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A TWO-DECADE WATERSHED APPROACH TO STREAM RESTORATION LOG JAM DESIGN AND STREAM RECOVERY MONITORING: FINNEY CREEK, WASHINGTON[1]

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ABSTRACT: A federal, state, and private partnership leveraged resources and employed a long-term, systematic approach to improve aquatic habitat degraded by decades of intensive forest management in Finney Creek, a tributary to the Skagit River of Northwest Washington State. After more than a decade of work to reduce sediment sources and the risk of landslides within the watershed, log jam installation commenced in 1999 and progressed downstream through 2010. Log jam design was adapted as experience was gained. A total of 181 log jams, including 60 floating log ballasted jams, were constructed along 12 km of channel. The goal was to alter hydraulic processes that affect aquatic habitat formation along 39 km of stream with emphasis on 18.5 km of lower Finney Creek. Aquatic habitat surveys over a five-year period show an increase in the area of large pools and an accompanying increase in residual and maximum pool depth in the lower river reach. Channel cross sections show a generally deeper channel at the log jams, better channel definition in the gravel deposits at the head of the log jams, and improved riffle and thalweg development below the log jams. Stream temperature in the upper river decreased by 1.0°F in the first three years, and 1.1°F in the lowest treated reach over nine years. There is a trend of less stream heating over the restoration time period. Photo points show that riparian vegetation is recolonizing gravel bars.

(KEY TERMS: restoration; watershed; temperature; fluvial processes; log jams; engineered log jams; monitoring; ballasted wood structures; long-term monitoring; design criteria; adapted design; floating log ballasted jams.)

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INTRODUCTION

Finney Creek, a 140 km^2 tributary to the Skagit River, is located in the foothills of the North Cascades mountain range of western Washington State. Finney Creek was intensively managed for timber production from the 1950s to the early 2000s. By the late 1980s, it became evident that land use was disrupting watershed functions and causing decreased quality of aquatic habitat. In particular, elevated runoff and sediment delivery caused extensive channel widening of Finney Creek. The physical changes in Finney Creek led to warmer instream water temperature and loss of channel complexity for native salmonid fish species.

Timber harvest on federal lands in Finney Creek ceased in the early 1990s under the Mt. Baker-

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Snoqualmie National Forest Land and Resource Management Plan (Forest Plan) (USDA Forest Service, 1990) as amended (USDA Forest Service and USDI Bureau of Land Management, 1994). The Forest Plan highlighted hydrologic cumulative effects and degradation of native salmonid habitat. Forest Service staff at that time committed to implement a long-term, multi-phased watershed restoration program to restore not only instream habitat conditions but, more generally, overall hydrologic processes and functions in the entire watershed.

Initial restoration work focused on minimizing sediment delivery to streams by stabilizing eroding hillslopes and roads, with particular effort devoted to roads at stream crossings. One technique, road decommissioning, was used to permanently close roads and leave them in a self-maintaining condition that would not contribute sediment to streams (Harr and Nichols, 1993).

This article describes the channel restoration phase of the long-term restoration program. Starting in 1999 individuals from the Mount Baker-Snoqualmie National Forest, North Cascades National Park and the Skagit Fisheries Enhancement Group started a structural channel restoration program involving both federal and private ownership along 12.2 km of Finney Creek. The program consisted of augmenting existing wood accumulations or creating new log jams to improve aquatic habitat by reintroducing channel complexity. Log jams alter local hydraulics and sediment transport and storage processes that contribute to the creation and maintenance of high quality habitat features. Project monitoring was incorporated to determine if the addition of large wood structures in Finney Creek improves aquatic habitat by stabilizing gravel bars, and creating a narrower and deeper channel resulting in cooler stream temperatures.

The team applied a systematic program of constructing instream structures, monitoring change and effects, evaluating performance, and progressively modifying designs to improve subsequent performance in reducing channel width, lowering water temperature, and restoring fish habitat complexity. This article summarizes 12 years of the ongoing program to recover natural watershed processes and functions in the Finney Creek Watershed.

Description of the Project Area

Finney Creek is 48 km west of the Cascade Mountain crest, approximately 24 km east of the town of Sedro Woolley (Figure 1). Elevation ranges from 1,549 m at Finney Peak to 41 m above mean sea level at the confluence of Finney Creek and the Skagit River. A series of glacial advances and retreats and volcanic eruptions from Glacier Peak to the southeast left Finney and other nearby peaks isolated in a sea of mudflow and glacial outwash deposits. Pleistocene glaciers left a veneer of till over the upper slopes and thick accumulations of glacial

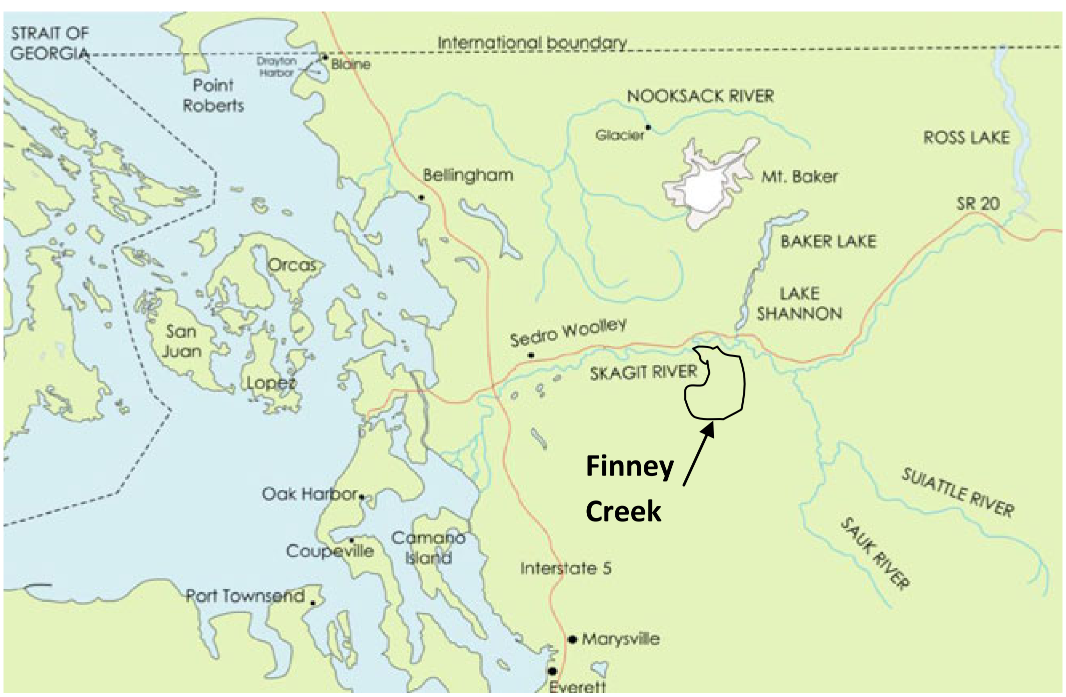

FIGURE 1. The Finney Creek Project Area in Northwest Washington State within the Skagit River Watershed.

outwash gravel, terrace deposits, and glacial-lacustrine sediments on the mid and lower slopes (Klungland and McArthur, 1989).

Annual precipitation varies from 127-178 cm in the lower watershed to 178-280 cm on the upper slopes. Seventy-five percent of the precipitation falls from September to May with snow accumulating above 760 m between November and April. At elevations of 760-1,070 m, snow accumulation is transitory. Rain-on-snow storms from October to February produce most of the annual peak flows in Finney Creek. Heavy rain and strong winds during these storms rapidly melt snow and often trigger debris and snow avalanches, debris torrents and slides. These storm events significantly influence the local landscape and stream processes.

Finney Creek is 38.6 km in length and flows along major fault contacts. A narrow gorge and cascade separate the watershed into upper and lower areas, and limit anadromous fish use to the lower 18.5 km of Finney Creek. Stream channels are deeply incised into steep slopes (>26°). Vegetative cover of the upper watershed is mostly young coniferous forest (western hemlock [*Tsuga heterophylla*], Pacific Silver Fir [*Abies amabilis*], western redcedar [*Thuja plicata*]) with a mosaic of various aged clearcuts. Narrow strips of deciduous forest and shrubs line the stream channels.

The less confined channel of lower Finney Creek (mouth to 18.5 km) follows an infilled fault trace (Klungland and McArthur, 1989) that controls the 800-m wide valley carved out of Darrington Phyllite Schist (Brown *et al.*, 1987). The channel meanders through glacial sediments (outwash gravel, terrace deposits, and glacial-lacustrine sediments). Channel gradient is 1-2% above a bedrock constriction at river mile (RM) 7 and 0.5% downstream of the constriction. The floodplain is currently dominated by deciduous forest species (red alder [*Alnus rubra*] and black cottonwood [*Populus tricocarpa*]) and interspersed conifer stands (Figure 2).

No long-term streamflow data are available; however, U.S. Geological Survey data from Finney Creek between 1943 and 1948 show a range of daily flows from 15.9 cubic feet per second (cfs) (0.45 m^3/s) to 2,931 cfs (83 m^3/s) (http://waterdata.usgs.gov/nwis/nwisman/?site_no=12194500&agancy_cd=USGS, *accessed* April 2008). Cummans *et al.* (1975) estimated a bankfull discharge at the mouth of Finney Creek of 5,085 cfs (144 m^3/s).

Significance of Finney Creek. The Skagit River historically supported the largest natural run of Chinook salmon in Puget Sound, and Finney Creek was once the most productive salmon stream in the lower Skagit River (WDFW and Western Washington Treaty Indian Tribes, 1994). The Skagit River contributes approximately 44% of the total anadromous fish production of the Puget Sound (Puget Sound Task Force-Pacific Northwest River Basins Commission, 1970).

FIGURE 2. The Broad Valley of Lower Finney Creek Looking Upstream.

Much of the lower Skagit River is diked and channelized, eliminating side channel and tributary habitat. Habitat of the tributaries, including Finney Creek, is considered of poor quality (WDFW and Western Washington Treaty Indian Tribes, 1994). Low gradient, gravel dominated Finney Creek has the potential to exhibit excellent habitat for eight species of Pacific salmonids: Chinook, chum, Coho, and pink salmon; steelhead, cutthroat, rainbow, and bull trout. The restoration of 18.5 km of lower Finney Creek represents a tremendous opportunity to provide a meaningful amount of quality habitat in the lower Skagit River.

Land Use History. Land ownership in Finney Creek is 59% federal, all in the upper watershed, and 41% state and private; with forest management being the predominant land use.

In the 1920s large cedar trees were harvested, cut into 1 m lengths, and floated down the lower 10 km of Finney Creek as shake (shingle) bolts. Surge flows from breaching a 1.8 m high dam on Finney Creek not only floated the cedar bolts but also scoured stream gravels harboring incubating eggs and sac fry. Small juvenile fish were swept downstream where they were subject to predation in the Skagit River. The channel was described as 20 feet (6 m) wide and one foot (0.3 m) deep with a water temperature of 52°F on July 20, 1921.

By the time large scale timber harvest officially ceased in 1990 over concerns for watershed cumulative effects and declining old growth habitat more than 275 km of National Forest System logging roads had been constructed in Finney Creek resulting in a road density of 1.56 km/km^2. Private land road densities exceeded 2.8 km/km^2 (Mt. Baker-Snoqualmie National Forest, 1999).

Problem Statement: Land Use and Geology and Their Effect on Stream Habitat

Timber harvesting and road construction have been shown to affect a number of watershed and stream processes that impact fish populations (Nehlsen *et al.*, 1991; Bisson *et al.*, 1992). Increases in sediment input have numerous effects on aquatic organisms (Waters, 1995), including reduced feeding success (Noggle, 1978), abrasion of gill tissues, reduced reproductive success (Swanson *et al.*, 1987), and direct mortality of eggs and alevins in stream gravels (Meehan, 1991). A study in Finney Creek (Coffin, 1991) showed water input to soils during rain-on-snow events was 21-96% greater in clearcuts over forested areas. Roads intercepted groundwater and precipitation, and more efficiently routed surface runoff to streams. These increases in delivery efficiency may alter peak storm runoff (Jones and Grant, 1996).

The local geology, land use, and rain-on-snow or major rain storms combine to destabilize several of the soil types in the watershed (Snyder and Wade, 1970). Increased water delivery to the soil and peak flow magnitudes are thought to be associated with a greater incidence of landslides in the watershed during the 1980s (Parks, 1992; Paulson, 1996). Almost two-thirds of inventoried landslides occurred in riparian areas and were associated with management activities (harvest units and roads). Sediment and debris from inner gorge landslides and road erosion blocked stream channels and caused dam-break floods (Mt. Baker-Snoqualmie National Forest, 1990). Deposited sediment filled pools (Nelson, 1998) and formed large gravel bars. Higher streamflows eroded the streambanks and widened the channel. The National Research Council (NRC) (1996) asserts that salmonid populations may be unable to rebound in degraded streams subject to elevated sediment input and removal of riparian vegetation superimposed on less frequent natural disturbances.

Bedload sediment is sorted, trapped, and stored around large wood elements in streams (NRC, 1996) and alters stream morphology, creating essential aquatic habitat such as deep pools and spawning gravels, multiple channels, sloughs, backwaters, and even lakes (Sedell and Froggatt, 1984; Triska, 1984). Because logging in Finney Creek included harvest of trees within the riparian zone and removal of logs that were in or near the channels, the amount of large wood in the stream channels rapidly decreased and remains low (Stan Zyskowski, USFS, 1994, unpublished data).

Altering the shade characteristics along a channel can adversely affect stream temperature (Brown, 1980) and elevated temperatures reduce fish survival (Beschta *et al.*, 1987; Berman and Quinn, 1990). Bank erosion and the removal of streamside vegetation dramatically reduced stream shade in Finney Creek, resulting in the violation of state stream temperature criteria, and causing Finney Creek to be listed as impaired in 1998. Kurt Buchanan (Washington Department of Fish and Wildlife, 1991, unpublished data) reported that Finney Creek, renowned for its trout fishing and robust spawning populations of thousands of Chinook, coho, and chum salmon, summer and winter steelhead, and cutthroat trout in the 1960s, deteriorated to virtually no salmon use with only one tributary supporting successful salmon and trout spawning.

Watershed analysis (Mt. Baker-Snoqualmie National Forest, 1999) and limiting factors analysis (Smith, 2003) concluded that salmon health in Finney Creek suffers from high water temperatures as well as extreme fluctuations in flow. Wet season flow fluctuations produce constant bed-load movement and result in extreme channel widths, loss of streamside riparian stands, and basic channel instability (Stan Zyskowski, USFS, 1994, unpublished data). Pool habitat lacks overhead cover and scour depth that would intercept cool groundwater.

The Response

Finney Creek watershed restoration on National Forest System lands began after the 1982/1983 winter storms generated a number of major landslides. The purpose of the first phase of restoration was to reduce sediment sources and the risk of additional landslides. Restoration activities focused on stabilizing road fills, hardening stream crossings, and improving road drainage. Funding was limited so the Forest Service sought partnerships to leverage resources. By 1995, the Forest Service treated 18.2 km of road for drainage deficiencies and decommissioned another 35 km (Beechie *et al.*, 1997). Road decommissioning removed drainage structures and unstable fill slopes to restore much of the hillslope hydrology (Harr and Nichols, 1993). In 1995, additional funding resulted from appropriations to implement the Forest Plan. Over two decades, more than 130 km of road were treated using funds secured by partners from various state and federal sources (San Dimas Technology and Development Center, 2009a, b). A study between 1995 and 1996 of stream habitat conditions in Finney Creek (Nelson, 1998) suggested that this work was contributing to channel recovery.

Washington State Forest Practices Rules regulate riparian protections, road management, and forest practices that affect mass wasting on state and private lands. Road treatments on private lands in Finney Creek began in 1994 and continue.

METHODS: INSTREAM RESTORATION APPROACH

The Finney Creek restoration project takes a long-term, systematic approach. Stream restoration projects typically treat one location or meander, or maybe a hundred to several hundred meters of channel. This project targets improvement of aquatic habitat along 18.5 km of lower Finney Creek by treating over 8 km in the lower watershed and 3.2 km in the upper watershed (Figure 3). A total of 1,881 logs have been imported and placed in 181 log jams covering 12.2 km of stream. Construction started in the upper watershed between 1999 and 2000, and progressed to the lower watershed for five construction seasons from 2003 through 2010.

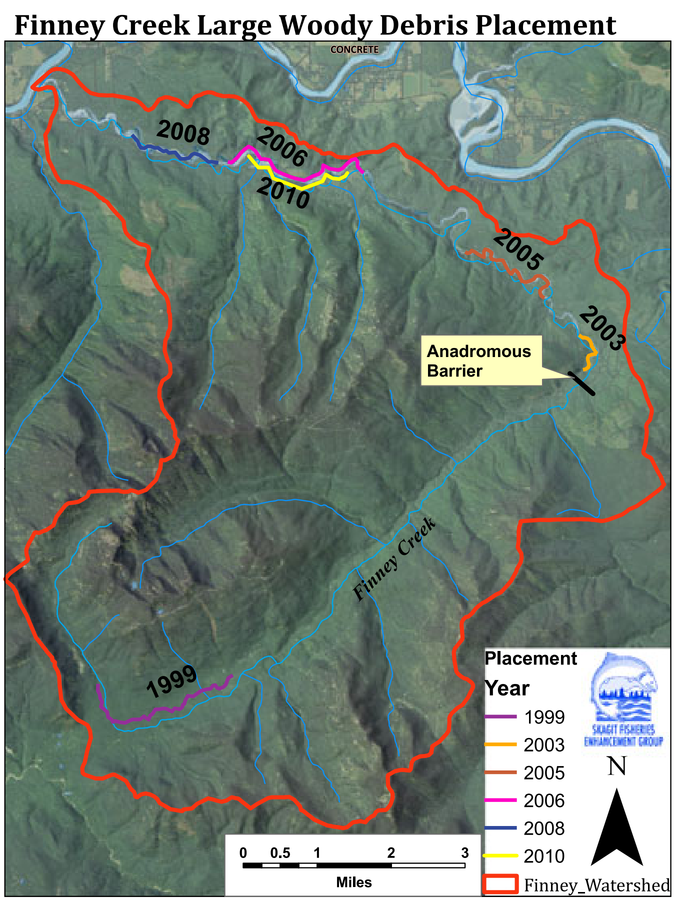

FIGURE 3. Finney Creek Project Reaches and Construction Years. Upper Finney Creek refers to the stream above the anadromous fish barrier at RM 11.5 and lower Finney Creek is downstream of the barrier.

Goal and Objectives

The goal of the instream work is to improve aquatic habitat using large woody material. The structures are not specifically "fish habitat" structures, but rather stream channel elements that influence stream bed scour and deposition by altering local hydraulics.

The objectives of the constructed log jams are to carry out the following:

1. Trap other wood moving down the channel, thus forming larger and more persistent wood jams that were characteristic of this channel type (Collins *et al.*, 1993).
2. Modify channel form and cross section and contribute to stream habitat complexity by doing the following:
   (a) reducing width-to-depth ratios by trapping sediment at the channel margins and forcing streamflow into a more concentrated thread to scour deeper pools and create a more defined thalweg (the stream profile line connecting the deepest points of the channel);
   (b) creating channel roughness elements to absorb stream energy, deflect flows away from vulnerable streambanks, and split flows to maintain side channels; and
   (c) creating more stable riffles for improved salmonid spawning gravels.
3. Provide more stable sites (gravel bars and streambanks) for the regeneration of riparian vegetation.

Site Selection and Construction

Upper Watershed. The 1999 and 2000 construction years treated 3.2 km (river kilometers 30.6-33.8) of unconfined channel in the upper watershed with a gradient less than 2% and elevated stream temperature. The construction of 74 log jams took advantage of existing sediment deposition areas, and in some cases, augmented naturally occurring wood accumulations that were too small and mobile. The existing jams consisted mostly of three to several 46 cm and smaller diameter red alder trees. These loose assemblages of trees broke apart under annual flow conditions.

The engineered log jams consisted of 15-20 logs placed on channel margins and the outside of meander bends to address sediment mobility and encourage vegetation development on gravel bars. A helicopter (Vertol 107) with 10,000 lb maximum lift capacity ferried logs from a nearby stockpile and staged them at pre-identified jam sites. Average ferry time was

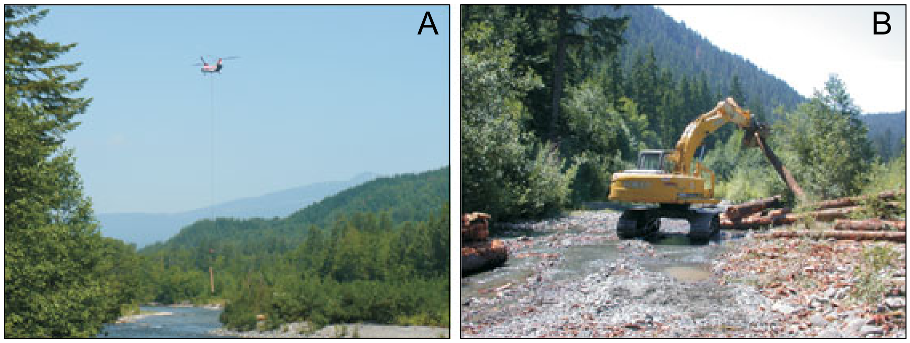

FIGURE 4. Helicopter Ferrying Logs to Jam Sites (A) and Excavator Construction of a Log Jam (B).

less than four minutes per turn, averaging 2,948 kg per turn. An excavator (Kolbelco 210) then placed the logs in the desired interlocking configuration (Figure 4); completing three to four jams per hour. After the excavator organized the logs into the jams, a hand crew drilled the logs and cabled them together.

Lower Watershed. A full channel evaluation identified natural hydraulic controls, either as bedrock or channel roughness elements, and where stream temperatures were elevated. Stream reaches where the evaluation showed a lack of channel roughness elements were observed for a number of years to determine where sediment and wood tended to accumulate. These sites were then augmented with engineered jams. The progression of log jam construction is shown in Table 1.

Vertical instability caused by bed scour is the leading cause of failure of stream habitat structures (Frissell and Nawa, 1992) and flood control channel projects (McCarley *et al.*, 1990). Channel instability, both vertical and horizontal scour, can undermine the integrity of both natural and engineered wood jams. Many engineered log jam designs prescribe fixed structures that, to function during flood events, require burial or anchors to fix the location and prevent downstream movement (Natural Resources Conservation Service, 2007; Herrera Environmental, 2008). Structures designed with fixed positions in the water column cause scour but have limited wood collection capability when submerged at high flows.

TABLE 1. The Number and Type of Log Jams Constructed in Upper and Lower Finney Creek, 1999-2010.

	Numbers of Log Jams						
	1999-2000	**2003**	**2005**	**2006**	**2008**	**2010**	
Reach	**½ in. (1.27 cm) Cable**	**5/8 in. (1.59 cm) Cable**					
Upper	74						
Lower		21	12	14			
Ballasted				3	27	30	
Total	74	21	12	17	27	30	181

A considerably different log jam construction technique was needed in lower Finney Creek to accommodate greater stream power and to address concerns that the jams would move and damage infrastructure. The wider stream channel and floodplain, lacking a well developed riparian forest, meant there were few obstructions to impede downstream log movement. Few natural structural elements existed on which large wood could lodge to form persistent jams. Previous work with large wood elements in local rivers including the manipulation of existing log jams and flying in logs (Doyle *et al.*, 2000; Nichols and Sprague, 2007) underscored the susceptibility of log jams to moving and dismantling during floods.

In addition to the 15-20 cabled logs technique of the upper reach, 60 of the 107 constructed jams in lower Finney Creek used a "floating log, ballasted jam" design. This unique type of engineered jam described as long-line cabled log jams in Nichols and Sprague (2003) (Figure 5) allowed more versatility in jam placement.

The floating log ballasted jam design, refined over the last 25 years, grew from a need for log jams that do not require extremely large logs, could be applied economically in remote locations, and mimic natural wood jams as much as possible. In addition to channel margins and meander bends, these jams are also constructed in higher energy locations, such as large lateral gravel bars and mid-channel bar apexes, with the intent of splitting the flow to stabilize the bar and accelerate desirable side channel development.

Log jams, both naturally occurring and engineered, contain one or more "key pieces"; large trees generally with the root wad attached and facing upstream, with enough mass to resist buoyant and shear forces. Abbe and Montgomery (2003) describe key "members" for a number of jam types in the Queets River on the

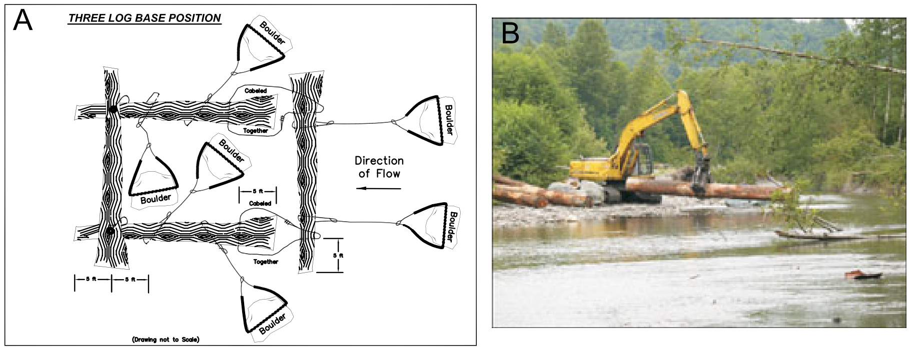

FIGURE 5. Floating Log Ballasted Jam Design Configuration (A) and Excavator Placement (B). Four core logs are cabled to ballast rocks and to each other.

Olympic Peninsula. Stable wood pieces anchor the jam and affect channel hydraulics and stream reach morphology (Montgomery *et al.*, 2003). Key piece size varies by stream type and size. The equivalent of a key piece for Finney Creek was achieved by using core logs (61-76 cm in diameter by 9 m long with a minimum small end diameter not less than 46 cm) plus two ballast rocks. Ballast rocks limit movement of each core log but the jam is still flexible.

The jam shape is integral to the structural stability and performance of the floating log ballasted jam. The front base log is placed perpendicular to the direction of flow. The other two base logs are placed perpendicular to the front log and parallel to the direction of flow. The last or top log is placed on top of and across the downstream ends of the two parallel base logs. This design mimics observed natural large log jam configurations found on gravel bars.

For ballasted log jams, the helicopter delivered four core logs and six ballast rocks, all pre-drilled, to each jam site. Ballast rocks ranged from 3,175 kg to 4,545 kg. The tracked excavator placed the ballast rocks and logs into the desired configuration (Figure 5) and laborers then cabled the logs to the ballast rocks and to one another.

Log Jam Design Considerations. The design of large wood jams must often consider the possibility that logs or jams could mobilize and damage downstream infrastructure. Design requirements to withstand shear and buoyant forces on log jams can be daunting, yet critical to their success (D'Aoust and Millar, 1999, 2000; Nichols and Sprague, 2003). Log jam design evolved during this project as experience was gained with regard to channel response and jam movement during floods. The experience of others with engineered log jam projects (Abbe and Montgomery, 1996; Doyle *et al.*, 2000; Abbe *et al.*, 2003; Ryan and Jensen, 2003; Nichols and Maudlin, 2007; Nichols and Sprague, 2007) helped refine design specifications. Three key design criteria were carried throughout the Finney Creek project; the mass of the jam must be sufficient to resist free movement downstream, deformation and some movement are desired and expected due to the dynamic forces experienced by the jams, and minimal construction disturbance to riparian areas and stream channels. In our experience, the second and third criteria are often not included in engineered log jam projects.

Flood water depth and flow velocity estimates are used to determine size of rock ballast to offset drag and buoyancy factors of both the logs and boulder anchors. Mass requirements are based on a 25-year flow event. However, some movement is expected from buoyant forces exerted through the cables and localized scour of the stream bed around boulders on ballasted jams.

Log cabling has also evolved with experience. The main criterion for cable length is that the logs remain at the top of the water column. If the cable is too short, the drag on the log at high flows will cause the log to submerge in the water column. The submerged logs do not effectively intercept other wood and cause additional drag on the ballast rocks. Cable length can be calculated using boat anchoring methodologies such as Chapman Piloting and Seamanship (Husick, 2009). Referred to as the "scope," cable length from log (boat) to boulder (anchor) is estimated as five times the water depth (5:1). Increasing the scope length to 7:1 or as high as 10:1 reduces the effect of surging or increases the length of time the log is in the upper water column. Cable lengths used in Finney Creek (8 m) were refinements from other projects and several iterations of cable length calculations. Additional length can be used where a higher degree of safety is desired. Cable length should be no less than 5 m (Husick, 2009).

On average, a three-person hand crew requires under an hour to cable ballasted jams and three hours for log only jams. Steel cables, 1.27 cm in diameter for the upper watershed and 1.59 cm for the lower watershed, were threaded through 2.54 cm holes drilled through rocks and logs and then wrapped around the logs. Wrapped cable alone is difficult to tighten and is subject to slipping off the log from stresses during floods and from slack that develops as the log shrinks from drying and deterioration. The small hole minimizes the effects of the cabling on the rate of wood deterioration, but allows for easy cable threading. A 4.6 m long hydraulic hose sleeve reduces cable abrasion by the ballast rocks as the cable rotates in the holes. Cable clamps and nuts were welded to prevent tampering and loosening under stress.

Monitoring Design

The partnership that supported this large scale restoration project was particularly interested in whether the techniques achieved the project objectives. To document the effectiveness of the project, a multi-faceted monitoring program was designed and instituted.

Aquatic Habitat Surveys. Aquatic habitat surveys were used to follow the overall change in habitat amount and quality. The survey protocol conforms to a modified Hankin and Reeves stream survey employed by the U.S. Department of Agriculture (USDA) Forest Service, Pacific Northwest Region (Region Six) (USDA Forest Service, 2007). Survey measurements include average length and width of all habitat units, pool maximum and residual depths, total number of large wood pieces, and the number of log jams having 10 or more interconnected pieces of large wood. Habitat units must have a length equal to or greater than the wetted channel width. Two basic types of habitat units are identified; fast water (riffles) and slow water (pools). The number of large woody pieces is also used in Finney Creek to determine if the log jams successfully trap additional wood.

Pools qualify as a habitat unit if they have little or no surface water gradient, a hydraulic control which spans the channel, and a residual depth. Residual depth is the difference in measurements between the maximum pool depth and the pool outlet depth. To be counted, wood pieces must be at least 7.5 m long and at least 30 cm in diameter 7.5 m from the large end. Part of the log must be within the bankfull channel.

Habitat surveys of upper Finney Creek in 1992 and 1999 serve as a baseline for the degraded condition of the stream. A posttreatment survey of upper Finney and pretreatment survey of lower Finney were conducted in 2002. Lower Finney posttreatment habitat surveys were conducted in 2004, 2007, and in 2009.

Channel Cross Sections. Surveyed stream channel cross sections were established 10 m downstream (cross section A), at the lower end (cross section B), and immediately upstream (cross section C) of log jams to document localized changes in stream bed morphology. Eighteen log jams in upper Finney Creek were monitored with cross sections from 2000 to 2006. Five log jams from the 1999 installation were monitored from 1999 to 2006.

Channel cross sections for lower Finney Creek were established at the head, middle, and lower end of log jams for the 2003 and 2005 project sites. Single cross sections at four representative channel locations within the 2006 and 2008 project reaches were established and monitored to better capture overall reach changes rather than just at log jam locations. These lower Finney Creek cross sections have one year of posttreatment data.

Photo Points. All log jams were photographed upon completion and located using GPS coordinates. Repeat photos of the wood jams after high flow events show the accumulation of wood that is not necessarily captured in the Aquatic Survey protocol. This is a qualitative documentation of how well the jams trap wood moving downstream and how the jams deform and shift (Stan Zyskowski, USFS, 2006, 2011, unpublished data).

Stream Temperature. Stream temperature is being used as an indicator of change in the Finney Creek system. If the stream channel is deepening and narrowing, and shade on the water is increasing, a decrease in water temperature is a barometer of that change (Brown, 1980; Beschta *et al.*, 1987). Optic Stowaway stream temperature loggers (Onset Computer Corporation, Bourne, MA) were used to monitor summer stream temperatures. Detailed temperature monitoring procedures used can be found in the lower Finney Creek Instream Quality Assurance Project Plan (Stan Zyskowski, NPS, USFS, SFEG, 2008, unpublished data) and Schuett-Hames *et al.* (1999). Pre-project stream temperature monitoring was initiated in 1998 in the upper watershed and in 2000 in the lower watershed. Temperatures were recorded every 24 min and daily minimum, maximum, and average temperatures were summarized. In addition seven-day moving averages for daily maximum and average temperatures were calculated and summarized.

RESULTS

Aquatic Habitat Surveys

Aquatic habitat surveys indicate some improvement in the quality of habitat in Finney Creek since implementation (Stan Zyskowski, USFS, 2009, unpublished data). While the number of pools decreased by 13% over the time period, the percent pool area increased by 27%. Pool depths appear to be increasing; however, the amounts are not much greater than measurement error. Residual pool depth increased by 4%, or approximately 0.05 m. Maximum pool depth also increased slightly; by 2%. These changes were somewhat greater for the period 2004-2007 and then reversed some between 2007 and 2009.

Although the changes are not statistically significant, they suggest that pool forming processes are scouring deeper and larger pools overall. Pools like those in Figure 6 were mostly absent prior to the project. These metrics imply that pool habitat is increasing in amount and quality in the lower treated reach.

Cross Sections. Interpretation of cross-section data is complicated by hydrologic variability over the course of the study and continued movement of sediment through the system. Finney Creek is not gaged; but there are long-term streamflow records for the North Fork Stillaguamish River that drains 679 km^2 on the southeast side of Finney Peak and the Sauk River (1,849 km^2) to the east southeast. Although the hydrology and storm patterns are somewhat different for these watersheds, they provide some indication of flood magnitudes during the Finney Creek monitoring period. One or both of these larger rivers experienced floods with recurrence intervals greater than 20 years in Water Years 2004, 2005, 2007, and 2009 (Table 2). Recurrence interval is the estimated time interval between floods of a given size. A five-year recurrence interval flood is the discharge that would be equaled or exceeded on average every five years. Flood events are important for shaping channel and floodplain morphology and for determining the success of the restoration work.

An in-depth analysis of the cross-section plots was conducted, but is not reproduced here. Plots of channel cross sections reveal some dramatic year-to-year changes and document areas of scour and deposition associated with the jam locations. Cross section B at Jam 64 (Figure 7A) illustrates small annual variability but overall little change in depth and cross section; whereas Jam 74 (Figure 7B) shows a persistent deepening and narrowing of the active channel. Site conditions at individual jams dictate changes in individual cross sections.

Cross section B at Jam 64 shows temporary scour of 1 m at mid cross section in 2002 and 2003. Approximately 0.25 m of aggradation is evident for 2005 and 2006 compared to the 2000 baseline. Cross

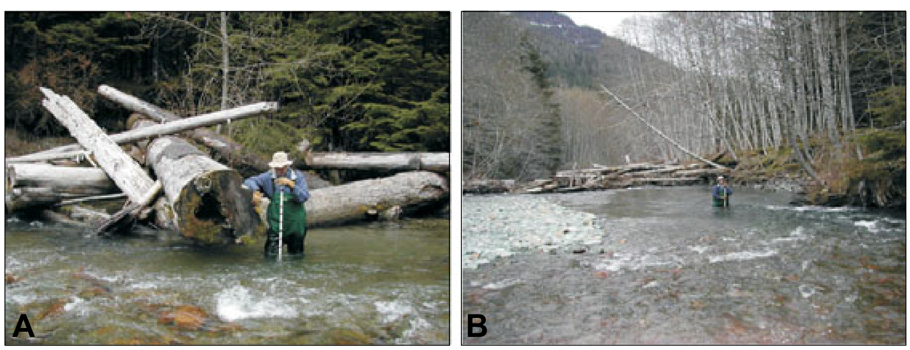

FIGURE 6. Pool Formation Adjacent to (A) and Upstream of (B) Wood Jams in Upper Finney Creek.

TABLE 2. Annual Peak Discharge from Two River Basins Neighboring Finney Creek. Water years shown, span the project monitoring period.

	Annual Peak Discharge (cfs)/Recurrence Interval (yrs) by Water Year						
USGS Station	2003	2004	2005	2006	2007	2008	2009
NF Stillaguamish River near Arlington, Washington	25,000/2.1	44,000/42	39,000/21	20,300/1.4	39,200/28	18,500/1.2	49,400/83
Sauk River near Sauk, Washington	34,200/2.2	106,000/83	55,000/6.4	20,200/1.3	86,400/28	45,700/4.0	41,700/3.2

Source: USGS National Water Information System, http://waterdata.usgs.gov/wa/nwis/sw.

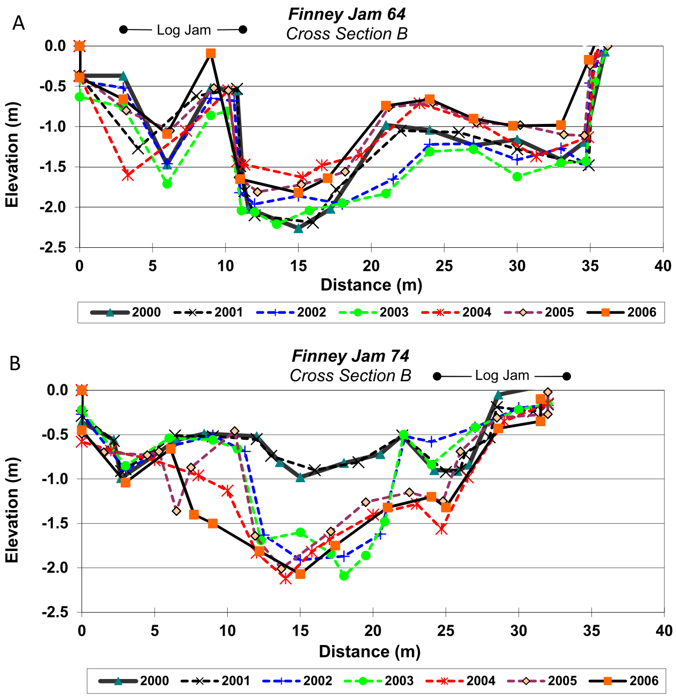

FIGURE 7. Upper Finney Creek Cross Sections. Jam 64 (A) shows little change (log jam is at left bank). Jam 74 (B) shows considerable scour (log jam is at right bank).

section B Jam 74 illustrates a scour of 1 m where there was little channel thalweg definition prior to log placement. Channel width fluctuated, narrowing in years without large floods and widening in flood years.

The upper cross section C at Jam 71 (Figure 8A) shows a tendency toward a deeper, more central channel position which fills and scours depending on flow conditions. Sixty-seven percent of the C cross sections have deepened. The lower cross section A at Jam 71 (Figure 8C) scoured during the October 2003 event (2004 measurements) and has remained incised since. However, only a third of the A cross sections show a similar scour pattern. Sixty percent of B cross sections show general scour similar to cross section B at Jam 71 (Figure 8B).

Cross-section data were analyzed for changes in channel width and two special metrics: (1) channel, area up to 1.0 m of depth, called the inner channel, and (2) channel area up to 1.5 m of depth, referred to here as the near bankfull channel. Bankfull stage (as defined and measured in Rosgen (1996)) was not well documented in the cross-section data and therefore not analyzed for change. No significant changes were found in overall channel width, inner channel width, or inner channel area. Inner channel area shows a slight increase (Table 3), but some cross sections show a dramatic decrease in inner channel area, especially at the lower end of some jams. The increase in channel area is greatest for A cross sections suggesting that the jams are creating additional

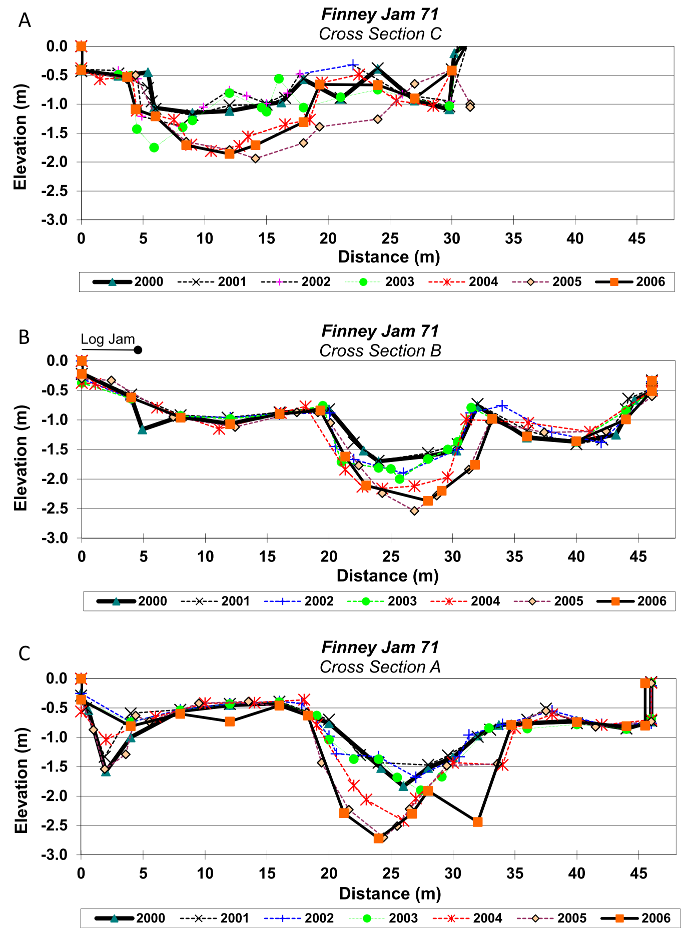

FIGURE 8. Three Upper Finney Jam 71 Cross Sections. Cross section A (10 m downstream of jam), cross section B (at lower end of jam), and cross section C (just upstream of jam), showing channel scour and tendency for increased channel depth and thalweg definition. Log jam is located between river kilometers 29.8 and 33.0.

scour downstream of the jams. These A cross-section channel area adjustments are accompanied by a slight increase in the inner channel width, but no increase in bankfull width.

The near bankfull channel area increased by 10% overall (Table 3). The greatest increase occurred just upstream and downstream of the jams.

Photo Points. The monitoring record includes repeat photos of all log jams. While the monitoring does not include vegetation transects to quantify colonization of gravel bars, repeat photographs of log jams show how vegetation is developing at some of the sites (Figure 9). Nichols and Sprague (2003) found that revegetation occurred rapidly after stabilizing banks with floating log structures.

Photo point documentation and GPS locator information facilitated the monitoring of jam movement. The October 2003 storm event (potentially a 40-80 year recurrence interval and peak flow for Water Year 2004) moved 9 of the 21 non-ballasted

TABLE 3. Mean Channel Area for Finney Creek Cross Sections. A comparison of inner channel and near bankfull channel areas.

Mean Channel Area	Inner Channel (1.0 m) Area (m^2) and (% change)		Near Bankfull Channel (1.5 m) Area (m^2) and (% change)	
	2000	2006	2000	2006
All cross sections	10.39	11.67 (+12%)	22.70	24.91 (+10%)
A — 10 m downstream	9.05	11.40 (+26%)	19.32	21.91 (+13%)
B — lower end	10.88	10.62 (−2%)	24.12	25.09 (+4%)
C — upstream	11.29	13.25 (+17%)	24.70	28.02 (+13%)

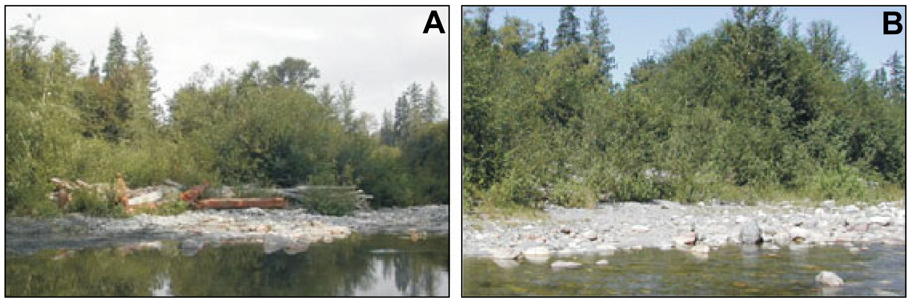

FIGURE 9. Photographs of Log Jam 5 in Upper Finney Creek. Note revegetation on a gravel bar protected by the jam after three years. (A) Photo taken July 2003; (B) photo is from July 2006.

log jams in the most confined lower reach immediately below the anadromous fish barrier. Eight of these mobilized jams traveled between 1.3 and 2.4 km downstream and the ninth jam moved 8.6 km downstream. Two log jams broke apart and the logs were transported to other accumulation points. The January 2009 storm moved 2 of 27 floating log ballasted jams short distances (up to 76 m) in the lowest treated reach of lower Finney Creek. These two jams were known to be under ballasted for a 25-year design storm due to lack of properly sized boulders. The January storm only generated a two- to five-year recurrence interval peak flow on the Sauk River, but the largest flow of record on the North Fork Stillaguamish River near Arlington, the drainage adjacent and immediately to the south of Finney Creek. The magnitude of the flood in Finney Creek is not known; however, observations indicate the January flow was greater than a two- to five-year event.

Stream Temperature. Stream temperature analyses for the Finney Creek study are summarized in Finney Creek Temperature Reduction Project, Temperature Study Results (Stan Zyskowski, USFS, 2009, unpublished data). The various analyses indicate there may be a slight decrease in stream temperatures in the project area over the monitoring period 2000-2009. Zyskowski compared stream temperature data for lower Finney Creek for 2005 and 2009 and showed a 23.5% reduction in the duration of warming periods (stream temperatures greater than 63.5°F) and a 1.1°F drop in the average stream temperature in the lowest treated section (river kilometer 4.0-6.4). Air temperature readings for the same period showed a 6% increase in number of readings greater than 63.5°F and an average that varied by only 0.05°F. Although not a rigorous statistical analysis, this suggests the beginning of a reduction in summer stream temperatures.

Scott Lentz (USFS, 2007, unpublished data) performed regressions comparing seven-day mean maximum stream temperatures for the period 2000-2005 between the treatment reach in upper Finney Creek and nearby Deer Creek (temperature monitoring in Deer Creek was terminated after 2005). The analysis shows that maximum temperatures were farther apart pretreatment (approximately 2.7°F) and then became more similar after treatment (approximately 1.6°F) indicating that the treated watershed is moving in the direction of the cooler control watershed.

An analysis of Finney Creek stream temperatures from 2000 through 2010 reveals a trend toward less time that stream temperatures exceed 63.5°F, the Washington State stream temperature standard for anadromous fish spawning, rearing, and incubation. Air temperature is one factor that influences stream temperatures and subtracting the amount of time air temperature exceeds 63.5°F removes that variable. The remaining time that stream temperatures exceed 63.5°F, would be more attributable to other factors that are affected by the restoration project; that is, general watershed conditions, riparian

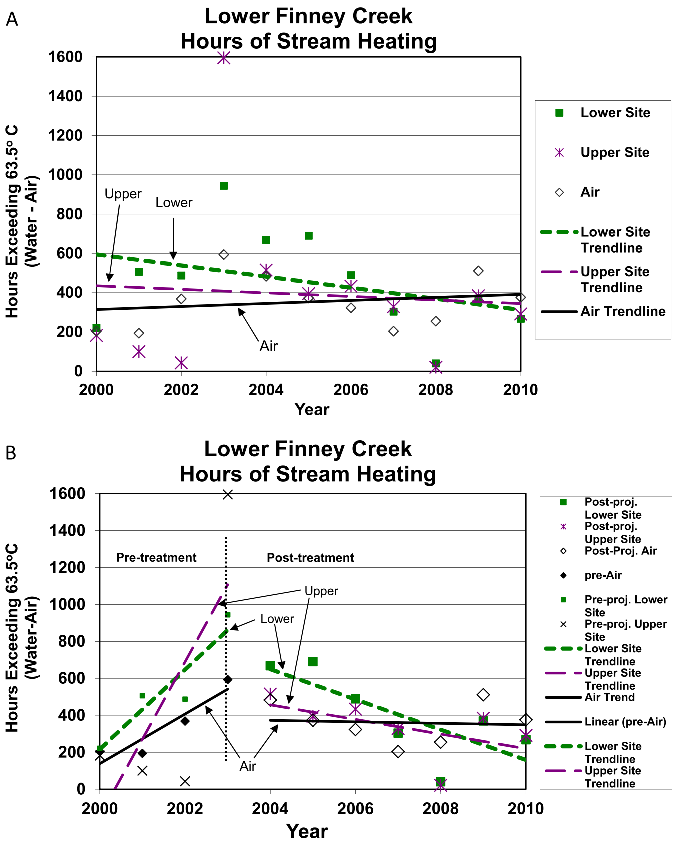

FIGURE 10. Plots of Stream Heating Changes During the Project. Stream heating is defined as the time stream temperatures exceed 63.5°F minus the time air temperature exceeds 63.5°F. The plot in (A) represents the entire project 2000-2010. The plot in (B) breaks the pre-treatment data at 2003, when structures were placed in lower Finney Creek: 2000-2003 represents the pre-project period and 2004-2010 the post-project period.

conditions, connection with and temperature of groundwater and hyporheic flow. The analysis shows a trend toward less stream heating over the restoration project time period (Figure 10A). In contrast, the general trend for air temperature shows an *increase* over the same time period. Because in-stream structures were not placed into the lower reach until 2003, temperature data for lower Finney could be divided into pre- (2000-2003) and post-project (2004-2010) time frames (Figure 10B). Since implementation in the lower river, the time stream temperature exceeds 63.5°F has decreased by as much as 17 days (400 h). Similarly, the upper reach of Finney Creek shows a slight decrease. While the trendline is steeper for the lower reach than the upper reach, both show a declining trend. Air temperature shows a minor decline for the period.

Large Wood. The tally of large wood shows a 20% increase in the number of large pieces from 2004 to 2009. The frequency of large wood increased from 23.7 pieces/km of stream in 2004 to 31.3 pieces/km in 2009. Half (48%) of the wood counted in 2009 is attributable to wood added as log jams by the restoration effort. The other half the recruited wood has mostly been trapped on wood jams. The number of log jams (10 or more interconnected pieces of qualifying wood) increased from 2.5/km in 2004 to 23.6/km in 2009.

DISCUSSION

The restoration of watershed and stream channel processes requires a multi-faceted and long-term commitment to implement treatments and monitor the results. The rehabilitation of Finney Creek started in the 1990s with critical management decisions that halted damaging land use practices and began watershed treatments to reduce sediment delivery to the stream network. Over a decade later, after hillslope processes started to stabilize and sediment delivery rates slowed, in-channel restoration treatments began.

Many stream channel restoration projects focus on relatively small reaches of rivers and site scale changes. The Finney Creek restoration project sought to restore a whole stream system. The treatments were designed to address the hydraulic and morphologic processes most responsible for conditions limiting the quality of salmonid habitat in lower Finney Creek. The processes of stream bed and bank erosion, sediment sorting and transport, and riparian vegetation community health were not properly functioning and the hydraulic forces of flood discharges had all but eliminated quality fish habitat features. Deep, cool pools were rare and the streambed substrate had become very mobile and uniform with little roughness to resist high flows. Stream temperatures were high enough to threaten survival of some salmon species and summer streamflows were becoming more subsurface in the deep gravel deposits. The 12 km of treated stream provide benefits to 37 km of main stem channel by trapping and storing gravel that would otherwise continue to disrupt channel stability. Slowing bank erosion assists in riparian vegetation recovery and stable gravel bars allow riparian vegetation to establish nearer the narrowing channel for better thermal regulation.

The jams have increased the complexity of the channel and reestablished the process of trapping and sorting mobile channel materials. Channel cross sections show a deeper channel at the head of the log jams and scour of pools at jams, with accompanying gravel deposition at the pool tail crest. Riffles and the thalweg have deepened below the log jams. This appears to result in more stable gravel bars and slower movement of sediment downstream. Further monitoring is needed to determine if these trends persist.

A series of jams (Figure 11) assisted in deepening of pools and defining a channel thalweg. Although flow levels and foliage are different in the photos due to the season, stabilization of the right bank area at and downstream (toward top of photo) of cross section D has begun (Figure 12). The gravel bar on the right bank has grown as the thalweg has migrated to the left.

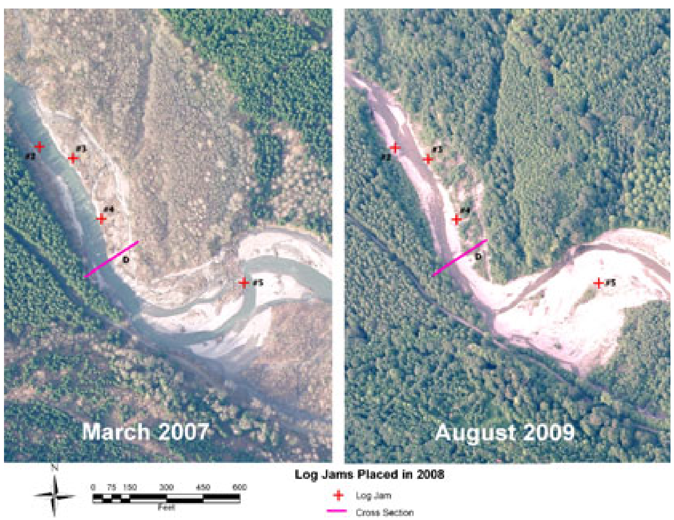

FIGURE 11. Aerial Photographs of the Lower Finney Stream Reach Containing Log Jams 2-5. Channel alignment is compared between March 2007 and August 2009. Although the difference in flow level obscures the changes, the area around Jam 5 increased in total stored sediment. Ground photographs document that Jam 5 is partially buried. The right bank above cross section D exhibits newly stored sediment along the lateral bar in 2009.

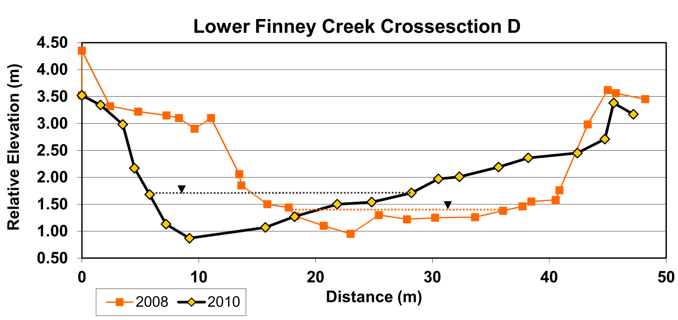

FIGURE 12. Cross Section D in Lower Finney Creek. This is the cross section shown in the aerial photographs in Figure 11 above. This cross section is not associated with a constructed log jam but is intended to capture channel change in the reach. Note the developing gravel bar on the right.

The constructed jams are catching additional wood pieces from the watershed which in turn enhance the features and functions of the jams (Figure 13).

A one degree (Fahrenheit) reduction in overall stream temperature and less time exceeding state standards for salmonids indicates that water temperature is trending downward. This apparent trend is observed in both the upper and lower watershed and may be the result of deeper scour of bed materials and the interception of greater volumes of hyporheic flow from the substrate.

Streamflow also exerts a major influence on summer stream temperatures as well. All else being equal, less streamflow volume would translate to higher temperatures; more streamflow volume would buffer heating processes, resulting in lower stream temperatures. Finney Creek is not gaged, so the North Fork Stillaguamish River streamflow records are a surrogate. During the period from 2004 through 2010, when stream temperatures appear to be less elevated, June mean monthly streamflow shows a slight increasing trend, July shows no trend, and August streamflow shows a slightly decreasing trend. The decreasing amount of time stream temperatures are greater than 63.5°F does not appear to be due to a greater amount of summer streamflow. In fact, less flow in August would be expected to result in higher stream temperatures.

The floating log ballasted jam technique has evolved over time to function in higher stream energy locations. The first jams, without ballast, were placed on channel margins so that they would not be subjected to the higher water velocities and transport forces. Those jams functioned well in the upper channel. In the simplified lower channel, with greater stream power and a higher incidence of surge flows produced by failure of channel-spanning log jams, the jams tended to move or break up during floods or when the channel margin shifted exposing them to greater shear stress. The ballasted jams provide more stability in higher energy and shifting channel sites.

There has been very little log jam movement in the upper reach other than localized shifting. Most of the log jam movement occurred in the lower reach where the increased stream power becomes a larger factor. Most jams that moved floated as a unit, because of the cables binding the logs together, and settled out in new locations.

Log jam transport during storms appears to start when loose logs collect and form channel-spanning jams. Water builds up behind the jam and as additional floating logs accumulate, the channel-spanning jam becomes unstable. When the jam breaches, the logs are moved downstream on the surge flow. This process started in the upper Finney reach during the 2003 storm and continued downstream. Evidence

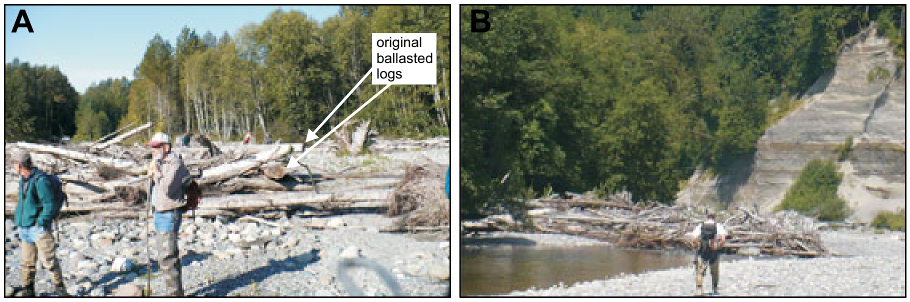

FIGURE 13. Photographs of Woody Material Collected at Floating Log Ballasted Jams. Photograph (A) is one year after jam construction. Cut log ends right of center are two of the initial four ballasted logs. The remainder of wood accumulated during high water. Note that wood accumulates on and under the floating log ballasted jam because the structure floats up in the water column during floods. Photograph (B) is of another jam two years after construction. Note that these jams have increased local channel complexity.

indicates that some constructed log jams actually acted as catch points for formation of channel-spanning jams. Catch points are normally channel constrictions or embedded or loose wood large enough to resist mobilization. Several jamming and breaching sequences may occur during a storm event.

Three of the jams in 2006 and all jams constructed in 2008 and 2010 included ballast rocks to limit mobilization. The additional mass allows a more aggressive placement onto mid-channel bars with greater potential to affect streamflow and achieve a broader set of desired results, such as splitting flows to maintain side channels, or deflecting flows away from vulnerable streambanks. It is imperative that ballast rock mass requirements are met during log jam construction. The two jams that moved in the January 2009 storm were known to have ballast rocks undersized for the site (a contract execution issue). The ballast rocks provide a significant drag on the logs that should maintain their position during common floods (two to five years), yet with sufficient buoyant and shear forces of large floods, the rocks may saltate along the river bed. This movement is more likely in channels with uniform substrate sizes, like lower Finney Creek.

Jam locations for this project were based on a number of years of observation of where natural wood jams form in rivers flowing from the western Cascade Mountains of Washington. The lack of adequately sized naturally occurring material and other stream and riparian conditions noted above prevented these accumulations from lasting long enough to effect stream complexity. Locating jams at natural accumulation sites increased the probability of success.

Using the helicopter and excavator combination for jam construction saves time and minimizes disturbance to the riparian zone and stream channel. Helicopter ferrying of logs means virtually no disturbance to riparian areas. The excavator traversed most gravel bars just once and the riparian zone twice.

Floating log ballasted jams have been successfully used in several projects to protect eroding roadway banks and improve salmon habitat along the North Fork Nooksack River, the Skagit River and a number of tributaries (Nichols and Sprague, 2003; Nichols and Maudlin, 2007).

Advantages of the Floating Log Ballasted Jam Design

Floating log ballasted jams function at all flow levels. The cabled logs float up as the flow increases and remain at or near the top of the water column, where they catch a high percentage of the drift debris. Slack cables reduce the shear stress on the logs and boulders. As the jam compresses with the falling water level the trapped logs are interwoven into the ballasted log configuration (Figure 13). If scour occurs around the ballast rocks, the rocks settle into the scour holes and likely become buried in the substrate during the falling limb of the hydrograph. These processes give way to the formation of larger and more stable log jams.

Floating log ballasted jam designs are more cost-effective and less disruptive than some other log jam designs (Nichols and Sprague, 2003). Other contemporary designs require digging or pile driving logs into the substrate to the depth of scour, or deeper, effectively burying most of the structure to gain stability. This causes immense disruption of the channel and riparian area during construction and creates a rigid, fixed channel element (hard point) to which the channel must react. Whole logs for structures are hard to find, difficult to transport, and limbs on whole trees are quickly abraded or peeled off by streamflow; attached root wads require extra ballast, as much as 60% more than just logs because of the additional surface area and volume. These other designs were rejected due to these factors and because a rigid, fixed channel element did not meet the objectives for Finney Creek.

Floating log ballasted jams increase channel roughness and rely on streamflow to develop habitat complexity instead of trying to install instant habitat. The jams cause local scour and deposition that helps sort gravel and increase pool size and complexity. Jams can be placed in opposition to one another to increase velocity over a short stream segment.

Effective jam placement requires accurate prediction of channel response and subsequent alignment. Bank protection can be achieved without placing jams against a streambank (Figure 14). The lead or upstream jam may be against the bank; but subsequent downstream jams can be placed on the gravel bar further away from the bank to increase deposition and expansion of the gravel bar. The channel thalweg is gradually moved away from the bank.

The success of the Finney project greatly benefited from observations of natural processes in Finney Creek and other streams, and making design modifications based on channel response to other log jam projects in the area. The following statements result from our observations:

- It is important to understand large scale channel sediment transport processes. Structures placed in natural sediment deposition zones only increase *local* scour and do not significantly alter channel reach scour.
- Structures located on the low bank side of the channel increase local scour. Placing structures on the high bank side of the channel causes bank scour and increases sediment production.

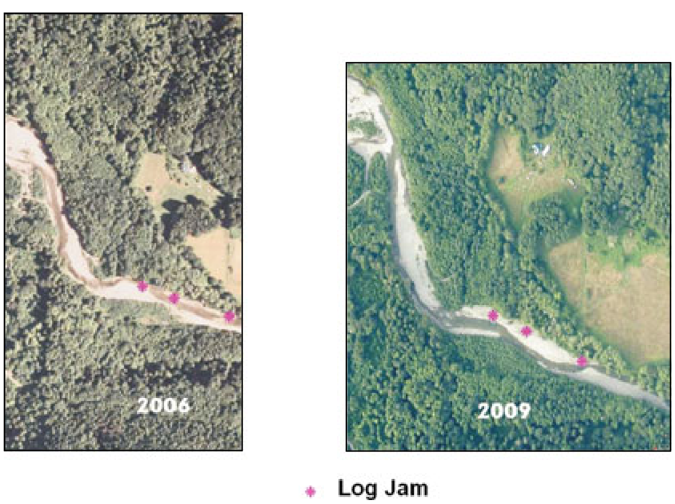

FIGURE 14. Aerial Photographs Showing Locations of a Set of Floating Log Ballasted Jams. The jams were set away and angled from the bank on the gravel bar instead of the traditional "at bank" bank protection configuration. The channel thalweg shifted away from the bank and channel complexity of the site increased. Traditional riprap placement by the landowner had previously failed

- Structures placed on the lower portion of floodplain terraces and gravel depositional areas interact with most flow events and affect channel roughness and complexity. Structures on top of terraces interact with floods and affect floodplain roughness.
- Wood jams are not effective ways to mitigate undersized bridges or culverts. The effects of those structures overshadow the desired effect of engineered log jams. Undersized structures require replacement with adequate designs for flow and bed-load conveyance.

Monitoring. Monitoring the effects of restoration work on this scale is challenging. Monitoring poses two major difficulties from start to finish. The first challenge is to get commitment (funding and other resources) to continue documenting change over a long period; well after the general flurry of interest by onlookers and bureaucrats has waned. The second challenge is to set up appropriate monitoring in the very beginning. This goes beyond the question of what is the appropriate monitoring technique(s), to how can the monitoring sift out all the natural variability in highly dynamic systems to show changes that result from the restoration treatment. The answers to these questions are not always known but consultation with experts, including statisticians, is helpful. Some flexibility in monitoring design is also required. If the chosen monitoring strategy is not adequately answering the monitoring questions the strategy should be revised.

Monitoring of Finney Creek restoration evolved over time. Initially, cross sections were located just at the log jam sites to follow the localized channel morphology. The trio of cross sections at jams captured specific site changes that were greatly influenced by the highly variable waves of sediment still moving through the system. More scour was anticipated at the log jams; however, channel scour appeared to also be occurring above and downstream of the jams. This monitoring approach did not provide information on the overall morphological changes occurring in the larger stream reach. What was happening between jams was not being captured.

To better capture how the channel as a whole is responding to the treatments, random cross sections were added along the lower reach in 2008 (one is depicted in Figures 11 and 12). These cross sections need additional years of data collection to capture natural variability in flow and sediment; but will hopefully document general channel change resulting from the restoration efforts. Cross sections are a time-intensive technique, but a useful element of a long-term monitoring program. Capturing the natural range of variability and equilibrium cross-section dimensions of the stream requires commitment.

Continued monitoring of the lower channel is warranted to determine the longevity of the jams and whether the natural processes of gravel sorting, wood recruitment, and sediment retention are enhanced by these structures. It will be many decades before large key pieces of wood are naturally recruited from the watershed because of the young age of the streamside forest communities. Monitoring will be important to determine if additional introduction of wood is warranted before natural recruitment resumes. However, this level of monitoring may not be practical for all restoration activities. Monitoring results of selected projects can establish a dataset on the effectiveness of restoration techniques.

CONCLUSIONS

The multifaceted and multiyear restoration program in Finney Creek appears to be altering local stream processes that lead to higher quality aquatic habitat. Although the change is not statistically significant, the trend is in the desired direction. The placement of large wood jams over 12 km of Finney Creek is replacing the structural key wood element missing from the watershed for decades. Additional wood that previously passed through the channel during a flood is now more likely to collect on the floating log ballasted jams. These wood jams are helping to trap and sort sediment in more stable gravel bars and to scour deeper, higher quality pools connected by deeper and more stable riffles.

Stream temperature appears to be responding to more consistent interception of cooler hyporheic flow in the deeper pools. There is less stream warming in the downstream reach compared to pretreatment data. Visual evidence suggests riparian vegetation is expanding onto the more stable gravel bars and behind large wood jams in both the upper and lower treatment reaches. Over time, maybe several decades, riparian vegetation is expected to provide additional stream shade to further lower water temperatures. Developing more effective shade ultimately depends on the growth of streamside trees, especially coniferous tree species that are more effective at changing the microclimate next to the stream channel compared to the existing alder/willow communities.

Definitive documentation of channel morphology and temperature recovery will require continued monitoring. A narrowing and deepening channel response may be reversed by large flood events for short periods of time; however, a positive trend toward a narrower and deeper channel is expected to continue over the long term.

Lessons Learned

This project demonstrates the difficulty of monitoring channel and habitat change specific to project treatments. Channel processes are messy and create a lot of "noise" in the data. This project was implemented over 10 years; the monitoring commitment must span an even longer period of time. The Finney Creek restoration monitoring strategy developed and evolved during the project, but could have benefited from more detailed planning in the beginning.

Photo documentation over time is an effective qualitative technique to show change, but if a quantitative measure is desired, riparian vegetation encroachment and revegetation should be measured. Temperature loggers were found to be cost-effective long-term monitoring tools.

Establish Good Control Sites. Establishing a good control site is essential for stream temperature monitoring. Deer Creek was a valid control stream, but was not directly linked with the Finney Creek project. When funding was insufficient for continued temperature monitoring in Deer Creek its use as a control stream was severely limited. The inclusion of air temperature monitoring did assist in interpreting the seasonal and annual climate variability, but without continuous monitoring of stream and air temperature in a well-chosen control watershed the interpretation of temperature data is compromised.

Measure Reach Scale Response. For long stream reach restoration projects, effective monitoring should measure reach processes/responses, not just localized site responses. If the goal is to affect reach scale responses, this will not be captured unless monitoring is designed to look beyond individual structures.

Ballasted Log Structures. Ballasted log structures proved to be more reliable than other cabled log designs or rigid channel elements in achieving the desired results. More aggressive placement allows working with important flow characteristics to split and direct flow vectors rather than merely deflecting flow at certain locations. The introduction of these log jams in uniformly low quality aquatic habitat systems introduced tremendously valuable stream complexity components that were otherwise lacking.

Remote Sensing. The capability of remote sensed data has emerged as a viable tool during the life of this project. The technology is now readily available to develop channel profiles and cross sections from aerial photography and other imagery. We attempted to utilize this tool but timing of photography (similar flow regime) was not controlled. This technique is valuable to long-term (decades) monitoring programs.

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