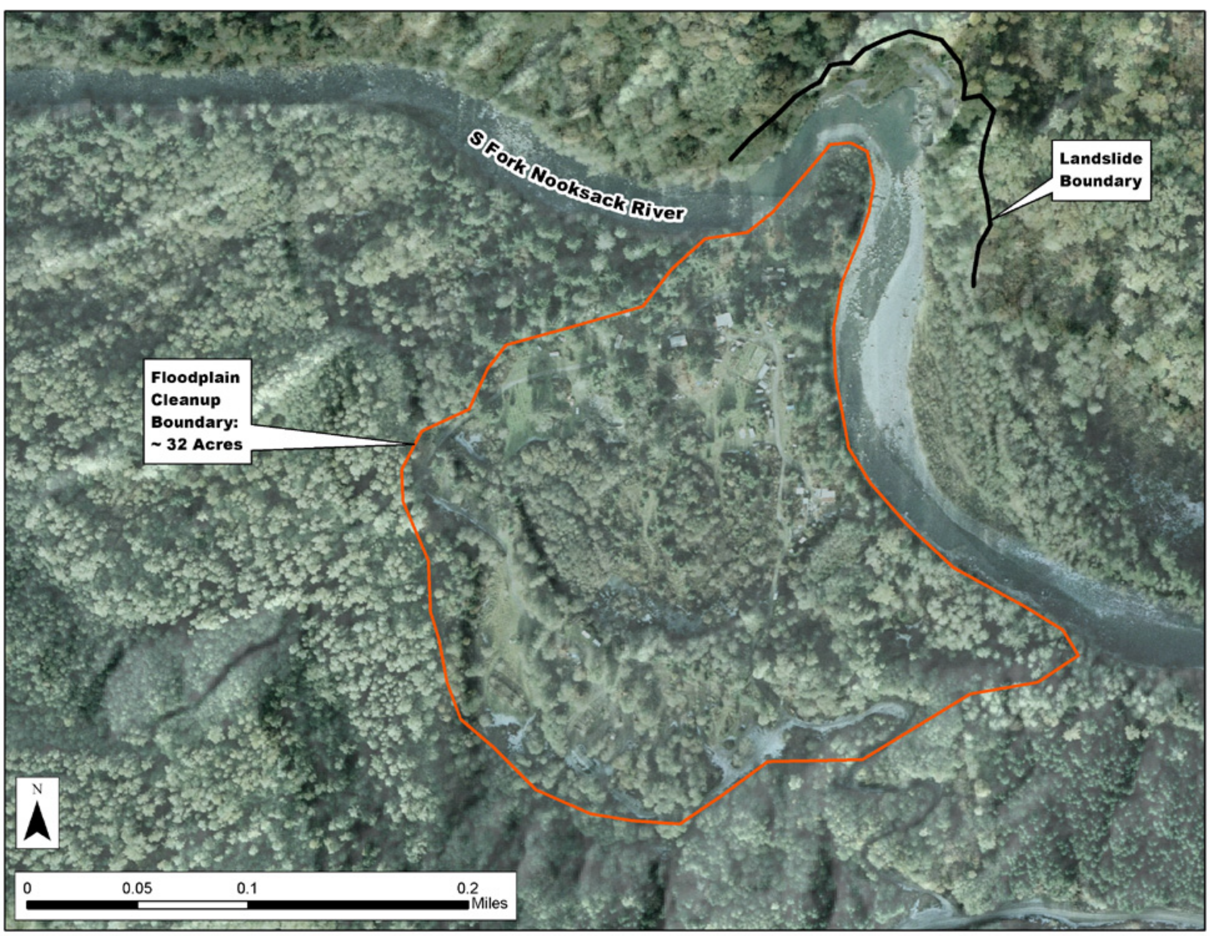


**Figure 91. Elk Flats project area.**

The riparian treatments associated with this project are expected to slightly improve stream shading and wood recruitment because most of the treated areas are located on a terrace more than 200 feet from the active channel. Removing the infrastructure and the associated bank armor from the channel migration zone will allow the channel to migrate into the southern terraces and move away from a large sediment source. With the channel no longer actively undercutting the slide, it may reach a more stable angle and become more stable. Allowing the channel to migrate will increase wood recruitment and subsequently slightly improve instream cover, increase pool frequency and gravel stability. The project is associated with the highest priority acquisition property.

The project is expected to improve rearing, spawning and incubation habitat in the reach over a longer timeframe as the channel migrates away from the landslide and into the forested terrace on the southern side of the river. Eliminating one of the largest point sources of fine sediment in the upper South Fork will improve downstream gravel quality and improve incubation success for spawning fish.

The site is currently held by a private landowner, who will need to be a partner if the project is to move forward. Access to the site is via the Sierra Pacific forest road system, with a road directly to the site. Successful implementation of the project will require the landowner to remove all structures from the channel migration zone.

### *River Mile-24 Instream Project*

This project area begins at the 200-Road Bridge and continues downstream just over a mile (RM 23.9-25.0). The project reach is dominated by low gradient riffle and run habitat, with only one large scour pool. The reach is characterized by large boulder substrate across a wide, shallow channel and no large.


**Figure 92. River mile-24 reach instream representation of instream/floodplain wood placement strategy.**

woody debris in the channel. The reach lies immediately downstream of a partial passage barrier and is often heavily used for spawning by Threatened chinook as they move back downstream from the barrier. While spawning gravel is present in the reach, it is patchy and often associated with the protected lee of the large boulders. The RM 24 Instream Project is designed to improve holding and rearing habitat in the reach by adding pieces of large woody debris to the margins of the channel and on exposed bars in areas where the channel and floodplain are fairly well connected (Figure 92). The added pieces are expected to also slow the transport of wood through the system. This reach of the river moves wood through comparatively quickly, limiting large pieces the opportunity to stall, settle, and function as habitat-forming elements. The placement design incorporates weaving or wedging large pieces between the bases of mature riparian trees on the streambank. This stabilization would allow the pieces to persist during high flow events, possibly racking transient wood and building, to some degree, jams on-site.

The project is expected greatly improve cover conditions for rearing and holding salmon. The added wood will likely increase pool frequency as small pools are scoured adjacent to some of the wood. This increase in bedform variation may have a slight impact on improved groundwater connection. The added flow impedance caused by the wood will likely lead to deposition of gravel in the low gradient channel and improved spawning habitat in association with the holding habitat.

The project is expected to provide improved holding habitat near heavily used spawning areas. The improved holding habitat in this reach will also benefit fish as they prepare to navigate the upstream barrier in years that it is passable. The instream wood will also provide improved cover and edge habitat for rearing juvenile salmon.

Given that the reach is inaccessible to large equipment and bears no large area for staging wood, recommendations for habitat restoration at the River Mile-24 site include manually placing large, key-sized pieces in the channel along banks and on bars, and partially in the channel floodplain. Transportation of materials into place throughout this reach is most feasible using a helicopter and on-the-ground guidance from a habitat biologist.

### *30 Mile Reach Project*

This project site is located at RM 30.8 on the South Fork, where Forest Road 330 crosses the channel. Historically, the reach has been heavily used by Threatened spring chinook for spawning, likely because an upstream passage barrier halted further upstream migration. More recent habitat mapping has shown a lack of quality spawning and holding habitat with little woody cover for juvenile rearing. The reach is negatively impacted by the 330-Spur Road Bridge, which constricts the channel and confines channel migration of the river. The bridge has led to undercutting of the northern hillslope and slumping into the channel. The sediment deposition upstream of the constriction has also created an opportunity to improve spawning and holding habitat with the addition of wood structures to the channel. Private and city landowners decommissioned the roads on the north side of the channel in the 1990s, but the concrete bridge was left in place. This habitat restoration project proposes to remove the bridge, its footings, and all road approach fill from the channel in order to allow the river to use its historic migration zone (Figure 93). In addition to widening the channel migration zone to pre-bridge construction measurements, the project includes adding ballasted wood instream structures to increase habitat diversity and woody cover.

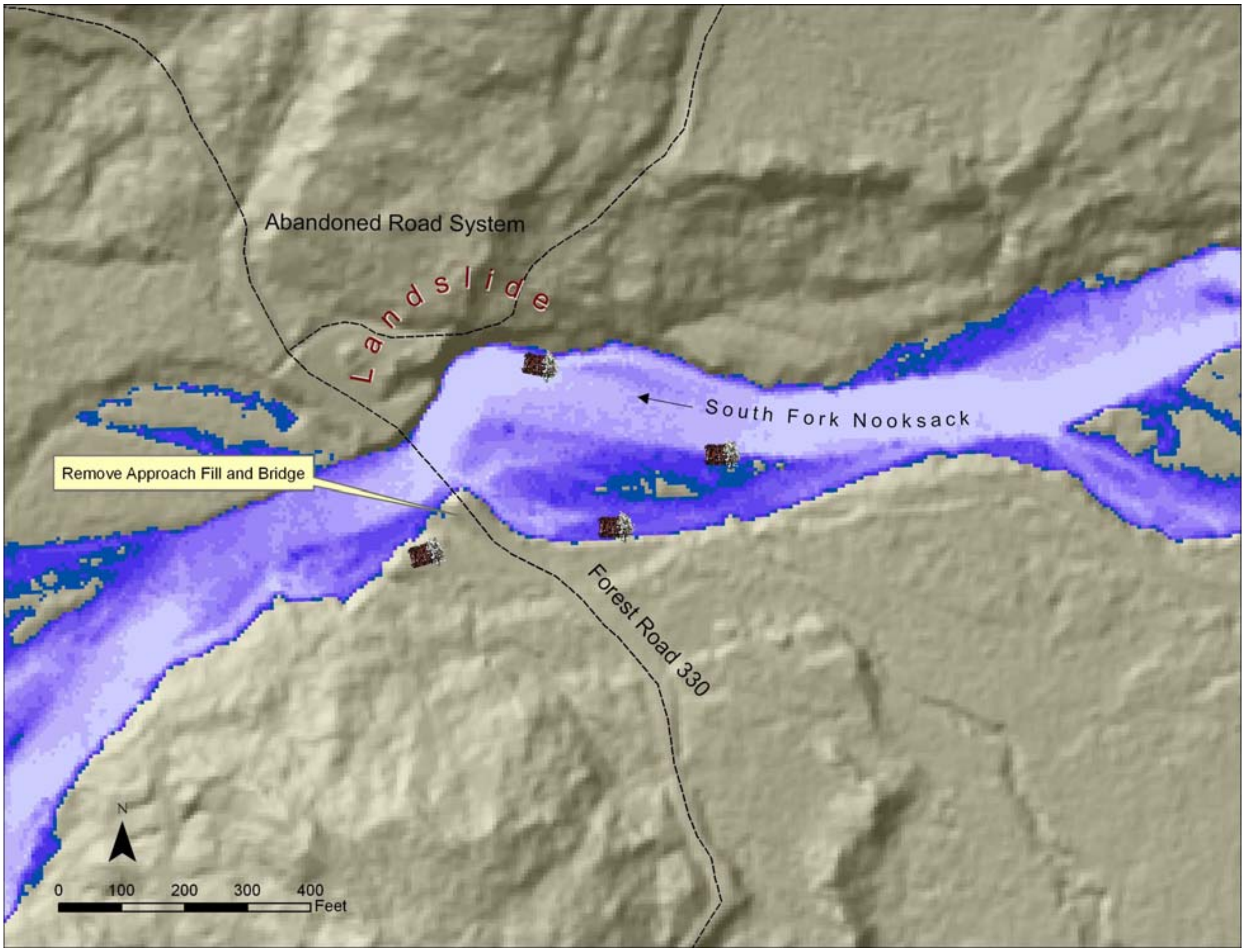


**Figure 93. Conceptual design for the RM 30 Project (based on Anchor Environmental 2007).**

The project is expected to stabilize a landslide that has resulted from the constriction at the bridge and halt a large fine sediment source to the river. Removing the bridge fill will also widen the floodplain slightly and encourage secondary channel formation and sediment deposition. The instream structures will provide instream cover and likely increase pool frequency by encouraging local scour. The local scour associated with the structures should increase the bedform variation and encourage greater interaction between the groundwater and surface water in a cooler reach of the river.

The project is expected to benefit the spawning, holding, incubation and rearing life stages in a historically productive reach of the river. Stabilizing the landslide is expected to reduce the impact of fine sediment on spawning gravel downstream of the site. Removing the floodplain constriction and placing instream structures should encourage pool formation and high quality cover in cooler water reach for fish that reach the upstream passage barrier and fall back to spawn in this reach.

The bridge is owned by Seattle City Light, which owns the surrounding property as mitigation for dams on the Skagit River. Access to the site is through the Sierra Pacific forest road system and down the 330 Road spur to the bridge. Seattle City Light has been an active cooperator in restoration activities in the past and would need to be a partner for the project to progress.

### *300-Road Bridge Removal*

This project site is located at RM 34.6 on the South Fork, where Forest Road 300 crosses the channel just downstream of Wanlick Creek. The wooden bridge has become structurally unsound and the roads west of the bridge are no longer in use. The location of the bridge crossing required several hundred feet of fill to raise the road above the floodplain of the South Fork Nooksack. The fill has halted channel migration and resulted in a constriction of the South Fork floodplain and sediment deposition upstream of the crossing. Floodplain habitat on the west side of the channel consists of old-growth conifer trees and relict side channels. Although the river may occasionally access its floodplain downstream of the bridge, the fill that creates the bridge's west approach impedes natural access to the floodplain (Figure 94).

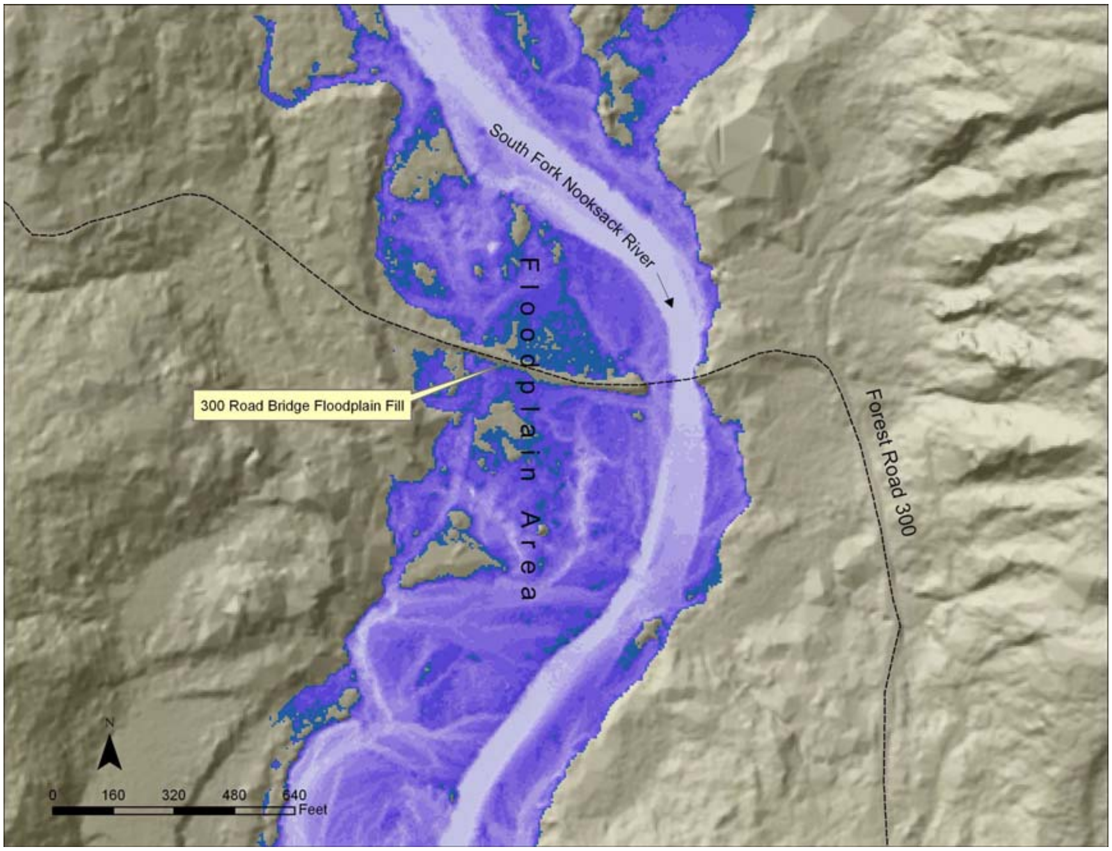


**Figure 94. 300-Road bridge removal project.**

Improving access through the reconnection of the channel to the floodplain would improve habitat diversity and quantity by increasing side channel development throughout intact riparian forest, improving sediment transport throughout the reach by reactivating the floodplain on either side of the bridge, and restoring channel width by removing significant volumes of artificial fill from the floodplain. The project will remove a constriction to the channel and improve floodplain functions, such as fine sediment deposition, wood recruitment, and secondary channel formation. These processes will lead to increase planform diversity and gravel stability in the channel, as well as potentially less fine sediment in downstream substrate.

The project may benefit fish populations, such as Threatened spring chinook, that do not directly use the project reach by increasing wood recruitment and sediment deposition that affect downstream fish populations. Bull trout and steelhead, which do use the reach, would benefit from the local habitat affects created by increased wood recruitment. These include pool formation and increased woody cover for rearing.

Access to the site is via Sierra Pacific Industries' private forest roads. The landowner, Sierra Pacific would need to be an active partner, as well as adjacent landowners such as the Department of Natural Resources and Seattle City Light.

## *Riparian Restoration Projects*

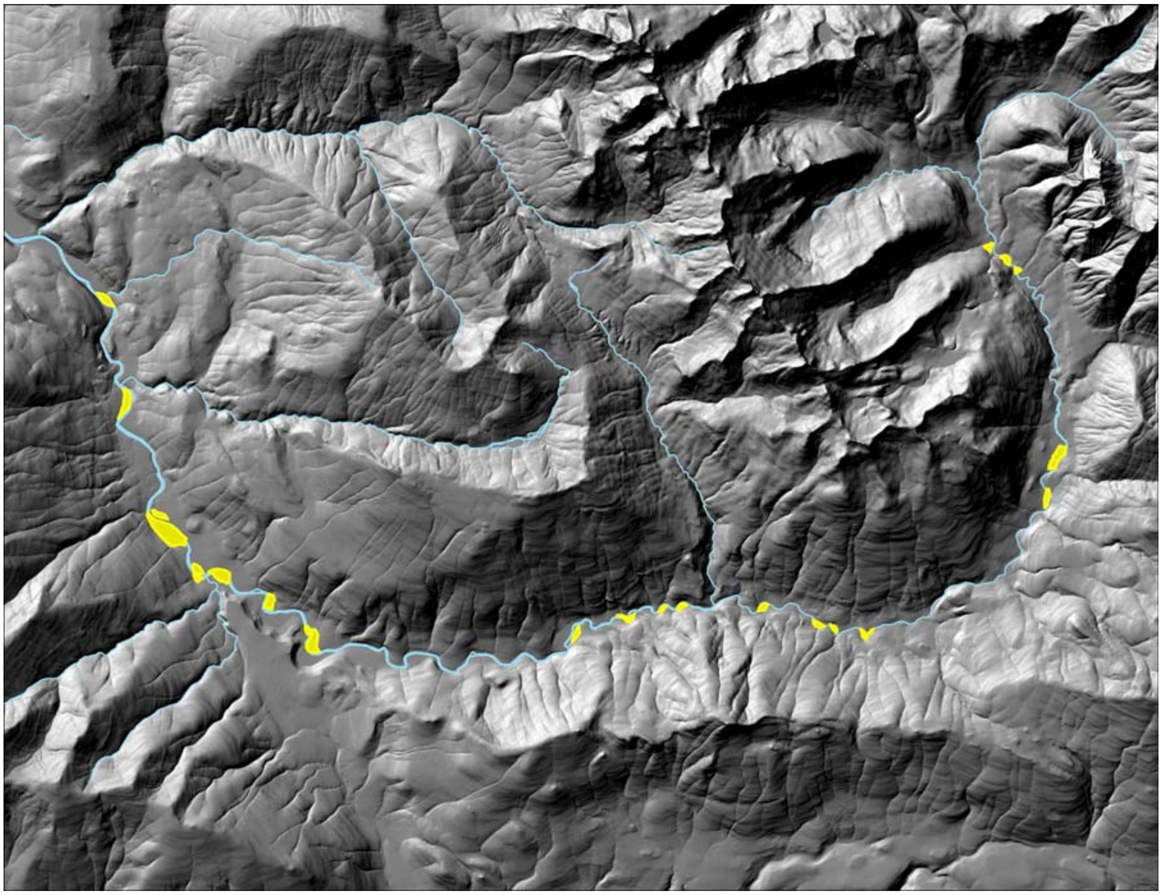

**Figure 95. High priority wood recruitment stands based on elevation height above the channel.**

These projects propose riparian treatment to encourage rapid growth of conifer trees that will help the stand provide large wood and shade more quickly to the channel. Projects areas are defined by their feasibility to recruit wood to the channel or their potential shade capacities. To identify priority wood recruitment stands, the high resolution DEM was used to find stands occupying areas that were likely to contribute wood to the channel. These areas were defined based on their elevation relative to the channel (less than 6 feet), their proximity to the channel and the lack of any impediments to channel migration (Figure 95). The 6-foot threshold was based on field mapping of the depth of easily eroded alluvium (commonly <2 meters) overlying the erosion-resistant glacial lake material that comprises the terraces. The results described 25 stands, ranging from 0.8 to 46 acres, as potential contributors of large wood to the channel (Table 27). The total area of the likely stands was 181 acres, of which conifer trees dominated less than 10 acres, and no stands were composed of mature trees (Duck Creek Associates 2000).

The improvement of shading along the river channel is of utmost importance in local strategy to lower water temperature. Shade modeling of the current riparian conditions through the upper South Fork showed that during the middle of the day, the combination of seasonal solar angles and the heights of existing riparian vegetation shaded the active channel 15-25% of the day. The current shade coverages were then compared to those presented by mature (potential) riparian conditions. The results in August, the warmest month, showed that while the current channel area is only 25% shaded at noon, is could be 65% shaded at noon if riparian stands were mature. By comparing the area of the active channel shaded under each scenario, the reaches that have been most heavily impacted by riparian harvest were identified as priority stands for detailed riparian assessment (Figure 96, Table 28).

**Table 27: Wood recruitment areas in the Upper South Fork.**

| Stand Characteristics | | | Acres | Ownership |
|---|---|---|---|---|
| Dominant Tree Type | Size | Density | | |
| Hardwood | Small | High | 46.4 | Sierra Pacific |
| Mixed | Small | High | 16.5 | Sierra Pacific |
| Hardwood | Medium | High | 16.4 | Sierra Pacific |
| Hardwood | Medium | High | 15.1 | WADNR |
| Mixed | Medium | High | 12.7 | WADNR |
| Hardwood | Small | High | 9.0 | Sierra Pacific |
| Hardwood | Medium | High | 7.6 | WADNR |
| Hardwood | Small | High | 6.1 | Sierra Pacific |
| Hardwood | Small | Sparse | 5.8 | Seattle City Light |
| Hardwood | Small | High | 5.2 | Sierra Pacific |
| Conifer | Medium | High | 4.2 | U.S. Forest Service |
| Mixed | Medium | Sparse | 4.2 | Seattle City Light |
| Hardwood | Small | High | 3.8 | Seattle City Light |
| Mixed | Medium | Sparse | 3.7 | Seattle City Light |
| Conifer | Medium | High | 3.2 | U.S. Forest Service |
| Hardwood | Medium | High | 2.7 | Sierra Pacific |
| Hardwood | Small | High | 2.7 | Seattle City Light |
| Hardwood | Small | High | 2.6 | Seattle City Light |
| Mixed | Small | High | 2.6 | Sierra Pacific |
| Hardwood | Small | High | 2.4 | Seattle City Light |
| Hardwood | Small | High | 1.9 | Seattle City Light |
| Hardwood | Small | Sparse | 1.9 | Seattle City Light |
| Hardwood | Small | High | 1.9 | Seattle City Light |
| Hardwood | Medium | High | 1.6 | U.S. Forest Service |
| Hardwood | Small | High | 0.8 | Seattle City Light |

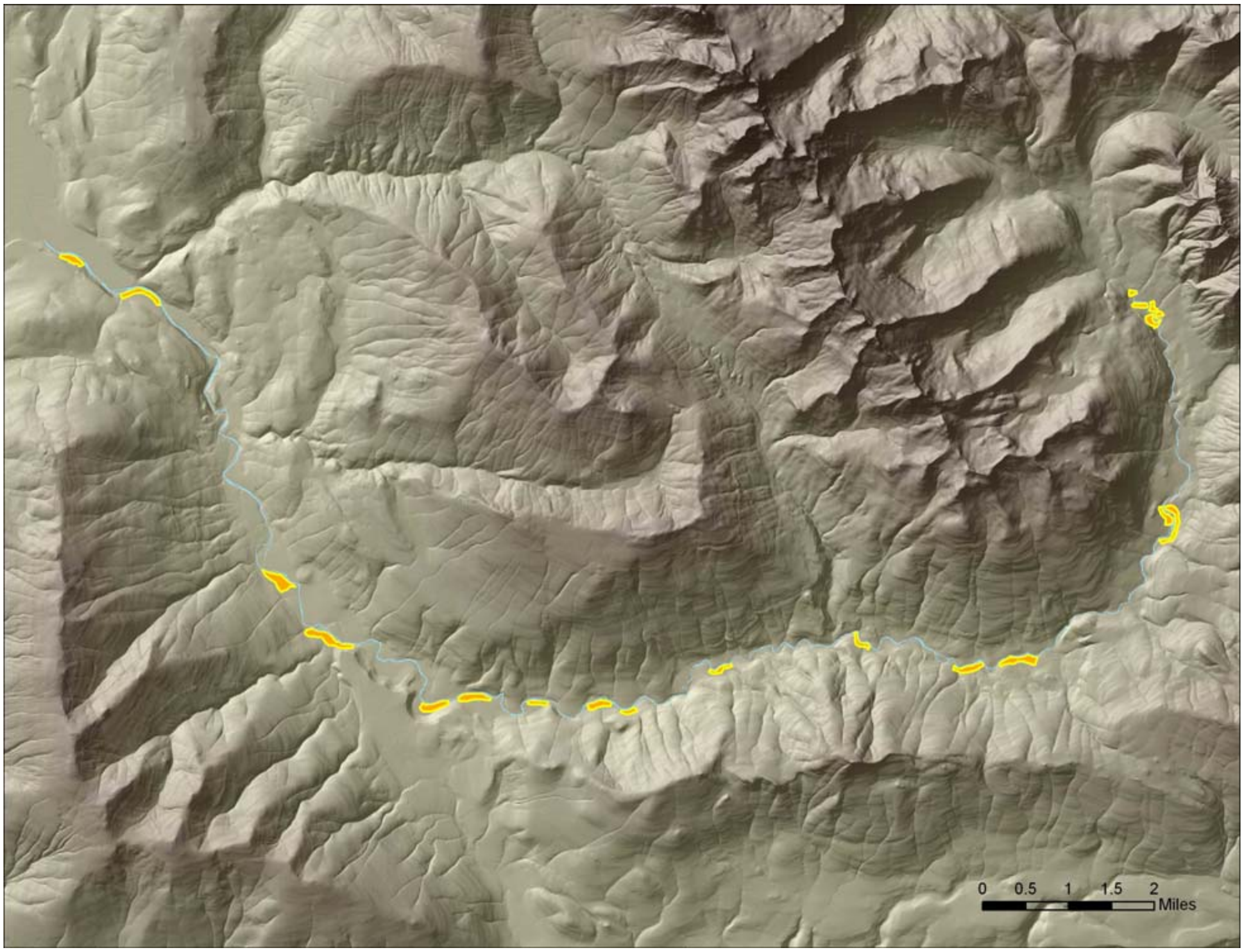


**Figure 96: Priority stands for riparian shade treatment.**

While these stands are likely to contribute LWD to channel, the current stand conditions make it unlikely that the wood will be large enough to be functional in a channel the size of the South Fork Nooksack. Riparian treatments such as inter-planting conifers in hardwood-dominated stands, establish forested buffers on unforested sites and thinning to encourage growth that is more rapid could all be employed to speed riparian function in the watershed. Other approaches include removing bank protection or floodplain fill to allow the channel to better access the riparian zone. On-going site assessment of the stands is central to characterizing the wood recruitment potential and the feasibility and design of riparian treatments to accelerate that potential. From this analysis, the development of prescriptions will allow for prioritization of sites for action.

**Table 28: Riparian shade priority stand characteristics.**

| Stand Characteristics | | Acres | Ownership |
|---|---|---|---|
| Dominant Tree Type | Density | | |
| Hardwood | Dense | 26.3 | Sierra Pacific |
| Hardwood | Dense | 22.6 | Sierra Pacific |
| Hardwood | Dense | 18.8 | Seattle City Light |
| Mixed | Sparse | 17.0 | Seattle City Light |
| Hardwood | Dense | 16.6 | WADNR, Ewing Family Trust |
| Mixed | Dense | 15.7 | Sierra Pacific |
| Hardwood | Dense | 14.9 | Sierra Pacific |
| Mixed | Dense | 13.1 | Seattle City Light |
| Hardwood | Dense | 11.9 | Seattle City Light |
| Mixed | Dense | 11.2 | Whatcom Land Trust |
| Hardwood | Sparse | 8.8 | Seattle City Light |
| Hardwood | Dense | 8.2 | U.S. Forest Service |
| Mixed | Sparse | 7.3 | Seattle City Light |
| Mixed | Dense | 7.2 | U.S. Forest Service |
| Mixed | Dense | 7.0 | Seattle City Light |
| Mixed | Sparse | 6.5 | Sierra Pacific |
| Hardwood | Dense | 5.0 | U.S. Forest Service |
| Hardwood | Dense | 4.9 | Seattle City Light |
| Hardwood | Dense | 2.9 | U.S. Forest Service |

### *Orphan Road Abandonment*

An orphaned road is a road or railroad grade that the forest landowner has not used for forest practices activities since 1974. Many of these roads are over-grown or closed off, but have not satisfied the abandonment process. Forest landowners were required to inventory and assess the risk to public resources, or public safety posed by orphaned roads in conjunction with the road maintenance and abandonment plan. Landowners are not obligated under forest practice rules to repair or abandon such roads, but they can voluntarily take this action. High-resolution topography data allows for the identification of old road and railroad grades that may have been missed as a part of the orphan road assessment (Figure 97). This project proposes to assess roads in the South Fork that have been missed, as well as development treatments for sections of road that requires action.

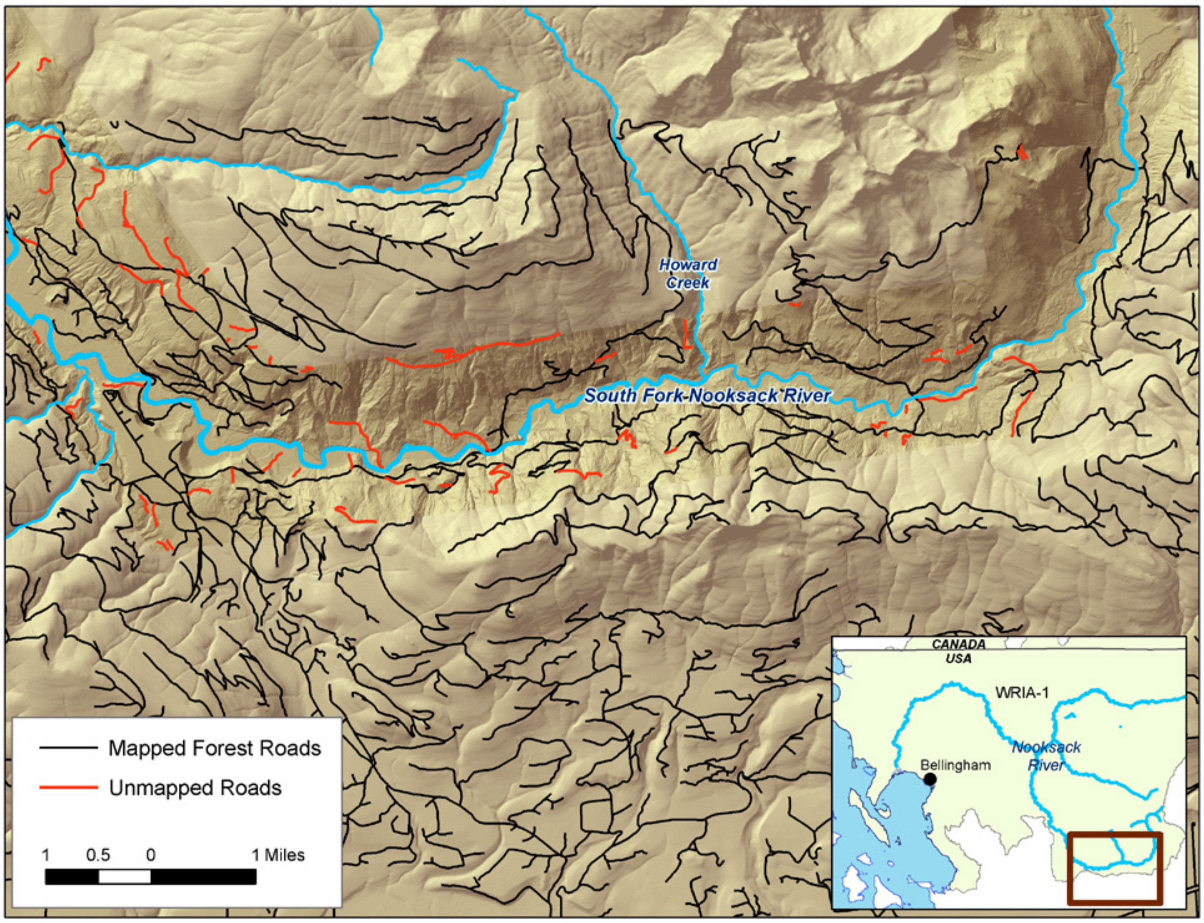


**Figure 97. Road network along the upper South Fork reach in the Skagit County half of the watershed; documented roads mapped by DNR (2000).**

Orphaned roads have the potential to negatively affect instream habitat through rerouting surface drainage or creating unstable slopes. Assessing and treating orphaned roads to the extent that treatments are indicated, helps to eliminate potential sediment sources in the watershed. Reducing fine sediment sources in the watershed will reduce the negative impacts of fine sediment on incubating eggs.

In the upper South Fork watershed, orphaned roads lie on property owned by a variety of public and private owners. Industrial timber companies and Seattle City Light have completed orphaned road assessments, but many roads identified in the LiDAR were not identified. Working with these landowners to characterize the roads and develop appropriate treatments is required for successful implementation of the project.

### *Priority Habitat Acquisitions*

Several areas of the watershed that have retained their natural habitat forming processes, and do not warrant restoration action, have been identified in the upper South Fork study reach. The protection strategy for the watershed is directed at the limitations of the Forest Practices rules that impact the protection of riparian habitat on property owned by small forest landowners. The strategy includes acquiring private in-holdings within the industrial forest area, and purchasing development rights on sensitive industrial forestland to prevent the conversion of these lands to higher impact land uses, for example, residential. The underlying objective of protection efforts laid out in the WRIA-1 Restoration Strategy is to halt further habitat degradation by preserving places within the watershed where ecosystem processes are functioning naturally and/or where existing land-use protections may be lacking. For example, protection targets include places where mature riparian forests provide shade and contribute large woody debris, areas where the river is free to meander and utilize its historic floodplain, and places where off-channel habitats connect to the river through streams.

More than 250 acres of stream-adjacent property along the upper South Fork are managed by several private landowners (Figure 98, Figure 99, Figure 100). The parcels are generally grouped into three areas: near Skookum Creek (RM 14), near the “New Bridge” crossing (RM 18), and near Elk Flats (RM 23). The parcels near Skookum Creek would facilitate the Saxon Road restoration project, as well as the restoration of a priority riparian shading stand (Figure 98). The three small parcels near New Bridge lie on the rim of a narrow bedrock reach (Figure 99). The Elk Flats area contains three large parcels along the southern bank of the river, and encompasses the only legal residential development in the watershed (Figure 100). Since several of these parcels include large portions of upland habitat, ideally the valley bottom could be purchased independently. Acquisitions were prioritized based on their habitat value, risk of continued degradation, and restoration project potential (Table 30). The habitat value is related to the size of parcel in the riparian management zone of the river, and the portion of each that is characterized by floodplain or terrace habitat.

Purchasing development rights from industrial timber companies would ensure that the property would not be subdivided and sold as rural residential property in the future, an ever-growing threat to landscape connectivity in Whatcom and Skagit County watersheds. The preservation strategy would maintain forest practice activities in the watershed, but continue to provide some protection to fisheries resources that comes from the Forest Practice rules.


**Figure 98. Priority individual in-holdings near Skookum Creek (RM 13).**

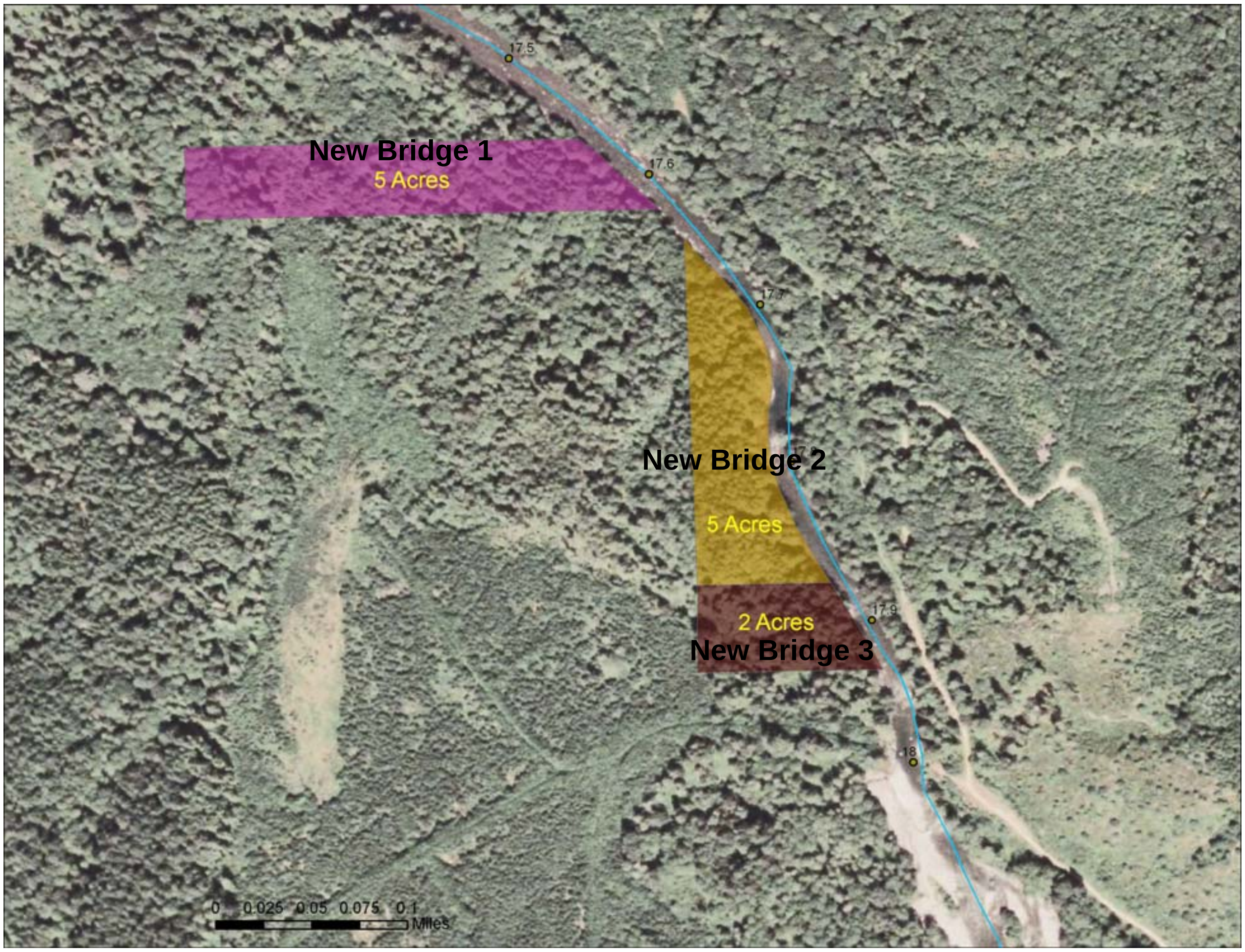


**Figure 99. Private in-holdings near New Bridge (RM 17.5).**

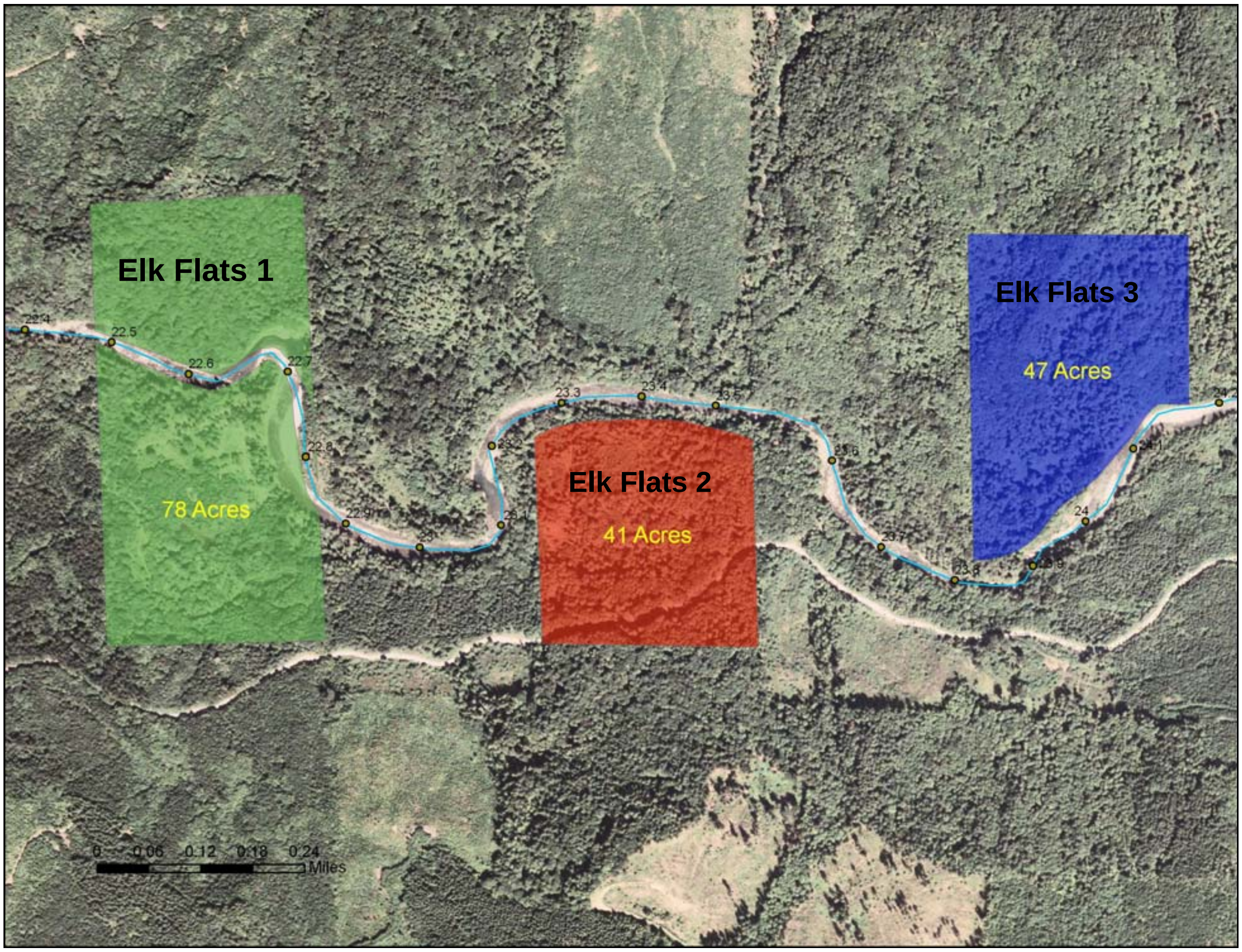


**Figure 100. Small private in-holdings near Elk Flats (RM 22.5).**

## Project Prioritization

Restoration projects were prioritized based on the expected degree of impact (direct or indirect) on the river, and the time assumed to pass until the impact from associated limiting factors is reduced. Magnitude of benefit rankings was assigned on a 5-point scale with "High" given 5 points, "Moderate" given 3 points, and "Low" given 1 point. The ranks were then summed for a total magnitude of benefit score. Project prioritization is an important element of prescribing actions for habitat restoration. Prioritizing provides for careful planning of temporal processes such as project sequencing, allocation of funds, and future funding applications. Higher priority projects gain added feasibility, and may increase a project's potential to permit funding.

### *Temperature*

#### Increase Channel Shading

- *High* - Project will result in a measurable decrease in summer water temperature in the reach.
- *Moderate* - Project improves riparian conditions (increased conifer component, wider buffer width, increased rate of growth) for future shading; or project encourages the stability of forested islands.
- *Low* - Project does not channel shading in the reach.

#### Improve Groundwater-Surface Water Connectivity

- *High* – Project increases bedform variation (i.e. pool development in a long glide) in a known groundwater influence reach

- *Moderate* – Project increases bedform variation in another reach, or increases flow impedance in an unconfined reach.
- *Low* – Project does not address groundwater-surface water connectivity

Provide Thermal Refuge

- *High* – Project will improve habitat quality in a cooler water refuge that maintains optimal temperature throughout the summer.
- *Moderate* – Project will improve habitat quality in a cooler water refuge that is cooler than the main channel temperature
- *Low* – Project does not address a known cooler water source

### *Sediment*

Reduce Fine Sediment in Substrate

- *High* - Project will result in a measurable decrease in fine sediment in spawning riffles.
- *Moderate* - Project will increase the floodplain area for fine sediment deposition; or project will increase flow impedance in the reach
- *Low* - Project does not address fine sediment in the substrate in the reach.

Reduce Sediment Sources

- *High* – Project stabilizes a fine sediment source that delivers sediment to the channel
- *Moderate* – Project addresses forest road stability; or project addresses sediment sources that do not deliver to stream channels.
- *Low* – Project does not address sediment sources

### *Habitat Diversity and Key Habitat*

Improved Instream Cover

- *High* – Project increases the amount of stable wood to more than 4 pieces per channel width; project removes bank armoring to allow wood recruitment
- *Moderate*- Wood is added to a reach, but does not meet the 4 piece threshold; or project treats riparian conditions that will allow improved wood recruitment (increased conifer component, wider buffer width, increased rate of growth)
- *Low*- Addressing instream cover is not a project component.

Increased Planform Diversity

- *High* – The project results in secondary channel habitat that maintains flow throughout the year.
- *Moderate* – Project results in the creation of a seasonal (high flow) secondary channel; or project stabilizes a forest island that will allow future side channel development
- *Low* - Project does not increase secondary channel quantity.

Increased Pool Frequency

- *High* - A 20% increase in pool units in the project reach.
- *Moderate* - Less than 20% increase in pools in the reach; or riparian treatments to improve wood recruitment (increased conifer component, wider buffer width, increased rate of growth).
- *Low* - Project is not expected to increase pool frequency.

Improved Gravel Retention and Stability

- *High* – Project results in stable, protected gravel patches for spawning.
- *Moderate* – Restores flow impedance in unconfined reaches to store gravel; or project removes barriers to migration and encourages floodplain development and function
- *Low* – Project is not expected to improve gravel retention and stability.

**Table 29. Upper South Fork habitat *restoration* project rankings.**

| Project Name | Temperature | | | Sediment | | Habitat Diversity | | | | Ranked Score |
|---|---|---|---|---|---|---|---|---|---|---|
| | Thermal Refuge | Shading | Ground-water Connection | Source Control | Fines in Substrate | Instream Cover | Planform Diversity | Pool Frequency | Gravel Stability | |
| Fobes Creek Island | 5 | 3 | 4 | 1 | 3 | 5 | 5 | 3 | 3 | **32** |
| Skookum Reach | 5 | 2 | 5 | 1 | 2 | 5 | 1 | 5 | 3 | **29** |
| 30-Mile Reach Project | 1 | 1 | 4 | 5 | 2 | 5 | 3 | 5 | 3 | **29** |
| Cavanaugh Creek Island | 5 | 3 | 2 | 1 | 1 | 5 | 5 | 5 | 1 | **27** |
| Saxon Road Project | 1 | 2 | 5 | 1 | 3 | 5 | 1 | 5 | 3 | **26** |
| Larson's Floodplain Refuge | 5 | 1 | 3 | 1 | 1 | 3 | 3 | 3 | 1 | **21** |
| RM 24 Instream Project | 1 | 1 | 2 | 1 | 1 | 5 | 1 | 3 | 3 | **18** |
| 300 Road Bridge Project | 1 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | 3 | **15** |
| Elk Flats Project | 1 | 2 | 1 | 3 | 1 | 2 | 1 | 2 | 1 | **14** |
| Riparian LWD Treatment | 1 | 2 | 1 | 1 | 1 | 3 | 1 | 3 | 1 | **14** |
| Riparian Shade Treatment | 1 | 3 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | **13** |
| Orphan Road Assessment | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 | **11** |

**Table 30. Upper South Fork Nooksack habitat *protection* project rankings.**

| Protection Project | Acres | Habitat Value | Near-term Habitat Risk | Restoration Potential | Rank |
|---|---|---|---|---|---|
| Elk Flats 1 | 78 | High | High | Elk Flats Project | **6** |
| Skookum 1 | 17 | High | Moderate | Saxon Road Project | **5** |
| Skookum 3 | 56 | High | Moderate | Priority Riparian Stand | **5** |
| Elk Flats 2 | 41 | High | Low | No Identified Project | **4** |
| Skookum 2 | 9 | Moderate | Moderate | Saxon Road Project | **4** |
| Elk Flats 3 | 47 | Moderate | Low | No Identified Project | **3** |
| New Bridge 2 | 5 | Moderate | Low | No Identified Project | **3** |
| New Bridge 3 | 2 | Low | Low | No Identified Project | **2** |
| New Bridge 1 | 5 | Low | Low | No Identified Project | **2** |

# Bibliography


Anderson, H.W., M.D. Hoover, and K.G. Reinhart. 1976. Forests and water: Effects of forest management on floods, sedimentation, and water supply. USDA For. Serv. Gen. Tech. Rep. PSW-18.

Bash, J., C. Berman, and S. Bolton. 2001. Effects of turbidity and suspended solids on salmonids. Center for Streamside Studies, Univ. of Washington, Seattle, WA.

Baxter, C.V., and F.R. Hauer. 2000. Geomorphology, hyporrheic exchange, and selection of spawning habitat by bull trout (*Salvelinus confluentus*). Can. J. Fish. & Aquatic Sci. 57(7): 1470-1481.

Berg, L. 1982. The effect of exposure to short-term pulses of suspended sediment on the behavior of juvenile salmonids. Pp. 177-196 in G.F. Hartman et al. [eds.]. Proceedings of the Carnation Creek Workshop: a ten-year review. Dept. Fish. And Oceans, Pacific Biological Station, Nanaimo, Canada.

Berg, L. and T.G. Northcote. 1985. Changes in territorial, gill-flaring, and feeding behaviour in juvenile coho salmon (*Oncorhynchus kisutch*) following short-term pulses of suspended sediment. Can. J. Fish. Aq. Sciences 42:1410-1417.

Berris, S.N. and R.D. Harr. 1987. Comparative snow accumulation and melt during rainfall in forested and clearcut plots in the western cascades of Oregon. Water Resources Research Vol 23: 135-142.

Bjornn, T.C. 1968. Survival and emergence of trout and salmon in various gravel-sand mixtures. In Proceedings, Forum on the Relation Between Logging and Salmon, p. 80-88. American Institute of Fishery Research Biologists and Alaska Dept. of Fish and Game, Juneau.

Bjornn, T.C., and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. Pp. 83-138 in W.R. Meehan [ed.]. Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitat. American Fisheries Society Special Publication.

Brett, J.R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus.* Journal of the Fisheries Research Board of Canada. 9:265-323.

Bosch, J.M. and J.D. Hewlett. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. J. Hydrology (55) 3-23.

Brooks, K.N., P.F. Ffolliot, H.M. Gregersen, and J.L. Thames. 1991. Hydrology and the management of watersheds. Iowa State University Press, Ames, Iowa. 392 pp.

Brown, G.W. and J.T. Krygier. 1971. Clear-cut logging and sediment production in the Oregon Coast range. Water Resources Research 7(75): 1189-1198.

Brown, L.R., P.B. Moyle, and R.M. Yoshiyama. 1994. Historical decline and current status of coho salmon in California. North American Journal of Fisheries Management. 14(2):237-261.

Burgner, R.L. 1998. Life history of sockeye salmon (*Oncorhynchus nerka*). Pages 3-101 *in*: C. Groot and L. Margolis, eds. Pacific Salmon Life Histories. UBC Press, University of British Columbia, Vancouver, BC, Canada.

Burns, J.W. 1972. Some effects of logging and associated road construction on northern California streams. Transactions of the American Fisheries Society 101(1):1-17.

Chamberlin, T.W., R.D. Harr, and F.H. Everest. 1991. Timber Harvesting, Silviculture, and Watershed Processes. In: *Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats*. American Fisheries Society Special Publication No. 19:181-205.

Conrad, J.F. 1965. Observations on "bad eggs" in Columbia River fall chinook salmon. Progressive Fish Culture. 27:42-44.

Cordone, A.J. and D.W. Kelley. 1961. The influences of inorganic sediment on the aquatic life of streams. California Fish and Game 47(2):189-228.

Dewberry, C. 2003. Snorkel Survey of the Acme to Saxon Bridge Section of the South Fork Nooksack River. Report to the Lummi Indian Nation, Natural Resources Department.

Gardner, M.B. 1981. Effects of turbidity on feeding rates and selectivity of bluegills. Transactions of the American Fisheries Society 110:446-450.

Harris, L. 1997. Disease in Wild Stocks is Focus of Conference. In: Northwest Indian Fisheries Commission News. 17(2):10.

Hart, J.L. 1980. Bulletin 180: Pacific Fishes of Canada. Fisheries Research Board of Canada, 3rd Ed. 740pp.

Healey, M.C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). Pages 311-394 *in*: C. Groot and L. Margolis, eds. Pacific Salmon Life Histories. UBC Press, University of British Columbia, Vancouver, BC, Canada.

Heller, P.L. 1978. Pleistocene geology and related landslides in the lower Skagit and Baker Valleys, North Cascades, Washington. Western Washington University M.S. Thesis. Bellingham, WA, 154 pp.

Hicks, M. 2000. Evaluating criteria for the protection of aquatic life in Washington's surface water quality standards. Publication No. 00-10-071. Washington Dept. of Ecology, Olympia, WA.

Hillman, T. W. 1989. Spatial interaction of juvenile chinook salmon and the redside shiner. Pages 209-247 in: Summer and winter ecology of juvenile chinook salmon and steelhead trout in the Wenatchee River, Washington, Don Chapman Consultants, Inc. final report to the Chelan County Public Utility District, Wash.

Hyatt, T.L. and R.J. Naiman. 2001. The residence time of large woody debris in the Queets River, Washington, USA. Ecological Applications, 11(1), pp. 191-202.

James, B.B., T.N. Pearsons, and G.A. McMichael. 1999. Washington Department of Fish and Wildlife, Spring Chinook Salmon Interactions, Indices, and Residual/Precocial Monitoring in the Upper Yakima Basin, Annual Report 1998 to the Bonneville Power Administration. Contract No. 1995BI64878, Project No. 9506409. BPA Report DOE/BP-64878-4.

Kauffman, J.B., R.L. Beschta, N. Otting, and D. Lytjen. 1997. An Ecological Perspective of Riparian and Stream Restoration in the Western United States. Fisheries 22(5):12-24.

Keppeler, E.T. and R.R. Ziemer. 1990. Logging effects on streamflow: water yield and summer low flows at Caspar Creek in northwestern California. Water Resources Research Vol 26(7): 1669-1679.

Koenings, J. 2006. Goal I: Develop Healthy and Diverse Fish and Wildlife Populations and Habitat for Nooksack River Chinook. Director's Report to the Fish and Wildlife Commission. WDFW, March 10, 2006. http://wdfw.wa.gov/depinfo/director/mar1006rpt.htm

Lewis, J. and R.M. Rice 1989. Critical sites erosion study, Vol II, Site conditions related to erosion on private timber lands in northern California. Report of a cooperative investigation by the Department of Forestry and Fire Protection and the Pacific Southwest Forest and Range Experiment Station. 95 pp.

Lewis, J. and R.M. Rice. 1990. Estimating erosion risk on forest lands using improved methods of discriminant analysis. Water Resources Research 26(8): 1721-1733.

Lloyd, D.S. 1987. Turbidity as a water quality standard for salmonid habitats in Alaska. N. American J. Fisheries Management 7:18-33.

LNR. 2005. Nooksack River Estuary Habitat Assessment. Lummi Nation Natural Resources Department report to the Salmon Recovery Funding Board, Washington State. IAC #01-1340N.

LNR. 2002. South Fork Nooksack River Historic-Scale Logjams Project Status. Lummi Natural Resources report to the Bureau of Indian Affairs and Centennial Clean Water.

LNR. 2001. South Fork Nooksack River Historic-Scale Log Jam Monitoring and Evaluation Plan with Baseline Conditions Report. Lummi Nation Natural Resources, Bellingham, WA.

Logan, P, and M.P. Brooker. 1983. The macroinvertebrate faunas of riffles and pools. Water Research. 17(3): 263-270.

Marine, K.R., and J. J. Cech. 2004. The effects of high water temperature on growth, smoltification, and predator avoidance in juvenile Sacramento River chinook salmon. North American Journal of Fisheries Management. 24:198–210.

Maudlin, M., T. Coe, N. Currence, and J. Hansen. 2002. South Fork Nooksack River Acme-Saxon reach restoration planning: analysis of existing information and preliminary recommendations. Lummi Natural Resources. Bellingham, WA. 127pp.

McCain, M., D. Fuller, L. Decker and K. Overton. 1990. Stream habitat classification and inventory procedures for northern California. FHC Currents. No.1. U.S. Department of Agriculture. Forest Service, Pacific Southwest Region.

McCullough, D.A. 1999. A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to chinook salmon. Preparted for the U.S. Environmental Agency, Region 10, Seattle WA. EPA 910-R-99-010.

McElhany, P., M.H. Ruckelshaus, M.J. Ford, T.C. Wainwright, and E.P. Bjorkstedt. 2000. Viable salmonid populations and the recovery of evolutionary significant units. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-NWFSC-42. 156pp.

Mobrand Biometrics. 2003. Ecosystem Diagnosis and Treatment (EDT) for the Nooksack River. http://www.mobrand.com/MBI/edt.html

Montgomery, D.R. and W.E. Dietrich. 1994. A physically based model for the topographic control of shallow land sliding. Water Resources Research 30(4): 1153-1171.

Newcombe, C. P., and J. O. T. Jensen. 1996. Channel suspended sediment and fisheries: a synthesis for quantitative assessment of risk and impact. North American Journal of Fisheries Management 16: 693-727.

Newcombe, C.P. and D.D. MacDonald. 1991. Effects of suspended sediments on aquatic ecosystems. N. American J. Fish. Management 11:72-82.

NMFS 2006. ESA Salmon Listings, updated June 8, 2006. Information accessed from: http://www.nwr.noaa.gov/ESA-Salmon-Listings/Salmon-Populations/Chum/

NMFS 1996. Making Endangered Species Act determinations of effect for individual or group actions at the watershed scale. National Marine Services Division. Environmental and Technical Services Division. Habitat Conservation Branch. "Matrix of Pathways and Indicators." http://www.nmfs.noaa.gov.

NOAA 2003. Proposed changes to the Washington State Surface Water Quality Standards. Correspondence between S. Landino of NOAA and T. Fitzsimmons of WDOE, March 5, 2003.

Noggle, C.C. 1978. Behavioral, physiological, and lethal effects of suspended sediment on juvenile salmonids. Thesis for a Master of Science, Univ. of Washington, Seattle, WA, USA.

Osbaldiston, R. 1995. Inventory of Mass Wasting Units and River Tributaries Along the South Fork of the Nooksack River. Report to Crown Pacific, LLC. Portland, OR.

Pleus, A.E., D. Schuett-Hames, and L. Bullchild. 1999. TFW Monitoring Program method manual for the habitat unit survey. Prepared for the Washington State Dept. of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-99-003. DNR #105. June.

Poole, G.C., and C.H. Berman. 2001. An ecological perspective on instream temperature: natural heat dynamics and mechanisms of human-caused thermal degradation. Envr. Management 27(6):787-802.

PSTRT, 2006. Ecological Integrity and Population Status of Chinook Salmon in Puget Sound Watersheds. A Puget Sound Technical Recovery Team working paper. May 25, 2006.

PSTRT, 2002. Planning ranges and preliminary guidelines for the delisting and recovery of the Puget Sound Chinook Salmon Evolutionary Significant Unit. Puget Sound Technical Team Report available from the Northwest Fisheries Science Center, Seattle, WA.

Rice, R.M., J.S. Rothacher, and W.F. Megahan. 1972. Erosional Consequences of Timber Harvesting: An Appraisal. National Symposium on Watershed in Transition.

Rice, R.M. and J. Lewis. 1991. Estimating erosion risks associated with logging and forest roads in northwestern California. Water Resource Bulletin 27(5):809-818.

Rice, R.M., 1995a. Forest Hydrologist. Personal Communication with Tom Grindeland. March 7, 1995.

Rice, R.M., 1995b. Forest Hydrologist. Personal Communication with Jeremy Freimund. July 18, 1995.

Roper, B.B., and D.L. Scarnecchia. 1994. Summer distribution of and habitat use by chinook salmon and steelhead within a major basin of the South Umpqua River, Oregon. Transactions of the American Fisheries Society. 123:298-308.

Rosenfeld, J.S., M.S. Porter, and E.A. Parkinson. 1999. Habitat Associations of Juvenile Cutthroat Trout and Coho Salmon: Implications for Forestry Impacts. From: Proceedings of the Biology and Management of Species and Habitats at Risk, Kamloops, B.C. February 1999. Pp. 15-19.

Runyon, J., C. Andrus, K. Bahus, K. Craig, R. Schwindt, and J. Souder**.** 2003. Elliott State Forest Watershed Analysis. Report prepared for the Oregon Department of Forestry, Salem, OR, by Biosystems, Inc., Corvallis OR.

Ryce, E.K.N., and A.V. Zale. 2004. Bacterial Coldwater Disease in Westslope Cutthroat Trout: Hatchery Epidemiology and Control. Final Report to: Wild Fish Habitat Initiative, Montana Water Center, Montana State University and the Partners for Fish and Wildlife Program, U.S.F.W.S. June 2004.

Schabetsberger, R., C.A. Morgan, R.D. Brodeur, C.L. Potts, W.T. Peterson, and R.L. Emmett. 2003. Prey selectivity and diel feeding chronology of juvenile chinook (*O. tshawytscha*) and coho (*O. kisutch*) salmon in the Columbia River. Fisheries Oceanography 12:523-540.

Schuett-Hames, D., A.E. Pleus, E. Rashin, and J. Matthews. 1999. TFW Monitoring Program: Method Manual for the Stream Temperature Survey. Prepared for the Washington State Dept. of Natural Resources under the Timber, Fish, and Wildlife Agreement. TFW-AM9-99-005. DNR # 107.

Selong, J.H., T.E. McMahon, A.V. Zale, and F.T. Barrows. 2001. Effect of temperature on growth and survival of bull trout, with application of an improved method for determining thermal tolerance of fishes. Transactions of the American Fisheries Society. 130:1026-1037.

Sigler, J.W., T.C. Bjornn, and F.H. Everest. 1984. Effects of chronic turbidity on density and growth of steelhead and coho salmon. Transactions of Amer. Fish. Society 113:142-150.

Soicher, A., T. Coe, and N. Currence. 2006. South Fork Nooksack River Acme-Confluence reach restoration planning: analysis of existing information and preliminary restoration strategies. Report to Salmon Recovery Funding Board, Olympia, WA. IAC #02-1500N.

Spatial Climate Analysis Service, Oregon St. University, http://www.ocs.oregonstate.edu/prism/

Spence, B.C., G.A. Lomnicky, R.M. Hughes and R. P. Novitzki. 1996. An Ecosystem Approach to Salmonid Conservation. Funded jointly by the U.S. EPA, U.S. Fish and Wildlife Service and National Marine Fisheries Service. Management Technology. Corvallis, OR. TR-4501-96-6057.

Tebo, L.B. 1955. Effects of siltation, resulting from improper logging, on the bottom fauna of a small trout stream in the southern Appalachians. The Progressive Fish Culturist: 64-70.

USEPA. 2003. Final Water Temperature Guidance, United States Environmental Protection Agency, Region 10, Seattle, WA. April, 2003.

USEPA. 1996. Ecological Restoration: A Tool to Manage Stream Quality. Environmental Protection Agency, Office of Water.

USFWS. 2004. Draft Recovery Plan for the Coastal-Puget Sound Distinct Population Segment of Bull Trout (*Salvelinus confluentus*). Volume I of II: Puget Sound Management Unit. Portland, OR. 389 + xvii pp.

USFWS. 1998. Bull Trout Interim Conservation Guidance. 47pp.

USGS. 2007. National Water Information System: Web interface with historic data for the Wickersham gage 12209000 in the South Fork Nooksack River, Washington. http://nwis.waterdata.usgs.gov/wa/nwis/

Washington State Fish and Wildlife Commission. 1997. Policy of the Washington Department of Fish and Wildlife and Western Washington Treaty Tribes on Wild Salmonids. Washington Fish and Game Commission, Olympia, WA. 68 p.

Watershed Sciences. 2002. Aerial Remote Sensing Surveys in the Nooksack River Basin: Thermal Imagery and Color Videography (FLIR). Preliminary Report to Nooksack Indian Tribe. March 28, 2002. Corvallis, OR.

WDFW, and Western Washington Treaty Tribes. 1994. 1993 Washington State Salmon and Steelhead Stock Inventory (SASSI). Appendix One: Puget Sound Stocks; North Puget Sound Volume. Olympia, WA.

Weitkamp, L. A., T. C. Wainwright, G. J. Bryant, G. B. Milner, D. J. Teel, R. G. Kope, and R. S. Waples. 1995. Status review of coho salmon from Washington, Oregon, and California. U.S. Department of Commerce. NMFS-NWFSC-24, 258 pp.

Whatcom County. 2006. Whatcom County Water Resources Department website accessed March 20, 2006. www.whatcomsalmon.wsu.edu.

Williams, R.W., R. M. Laramie, and J.J. Ames. 1975. A Catalog of Washington Streams and Salmon Utilization. Washington State Department of Fisheries, Olympia, WA.

Williams, I.V. 1973. Investigation of the pre-spawning mortality of sockeye in Horsefly River and McKinley Creek in 1969. Progress Report to: International Pacific Salmon Fisheries Commission (IPSFC). 27(2): 42pp.

WOW. 2004. Water on the Web. National Science Foundation: Turbidity and its effects on aquatic organisms. http://www.waterontheweb.org/under/waterquality/turbidity.html

WRIA-1 SRFB (Salmon Recovery Funding Board). 2005. Water Resource Inventory Area (WRIA)-1 Salmonid Recovery Plan (*draft)*. Submitted to Shared Strategy for Puget Sound October 2005.

Wright, K.A., K.H. Sendek, R.M. Rice, and R.B. Thomas. 1990. Logging effects on streamflow: storm runoff at Caspar Creek in northwestern California. Water Resources Research 26(7):1657-1667.

Ziemer, R.R. 1987. Water yields from forests: an agnostic view. In: Callaham, R,Z. and J.J. DeVries, Tech. Coord., Proceedings of the California Watershed Management Conference, November 18-20, 1986, West Sacramento, California. Wildland Resources Center, Univ. Calif., Berkeley, CA. Report No. 11: 74-78.

Ziemer, R.R. 1981. Storm flow response to road building and partial cutting in small streams of northern California. Water Resources Research 17(4):907-917.

## Personal Communications

Currence, Ned. Habitat Biologist for Nooksack Natural Resources, Deming, WA. July, 2007; November, 2006.

Dunphy, Gregg. Timber, Fish, and Wildlife Manager for Lummi Nation Natural Resources, Bellingham, WA. June, 2006.

Finkbonner, Bill. Skookum Creek Hatchery Manager for Lummi Nation Natural Resources, Bellingham, WA. December, 2006.

Huddle, Doug. Retired Fish Biologist for Washington Department of Fish and Wildlife, LaConner, WA. November, 2006.

Pfundt, Adam. Fish Biologist for Lummi Nation Natural Resources, Bellingham, WA. June 2006.

# Appendix A: Glossary and Abbreviations

**Alevin**: Salmonid life stage depicting newly hatched fish that utilize a yolk sac on their ventral surface for nourishment.

**Alluvial**: Pertaining to or composed of substrates deposited by a stream or flowing water. Alluvial deposits usually occur after a flood event.

**Anadromous**: A fish born in fresh water, migrates to the ocean to grow and live as an adult, and returns to its natal fresh water stream to spawn.

**Bedload**: Sediment particles that are moved on or immediately above the streambed, such as the larger heavier particles (gravel, boulders) rolled along the benthic surface; the part of the load that is not continuously in suspension.

**Braided Channel**: A section of stream that forms an interlacing network of branching and recombining channels separated by islands and channel bars.

**Canopy Cover**: Vegetation projecting over a stream, including crown cover and overhang cover.

**CFS**: Cubic Feet per Second. Standard measure of stream discharge in this report.

**Channel Stability**: The ability of a stream, over time and in the present climate, to transport the sediment and flows produced by its watershed in such a manner that the stream maintains its dimension, pattern, and profile without either aggrading or degrading.

**Connectivity**: Suitable stream conditions that allow fish and other aquatic organisms to move freely up and downstream; habitat linkages that connect to other habitat areas.

**Core Habitat**: Habitat that encompasses spawning and rearing (foraging, migrating, and overwintering) habitat for salmonids. Defined by USFWS as habitat that contains, or if restored would contain, all of the essential physical, chemical, and biological elements to provide for the security and allow for the full expression of life history stages for salmonids.

**CMZ**: Channel migration zone.

**Discharge**: With reference to stream flow, the quantity of water that passes a given point in a measured unit of time. This report uses CFS (cubic feet per second).

**Distributary Channel**: A natural stream channel that branches from a main channel that it may or may not rejoin.

**Escapement**: The number of adult fish from a specific population that survive spawning migrations and enter spawning grounds.

**ESU**: Evolutionarily Significant Unit. A population or group of populations of salmon that is reproductively isolated from other populations and contributes substantially to the evolutionary legacy of the biological species (NMFS).

**Fines**: Sediment with particle sizes of 2.0 mm or less, including fine sand, silt, and clay.

**Floodplain**: Habitat adjacent to stream channels, typified by flat ground that submerges during flood events. Areas known to absorb a portion of sediment and nutrients delivered by floodwater.

**Fry**:  Salmonid life stage depicting young, recently hatched fish that have absorbed their yolk sacs and are able to feed on organic material in the stream.

**Juvenile**:  Salmonid life stage that follows the fry stage.  Salmonid juveniles vary by species whether they outmigrate to sea during the first year of life (ocean-type), or whether they rear in their natal stream for 1or more years before they outmigrate (stream-type).

**LNR**:  Lummi Nation Natural Resources Department, Lummi Nation, Whatcom County.

**LWD**:  Large Woody Debris.  Large pieces of wood that includes all parts of a tree such the root ball and limbs; woody material with a minimum diameter of 10 cm (4 in.), and a minimum length of 1 m (3.3 ft.).

**Mass Wasting**:  Loss of large amounts of material in a short period of time; downward movement of land mass material or landslide.

**NMFS**:  National Marine Fisheries Service.

**NNR**:  Nooksack Natural Resources Department, Nooksack Tribe, Whatcom County.

**NOAA**:  National Oceanic and Atmospheric Administration.

**NTU**:  Nephelometric Turbidity Units; standard measurement of water clarity.

**PFC:**  Properly Functioning Condition.  Established by the NMFS in 1996, these standards are often referred to when characterizing river habitat that supports species in peril.

**PSTRT:**  Puget Sound Technical Recovery Team.

**Redd**:  Gravel nest built into the streambed by a female salmonid, for the fertilization and incubation of her eggs.  One redd may contain several nests built by the same female.

**Riparian**:  Area with distinctive soils and vegetation between a stream or other body of water and the adjacent upland.  It includes wetlands and those portions of floodplains and valley bottoms that support riparian vegetation.

**Riprap**:  A common type of streambank armoring or protection from erosion, formed of large rocks.

**Salmonid**:  Fish of the family Salmonidae, including salmon, trout, grayling, chars, and whitefish.

**Scour**:  Concentrated erosive action by stream water, as on the outside curve of a bend; also a place in a streambed swept clear by swift flows.

**Smolt**:  A juvenile salmonid migrating to the ocean and undergoing physiological changes to adapt its body from a freshwater environment to a marine environment.

**Stock**:  Fish belonging to the same population, spawning in a particular stream in a particular season.

**USF:** Upper South Fork Nooksack River.

**USFS**:  United States Forest Service.

**USFWS**:  United States Fish and Wildlife Service.

**Watershed**:  The area of land from which rainfall or snow melt drains into a stream.  Ridges of higher ground generally form the boundaries between watersheds.

**WDFW**:  Washington State Department of Fish and Wildlife.

**WDNR**:  Washington State Department of Natural Resources.

**WRIA**:  Watershed Resource Inventory Area.  Washington State is comprised of eighteen WRIAs; the Nooksack WRIA is number one, and is referred to as WRIA-1.

# Appendix B: Historic Land Use Photos

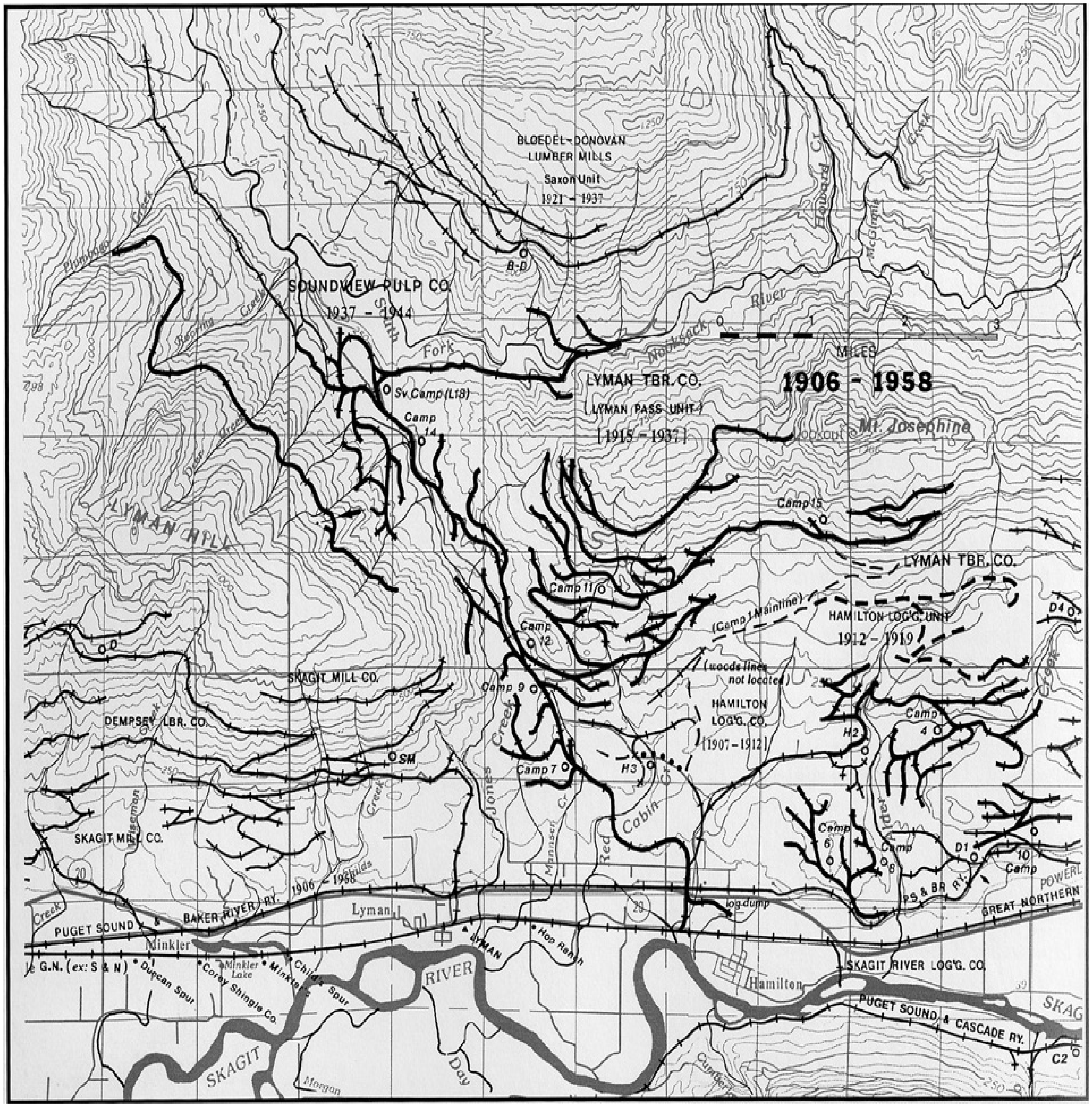


**Figure 101. Map of the Puget Sound and Baker River Railway, constructed in 1906.** ***Map by RD Jost, 1989.***

**Figure 102. Steam shovel digging railroad cut 51 feet deep.** ***D. Kinsey, courtesy Whatcom County Museum of History and Art.***

**Figure 103. The original Red Cabin Creek Bridge just before completion in 1908.** ***D. Kinsey, courtesy Whatcom County Museum of History and Art.***

**Figure 104. The second (replacement after the first bridge burned) Red Cabin Creek Bridge, 600-feet long and 132-feet high.** ***C. Kinsey, University of Washington.***

**Figure 105. The second Red Cabin Creek Bridge in progress. Stacked bents ready to be raised into position by the yarder.** ***C. Kinsey, University of Washington.***

**Figure 106. The Cavanaugh Creek trestle passing over two streams and dividing the ridge between them. *D. Kinsey, Whatcom Museum of History and Art.***

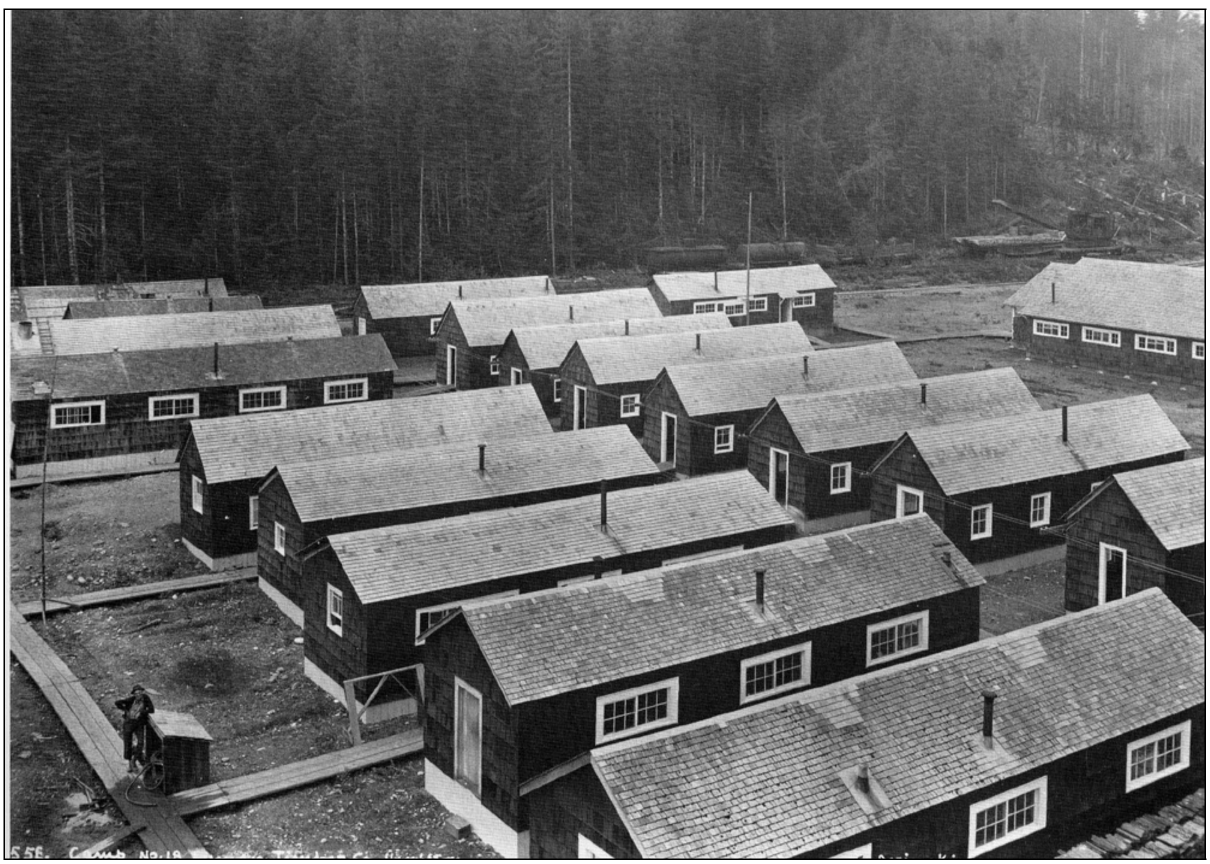

**Figure 107. Lyman Timber Company's Camp 18, the last one built for the company. Currently the site of the 160-Road spur from the mainline 100-Road. The 160-Road crosses the South Fork at Larson's Bridge, RM 20.6. *D. Kinsey, courtesy Whatcom Museum of History and Art.***


**Figure 108. A 115-inch diameter log awating shipment, dating about 1902.** ***Bill Mason*.**

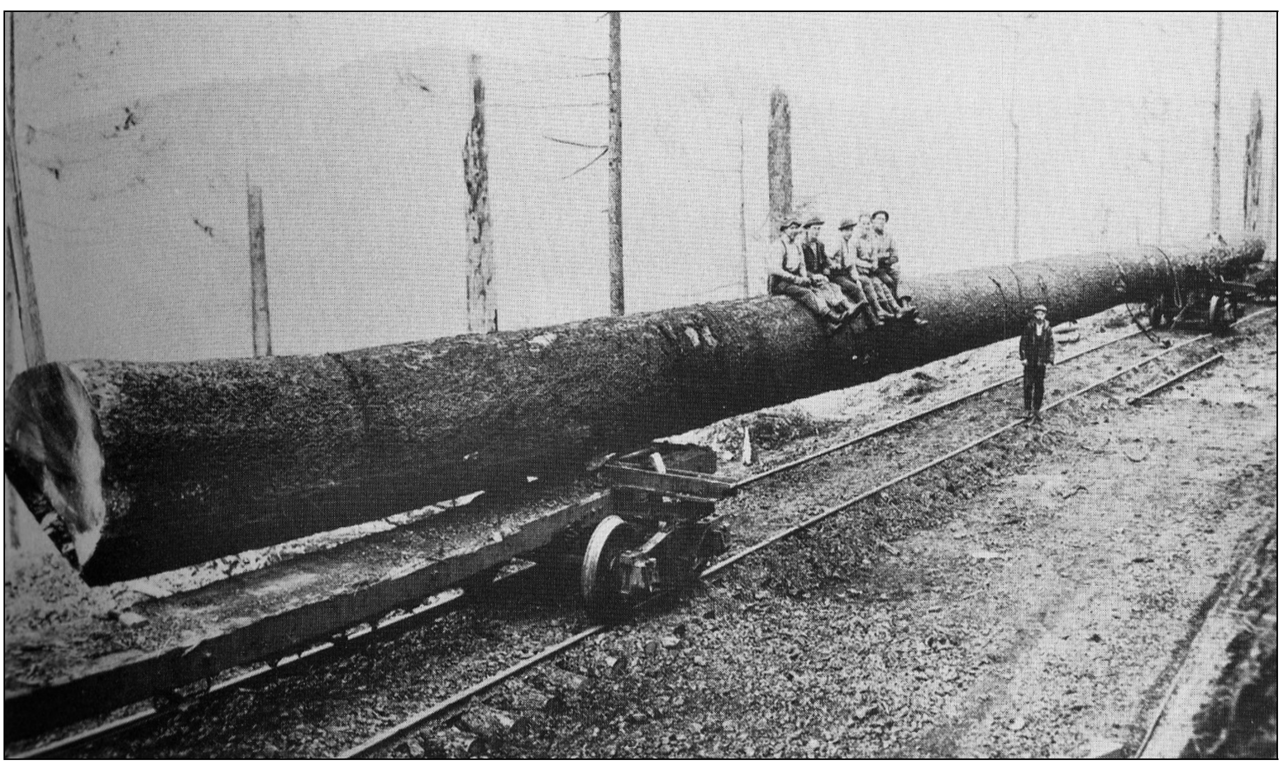

**Figure 109. One log carried between two rail cars, hauling out of Camp 11.** ***D. Kinsey, courtesy of Naomi Ecret*.**

**Figure 110. Almost a mile in length with grades to 45%, this railroad incline operated in the early 1920s. Three loaded log cars were dropped down the incline during each operation. In this view, the cars are just arriving (note cable beside track).** ***D. Kinsey, Al Hodgin*****.**

**Figure 111.  Load of logs in the South Fork Nooksack watershed, north of Hamilton.  *Dennis Thompson collection*.**

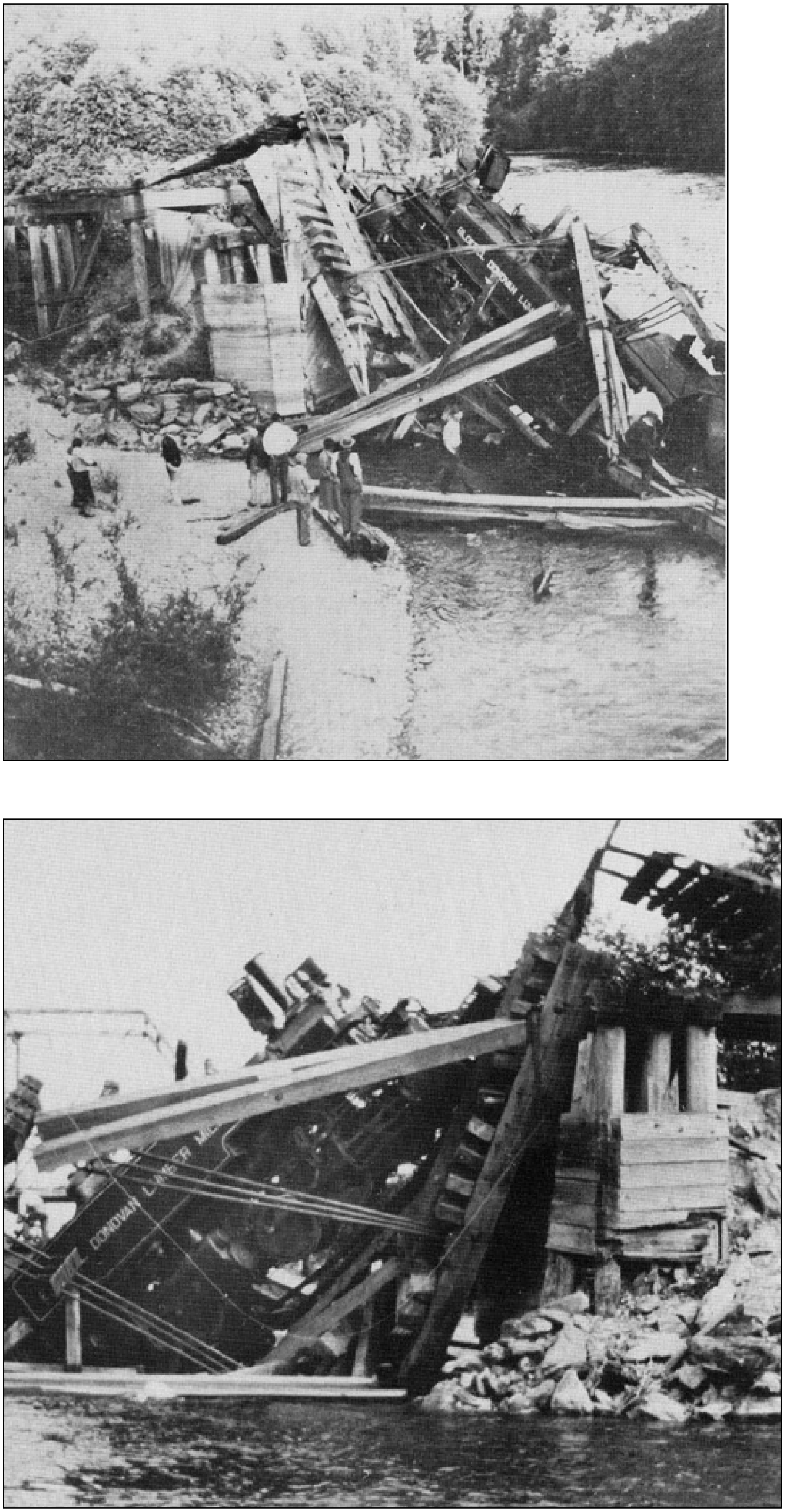

**Figure 112. The Saxon Bridge (RM 12.8) collapses into the South Fork Nooksack River in 1934.** ***George Nesset photos.***

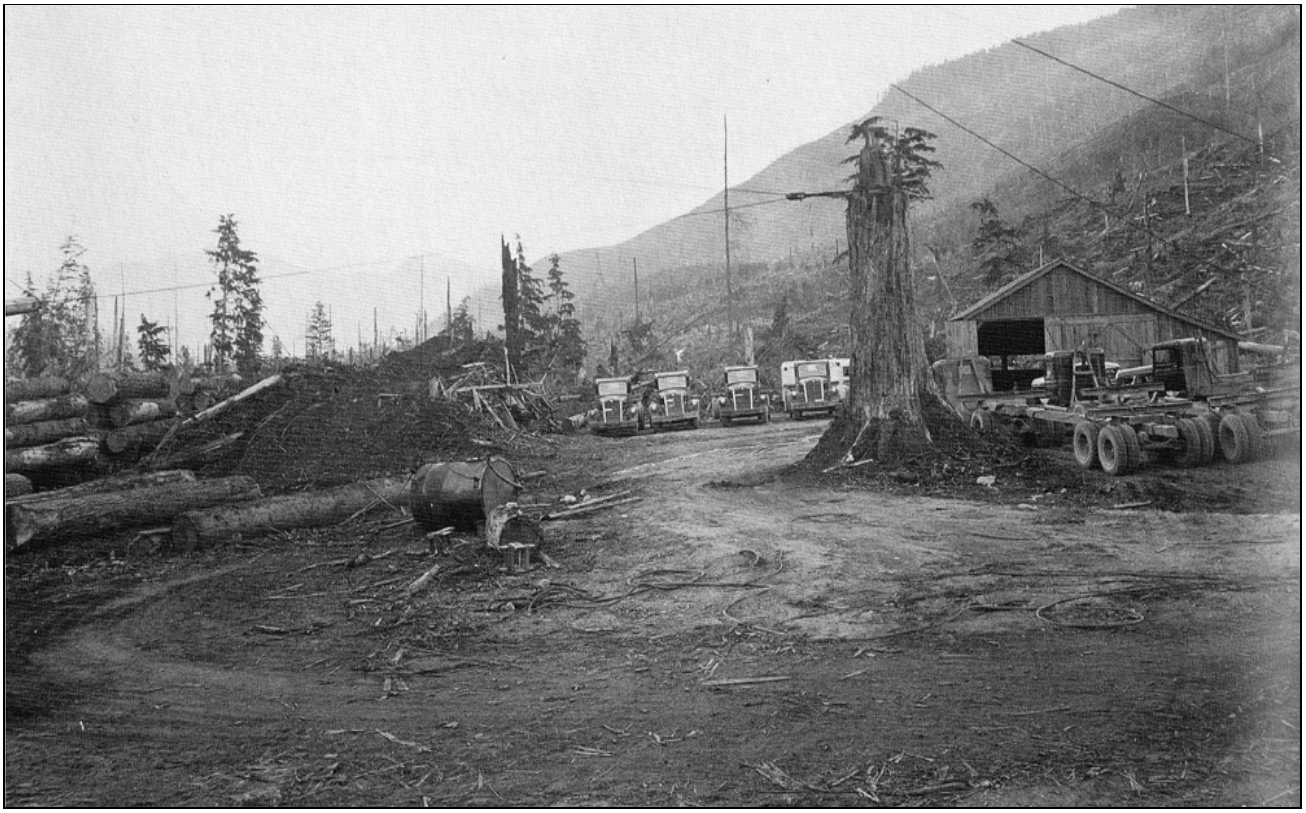

**Figure 113. Reloading trucks at Camp 18.** ***D. Kinsey, Whatcom Museum of History and Art.***



Photos are reproduced in the book, “Logging Roads in Skagit County: The First Comprehensive History of The Logging Roads in Skagit County, Washington, USA.”

Author: Dennis Blake Thompson

ISBN 0-915370-06-9