Snohomish County Public Works Department

Surface Water Management Division

2009 Project Effectiveness Monitoring Program Report

Twin Creeks Recovery Project, North Creek, 5-year Monitoring Results

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<u>Twin Creeks Project</u> – 5-year Engineering and Habitat Summary & Recommendations

Project Name: Twin Creeks
Project Location: North Creek at 208th Ave SE.
Project Managers: Craig Young, Bob Aldrich, Dave Lucas
Construction Date: 2003
Dates of Monitoring: 2001, 2003, 2004, 2008
Monitoring Staff: Frank Leonetti, Brett Gaddis

The Twin Creeks Project on North Creek near "Thrasher's Corner" was implemented in 2003 after securing an 8-acre Conservation Easement. This project was implemented as part of Snohomish County's commitment to salmon recovery in WRIA 8. The total project cost to construct was $151,573, which included $134,024 from NOAA and King County (grants) and other in-kind donation. Snohomish County costs (to 2004) totaled $17,550.03.

Type of Project: Habitat Restoration
Overall Project Goals:
1.) Control erosion near mobile homes and limit erosion elsewhere.
2.) Add woody debris for habitat enhancement.
3.) Enhance pool habitat quantity and quality.
4.) Enhance side channels.
5.) Re-habilitate the stream buffer with native vegetation.

Project components: Installed 170 pieces of LWD, Planted 2 acres of stream buffer

Table. Comparison of pre-construction and current project conditions based on project goals.

Project goal	Pre-construction condition	Current condition
Control Erosion	60' eroding stream bank	No new erosion
Add woody debris	50-97 pieces/km 0.03-0.05 key pieces/km	LWD meets or exceeds habitat performance criteria; >80% stability or retention
Enhance habitat	3.8% cover over pools	Fish concealment cover (19%) over pools nearly meets habitat performance target (20%).
Enhance pool habitat	17 pools; 31% pool area; 29 pools/km; 3.6 CW/pool spacing; 0.61 m avg. pool depth; one wood-formed pool (6%).	34 pools; 47% pool area; 64 pools/km; 1.7 CW/pool spacing; 0.5 m avg. pool depth; 80% of pools formed by LWD.
Enhance side channels	127 m^2	140% increase in side channel area.
Improve stream buffer	2 ac. blackberry & knotweed; 8 conifer trees > 0.55 m diameter.	Removed blackberry and knotweed; planted 2 ac., planted > 1,800 conifers. Low plant survival, but increase in overall cover.

Monitoring staff observations and recommendations:

- Anchor wood in jam configurations to create greater effective mass and flow resistance and increase wood abundance to maximize functions and length of project life. Pieces smaller than "key" size dimensions shouldn't be placed individually. Don't impale wood in streambanks.

- Impaling LWD into streambanks may have destabilized some banks at this site directly or indirectly due to wood buoyancy/vibration during flooding.

- Don't anchor wood that is large enough to form pools based on minimum functional diameter and if length is greater or equal to bankfull width.

- Alternate banks for sequential wood placement to limit abandonment of placed LWD.

- Avoid LWD placement on top of existing bars, where sediment deposition alone would tend to move the thalweg. If possible, place LWD at the apex of a bar, in meander bends, or on banks in alternating (left bank-right bank sequence).

- Expect erosion to propagate elsewhere – opposite bank downstream erosion in a non-hazard area has led to both sediment recruitment and habitat complexity.

- Target LWD jam placement for pool enhancement based on pool frequency, spacing and area criteria from best available science.

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Department of Public Works

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Contributing Staff
The following people have made significant contributions to monitoring this project and to the completion of this report: Dave Lucas, Andy Haas, Michael Purser, Ted Parker, Chris Nelson, Tim Walls, Craig Garric, Kathy Thornburgh, and Josh Kubo (intern).

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Executive Summary

For the Twin Creeks Recovery Project on North Creek, Snohomish County proposed to restore streambank stability, normative large woody debris frequency, and native riparian vegetation to an approximately 1800 lineal foot segment of North Creek, near the confluence with Silver Creek in a critical stream reach for salmon habitat restoration.

The success of this project is judged based in part on several indicators of habitat performance, as measured based on project and monitoring objectives applied within both the treatment area (approximately 260 m) and adjacent untreated up- and down-stream areas (302 m). Monitoring objectives derive from monitoring questions specific to individual project objectives and hypothesized performance related to channel responses, bank conditions, woody debris metrics, habitat conditions, vegetation growth and survival, temperature, sediment, and biological monitoring.

Twin Creeks project objectives were as follows:

> ***Project Objective 1*** - Control erosion at one hazardous location (mobile homes) and limit new bank erosion elsewhere.
>
> ***Project Objective 2*** – Increase side channel connections and area.
>
> ***Project Objective 3*** - Augment woody debris abundance consistent with properly functioning conditions for a Puget Sound lowland stream.
>
> ***Project Objective 4*** – Enhance pool habitat quantity and quality.
>
> ***Project Objective 5*** – Plant native vegetation within 150 foot corridor within the easement area to obtain 50% conifer cover at maturity.

For most of the project objectives, monitoring results suggest high effectiveness of our treatments based on implementation performance after 5 years. At the same time, we observed higher than anticipated streambank instability and possible increase in supply of finer sediments. Otherwise we found;

- High LWD stability,
- High LWD retention within the project area,
- Rapid pool-forming response and persistence due to LWD placement (particularly in jam formations), and
- Substantially higher fish cover from both placed LWD and naturally recruited LWD after 5 years.

The amount of new LWD in 2008 was large compared to 2003/2004 and much of it was highly functional in terms of pool formation and cover as well as average size in comparison to placed LWD. Placed wood, after 5 years, appeared to be less functional; perhaps due to stream meandering or sedimentation that may have shifted the stream

course away from anchored woody debris. Long term monitoring (10 years) will be needed.

After 5 years, pool frequency and total pool area has increased substantially to nearly meet both performance targets. New naturally-recruited LWD appears to have been important to increasing or maintaining these pool conditions. After 5 years, pools formed by naturally-occurring LWD (in some cases by downed trees and root wads) appeared larger in size than those formed by placed LWD.

New channel roughness from LWD and strategically placed LWD jams, in combination with 4 large flooding events, appears to have led to channel shifting and side channel expansion compared to pre-project conditions. We surmise floodplain storage has increased as a result, but changes, if any, in water surface elevation (for a given discharge) are not known. Phase II of the Twin Creek project (Built in 2008) will promote greater floodplain connectivity and habitat formation as well.

At Twin Creeks, over three acres of the conservation easement have been planted to date after removal of invasive vegetation species, principally Himalayan blackberry and knotweed species. Other natural recruitment of alder trees has also contributed to rapid vegetation density and cover and in some locations, bank stabilization.

Our project recommendations for monitoring, design and implementation to enhance future effectiveness at this site or others include the following:

Monitoring:

- For individual projects, a Before-After-Control-Impact (BACI) study design is preferable to either a retrospective or before-after design. Select a control site (preferably upstream) that is long enough and in a similar geomorphic setting (gradient, confinement, substrate size) to adequately control for the potential treatment effects. At Twin Creeks, the "control" area was probably too short and split between upstream and downstream areas.

- Channel dimensions – at the project scale, a longitudinal topographic survey as well as regularly spaced cross section topographic survey should be implemented and repeated at each monitoring interval to quantitatively summarize changes in habitat unit composition, residual thalweg depth, channel alignment, and streambed aggradation or incision.

- LWD – In future years, measure the length and diameter (at the length mid-point to facilitate volume calculations) of individual pieces of LWD. At the project scale we are interested in functional responses due to project treatments and better quantifying LWD size will help improve estimates of piece functions related to piece size that should vary among projects implemented in different size streams/rivers. At the same time, each piece should be noted for how much flow the piece intercepts (as a percent of wetted width). A piece that intercepts 50% of flow will span ½ the distance of the wetted channel. All wood should be tagged or otherwise individually identifiable.

- Temperature – In advance of site specific treatment design, stream temperature should be investigated as part of project feasibility analysis. In many streams, summer stream temperature may be highly variable even among nearby locations due to tributary influences or groundwater discharge. Some sites may be too warm for fish use during summer and structural habitat enhancement may not be beneficial if high quality summer rearing habitat is the primary objective. Alternative site locations may be needed.

- Sediment – for the project scale, consider multiple approaches to sampling sediment in order to detect with statistical confidence changes in fine sediment composition. Multiple techniques could include more pebble count locations, pebble counts at multiple, evenly spaced transect locations, visual estimation of surface fine sediments at riffles using a grid method, or grab samples of streambed gravel for volumetric (mass) analysis of fine sediment content. Because fine sediments can be supplied within the project area from (treated or untreated) eroding streambanks, as a result of channel expansion from LWD placement, or conceivably, from cleared riparian areas (prepared for planting), it is important to quantify streambed sediment changes in order to more comprehensively interpret project outcomes, even if sediment is not a targeted parameter.

- Be sure data management precautions exist to prevent loss of (electronic) data over years, either by printing raw data or improving file storage management, access, and security (from accidental deletion or file movement).

Treatment Design:

- Don't impale wood into stream banks, especially as an approach to "anchor" smaller single pieces. Impaling LWD into streambanks may have destabilized some banks at this site directly or indirectly due to wood buoyancy/vibration during flooding.

- If possible, place all small wood and any pieces without root wads into jam accumulations

- Don't anchor wood that is large enough to form pools based on minimum functional diameter and if length is greater or equal to bankfull width. Minimally anchoring LWD will allow for some movement during flooding that will likely keep LWD in alignment with the channel thalweg.

- If possible, alternate banks for sequential wood placement to limit abandonment of placed LWD due to stream course shifting where that may be likely. This may not be a concern if naturally erosion resistant banks are opposite from placed LWD.

- Where bank stabilization is needed or required, allow for additional downstream channel capacity. Otherwise, expect bank erosion to transfer downstream, especially if other LWD placement occurs downstream of treated banks.

- If possible, avoid LWD placement on top of existing bars, where sediment deposition alone would tend to move the thalweg. If possible, place LWD at the apex of a bar, in meander bends, or on banks in alternating (left bank-right bank sequence).

Introduction

Salmon recovery efforts in watersheds focus heavily on restoration of aquatic habitat and riparian conditions to ameliorate habitat limiting factors for salmon populations, and often are the predominate tool used to improve habitats for fish. At the same time, many projects (even given their high expense) deliver uncertain results. This is partly due to a paucity of effectiveness monitoring information in the first place, and, secondly, a lack of knowledge drawn from such efforts to better guide implementation of various techniques (Roni et al. 2002). In urban areas, site-specific restoration of habitat features is often undertaken even though extensive alteration of hydrologic, sediment and riparian processes present challenges or barriers to success (Larson et al. 2001). In Snohomish County, North Creek, a tributary to the Greater Lake Washington/Sammamish Watershed (aka WRIA 8), has become increasingly urbanized while nevertheless retaining use by Chinook, coho, and sockeye salmon, among other fish species.

In North Creek, habitat degradation and water quality impairment, in general, has occurred over many decades as a direct result of historic land clearing (due to logging, for example) and stream channelization (due to rural development and initial road building, for example) affecting hydrologic and sediment processes (Snohomish County 2002). More recently, habitat degradation is associated with urban growth. Specific watershed conditions and issues that contribute to habitat limiting factors for salmon in North Creek include degraded riparian buffers, impaired water quality, and increased flooding from urbanization and insufficient stormwater control. At the project site, riparian conditions have been degraded by the loss of natural and mature riparian cover, streambank erosion, and armoring placed to protect private property. Stream habitat complexity is poor as indicated by low pool quantity and quality and low levels of small and large woody debris in North Creek (see data table and definitions below; King County 2001, Snohomish County 2002). While acknowledging the challenge of implementing successful restoration to achieve biological or population outcomes for salmon species in urban areas, Snohomish County sought to restore some habitat conditions believed to provide mitigative value consistent with life history requirements for salmon. At the Twin Creeks Recovery Project on North Creek, Snohomish County proposed to restore streambank stability, normative large woody debris frequency, and native riparian vegetation to an approximately 1800 lineal foot segment of North Creek in the Greater Lake Washington/Sammamish Watershed (aka WRIA 8).

The Twin Creeks project is located (Figure 1) in North Creek in a low gradient (<1.0% slope) and generally unconfined stream reach, immediately upstream from 208th St SE (aka Filbert Rd.), at the confluence with Silver Creek. This location is cited as a critical stream reach for salmon habitat restoration in the WRIA 8 Chinook Salmon Recovery Plan (adopted by NOAA in 2007), in part, because this reach was ranked highly for its protection and restoration value based on Ecosystem Diagnosis and Treatment (EDT) modeling implemented for the WRIA 8 Technical Advisory Group (Mobrand Biometrics 2003). Within the project vicinity there is low to medium density residential land use. Between here and the City of Mill Creek (upstream) is the least developed area along the mainstem within unincorporated Snohomish County and retains the widest stream buffer widths with only one improved road crossing (at 196th St SE). To implement this project, Snohomish County secured an 8-acre conservation easement on private property and received grant funding from NOAA, King County, and National Fish and Wildlife Foundation. Stream habitat baseline data (King County 2001, Snohomish County 2002) informed the technical basis for this project and monitoring.

Figure 1. Twin Creeks project site. The yellow boundary shows the approximate conservation easement that includes Silver Creek (from the east) and North Creek (flow direction is top-bottom in figure). Photo is from 2003.

The success of this project will be judged based on several indicators of habitat performance, as measured based on monitoring objectives applied within both the treatment area (approximately 260 meters length) and adjacent untreated up- and down-stream areas (302 m). Monitoring objectives derive from monitoring questions specific to individual project objectives, treatment types and hypothesized performance related to channel responses, bank conditions, woody debris metrics, habitat conditions, vegetation growth and survival, temperature, sediment, and biological monitoring. Therefore, this approach to monitoring and evaluating outcomes is organized based on project objectives, treatment design, monitoring questions, monitoring objectives, and habitat or indicator performance. At the same time, some of the monitoring effort reflects concerns regarding beneficial limits to project performance (from the urban setting) or uncertainty of project effects on non-treated habitat conditions, specifically temperature and sediment.

Project Objective 1 - <u>Control erosion at one hazardous location (mobile homes) and limit new bank erosion elsewhere</u>

  a. Treatment design – Streambank placed and anchored woody debris at hazard location.
  b. Monitoring question – Is bank instability staying the same or decreasing in the project reach? Is erosion controlled at the hazard location?
      i. Monitoring objective – identify and measure streambank erosion within the survey (control and treatment) area and, in particular, at one location (totaling approximately 60 left bank linear feet) where use of bioengineering techniques is applied to halt erosion currently threatening 3 mobile homes.
          1. Indicator performance – no new erosion at this mobile home site; no increased bank instability in segment; no difference compared to non-treated control locations.

Project Objective 2 – <u>Increase side channel connections and area</u>

  a. Treatment design – streambed surface weirs for grade control, woody debris placement at island apex or flow split for flow control
  b. Monitoring question – Are side channel lengths and/or total area (or wetted area) increasing? Is side channel habitat area increasing as a greater fraction of total channel area?
      i. Monitoring objective – identify and measure length and width of all side channels (total and wetted dimensions) separated from the main flow by a forested island (with tree growth greater than 5-years age and 50% cover of mid-channel island); classify habitat types (riffle, pool, other) and measure wetted area by habitat types within side channels; estimate total wetted area as a fraction of total mainstem channel area.
          1. Indicator performance – no target or threshold selected; increasing side channel length and area compared to pre-construction condition are expected.

Project Objective 3 - <u>Augment woody debris abundance consistent with properly functioning conditions for a Puget Sound lowland stream.</u> Relative to a disturbed urban setting, we expect instream placement of LWD to produce habitat enhancement more typical of undisturbed streams.

  a. Treatment design – Woody debris (anchored and unanchored pieces) placed in jams or singly at channel margins, channel center, on streambanks or near flow splits, or impaled into streambanks or streambed.
  b. Monitoring question – potential functions provided by woody debris placement include scour for pool formation, bank protection, sediment retention or grade control, and fish concealment cover – if LWD is stable and resists stream discharge. Specifically; Is LWD retained within the

project area at sites of original placement? Does LWD directly form more pools? Does LWD provide more fish concealment cover? Does LWD protect eroding banks where placed to accomplish such function? Does LWD retain or store sediment as a discrete function for individual pieces or jams? More generally, are these functions sustained over time?

i. Monitoring objective – inventory placed and natural LWD meeting minimum size criteria, document placement locations, stability, movement and export, and summarize woody debris frequency, loading, and functions.
    1. Indicator performance – LWD meets or exceeds habitat performance criteria; >80% stability or retention within the project area. Compare to non-treated control locations and non-urban streams in Snohomish County.

Project Objective 4 – <u>Enhance pool habitat quantity and quality</u> via woody debris placement.

a. Treatment design – See Project Objective 3.
b. Monitoring question – Are pools more frequently spaced as a result of project implementation? Does LWD directly form more pools? Is pool area greater than before treatment? Are pools deeper? Is fish concealment cover over/in pools and other habitat types greater than before and meeting selected performance criteria?
    i. Monitoring objective – identify and measure length and with of all wet habitat units and classify to type (riffle, pool, other); measure pool maximum depth and riffle depth; estimate frequency or spacing interval among pools and estimate total areal composition of pools; measure length and width of cover for fish either underwater or overwater (within 30 cm height).
        1. Indicator performance – Pool frequency and area meet or exceed performance criteria; Fish concealment cover exceeds minimum habitat performance (20%).

Project Objective 5 – <u>Plant native vegetation within 150 foot corridor within the easement area to obtain 50% conifer cover at maturity.</u>

a. Treatment design – Remove and manage invasive species, amend soils, and plant native mix of shrubs and trees.
b. Monitoring question – Is native vegetation surviving at projected rates? Is cover of native vegetation increasing? Is management of invasive species decreasing invasive cover? Is stream bank cover and stream shading increasing from vegetation restoration?
    i. Monitoring objective – establish line and belt transects across 150 foot project corridor. Measure species survival, growth and cover. Measure vegetation canopy cover at the edge of the streambanks and at the stream center at 11 evenly-spaced stream transects.

1. Indicator performance – Mature tree density to create 50% cover must be over 35 trees per acre. Plant survival at 3 years should be greater than 75%. No thresholds were set for total native plant cover or invasive species cover. Cover over stream channel should be >90% at the streambank edge and >70% at the center of the channel for this site.

Project Implementation

From the outset, we established targets or benchmarks for habitat conditions to guide design objectives within the 1800 lineal foot segment (562 meters) of North Creek. The target or benchmarks were based on several regional standards for habitat suitability which are included under "criteria" in Table 1. A target for project site conditions was established based on these criteria (e.g. NOAA 1996, WFPB 1997, Fox 2001), which led to proposed design objectives (final column in Table 1). In addition to augmenting LWD abundance and frequency to normative levels for a Puget Sound lowland stream, we additionally based our design and construction on clustering wood into jams based upon supporting data from elsewhere in North Creek (King County 2001) that indicate pools are formed 85% of the time at wood debris jams, whereas pools are only formed approximately 20% of the time by individual pieces of LWD.

<u>Treatments</u>

Wood placement

Although the conservation easement includes 562 m of North Creek, woody debris placement was more limited within this area - approximately 260 m in the middle of the easement. Both upstream and downstream untreated control areas were monitored in the easement area.

In summer 2003, a total of 170 pieces of conifer wood (plus 1 re-positioned alder stump) at least 2 m in length and 10 cm diameter were placed along 260 meters of North Creek. Prior to project implementation in 2003, only 31 pieces of woody debris (>2.0 m/ >10 cm) were located in the mainstem channel within the project area (562 m). In an earlier survey in 2001, 57 pieces woody debris were inventoried (590 m). Overall, the woody debris placement totals were slightly less than the target amount (170 pieces vs. 175 pieces, respectively).

During construction, 88 pieces were anchored to the streambed or banks with cable or chain and pneumatically-driven earth anchors. Eighty-two pieces were not anchored with artificial materials, but of these, 76 pieces were set by force (impaled) into the streambanks or bed using heavy equipment. Many pieces were placed as part of constructed jams at streambanks or the channel center (Figure 2 and Figure 3), while other pieces were placed individually. The remaining 6 pieces were pinned under other anchored pieces or placed with most of the log on top of the streambank.

Table 1. Twin Creeks baseline site conditions, habitat performance criteria and targets with design objectives. Targets; + = increase; / = no change; - = decrease in conditions; NA = not applicable; numeric targets proposed.

	Channel and Habitat Indicators	Baseline[1]	Performance Criteria	Targets	Design Objective
Channel	Channel gradient (%)	0.60%		/	
Channel	Surveyed length (m)	590/562		/	
Channel	Mean bankfull width, CW (m)	9.4		/	
Channel	Mean bankfull depth (m)	0.56		/	
Channel	BFW:BFD ratio	16.9	10-12	NA	no design objective
Channel	Confinement	Unconfined		/	
Pools	Total number pools	17	0.25m rpd	30	13 new pools
Pools	Pool frequency (pools/km)	29	35	35	
Pools	Pool spacing (# of bankfull widths)	3.6	2	2	
Pools	Mean functional pool area (m^2)	73.3		+	
Pools	Mean residual pool depth (m)	0.61		+	
Pools	Number pools ? 1m deep	4		5	+1 deep pool
Pools	Pool surface area (%)	28 / 31 [1]	50	50	
Pools	Fish concealment cover, % (pools)	3.8	20	20	
Wood	Woody debris count (pieces, >2.0 m/>0.10 m)	57 / 31 [1]		236	175 pieces
Wood	Woody debris freq. (pieces/km, >2.0 m/>0.10 m)	97	150-400	400	
Wood	Woody debris freq. (pieces/CW)	0.92	2-4	2	
Wood	LWD freq. (key pieces/km >10m/ >0.55 m, WCC)	0	50	50	20-30 key pieces
Wood	LWD freq.(pieces/CW)	0	>0.3	>0.3	
Wood	LWD debris jam freq. (jams/km)	0		3-5	3-5 jams
Sediment	Mean surface fine sediment, % (<6.4mm)	14.8	10-17	NA	no design objective
Sediment	Stand. Dev. Surface Fine Sediment	9			
Sediment	Geometric mean, D50, n=2	35.4			

1 - Baseline conditions from 2001 and/or 2003 surveys; rpd - residual pool depth

Criteria and targets are principally developed from NOAA (NMFS 1996), WDNR Watershed Analysis (WFPB 1997), and Fox (2001)

Figure 2. LWD pieces impaled into streambank as part of larger LWD debris jam (27 pieces).

Overall, LWD was placed in 17 locations (Figure 3), mostly in 12 LWD jam formations. In total, 124 of 170 pieces (73%) were placed in LWD jams, where at least 6 pieces touched together. Of these, 82 pieces were anchored and 42 were not anchored, but were set into the streambanks as described above. Individually, jams contained 6-27 pieces.

Planting

6740 plants, 1240 of which were conifer trees, were planted among 3.7 acres of the approximately 8-acre conservation easement over a span of five years (2003-2008, Figure 3). Prior to planting, extensive fields of mostly Himalayan blackberry were cleared from the 3.7 acres. Other knotweed species were also removed by hand and treated with aerial foliar spray approved by Washington State Department of Ecology for aquatic applications.

Pre-planting monitoring was not conducted, however based on post-planting transect data, the density of conifer trees on site before construction was 11 trees per acre (TPA). Large conifer trees able to produce woody debris in streams were rare. Assuming individual canopy cover of mature conifer trees is 5-7 meters diameter; the pre-planting conifer density was 30% below the target level of 50% canopy cover at maturity.

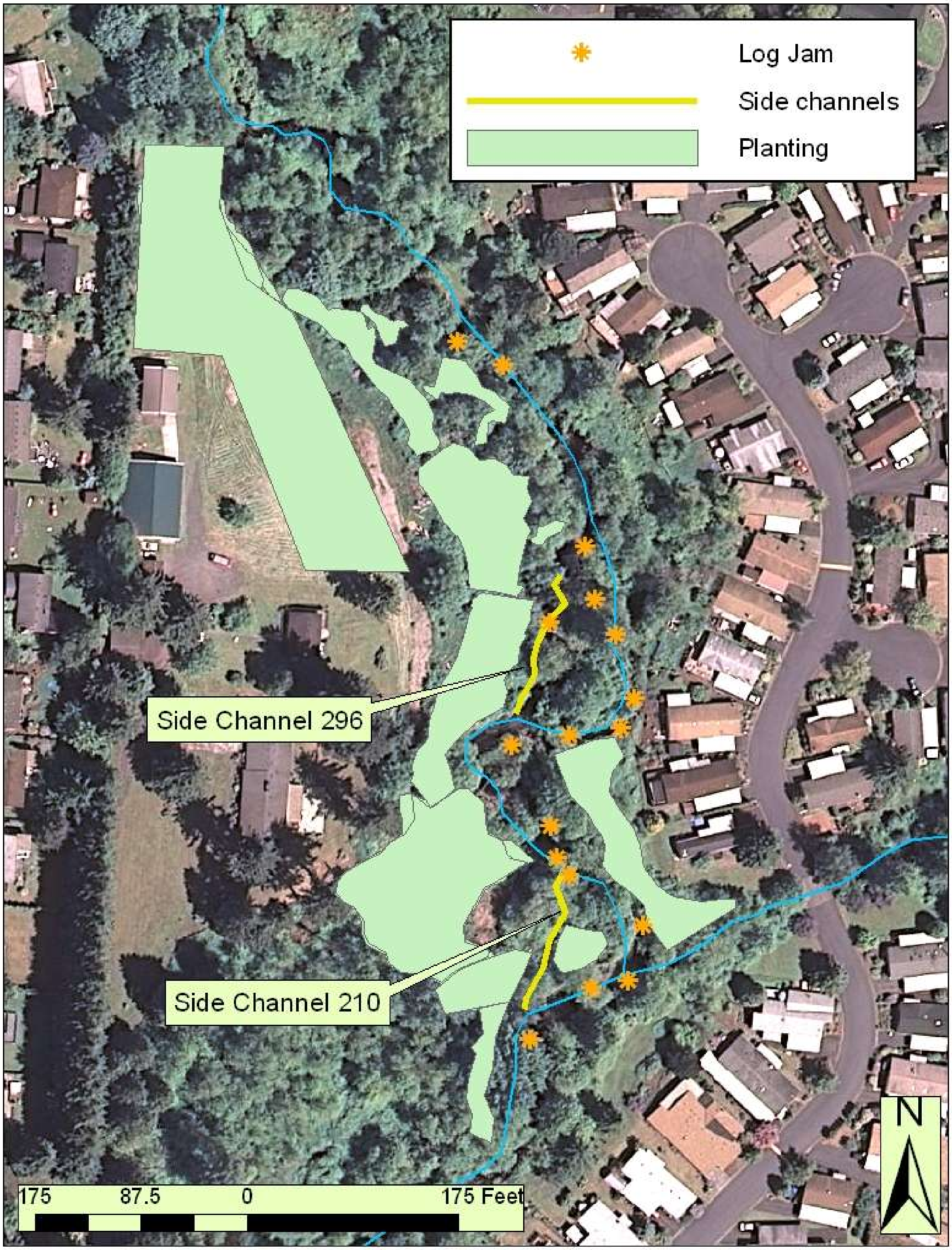

Figure 3. Twin Creeks treatment area.

Methods

This report focuses on monitoring effectiveness of treatments and outcomes. Pre-project baseline monitoring data were collected in 2001 (Snohomish County 2002) and 2003 by Snohomish County at the project site and in adjacent North Creek stream reaches. Post-project monitoring was implemented in 2004 and 2008.

Snohomish County's wadable stream habitat inventory protocol (Snohomish County 2002a and Rustay et al. 2008) was used to implement pre- and post-construction habitat surveys for LWD and other habitat/stream features. For LWD, we measured all wood ≥2m long and ≥0.1 m diameter, and identified whether the piece was part of a jam (minimum 3 pieces) or single. We indicated whether the piece was natural or placed, anchored (y/n), stable (y/n), contained a rootwad (y/n) and, qualitatively, what functions were supported; pool scour, fish cover, bank protection, sediment retention. A piece was considered to be stable if it was anchored, placed on top of the streambank, or had a length greater than the channel bankfull width.

We assessed the amount of fish concealment cover within or directly above wetted habitat units regardless of water depth. Fish concealment cover consisted of overhanging banks or vegetation within 30cm of the water surface (consistent with our densiometer method for measuring canopy cover within 30 cm of the water surface), woody debris of any size not embedded in banks or the streambed, or large rocks/boulders/riprap with cover. We measured the length and width of cover area to the nearest centimeter regardless of depth of cover and noted whether cover was contained in a pool, riffle or other habitat type. We generated an estimate of total cover (m^2), percent cover based on total habitat area, percent cover over pools, and % cover attributed to placed woody debris and naturally occurring woody debris.

To monitor stream temperature, we followed Washington State Department of Ecology guidelines for continuous temperature recording (Bilhimer and Stohr 2008). Vegetation monitoring protocols are the 2003 guidelines created for the Snohomish County Native Plant Program.

Results and Discussion

Results are organized based on project objectives and monitoring indicators. General observations are reported first followed by results relating to specific project objectives.

Since the project was constructed in August 2003, several significant flood events have occurred in 2003 (October and November), 2006 (January) and 2007 (December) (Figure 4 of flows at 240th St SE). The estimated daily peak flows associated with these 4 floods were, respectively, 387 cfs, 536 cfs, 702 cfs and 1415 cfs. These flows ranged in approximate recurrence from 25-100-year intervals (based on tables from Draft North Creek Flood Hazard Reduction Plan, CH2MHill, 1995) and appear to be larger than most recent floods since stream gaging began in 1988 (Figure 4).

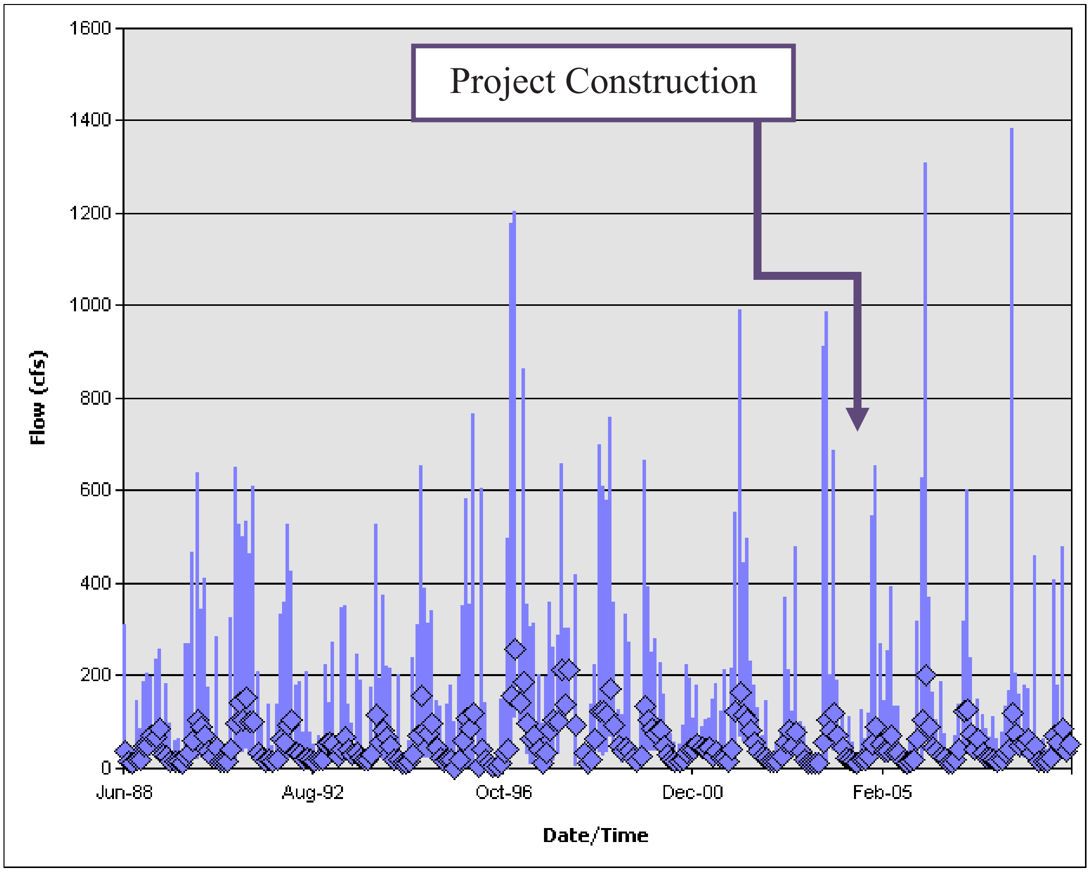

Figure 4. North Creek monthly mean flow discharge recorded at 240th Street SE, 2.5 miles downstream from Twin Creeks.

Project Objective 1 - Control erosion at one hazardous location (mobile homes) and limit new erosion elsewhere

a. Treatment design – Streambank placed and anchored woody debris at hazard location.
b. Monitoring question – Is bank instability staying the same or decreasing in the project reach? Is erosion controlled at the hazard location?
    i. Monitoring objective – identify and measure streambank erosion within the survey area and in particular at one location (totaling approximately 60 linear feet) on the left bank where use of bioengineering techniques is applied to halt erosion currently threatening 3 mobile homes.
        1. Indicator performance – no new erosion at this mobile home site; no increased erosion in segment; no difference compared to non-treated control locations.

At the erosion hazard mentioned above, 27 pieces LWD were placed and anchored together along the streambank. Several pieces were impaled higher than others (e.g., Figure 2). No new erosion has occurred at this location since project implementation. We observed flooding in 2003 produced no erosive flows at the streambank margin. In fact, wood placed at this location appeared to create low velocity eddies (Figure 5a). In five years, no additional woody debris has recruited to this location, potentially due to the channel shift described below. This location is now part of a side channel that has narrowed from vegetation encroachment, but nevertheless still supports summer base flow (Figure 5b).

Figure 5a. Mobile home bank stabilization site during October 2003 high flow event.

Figure 5b. Mobile home bank stabilization treatment in 2003 (left) and 2008 (right).

Within the project area as a whole (562 m survey length), streambank instability has been higher within the LWD placement area (260 m). Instability has likely increased due to a channel shift, side-channel expansion, meander translation, and other bank scouring since 2003. Unfortunately, bank instability data from 2003 were lost or corrupted, and, prior to that, in 2001, no bank instability was noted (see Table 1) – which is highly unlikely to have been the case. In 2004, after the first year of project monitoring, instability totaled 16% over the total length of both streambanks combined, with 19.1% in the LWD treatment area. In 2008, instability was still 16% overall, with 19.5% in the LWD treatment area. The non-treated area had less bank instability, 13.5% and 12.9%, in 2004 and 2008, respectively.

We observed tree recruitment from eroding banks at several locations (at least 4 trees from eroding banks), and significant lateral erosion shifted one meander bend approximately 2-3 meters depending on GPS locations of new bank instability and the original topographic survey of the streambank edge. Here, a large alder tree has been recruited to the channel. High function appears to be associated with newly recruited wood (see below), but some apparent meander translation away from placed LWD structures may be occurring. Thus, although limiting new bank erosion was believed to be reasonable project objective, it's not clear that that outcome was feasible. Instead, it appears additional channel roughness, combined with large flow events increased erosion at locations without placed bank protection and, as a result, triggered new woody debris (see below) and sediment/gravel recruitment from the floodplain.

Project Objective 2 – Increase side channel connections and area

c. Treatment design – streambed surface weirs for grade control, woody debris placement at island apex or flow split for flow control
d. Monitoring question – Are side channel lengths and/or total area (or wetted area) increasing? Is side channel habitat area increasing as a greater fraction of total channel area?
    ii. Monitoring objective – identify and measure length and width of all side channels (total and wetted dimensions) separated from the main flow by a forested island (with tree growth greater than 5-years age and 50% cover of mid-channel island); classify habitat types (riffle, pool, other) and measure wetted area by habitat types within side channels; estimate total wetted area as a fraction of total mainstem channel area.
        2. Indicator performance – no target or threshold selected; increasing side channel length and area compared to pre-construction condition are expected.

The prevalence of large flow events, as mentioned (Figure 4), has likely increased channel dimensions at the project site in order to convey greater flow volume during these floods, but topographic measurements are not yet available. At one side channel location (Station 296, Table 2), major channel expansion and a thalweg shift has occurred. Here, the previously minor right bank side channel was measured as having a toe-toe cross channel width of 2.3 meters (Table 2). In 2008, this dimension had expanded nearly 200% to 6.5 meters and contained the main flow of North Creek, thereby switching the "side channel" location to the previous mainstem channel. Overall, side-channel area in 2008 has increased by 140%. Other evidence of channel expansion from flooding comes from within Silver Creek (part of the easement area), where channel expansion has increased by 40% between 2008 and 2002 at 2 cross-section locations. Average toe-toe dimensions have increased from 2.6 meters wide to 3.7 meters wide.

Table 2. Side channel changes among years at two locations.

Station	**Year**	**2003**	**2007**	**2008**	**% Increase**
210	Total Length	34.3	23.1	30.2	
	Total Width	1.5	3.0	2.6	
	Area (m^2)	51.5	69.3	78.5	53
Station		**2003**	**2007**	**2008**	
296	Total Length	33.0	61.9	73.2	
	Total Width	2.3	3.8	3.1	
	Area (m^2)	75.9	235.2	226.9	199
Total Side Channel Area (m^2)		127	305	305	140

Project Objective 3 - <u>Augment woody debris abundance consistent with properly functioning conditions for a Puget Sound lowland stream.</u> Relative to a disturbed urban setting, we expect instream placement of LWD to produce habitat enhancement more typical of undisturbed streams.

c. Treatment design – Woody debris (anchored and unanchored pieces) placed in jams or singly at channel margins, channel center, on streambanks or near flow splits, or impaled into streambanks or streambed.
d. Monitoring question – potential functions provided by woody debris placement include scour for pool formation, bank protection, sediment retention or grade control, and fish concealment cover – if LWD is stable and resists stream discharge. Specifically; Is LWD retained within the project area at sites of original placement? Does LWD directly form more pools? Does LWD provide more fish concealment cover? Does LWD protect eroding banks where placed to accomplish such function? Does LWD retain or store sediment as a discrete function for individual pieces or jams? More generally, are these functions sustained over time?
    ii. Monitoring objective – inventory placed and natural LWD meeting minimum size criteria, document placement locations, stability, movement and export, and summarize woody debris frequency, loading, and functions.
        2. Indicator performance – LWD meets or exceeds habitat performance criteria; >80% stability or retention within the

project area. Compare to non-treated control locations and non-urban streams in Snohomish County.

Project Objective 4 – Enhance pool habitat quantity and quality via woody debris placement.

c. Treatment design – See Project Objective 3.
d. Monitoring question – Are pools more frequently spaced as a result of project implementation? Does LWD directly form more pools? Is pool area greater than before treatment? Are pools deeper? Is fish concealment cover over/in pools and other habitat types greater than before and meeting selected performance criteria?
    ii. Monitoring objective – identify and measure length and width of all wet habitat units and classify to type (riffle, pool, other); measure pool maximum depth and riffle depth; estimate frequency or spacing interval among pools and estimate total areal composition of pools; measure length and width of cover for fish either underwater or overwater (within 30 cm height).
        2. Indicator performance – Pool frequency and area meet or exceed performance criteria; Fish concealment cover exceeds minimum habitat performance (20%).

Habitat monitoring surveys were implemented on the following dates (Table 3) with accompanying estimated flow discharge based on records from continuous flow gaging on North Creek at 196th St SE, approximately 1 kilometer north of Twin Creeks.

Table 3. Habitat survey dates among years and estimated flow.

Year	2003	2004	2008
Survey date(s)	July 22	July 28	Oct 1
Flow, avg. day (cfs)	5.1	5.6	5.9

Project performance goals and objectives were tested relative to the LWD installation. Two of these objectives were related to flooding, and performance was met. They are; 1.) Bank stabilization with bio-engineered techniques to prevent streambank erosion along approximately 60 lineal feet near 3 mobile homes (see Figures 3 and 5), and 2.) Side channel flood capacity expansion in order to distribute flows across entire available floodplain.

To evaluate other project performance objectives related to LWD placement, we consider the following; LWD movement and characterization of wood that moves (size, anchor type, distance traveled); LWD habitat suitability rating, pool formation from LWD (increase in pool frequency) and suitable habitat changes resulting from LWD placement (increase in total pool area, pool cover, and pool depth).

Wood movement

In 2003, Eighty-eight (88) pieces were anchored to the streambed or banks (Table 3). Eighty-two pieces were not anchored with artificial materials, but of these, 76 pieces were set by force (impaled) into the streambanks or bed using heavy equipment. The remaining 6 pieces were pinned under other anchored pieces or placed with most of the log on top of the streambank.

Wood was placed in 16 locations, mostly in 12 LWD jam formations. In total, 124 of 170 pieces (73%) were placed in LWD jams. Of these, 82 pieces were anchored, 42 were not anchored but were set into the streambanks as described above. The largest jam contained 27 pieces and the smallest was made up of 6 pieces.

Table 4. LWD by placement in jams or singly and anchor type with wood movement results from 2003 to 2004.

	un-anchored			anchored	
	moved	stable		stable	moved
in jams, 36 impaled	2*	40	5% moved	83	0
single, all impaled	20**	20	50% moved	5	0

* Formed part of new jam 26 m downstream $\chi 2 = 21.4$, $p<0.001$

**Only 3 out of 20 pieces did not recruit to other placed LWD jams

The first year monitoring results clearly indicate that unanchored pieces in jams were more stable than unanchored pieces placed singly within the reach (Table 3, Chi-square goodness-of-fit test, $\chi^2 = 21.4$, $p<0.001$). It is important to note that the majority of the "unanchored" pieces were actually impaled into the streambanks or streambed. Of the pieces placed singly, pieces that were stable tended to be impaled in the streambed (evidently below the depth of recent scour), where they accumulated additional debris. Pieces placed directly into the streambank, without anchoring or ballast tended to move, likely due to bank erosion (see above).

All of the pieces that moved were accounted for within the stream reach and of the 20 unanchored single pieces that did move in the first year (Table 3), only 3 pieces did not recruit to other placed LWD jams. The average and median distance of displacement for these pieces was 48 meters. Finally, it can be calculated that single, unanchored pieces (not part of a jam) that moved were the smallest on average of all pieces placed (2.6 m long and 19 cm diameter) and were significantly shorter (about 1.0 m) than unanchored pieces placed as part of a jam (t-test of means; t=2.1, d.f.=82, $p<0.05$). Our limited testing did not determine which factor (length or jam association) is more important but both likely contribute to piece stability. If small pieces are going to be used as part of project implementation they should always be placed as part of a jam formation, unless, of course, LWD transport is a project goal. .

In 2008, five years after construction, we inventoried previously placed LWD and naturally occurring wood throughout the reach and at the wood placement locations. Whereas 22 pieces had moved previously during the 1st year after construction, we found an additional 13 pieces could not be accounted for at their original placement locations.

After five years we estimate 80% of all pieces remain at their original location. As described earlier, most pieces were placed at 16 locations (12 jams). At 9 of these sites, no wood has moved. Two locations have lost most of the wood (with 6 out of 32 pieces remaining). All of these pieces were impaled in the bank or streambed as single pieces in series along an outside meander and in the side channel that has enlarged dramatically (see above).

Whereas after the first year of monitoring we determined no wood floated out of the project site, after 5 years, we are unsure. Including the additional 13 pieces that moved between 2004-2008, we accounted for 22 out of 35 pieces that were placed originally but moved to a new location within the project site. We were confident in our identification of these pieces as part of the original project because pieces were either tagged, were relatively new conifer trees free of limbs (that had been cut), or had cut (square) ends. Therefore, it's possible 13 out of 170 pieces placed have moved out of the stream reach (downstream from 208th St SE). We conclude wood retention has been high (92%), even given large flow events, many smaller placed pieces, mass movement at 2 locations, and an original complement of almost 50% unanchored pieces.

In 2008, in addition to wood retention we documented increased abundance in the treatment area (55 new pieces) as well as up-stream and downstream control areas (47 pieces). In 2008, 8 new pieces exceeded 9.4 m length (the bankfull width) and 30 cm diameter (containing a rootwad), of which, 7 were recently downed trees. Six of these LWD pieces were in the treatment area. We suspect most other wood originated within the project area or from immediately upstream. Non-project wood loading in the treatment area equaled 1 piece every 4.7 m. In the up-stream and downstream areas, wood loading was 1 piece every 6.4 m. The current rate of bank instability (19.5% in treatment area and 12.9% elsewhere) is reflective of channel adjustment at this site due to wood placement, large flood flows and some gravel accumulation. Whereas most of the new large wood comes from undercut downed trees, smaller wood has likely originated from the tops of laterally eroding banks, floodplain recruitment, breakup of downed trees or other wind throw. The average volume of newly recruited pieces of wood was 0.37 m^3 (primarily due to length), greater than 57% of all the placed pieces, suggesting the size of naturally recruited woody debris from even degraded stream buffers can exceed the size of artificially placed pieces.

For direct comparison to previous estimates of LWD frequency and loading, we only include wood surveyed in the mainstem. We also inventoried wood in side channels where phase 2 of the Twin Creeks project has been implemented, but these pieces are excluded from our current calculation of LWD metrics.

LWD Habitat Suitability Rating

Prior to project implementation, woody debris abundance was very low and did not meet any LWD criteria threshold for suitable habitat conditions (refer to Table 2). No key pieces were present. After project implementation, based on LWD placement alone, a total of 37 pieces out of 170 placed met or exceeded Snohomish County criteria for consideration as LWD (>7.6 m/>30 cm). The complement of restored LWD, in addition to existing smaller wood exceeded most woody debris abundance thresholds in 2004 (Table 4). In particular, woody debris frequency exceeded 350 pieces per kilometer in the entire project area (Figure 6), with an even higher abundance in the LWD treatment area. This increase is all the more evident based on 5th-year monitoring in 2008. In the treatment area, woody debris frequency was estimated to exceed 800 pieces/km. LWD frequency in natural forested areas in western Washington ranges from 241-643 pieces/km (Ralph et al. 1994), 225-1,087 pieces/km (Beechie and Sibley 1997) or 292-634 pieces/km (Fox 2001), as reported in these studies. Thus, for the time being, there is a robust wood load.

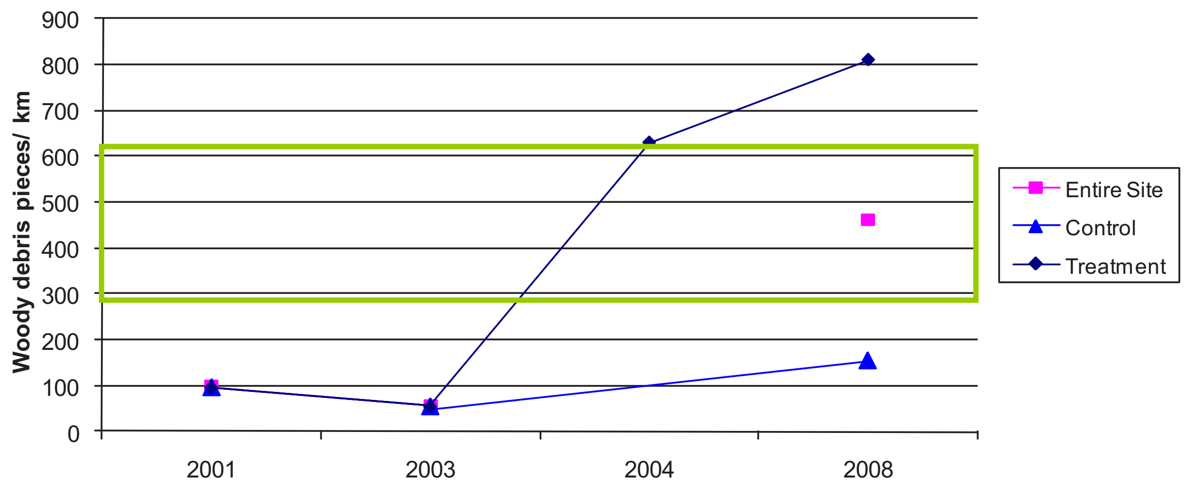

Figure 6. Changes in woody debris frequency among years in the control and treatment areas. Boxed area represents 25th-75th percentile suitable condition range in Fox (2001).

Whereas all wood debris abundance and frequency estimates appear to meet or exceed suitable habitat criteria, Table 4 shows that the largest class of LWD that would be considered a "key" piece is not present at Twin Creeks based on definitions of such pieces (i.e.; NOAA 1996; WFBP 1997). It is believed that many pieces placed at Twin Creeks act as key pieces for pool formation, sediment storage, future debris entrainment, and channel planform control because numerous pieces are longer than the average bankfull width of 9.4 meters (30 of 170 pieces placed are >9.4 m), many have root wads >1 m diameter (15 out of 30), and most large pieces are anchored (26 out of 30), thereby attaining a greater effective mass contributing to flow resistance.

Other investigators report that LWD functions (i.e. pool formation) are dependent on piece size but scaled to channel width (Beechie and Sibley 1997). For example, Beechie and Sibley (1997), report that the minimum wood size able to form pools decreases as channel width decreases based on a linear relationship, where wood diameter$_{(pool)}$ = 0.028 (BFW) + 0.0057. At Twin Creeks, the potential minimum functional piece diameter would be 27cm, suggesting the functional significance of the large wood size criterion from NOAA (1996; >10 m long and >0.55 m diameter) is not applicable (to pool formation) in smaller streams.

Table 5. Twin Creeks, woody debris performance criteria for suitable habitat condition and pre- and post-project results for all woody debris (>2m length, >10 cm diameter) and larger size classes. Shaded cells represent those LWD metrics that meet or exceed targets or habitat standards.

		2001 - pre	**2003 - pre**	**2004 – year 1**	**--------------2008 – Year 5-------------**		
Woody debris metrics; All woody debris (AWD) or large woody debris (LWD)	Suitable Habitat Condition	Total site	Total site	Total site	Total site	Treatment	Control
Survey length (m)	N/A	590*	562	562	562	260	302
Piece count, all	N/A	57	31	200 (170 placed)	260 (158 placed)	213	47
AWD frequency (>2m/>10cm); WFPB 1997	2-4 pieces/ CW	0.9	0.52	3.3	4.3	7.6	1.46
AWD frequency; Fox 2001	292-634 pieces/ km	97 pieces/ km	55 pieces/ km	355 pieces/ km	462 pieces/ km	810 pieces/ km	156 pieces/ km
LWD (key pieces >10m/0.55m or 2.5 m^3) (NOAA 1996, WFPB 1997)	0.3 pieces/ CW	0 pieces/ CW	0 pieces/ CW	0 pieces/ CW	0 pieces/ CW	0 pieces/ CW	0 pieces/ CW
LWD (key - >9.4 m length >30 cm diam., w/rootwad); WFPB 1997	0.3 pieces/ CW	0.05 pieces/ CW	0.03 pieces/ CW	0.13 pieces/ CW	0.26 pieces/ CW	0.5 pieces/ CW	0.06 pieces/ CW
LWD total volume (Fox 2001); # key pieces, based on piece volume ≥2.5 m^3	28-99 m^3/ 100m; 4-11 pieces/ 100m	N/A	<1 m^3/ 100m 0 pieces	22 m^3/ 100 m 0 piece	25.5 m^3/ 100 m 1 pieces		
Wood loading (#/m^2), (based on Beechie and Sibley 1997; Montgomery et al. 1995)	0.031-0.067 #/m^2	0.01 / m^2	<0.007/m^2	0.058/ m^2	0.071/ m^2	0.087/ m^2	0.016/ m^2

Even still, "key" piece frequency (>9.4 m, >30 cm) was low because large trees are (by-in-large) absent from the site, and for restoration, large pieces are the most difficult to procure, either in terms of cost or availability. As part of pre-project vegetation mapping, only 8 conifers exceeding 55 cm diameter were present within 150-ft of North Creek within the easement, This serves to highlight the need for adequate riparian buffer width protection and vegetation enhancement in order that all woody debris size classes will be replenished over time, but particularly the largest sizes at substantial cost savings compared to artificial placement. In the meantime, from a project design and habitat effectiveness standpoint, placing and anchoring woody debris in aggregations (or jams) to replicate key piece functions will be required.

Pools

Within the stream reach (including up- and downstream from project construction) there were 17 pools (>0.25 m residual pool depth) prior to project implementation. After one year, the number of pools increased to 33 (Table 5), and numbered 34 in 2008. Within the project construction limits (260 m), pool number increased from 10 to 20. Nine of the 10 new pools were associated with placed LWD and five of the existing pools were augmented with woody debris. Pool frequency and total pool area increased substantially (Table 5), especially within the construction area. The physical distance among pools also decreased, on average as more pools were formed. In most instances, project performance targets for pool habitat were met either after one year or 5 years, except for total percent pool area, which nonetheless increased from approximately 31% to 47 % in 5 years.

Table 6. Pre- and post-project pool statistics. Shaded cells represent those pool metrics that meet or exceed targets or habitat standards.

Pool metrics	Target	Pre-project	---------------Post-Project-------------	
		2001/ 2003	2004	2008
Stream reach		590m	562m	562m
Total pools	30 pools	17 (7 >0.6 m deep)	33 (10 >0.6 m deep)	34 (10 >0.6 m deep)
Pool frequency	35 / km	29/ km	61/ km	64/km
Pool frequency	> 0.5 / CW	0.33 / CW	0.58 / CW	0.61/CW
Pool spacing	≤2 BFW	3.6	1.7	1.7
Percent Pool Area	> 50%	30.8 %	41.3 %	46.6%
Pool Avg. Size		58.8 m^2	40.8 m^2	45.7m^2
Pool Avg. Max Depth		0.80 m	0.7 m	0.66 m
Pool Avg. RPD		0.61 m	0.48 m	0.5m
Pools ≥1 m deep	5	4	3	5

Pool metrics	Target	Pre-project	--------------Post-Project------------	
		2001/ 2003	2004	2008
LWD formed pools only		1 out of 17 pools	15 out of 33 pools	27 out of 34 pools
From placed wood		0	10	7
From "Natural" wood		1	5	20
LWD Pool Avg. Size			22.2 m^2	54.8 m^2
LWD Pool Avg. Max Depth			0.64 m	.61
LWD Pool Avg. RPD			0.40 m	0.44

By 2008, the total number of wood formed pools increased substantially even though the number of pools apparently formed by placed LWD after 2003 decreased from 10 to 7 pools. The number of pools formed from naturally occurring wood increased from 5 to 20 pools after five years, presumably as a direct result of re-arrangement of existing wood and new woody debris recruitment, including 7 downed trees. At the remaining 14 wood placement locations (2 other sites were mostly removed) several factors appear to effect changes in decreasing pool habitat functions: meander translation away from placed structures, channel switching, sedimentation, and lost pieces. We believe these mechanisms contributed to fewer pools formed by placed structures after 5 years.

The number of pools greater than 1m deep decreased initially, and then increased by 2008. The reduction in average residual pool depth in 2004 was attributable to the formation of new pools that, in some cases, barely qualified as pools based on residual pool depth (but nevertheless were consistent with our monitoring criteria). By 2008, average depth had not increased, even though a deeper pool had formed, suggesting a few deeper habitats were on average offset by shallower pools. Although in 2008, there were slight decreases in mean maximum depth and mean residual pool depth, paired t-tests on the monitoring data collected from the 19 existing pools (pre- and post construction) reveal no significant differences in pool area, maximum depth, and residual pool depth. Due to the new sediment supply within the stream reach (associated with bank instability) and possible sediment transport from upstream, an increase in sediment load may reduce pool depth as well as increase sediment storage, but anecdotally there does not appear to be any change in streambed elevation. Future cross sectional and longitudinal topographic surveys will help answer this question

Fish Cover

We assessed the amount of fish concealment cover within or directly above wetted habitat units regardless of water depth. Fish concealment cover consisted of overhanging banks or vegetation within 30cm of the water surface, woody debris of any size not embedded in banks or the streambed, or large rocks/boulders/riprap with cover. Total cover increased in each monitoring year. We did not correct for any difference in wetted area among years that could have contributed to variation in cover based on differences in wetted width, primarily affected by flow. Cover as a percentage of pool area (Figure 7, right axis labels) increased from 3.8% (2003) to 14.5% (2004) to 19.0% (2008). This increase may have been due to the 37% total increase in pool area – that is; cover over more of the channel area could be counted specifically as pool cover.

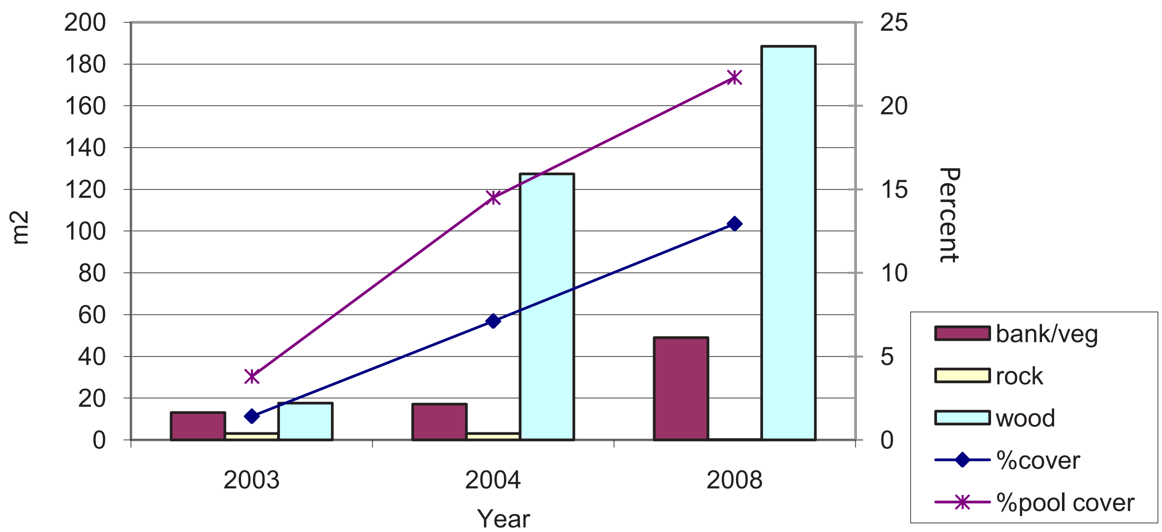

Figure 7. Total fish concealment cover by cover type, as a percent of total wetted area and as a percent of cover over pools.

We observed a 10-fold increase in the amount of wood-formed cover between 2003 and 2008 (Figure 7), due to both an increase from placed wood and from newly recruited wood in 2008 (Figure 8). In 2004, 90% of wood cover was attributed to wood placement. In 2008, 50% of wood cover was attributable to natural wood cover. The decrease in total amount of cover from placed wood reflects the reduction in number of wood formed pools (from placed wood) and apparent channel adjustment away from anchored wood locations as discussed earlier.

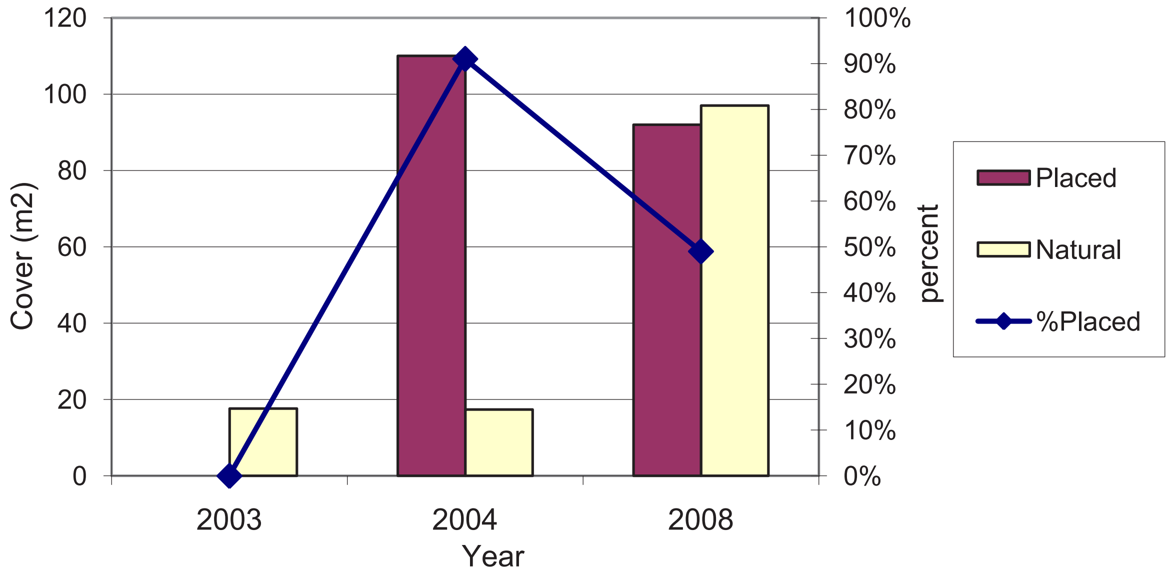

Figure 8. Total cover (m^2) and percent cover by woody debris between placed and natural wood categories among monitoring years.

Project Objective 5 – <u>Plant native vegetation within 150 foot corridor within the easement area to obtain 50% conifer cover at maturity.</u>

c. Treatment design – Remove and manage invasive species, amend soils, and plant native mix of shrubs and trees.
d. Monitoring question – Is native vegetation surviving at projected rates? Is cover of native vegetation increasing? Is management of invasive species decreasing invasive cover? Is stream bank cover and stream shading increasing from vegetation restoration?
    ii. Monitoring objective – establish line and belt transects across 150 foot project corridor. Measure species survival, growth and cover. Measure vegetation canopy cover at the edge of the streambanks and at the stream center at 11 evenly-spaced stream transects.
        1. Indicator performance – Mature tree density to create 50% cover must be over 35 trees per acre. Plant survival at 3 years should be greater than 75%. No thresholds were set for total native plant cover or invasive species cover. Cover over stream channel should be >90% at the streambank edge and >70% at the center of the channel for this site.

Table 5 lists the plant species installed at Twin Creeks by year. Approximately 2 acres of Himalayan blackberry, reed canary grass, and Japanese knotweed were cleared in August 2003 by mowing, grubbing, and hand labor. In 2005 and 2008, foliar applications of an aquatic approved herbicide glyphosate were conducted. Though this seems to have decreased the total invasive cover (Table 7), monitoring in 2008 was conducted after the herbicide application and after Phase II construction eliminated many invasive species. Though total invasive species cover is expected to decrease, the diversity of invasive species has increased. Management of these species will continue until they no longer interfere with native plant survival, or as long as state invasive species law mandates.

Table 7. Planting inventory at Twin Creeks.

Species (common name)	Species (Latin name)	2002-2003	2003-2004	2007-2008	2008-2009
grand fir	*Abies grandis*		540		25
vine maple	*Acer circinatum*		40		100
big leaf maple	*Acer macrophylla*		25		60
red alder	*Alnus rubra*	10			
serviceberry	*Amalancher alnafolia*		15		
red-osier dogwood	*Cornus stolonifera*	10	530	50	405
twinberry honeysuckle	*Lonicera involucrata*		499	25	100
Indian plum	*Oemleria cerasiformis*		492		200
Pacific ninebark	*Physocarpus capitatus*		585	50	300
Sitka spruce	*Picea sitchensis*		210		75
shore pine	*Pinus contorta*				50
black cottonwood	*Populus balsamifera ssp. trichocarpa*		94		
swordfern	*Polystichum munitum*		20		
Douglas fir	*Pseudotsuga menziesii*	3	190		75
cascara	*Rhamnus pusheriana*		22		20
stink current	*Ribes bracteosum*		100		
red flowering currant	*Ribes sangunium*	10			
baldhip Rose	*Rosa gymnocarpa*		20		40
Nootka rose	*Rosa nutkatana*	10	20		200
pea fruited rose	*Rosa pisocarpa*		20		217
thimbleberry	*Rubus parvafolium*		25		200
salmonberry	*Rubus spectabilis*		210		196
Sitka willow	*Salix sitchensis*			25	100
red elderberry	*Sambucus racemosa*				100
Douglas spirea	*Spirea douglasii*	20			
snowberry	*Symphocarpus albus*	10	45		200
western red cedar	*Thuja plicata*		208		125
western hemlock	*Tsuga heterophylla*		255		50
Total count		**73**	**3679**	**150**	**2838**

Table 8. Invasive species cover. N/A are for species not measured. Trace means species were found on site at less than 1% cover.

Species	2004 % Cover	2008 % Cover
Phalaris arundinacea (reed canary grass)	41 ± 35	15 ± 10
Polygunum spp (knotweed)	7 ± 17	trace
Rubus discolor (Himalyan blackberry)	52 ± 36	12 ± 5
Rubus Laciniatus (evergreen blackberry)	10 ± 24	trace

Cirsium vulgare (bull thistle)	N/A	trace
Convolvulus arvensis (bind weed, morning glory)	N/A	trace
Solanum dulcamara (bittersweet nightshade)	N/A	trace

After clearing and project construction, the entire area was covered with a native fescue hydroseed, as planting commenced (winter 2003-2004). Individual plant size varied, especially so for select tree species (mostly western red cedar and vine maple). Some individual ball and burlap plants ranged up to 15 feet in size, and 18 large cedar trees (>15 ft) were planted at the margin of the low floodplain terrace. Initial results from monitoring 2003 plantings show good survival in the first year, followed by a dramatic down turn by 2008 (Table 8). This decrease in survival is attributed to bank erosion that washed out many plantings, ongoing construction between 2004 and 2008 that trampled and covered many plants, and competition from naturally recruited alder and cottonwood (poplar) trees throughout the site. Cover measurements bear this out and show an increase in deciduous canopy, despite low survival. Conifer survival was low and correlates with the low cover. These measurements were taken before the 2008-2009 planting, which added 400 additional trees to the site. Variation among transects throughout the site for survival and cover indicate that some areas in the site have done better than others. This may correlate with invasive species distribution through the site, and indicate that microhabitats are forming. Data from future monitoring will help answer this question.

After planting approximately 330 conifers per acre, and in consideration of the remaining trees standing, we believe site planting will create conifer cover well over the 50% target. This calculation includes the expectation that there will be 50% mortality before maturity, and that many trees will have smaller canopies than 5 meters in diameter due to growing conditions under deciduous canopy cover.

Table 9. Percent survival and cover of the 2003 installed plantings separated into functional groups.

	2004		**2008**	
Canopy Type	Survival	Cover	Survival	Cover
Conifer	96 ± 9	14 ± 9	54 ± 15	7 ± 11
Deciduous	100 ± 0	9 ± 5	18 ± 16	61 ± 27
Shrubs	97 ± 5	31 ± 14	8 ± 9	68 ± 14

The stream canopy cover (from existing and planted vegetation) provides shading, cover, leaf litter, food supply, and other functions to North Creek. We measured canopy cover at the edge of streambanks and at the center of the stream using a convex spherical densiometer. Stream surveys implemented prior to planting (2001/2003) did not include any measurement and assessment of bank canopy cover or cover (shading) to midstream. Thus, we cannot make any comparison to pre-project bank conditions. Although some planting was on streambanks, much of the planting was farther back from the stream edge. Potential canopy cover from planting farther from the streambank will take longer to develop. Canopy cover summary conditions are reported in Table 9 for treatment and control areas. We observed the treatment area already had higher stream center and bank percent cover than the untreated area in 2007. We attribute much of the bank cover to planting efforts and to heavy natural recruitment of alder and cottonwood, as described above. In contrast, control areas had lower canopy cover at both the center of the channel and at the streambanks and do not meet our established cover criteria (Table 9).

Table 10. 2007 vegetation canopy cover for the planted treatment area and untreated area measured at the center of the stream channel and at each bank.

Treatment area	Count	Mean	Stdev	Min/Max	Percent Cover	Minimum Target
Center cover	28	13.3	4.0	2/17	78	70
Bank cover	14	16.5	1.2	13/17	97	90
Untreated area						
Center cover	16	9.5	5.5	0/16	56	70
Bank cover	8	15.0	2.8	10/17	88	90

As mentioned earlier, some monitoring reflects concerns regarding ecological limits to project performance (from the urban setting) or uncertainty regarding project effects on non-treated habitat conditions, specifically temperature, sediment and biotic integrity (as measured by benthic index of biotic integrity).

Temperature

North Creek is designated as a salmon spawning, rearing and migratory habitat area, and as such, the temperature compliance standard for the 7-day average daily maximum is 17.5° Celsius. We monitored stream temperature here in 2002, 2005, 2007, and 2008 at up to 3 locations in the project vicinity. Our temperature sampling sites in North Creek were downstream from Silver Creek (approximately 110 meters), upstream from Silver Creek (approximately 110 meters), in Silver Creek (upstream approximately 30 meters upstream from the confluence with North Creek), and a location to collect air temperature. All sites were completely shaded throughout the summer. The North Creek location upstream of Silver Creek appears to exceed the temperature criteria in 3 out of 4 sample years (Table 10), and in 2008, in particular, exceeded temperature standards 21.5% of the time.

Our sampling suggests that Silver Creek, which itself receives spring-fed discharge during summer, dramatically affected downstream temperature in North Creek in 2008 within our project area. In 2008, we observed North Creek downstream from Silver Creek was up to 2.5 degrees cooler during the warmest summer temperatures than the North Creek location upstream from Silver Creek – a distance of separation of 225 meters. Temperature sampling in 2007 showed a similar pattern but no dramatic differences. Sampling in 2002 confirmed that lower Silver Creek (our monitoring location) is strongly influenced by discharge from Sulfur Spring Creek which directly discharged uniformly cold groundwater throughout the summer (mean 7-day average daily maximum = 11.8° C).

Table 11. Twin Creeks summer water temperature summary statistics among years for several project area locations compared to North Creek temperature criterion (17.5 °C).

Year, Period	Site	Days	Instant Max T °C	Mean 7DAD Max T°C	Days >17.5 °C	Time, % days >17.5 °C
2002, 6/24-9/30	Upstream	99	18.3	15.0	0	0
2005, 6/24-9/30	Upstream	99	18.1	15.6	4	4.0
2007, 6/26-10/1	Upstream	95	19.4	15.4	8	8.4
	Silver Cr.	95	17.9	14.7	0	0
	Downstream	95	19.0	15.3	4	4.2
2008, 6/24-9/30	Upstream	99	20.1	15.8	20	21.5
	Silver Cr.	99	17.5	14.6	0	0
	Downstream	99	17.3	14.5	0	0

In 2008, temperature data were also available from other North Creek locations upstream from our project site, including at 164th St. and 196th St (Figure 9). The temperatures at these locations are cooler than at Twin Creeks. In general, water temperature appears to increase in a downstream direction over the course of several miles. At the 196th St stream gage, temperature exceeded the temperature standard 3.2% of the time (3 days) in 2008. Between 196th St. and the Twin Creeks project site, downstream warming in this ¾ mile segment of North Creek led to three weeks additional water temperature exceedance in 2008, until becoming abruptly cooler at the confluence with Silver Creek.

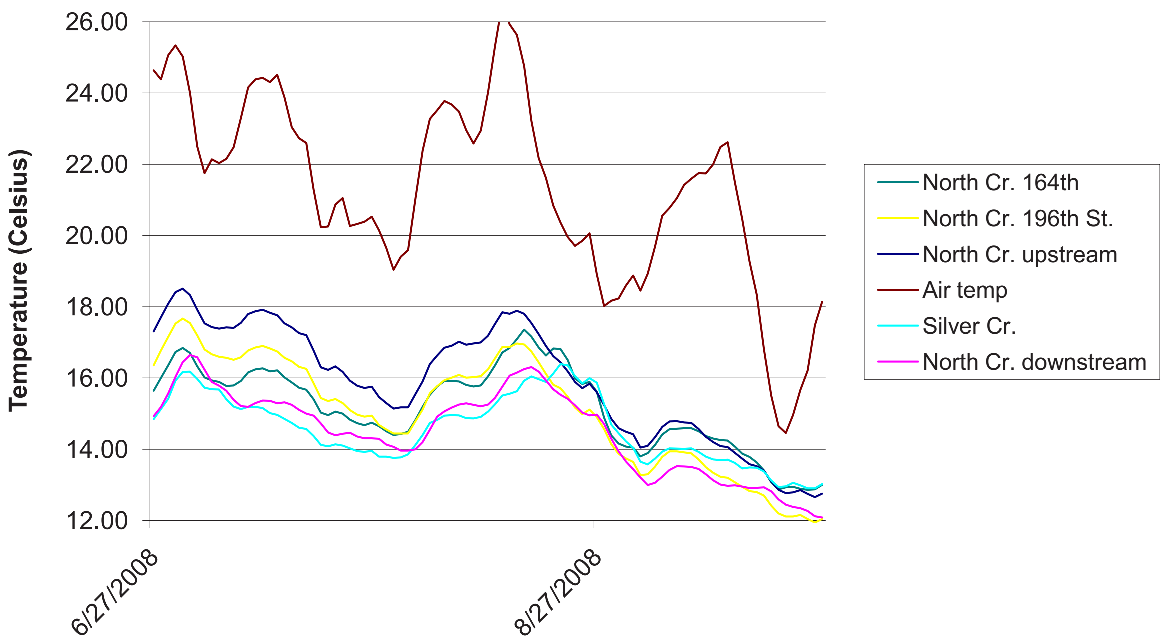

Figure 9. North Creek water temperatures among several sites over three months. Legend site labels correspond with upstream-to-downstream sample locations separated over three miles.

Silver Creek appears to buffer water temperature the most in North Creek (at least downstream to our sample site) during the warmest days. We found the absolute difference in temperature ranged from 0.26-2.6° C and this absolute difference was strongly correlated with air temperature (r^2=0.72), presumably because stronger groundwater influence in Silver Creek (originating from Sulfur Springs Creek) kept Silver Creek temperatures comparatively low no matter the air temperature. That is; temperature variability in Silver Creek was low relative to daily air temperature fluctuations and as compared to the upstream North Creek location.

Finally, the difference in temperature between upstream and downstream locations in North Creek may also become less pronounced if the relative flow contribution of Silver Creek declines more than North Creek over the course of warm summer months. Silver Creek is not gaged and we did not measure flow during 2008. North Creek discharge apparently reached a summer base flow of approximately 4-5 cfs (at the 196th St stream gage, Table 3).

These results and our additional interpretation have significance for testing project effectiveness and apply to restoration planning. With regard to effectiveness, temperature impairment (or other water quality concerns) may limit the suitability of habitat for fish, even where structural habitat (e.g.; pools, woody debris, bank cover) is demonstrably enhanced. With regard to restoration planning, at Twin Creeks, an 8-acre conservation easement was obtained. However due to ease of access and other factors, we chose to implement most of the project upstream of the thermal cooling from Silver Creek. In all, we enhanced approximately 307 m upstream (including planting) and only 48 m downstream of Silver Creek. Although benefits from documented habitat enhancement likely have mitigative value upstream, the absolute maximum benefit from similar treatments might have accrued downstream.

Since there are several tributaries to North Creek elsewhere in the subbasin that contribute groundwater discharge during summer months (i.e., Palm Creek, Coal Creek, Penny Creek, Sitka Creek), we envision several North Creek reaches with low summer temperatures that likely degrade (warm up) downstream from the cool water source. This could lead to substantial patchiness in temperature quality among stream reaches in North Creek, potentially exacerbated by riparian degradation and any reduction in tributary summer base flow (predominantly ground-water fed). By bridging longitudinal stream corridor “gaps” in thermal quality with targeted riparian enhancement, greater temperature continuity may be achieved, especially if temperature exceeds standards in these gaps, affecting growth, survival and migration. Based on this scenario, the number of days with temperature exceedances among all locations might not be reduced, but the total number of locations affected and the total area affected could be reduced.

Substrate

Substrate size in streams can be altered by local or watershed disturbance from land clearing and streambank erosion in developed settings. Excessive supply and delivery of finer substrates (<6 mm) can degrade habitat quality for fish and other aquatic life, thereby limiting productivity. We sampled streambed surface substrate using a commonly applied pebble count technique in 2003, 2004 and 2008. Substrate size was measured in 2001 using a different technique (visual estimation using a wire grid) and results are reported in Table 1. Based on the grid technique, surface fine sediment <6.4mm was estimated to be 14.8% among four riffle locations. In 2003, percent average fine sediment <6.0 mm was estimated to be 1.5% among four riffles. Each of these techniques likely provides a relative estimate of the amount of fine sediment but neither measures the actual fine sediment content that could impact incubating salmonid eggs within gravel substrates. We consider the relative changes among years using the pebble count technique. After project implementation in 2003, the composition of surface particle sizes among several locations became much finer (Table 11) by 2008.

Table 12. Estimated percent composition of substrate sediment <6mm among several sites and years of sampling.

		Year		
Location	Sample	2003	2004	2008
Control	Site 1		12%	12%
Treatment	Site 2	1%	12%	14%
Treatment	Site 3	1%	4%	16%
Treatment	Site 4	2%	8%	
Control	Site 5	2%		
Average[1]		1%	8%	15%

1 - among sites 2, 3, 4

Although sampling among sites in 2008 was incomplete, the abundance of more fine sediment is visually apparent. At site # 3, in particular, the substrate size composition among years demonstrably becomes finer as more of the total substrate sample falls into finer size class categories (Figure 10). The change in abundance of fine sediment may be widespread in North Creek, but also may be localized to the project site. As indicated, new erosion of banks and side channel expansion would have supplied fine sediment to North Creek at this project. A 40% channel expansion in Silver Creek, as measured, also could have delivered fine sediment to North Creek. Other field surveys of North Creek (and tributaries) proposed for 2009 will allow us to estimate whether fine sediment at Twin Creeks is locally elevated, reflecting major project changes, or is more widespread, reflecting wider watershed disturbance.

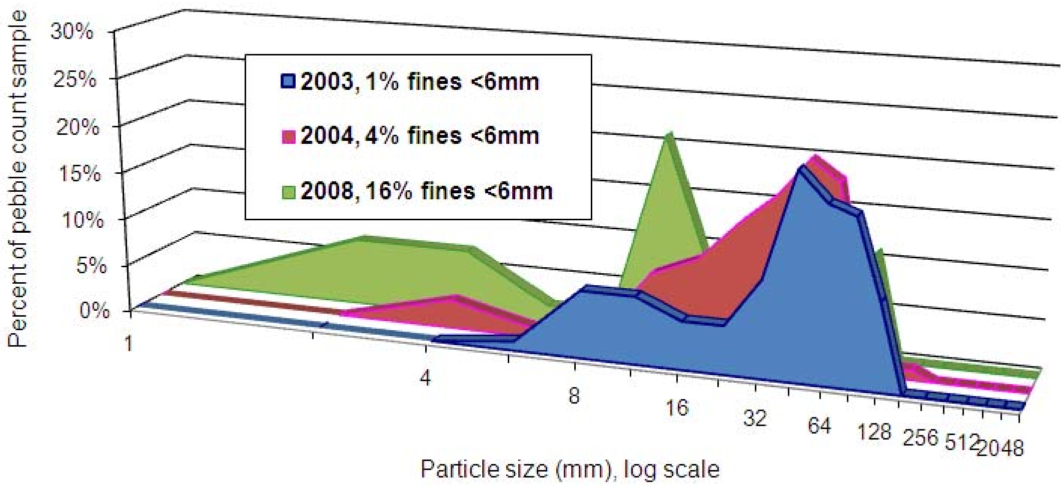

Figure 10. Twin Creeks, pebble count site #3, substrate particle size distribution among sample years and percent fine sediment <6mm, as measured by pebble count methods.

Benthic Index of Biotic Integrity (BIBI)

The biotic integrity at Twin Creeks as measured by 10 metrics of the stream benthic invertebrate community was first estimated in 1995. Other locations in North Creek have also been monitored for biotic integrity in the last 15 years. Biotic integrity index values for Twin Creeks are shown in Figure 11. Whereas there appears to an increase in biotic integrity scores after project implementation in 2003, other North Creek locations also appear to increase during this time, limiting interpretation of restoration effectiveness relative to wider improvement (or upward variance) in B-IBI scores. After sampling in 2008, the B-IBI score at Twin Creeks appears to be the highest in all of North Creek, suggesting additional improvement is not likely. Future sampling at Twin Creeks and elsewhere among urban(izing) subbasins will help us to interpret existing status and future changes in B-IBI at Twin Creeks.

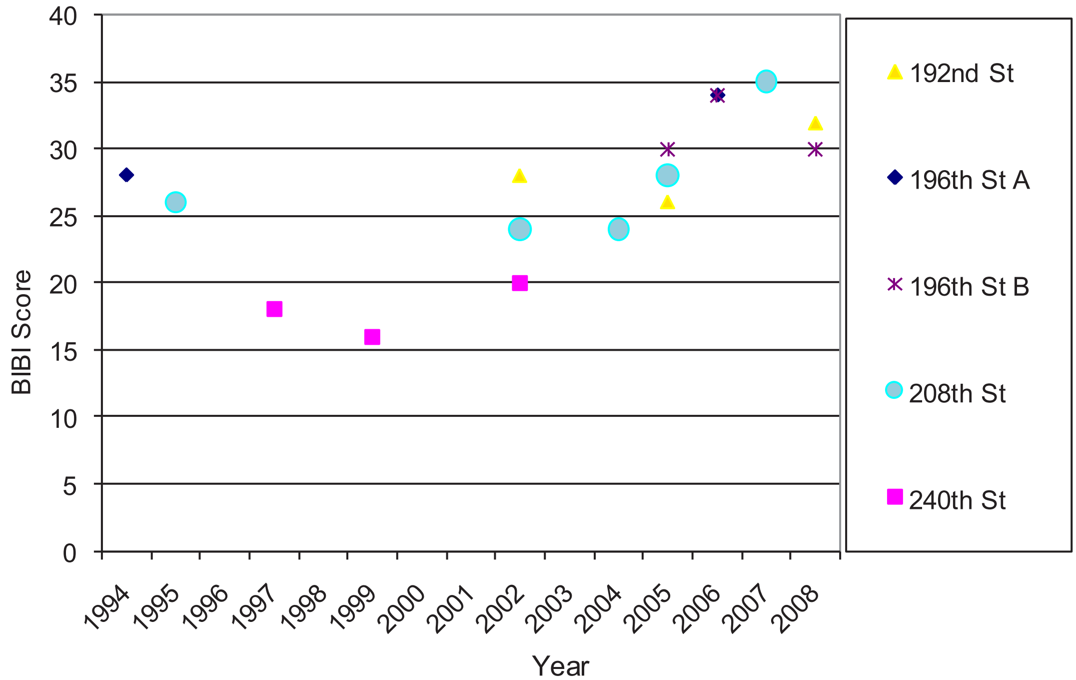

Figure 11. North Creek B-IBI values among several locations, including Twin Creeks (@208th St). Sample locations are denoted by nearest cross street and are ordered north to south, spanning 3.6 stream miles (192nd-240th). Sampling occurred in 2 years prior to project implementation in 2003 and three years post-project implementation.

Conclusions and Recommendations

For most of the project objectives, monitoring results suggest high effectiveness of our treatments based on implementation performance after 5 years. At the same time, we observed higher than anticipated streambank instability and possible increase in supply of finer sediments as a result. Otherwise we found;

- High LWD stability,
- High LWD retention within the project area,
- Rapid pool-forming response and persistence due to LWD placement (particularly in jam formations),
- Substantially higher fish cover from both placed LWD and naturally recruited LWD after 5 years, and
- Low plant survival but rapid increase in cover.

The amount of new LWD in 2008 was large compared to 2003/2004 and much of it was highly functional in terms of pool formation and cover as well as average size in comparison to placed LWD. Placed wood, after 5 years, appeared to be less functional; perhaps due to stream meandering or sedimentation that may have shifted the stream course away from anchored jams. Long term monitoring (10 years) will be needed.

After 5 years, pool frequency and total pool area has increased substantially to nearly meet both performance targets. New naturally-recruited LWD appears to have been important for increasing or maintaining these pool conditions. After 5 years, pools formed by naturally-occurring LWD (in some cases by downed trees and root wads) appeared larger in size than those formed by placed LWD.

The new channel roughness from LWD and strategically placed LWD jams, in combination with 4 large flooding events, has led to channel shifting and side channel expansion compared to pre-project conditions. We surmise floodplain storage capacity has increased as a result. Phase II of the Twin Creek project (Built in 2008) will promote greater floodplain connectivity, flood storage, and habitat formation as well.

At Twin Creeks, over three acres of the conservation easement have been planted to date after removal of invasive vegetation species, principally Himalayan blackberry and knotweed species. Other natural recruitment of alder trees has also contributed to rapid vegetation density and cover and in some locations, bank stabilization.

Our project recommendations for monitoring, design and implementation to enhance future effectiveness at this site or others include the following:

Monitoring:

- For individual projects, a Before-After-Control-Impact (BACI) study design is preferable to either a retrospective or before-after design. Select a control site (preferably upstream) that is long enough and in a similar geomorphic setting (gradient, confinement, substrate size) to adequately control for the potential treatment effects. At Twin Creeks, the “control” area was probably too short and split between upstream and downstream areas.

- Be sure data management precautions exist to prevent loss of (electronic) data over years, either by printing raw data or improving file storage management, access, and security (from accidental deletion or file movement).

- Channel dimensions – at the project scale, a longitudinal topographic survey as well as regularly spaced cross section topographic survey should be implemented and repeated at each monitoring interval to quantitatively summarize changes in habitat unit composition, residual thalweg depth, channel alignment, and streambed aggradation or incision.

- Sediment – for the project scale, consider multiple approaches to sampling sediment in order to detect with statistical confidence changes in fine sediment composition. Multiple techniques could include more pebble count locations, pebble counts at multiple, evenly spaced transect locations, visual estimation of surface fine sediments at riffles using a grid method, or grab samples of streambed gravel for volumetric (mass) analysis of fine sediment content. Because fine sediments can be supplied within the project area from (treated or untreated) eroding streambanks, as a result of channel expansion from LWD placement, or conceivably, from cleared riparian areas (prepared for planting), it is important to quantify streambed sediment changes in order to more comprehensively interpret project outcomes, even if sediment is not a targeted parameter.

- LWD – In future years, measure the length and diameter (at the length mid-point to facilitate volume calculations) of individual pieces of LWD. At the project scale we are interested in functional responses due to project treatments and better quantifying LWD size will help improve estimates of piece functions related to piece size that should vary among projects implemented in different size streams/rivers. At the same time, each piece should be noted for how much of the bankfull width the piece obstructs (based on the categories; 0%, <10%, 10-40%, 40-75%, >75%). A piece spanning ½ the bankfull distance will be classified as 40-75% obstruction. All wood should be tagged or otherwise individually identifiable.

- Temperature – In advance of site specific treatment design, stream temperature should be investigated as part of project feasibility analysis. In many streams, summer stream temperature may be highly variable even among nearby locations due to tributary influences or area groundwater discharge. Some sites may be too warm for fish use during summer and structural habitat enhancement may not be beneficial if high quality summer rearing habitat is the primary objective. Alternative site locations may be needed.

Treatment Design:

- Don't impale wood into stream banks, especially as an approach to "anchor" smaller single pieces. Impaling LWD into streambanks may have destabilized some banks at this site directly or indirectly due to wood buoyancy/vibration during flooding.

- If possible, place all small wood and any pieces without root wads into jam accumulations

- Don't anchor wood that is large enough to form pools based on minimum functional diameter and if length is greater or equal to bankfull width. Minimally anchoring LWD will allow for some movement during flooding that will likely keep LWD in alignment with the channel thalweg.

- If possible, alternate banks for sequential wood placement to limit abandonment of placed LWD due to stream course shifting where that may be likely. This may not be a concern if naturally erosion resistant banks are opposite from placed LWD.

- Where bank stabilization is needed or required, allow for additional downstream channel capacity. Otherwise, expect bank erosion to transfer downstream, especially if other LWD placement occurs downstream of treated banks.

- If possible, avoid LWD placement on top of existing bars, where sediment deposition alone would tend to move the thalweg. If possible, place LWD at the apex of a bar, in meander bends, or on banks in alternating (left bank-right bank sequence).

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