# Influence of Habitat Complexity and Floodplain Reconnection Projects on the Physical and Biological Conditions of Seattle Urban Streams: Pre-Project Monitoring. Final Progress Report, 2005-2007.

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## Table of Contents

Table of Contents ..... ii
List of Figures ..... iii
List of Tables ..... v
Abstract ..... vi
Introduction ..... 1
  Study Area ..... 9
Methods ..... 19
  Channel morphology, streambank condition, and vegetation ..... 19
  Hyporheic Investigations ..... 21
  Hydraulic Investigations ..... 23
  Instream Habitat ..... 24
  Fish ..... 27
  Benthic Invertebrates ..... 28
  Periphyton ..... 29
Results and Discussion ..... 29
  Channel morphology, streambank condition, and vegetation ..... 29
  Hyporheic Investigations ..... 37
  Hydraulic Investigations ..... 44
  Habitat and Cover ..... 46
  Fish ..... 54
  Benthic Invertebrates ..... 62
Summary ..... 65
  Physical ..... 65
  Biological ..... 65
Problems ..... 66
Recommendations ..... 68
Acknowledgements ..... 69
References ..... 70
Appendices ..... 75

Final 10/2008

## List of Figures

Figure 1. Photos of the 95th St Control (above) and Treatment (below) reaches, Thornton Creek, Seattle, March 2006. ..... 11
Figure 2. Photos of the North Fork Confluence Treatment (above) and Control (below) reaches, Thornton Creek, Seattle, July 2006. ..... 13
Figure 3. Photos of the South Fork Confluence Treatment (above) and Control (below) reaches, Thornton Creek, Seattle, July 2006. ..... 15
Figure 4. Photos of the Knickerbocker Control (above) and Treatment (below) reaches, Thornton Creek, Seattle, July 2006. ..... 17
Figure 5. Restoration (treatment) and control reaches sampled in the Thornton Creek watershed during this study. ..... 18
Figure 6. Piezometer and stilling well installed at the 95th Street treatment reach on Thornton Creek in June 2006. The piezometer was installed at a depth of 1.3 m within the streambed and equipped with a pressure transducer and thermographs to monitor water depth and temperature gradients within the well. The stilling well was equipped with a pressure transducer to measure water surface elevation and surface temperatures. ..... 22
Figure 7. Example of locations where velocity measurements would be obtained during peak flows to determine velocity gradients, velocity shadows, and high-velocity cores, to construct isovel diagrams, and develop hydraulic models. Locations of measuring points and verticals at each of the three reference cross sections at the 95th Street reaches and at the Knickerbocker treatment reach in Thornton Creek were based on isovels (lines of constant velocity) and transition zones. ..... 24
Figure 8. Beaver dam constructed in the 95th Street treatment reach on Thornton Creek, July 2006. ..... 32
Figure 9. Temperature (ºC) differences between surface water and shallow (10 cm deep) inter-gravel water recorded at 95th Street (95) and Knickerbocker (KNK) control (C) and treatment (T) reaches, on Thornton Creek. Inter-gravel temperatures were recorded during summer base flow conditions on September 7, 8, (95th Street reaches) and 28, (Knickerbocker reaches) 2006. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles. ..... 42
Figure 10. Vertical temperature gradient in the streambed substrate, as a function of bottom level piezometer temperature on September 4, 2006. ..... 44
Figure 11. Percent habitat available at 95th Street (95), Knickerbocker (KNK), and North (NFC) and South (SFC) Fork Confluence control (C) and treatment (T) reaches in Thornton Creek between August 30 and September 14, (summer) 2005, March 14 and March 21, (winter) 2006, and July 17 and August 1, (summer) 2006. Numbers above the bars represent total surface area ($m^2$) ..... 48
Figure 12. Photo of complex pool habitat formed by a log jam in the Knickerbocker control reach, Thornton Creek, September 2006. ..... 50

Final 10/2008

Figure 13. Photo of complex pool habitat formed by large wood at the 95th Street treatment reach, Thornton Creek, September 2005. ..... 50
Figure 14. Photo of complex pool habitat formed by large wood in the North Fork Confluence control reach in Thornton Creek, September 2006. ..... 51
Figure 15. Percent cover type ($m^2$) available at 95th St (95), Knickerbocker (KNK), and North (NFC) and South (SFC) Fork Confluence control (C) and treatment (T) reaches in Thornton Creek during between August 30 and September 14, (summer) 2005, March 14 and March 21, (winter) 2006, and July 17 and August 1, (summer) 2006. Cover types are as follows: CBJ = complex beaver jam, CLJ = complex log jam, FW = fine wood, HC = hydraulic cover, OHV = overhanging vegetation, RC = rock cover, SWL = single wood large, SWP = simple wood pile, SWS = single wood small, and UB = undercut bank. Total cover surface area ($m^2$) is listed above each bar. ..... 52
Figure 16. Length-frequency histograms of cutthroat trout captured between August 30 and September 14, (summer) 2005, March 14 and March 21, (winter) 2006 from 95th St (95), Knickerbocker (KNK), North (NFC) and South Fork Confluence (SFC) control (C) and treatment (T) reaches on Thornton Creek. ..... 59
Figure 17. Length-frequency histograms of coastrange sculpin, prickly sculpin, and coho salmon captured between August 30 and September 14, (summer) 2005, March 14 and March 21, (winter) 2006 from 95th Street (95) and North Fork Confluence (NFC) control (C) and treatment (T) reaches on Thornton Creek. ..... 61
Figure 18. BIBI scores measured at 95th Street (95) and Knickerbocker (KNK) control (C) and treatment (T) reaches in Thornton Creek, August 2005. ..... 63

Final 10/2006

## List of Tables

Table 1. Proposed hypothesis, study parameters, relevance, sampling protocols, and metrics where proposed sampling will occur..... 4
Table 2. Description and abbreviations of cover types documented within control and treatment reaches in Thornton Creek between August 30 and September 14, (summer) 2005, March 14 and March 21, (winter) 2006, and July 17 and August 1, (summer) 2006. ..... 26
Table 3. Summary of channel morphology at Knickerbocker and 95th Street control and treatment reaches, Thornton Creek. Within each reach, transects were arranged from upstream to downstream. Regional curve estimates of bankfull cross sectional area are from Castro and Jackson (2001). Bankfull dimensions, width, depth, and cross sectional area refer to the elevation of the top of bank, i.e., the slope break where the near vertical and usually un-vegetated streambank transitions into the adjoining upland surface. In cases where slope or morphology changed noticeably within the reach, average slopes were computed for the upstream and downstream portions separately (in order from top to bottom in the table)..... 35

Final 10/2008

## Abstract

We documented pre-restoration physical and biological conditions at four reaches in Thornton Creek, 95th Street, N.F. Confluence, S.F. Confluence, and Knickerbocker. For each study site (treatment) a control reach was selected. The purpose of this report is to provide a summary of pre-project data collected during the first year and a half of this long-term monitoring project to evaluate the effectiveness of Seattle Public Utilities (SPU) habitat complexity projects. Physical conditions documented included channel morphology, streambank condition, vegetation, regional surface/groundwater interactions, and hydraulic interactions, and instream habitat. Biological conditions included fish, benthic invertebrates, and periphyton.

Final 10/2008

## Introduction

The listing of Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*) as threatened (Federal Register Volume 64, 14308) has raised awareness of land use impacts and other management activities on salmonids in the region. This awareness has resulted in significant efforts to restore and protect salmonid habitat throughout the region, including in the City of Seattle. Seattle Public Utilities (SPU) has conducted numerous aquatic habitat restoration projects, costing millions of dollars over the past decade. These projects have addressed the hydrologic, water quality, and habitat degradation resulting from urbanization within the city of Seattle. However, the effectiveness of these projects and the accuracy of SPU's assumptions regarding limiting factors in these urban streams have not been assessed.

Urbanization degrades lotic systems by modifying the physical processes which influence stream habitats. Physical changes resulting from urbanization include hydrologic (Moscrip and Montgomery 1997; Fitzpatrick et al. 2005; Konrad and Booth 2005) and geomorphic alterations (Fitzpatrick et al. 2005). For example, peak flow increases with increased urban land use (Moscrip and Montgomery 1997; Fitzpatrick et al. 2005; Konrad and Booth 2005). Increased peak flow may result in increased channel size (Fitzpatrick et al. 2005) and channel simplification in the form of reduced pool habitat (Silva 1995; Cooper 1996). Large wood is also reduced as urbanization increases (Cooper 1996; Finkenbine et al. 2000). Changes in substrate composition have been related to urbanization in some cases (Cooper 1996) but not others (Fitzpatrick et al. 2005). These physical changes often result in biological changes.

Biological communities are generally impacted as a result of the physical changes associated with urbanization. These impacts are observed throughout the aquatic community. Macroinvertebrate communities are negatively impacted by increased urbanization based on the relationship between benthic index of biotic integrity (BIBI) scores and measures of urbanization (Cooper 1996; Morley and Karr 2002; Booth et al.

Final 10/2008

2004). The diversity (Serl 1999; Wang et al. 2000; Long and Schorr 2005), abundance (Weaver and Garman 1994; Wang et al. 2000), and health (Wang et al. 2000; Fitzpatrick et al. 2005; Long and Schorr 2005) of the fish community, based on the fish index of biotic integrity (IBI) also generally decreases with increasing urbanization. However, others have shown that urbanization has little influence on fish community health based on individual fish metrics (Lin and Ambrose 2005) or the IBI (Limburg et al. 2005). With relationships not clearly understood, the best method of restoring these biological communities in urban systems is unclear.

There is limited information regarding the effectiveness of different restoration activities in heavily urbanized streams (Morley and Karr 2002; Booth et al. 2004; Brown et al. 2005). In addition, different methods of restoration have been proposed. Finkenbine et al. (2000) suggest that large wood introductions would be an important strategy for stabilizing urban streams. In contrast, Konrad and Booth (2005) suggest that reducing the hydraulic effects of urbanization is most important. SPU has committed significant resources to reducing hydraulic effects and restoring habitat complexity through large wood introductions and floodplain restoration. They have also identified a need to monitor the effects of these restoration activities, which will allow them to prioritize those activities that are most effective.

Thornton Creek, like many urban streams (see above), suffers from an altered hydrologic system, which has resulted in habitat degradation (TCWMC 2000). The TCMWC (2000) identified three major problems in this watershed that directly influence the health of the aquatic ecosystem: high stream flows resulting from stormwater runoff, degraded water quality and habitat degradation. Excessive stormwater runoff has resulted in significant erosion of stream banks and bed scour (TCWMC 2000). This has resulted in stream channelization and reduced in-stream large wood (TCWMC 2000). These physical alterations have negatively influence the biological communities in this system (Cooper 1996; Serl 1999)

Final 10/2008

The specific objectives of the habitat complexity monitoring are to determine: 1) if reconnecting the creek and floodplain and adding in-stream structures (large wood) will improve channel conditions and habitat complexity and 2) if these increases in channel and habitat complexity will promote more abundant or diverse aquatic communities (Table 1). The purpose of this report is to provide a summary of pre-project data collected during the first year and a half of this long-term monitoring project to evaluate the effectiveness of SPU's habitat complexity projects.

Final 10/2008

Table 1. Proposed hypothesis, study parameters, relevance, sampling protocols, and metrics where proposed sampling will occur.

| **Hypotheses** | **Study Parameter** | **Relevance** | **Sampling Protocols** | **Metrics** |
|---|---|---|---|---|
| Through improved channel complexity, habitat complexity restoration projects will promote more abundant or diverse benthic invertebrate and fish communities. | Fish | Biological impetus for restoration work; as top stream predators, integrator of overall watershed health | Multiple-removal electrofishing for estimating population size, PIT tagging of fish in Piper s to monitor movement, growth and survival (Carle & Strub 1978; Murphy & Willis 1996; Roni & Fayram 2000) | 1. Taxonomic composition<br>2. Density<br>3. Size distribution<br>4. Total biomass<br>5. Growth<br>6. Movement<br>7. Survival |
| | Benthic Invertebrates | Excellent indicator of local site condition; key food source for fish; major nutrient cyclers; relatively quick response time; existing long-term SPU monitoring data | SPU urban creeks benthic invertebrate sampling protocol (Reed 2005). | 1. B-IBI |
| | Periphyton | Sensitive to changes in substrate, flow, and water chemistry; good indicators of water quality; key food source for invertebrates; quick response time | Periphyton sampling will follow USGS NAWQA protocols (Moulton et al. 2002) | 1. Total organic matter density<br>2. Total inorganic matter density<br>3. Chlorophyll–*a* density<br>4. Diatom taxonomic composition |

Final 10/2008

| Hypotheses | Study Parameter | Relevance | Sampling Protocols | Metrics |
|---|---|---|---|---|
| Reconnecting the creek and floodplain (through armoring removal) and adding structure will improve creek channel conditions and complexity. | Habitat Type | Physical template for stream biota; may change as a result of flow alteration | Classification of habitat types (pool, riffle, etc.) within study reaches will follow the protocols of Bisson et al. 1982 | 1. Habitat diversity<br>2. Riffle:pool ratio<br>3. Pool dimensions |
| | | | Cover (wood, hydraulic, and rock) within treatment and control reaches will be sampled following USFWS protocols (Peters et al. in prep.) | 1. % wood cover in wetted width<br>2. % hydraulic cover in wetted width<br>3. % rock cover in wetted width<br>4. % undercut banks |
| | Channel morphology | | Establishment of monumented cross-sections and long-profiles will follow USFS protocols (Harrelson et al. 1994) | 1. Channel gradient<br>2. Channel width<br>3. Depth diversity<br>4. Channel incision (entrenchment ratio)<br>5. Streambank condition |
| | Streambed Substrate | Stream biota such as benthic invertebrates and periphyton are | 1. Volumetric sampling<br>2. Streambed | 1. Bed surface size distribution ($D_{50}$, $D_{16}$) |

Final 10/2008

| Hypotheses | Study Parameter | Relevance | Sampling Protocols | Metrics |
|---|---|---|---|---|
| | | sensitive to changes in streambed particle size; particle size may change as a result of proposed restoration | photography | 2. Relative roughness ($D_{84}$:bankfull depth)<br>3. Bulk size distribution (including embedded fines)<br>4. Qualitative mapping of reach substrates |
| | Streambed Sub-surface | Bedload sediment regime indicated by subsurface size distribution and comparison of surface to subsurface; hyporheic environment affected by subsurface fine sediment content | Volumetric sampling | 1. Sub-surface size distribution<br>2. Surface to subsurface size ratio |
| | Hyporheic Reach-scale Monitoring (Regional influx/efflux of groundwater) | Influences spawning habitat quality, temperature recovery | Piezometer well, hydrostatic head, and temperature profile | Magnitudes of groundwater influx/efflux to reach |
| | Hyporheic Intensive Sampling (Local patterns of upwelling/downwelling) | Influences spawning habitat quality, temperature resilience and micro-habitat diversity | One-day intensive streambed temperature mapping (winter, summer) | Pattern of upwelling and downwelling within reach |

Final 10/2008

| Hypotheses | Study Parameter | Relevance | Sampling Protocols | Metrics |
|---|---|---|---|---|
| | Floodplain access and hydraulic conditions | Off-channel habitat and low-velocity refugia affect rearing habitat quality; overbank flow influences riparian zone succession, sediment storage, groundwater recharge and reduction in scouring forces | 1. Hydraulic modeling<br>2. Velocity profiling | 1. Frequency and duration of overbank flows<br>2. In-channel erosive (scouring) forces or shear stress<br>3. Peak flow channel velocity distribution |
| | Streambeank vegetation | Streambank stability and erosion rates affected by vegetation type and condition | Mapping of streambank vegetation type and condition | Erodability index |
| | Hydrology | Hydrologic alteration to urban creeks has profoundly affected stream biota (Booth et al. 2004); restoration projects seek to improve hydrologic condition | SPU will maintain existing hydrologic gauges and install new ones as appropriate for project monitoring | 1. Mean daily flows<br>2. Mean monthly flows<br>3. Number of peak flow events<br>4. Flashiness<br>5. TBD by SPU |
| | Temperature | Stream biota are dependent on specific temperature ranges for optimal health; seasonal temperature patterns | Installation of continuously-recording temperature loggers set to record at hourly intervals | 1. Mean daily temperature range<br>2. Seasonal temperature patterns |

Final 10/2008

| Hypotheses | Study Parameter | Relevance | Sampling Protocols | Metrics |
|---|---|---|---|---|
| | | may change as a result of restoration | | |

Final 10/2008

*Study Area*

The Thornton Creek watershed has been described by several authors (Olthof 1994; Serl 1999; TCWMC 2000; SOTW 2007). Thornton Creek drains a nearly 30 $km^2$ watershed located in the north end of the city of Seattle, between Puget Sound and Lake Washington. The watershed has a maximum elevation of approximately 150 m and a minimum elevation of 2.5 m at the mouth. The Thornton Creek watershed has approximately 24 kilometers of stream flowing through three major sections, the North Fork, the South Fork and the main stem. The primary geology of the watershed is Vashon till, a compressed aggregate of silt, sand, gravel and clay (hardpan) (TCWMC 2000). The watershed receives nearly 89 cm of precipitation annually, which falls primarily as rain between October and May (TCWMC 2000). This rainfall results in the following estimated (hydraulic models) bankfull discharges for the three sections: Mainstem 65 cfs; South Fork 159 cfs; and North Fork 167 cfs (TCWMC 2000). The main stem has a lower bankfull discharge due to a storm bypass which flows from Meadowbrook Pond to Lake Washington (TCWMC 2000).

The Thornton Creek watershed is extensively developed. Residential, roads and right of ways, and commercial development constitute 53%, 26%, and 8% of the total land use to date respectively. The primary source of development is from single family residences, which make up 49% of the development (SOTW 2007). Impervious surfaces cover 59% of the watershed and extensive development has generally resulted in degraded habitat conditions throughout the stream (SOTW 2007). These have been summarized as poor habitat complexity, altered hydrology, channel straightening and armoring, and poor connectivity between the stream and its floodplain (SOTW 2007). Habitat degradation has influenced the aquatic community in this system.

The aquatic community in Thornton Creek can generally be described as unhealthy. BIBI scores for Thornton Creek are low (TCWMC 2000; SOTW 2007) and average prespawn mortality for coho salmon is the highest (79%) among Seattle's creeks (SOTW 2007). Cutthroat trout are the dominant salmonid species and the proportion of cutthroat

Final 10/2008

in a system generally increases with urbanization (Serl 1999). Fish species diversity generally declines upstream from the mouth and non-native species are quite common in the watershed. The following fish species have been observed in Thornton Creek: Chinook salmon, coho salmon (*O. kisutch*), steelhead (*O. mykiss*), rainbow trout, cutthroat trout (*O. clarki*), threespined stickleback (*Gasterosteus aculeatus*), coastrange sculpin (*Cottus aleuticus*), prickly sculpin (*C. asper*), lamprey (unidentified species) (Petromyzontidae), pumpkinseed sunfish (*Lepomis gibbosus*), juvenile sunfish (unidentified) (Centrarchidae), rockbass (*Ambloplites rupestris*), largemouth bass (*Micropterus salmoides*), and oriental weatherfish (*Misgurnus anguillicaudatus*) (Lantz et al. 2006).

We are collecting pre-project data at four sites in Thornton Creek, 95th Street, N.F. Confluence, S.F. Confluence, and Knickerbocker (Figure 1). Each study site (treatment) has a control reach, generally located within 0. 5 km of the treatment reach. The 95th Street treatment reach is located approximately 0.6 km upstream from Lake Washington and its control reach is located approximately 0.5 km upstream of the lake. Both reaches are generally incised with the treatment reach containing more wood cover than the control reach. Both reaches consist of pool, riffle, run, and glide habitats. The treatment reach is approximately 75 m long, with an average low flow wetted width of 4.4 m (Appendix A: Table A.1). Vegetation within the 95th Street treatment reach is dominated by native plant species. The reach is well forested, having a mature canopy dominated by Black cottonwood (*Populus tricocarpa)* and Western red cedar (*Thuja plicata*). Mid canopy is dominated by red osier dogwood (*Comus stolonifera*), Indian plum (*Osmaronia cerasiformis*), Oregon Crabapple (*Malus fusca*), and red elderberry (*Sambucus racemosa*). The 95th Street control reach is approximately 50 m in length, with an average low flow wetted width of 5 m. Both left and right banks are armored in some places with large rock. This reach is also well forested, having a mature canopy dominated by native species including Black cottonwood, Bigleaf maple (*Acer macrophyllum*) and Western red cedar. The mid canopy is dominated by immature Bigleaf maple, smaller willows (Salix sp.) and invasive Himalayan blackberry (*Rubus discolor*).

Final 10/2008

Figure 1. Photos of the 95th St Control (above) and Treatment (below) reaches, Thornton Creek, Seattle, March 2006.

Two treatment reaches occur at the confluence of the North and South Forks, which is located 2.2 km upstream of Lake Washington. The North Fork treatment reach begins at the confluence and extends up the North Fork of Thornton Creek for approximately 40 m.

During low flow periods its average wetted width measures approximately 2 m (Appendix A: Table A.1). The North Fork treatment reach consists primarily of riffle, glide, and run habitat. This reach is devoid of any mature canopy and is bordered by private residences that have been recently purchased by SPU. Wood is embedded into the right bank for stabilization and runs the entire reach, creating shallow undercut habitat. Both banks are heavily vegetated by Himalayan blackberry. The control for this reach is located approximately 0.3 km upstream in the North Fork between 113$^{th}$ Ave NE and 115$^{th}$ Ave NE. The control reach consists of pool, riffle, and glide habitat. This reach is also bordered by private residences; however, unlike the treatment reach, a mature canopy exists consisting primarily of Bigleaf maple and Western red cedar**.** The left and right banks are composed primarily of English ivy (*Hedera helix*), Himalayan blackberry, lady fern (*Athyrium flix-femina*), and salmonberry (*Rubus spectabilis*).

Final 10/2008

Figure 2. Photos of the North Fork Confluence Treatment (above) and Control (below) reaches, Thornton Creek, Seattle, July 2006.

The South Fork treatment extends upstream from the confluence with the North Fork for approximately 40 m. Private residences border this reach, one of which has recently been purchased by SPU, and the entire section is armored with concrete. The low flow wetted width averages approximately 2 m (Appendix A: Table A.1). Riparian cover is sparse and the creek is partly shaded by a willow tree located in the upper portion of the reach on the SPU property. Invasive Himalayan blackberry are established on the left bank near the confluence. The South Fork control reach is located approximately 0.2 km upstream from the confluence in the South Fork and is bordered by Nathan Hale High School property. This reach is approximately 40 m in length, with an averaged low flow wetted width of 2 m. The channel has been straightened and confined. The dominant overstory consists primarily of non native Lombardi poplars (*Populus nigra*), which were planted for bank stabilization. The left bank is primarily composed of Himalayan blackberry and the right, giant knotweed (*Polygonum sacalinense*) and Unident grass spp.

Final 10/2008

Figure 3. Photos of the South Fork Confluence Treatment (above) and Control (below) reaches, Thornton Creek, Seattle, July 2006.

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The Knickerbocker treatment reach is located at river kilometer (rkm) 1.6 of the South Fork. The control reach is located at approximately rkm 1.8. The treatment reach is channelized and heavily armored with rip rap. The reach measures approximately 80 m in length, with an average low flow wetted width of 2 m (Appendix A: Table A.1). The treatment reach consists of pool, run, riffle, glide, and cascade habitat. Vegetation within the Knickerbocker treatment reach is dominated by turf forming grasses. The reach is open with no substantial tree canopy. Sporadic mid-canopy sized trees and shrubs include laurel (*Laurus sp*.), red alder (*Alnus rubra*), orange eye butterfly bush (*Buddleja davidi*), ornamental cherry (*Prunus sp*.), and salmonberry. Himalayan blackberry and giant knotweed occur in abundance. The Knickerbocker control reach flows through Seattle City Parks property within a steep ravine. The reach is approximately 80 m in length with an average wetted width of 3 m, characterized by meandering pool-riffle morphology, with additional glide, run, and side channel habitat. This reach is heavily forested, the dominant canopy species being Bigleaf maple and Red alder. The mid canopy is dense, consisting of Holly (*Ilex sp*.), laurel, Himalayan blackberry, salmonberry, and copious amounts of English ivy, climbing nightshade (*Solanum dulcamara*), giant knotweed, and Indian plum (*Osmaronia cerasiformis*).

Final 10/2008

Figure 4. Photos of the Knickerbocker Control (above) and Treatment (below) reaches, Thornton Creek, Seattle, July 2006.

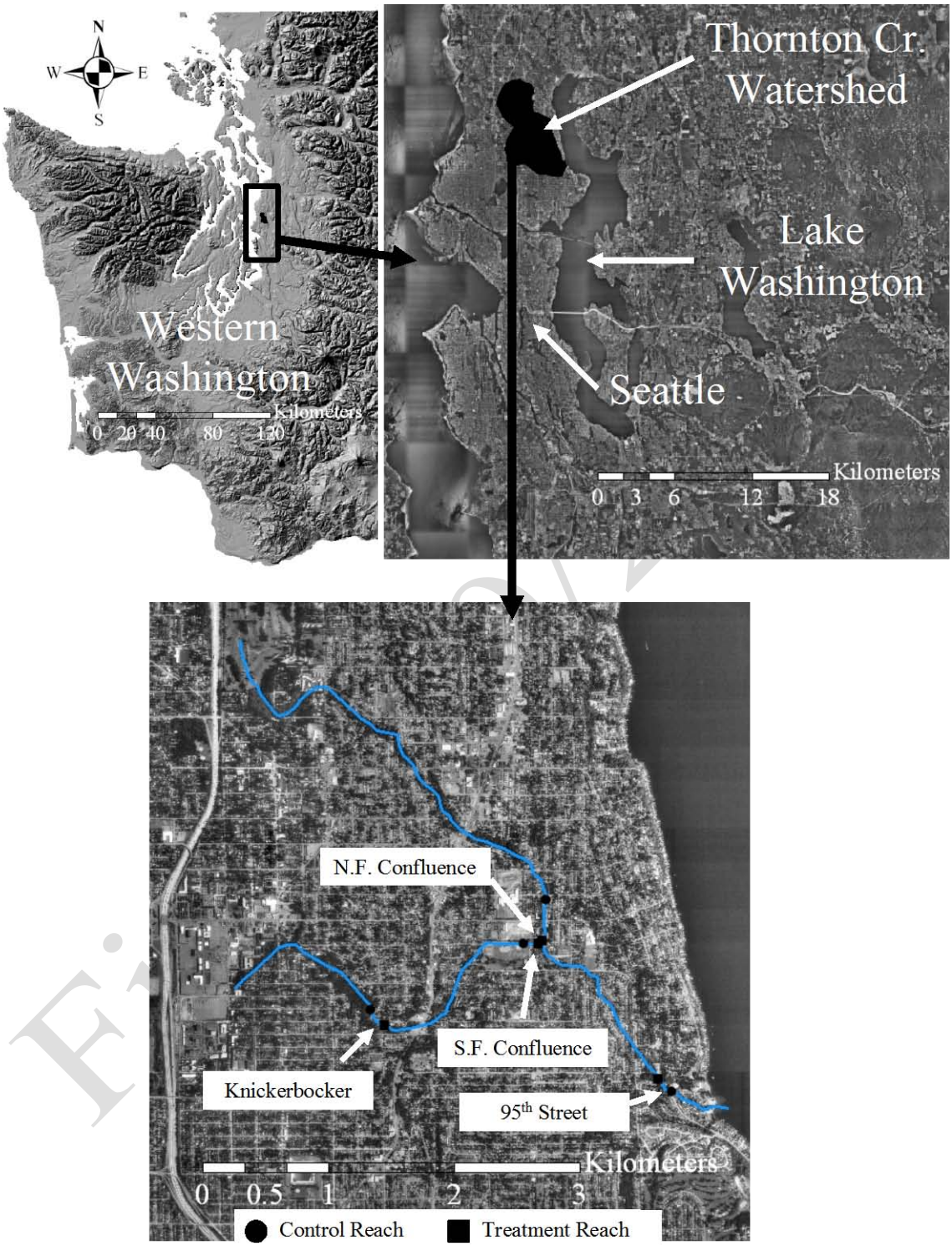


Figure 5. Restoration (treatment) and control reaches sampled in the Thornton Creek watershed during this study.

## Methods

*Channel morphology, streambank condition, and vegetation*

Detailed characterization of baseline reach channel morphology was accomplished at the 95th Street and Knickerbocker reaches by means of a total station survey. The objective of this survey was to obtain typical habitat unit cross sections, planform pattern and longitudinal profile with sufficient quantitative accuracy to detect magnitude and trajectory of changes over a period of one to several years.

Measurements were generally made during winter baseflow while vegetation was dormant. Following methods outlined by Harrelson et al. (1994), a set of three permanent cross-sections was established per site, generally in a representative pool, riffle, and pool tail-out depositional (response) zone. These "representative" cross-sections were chosen to be typical of reach morphology including streambed and streambank conditions, and/or habitat of interest such as large wood complexes. Cross sections were marked with permanent rebar headpins placed outside the bankfull channel zone (area reasonably accessible to peak flow water levels). Where feasible, gage plates were installed in the vicinity of each cross section for rapid visual water level measurement (for velocity profile measurements – see Velocity Profile Section).

The headpins and gage plates were surveyed on a locally established datum relative to permanent benchmarks such as rebar posts or existing cultural features. Bed configuration at the cross sections was described by surveying points along the cross section spaced closely enough to define bed forms and slope breaks. Generally, points were surveyed at topography break points or 0.3 m intervals, whichever was closest.

Streambank edges, top of banks, terrace surfaces, and hillslope bases were also

Final 10/2008

surveyed. Each permanent cross-section was also bracketed by at least four detailed transects, spaced upstream and downstream of the cross section to cover a zone at least a channel width in longitudinal extent centered on the cross section. These additional transects are surveyed with sufficient detail to characterize major streambed features, but are less detailed than the cross section itself (5 to 10 points within the active channel, in addition to bank edges and top of bank). The purpose of these additional transects is to characterize changes that may occur near, but not on, the cross section, without the expense of installing large numbers of closely-spaced monumented cross sections. The USFWS will then have the option of using topographic analysis software, to generate other cross sections within the footprint of these transects. This will increase the probability of detecting channel changes within the reach.

Longitudinal profiles of each reach were obtained as part of the total station survey, following procedures described in Harrelson et al. (1994). Survey points included the thalweg, channel edges, and top of bank at slope breaks and dominant features. Survey points were taken at the upstream and downstream end of each habitat unit (e.g., riffle, pool, etc.).

A semi-quantitative assessment of streambank condition and erodibility was conducted at the 95th Street and Knickerbocker reaches, following methods developed by Rosgen (2001). Bank height ratio, bank angle, rooting depth ratio, root density, bank protection, streambank soil texture (grain size) and structure (layering) were estimated and used to compute a Bank Erosion Hazard Index (BEHI) value. These BEHI values, in turn, were interpreted on a descriptive scale ranging from very low to extreme erodibility. Bank height ratio and rooting depth ratio require an estimate of geomorphic bankfull (floodplain) elevation in relation to total bank height and rooting depth, respectively. Since no reliable natural floodplain depositional features existed at most of the study sites, bankfull elevation was estimated by using rough channel cross sections obtained during the streambank surveys at each station to compute the water surface elevation given a cross sectional area equivalent to that indicated from regional relationships. Regional relationships for bankfull cross sectional area were obtained from Castro and

Final 10/2008

Jackson (2001). Soil texture was described using a simplified field version of the Unified Soil Classification system (Howard 1986).

Streambank condition was evaluated and vegetation identified at 10-meter intervals on each side of the channel. A series of permanent 10-meter wooden reference pins were placed along the left top of bank for consistency of longitudinal stationing, allowing the vegetation, streambank and other surveys to be formally tied into the total station site survey. In most cases, vegetation was identified to species level, except for grasses. Dominant riparian canopy (overstory) and mid-canopy species were also noted.

*Hyporheic Investigations*

Regional surface water/ground water interactions are being studied at the 95th Street and Knickerbocker reaches by continuously recording subsurface water levels and temperatures. Within each reach, a steel piezometer well was installed to a depth of approximately 1.3 m below the streambed at a mid-channel location within a pool (Figure 2). A pressure transducer (Onset Computers, Hobo Water Level Logger model U20-001-01) and vertical array of 2 thermographs (Onset computers, Hobo Water Temp Pro v2) were installed in the piezometer to measure water depth and temperature gradients within the well. A stilling well was also installed near the streambank with a pressure transducer for obtaining water surface elevation measurements and surface water temperatures. The tops of the wells were surveyed relative to permanent benchmarks using level survey techniques (e.g., Harrelson et al. 1994). Data from the thermographs and transducers were downloaded monthly. Water levels within the wells were also measured monthly, with a hand-held measurement tape, to calibrate the transducers.

Final 10/2008

Figure 6. Piezometer and stilling well installed at the 95th Street treatment reach on Thornton Creek in June 2006. The piezometer was installed at a depth of 1.3 m within the streambed and equipped with a pressure transducer and thermographs to monitor water depth and temperature gradients within the well. The stilling well was equipped with a pressure transducer to measure water surface elevation and surface temperatures.

An intensive hyporheic survey to delineate zones of local upwelling and downwelling was conducted at the Knickerbocker and 95th Street reaches during stable, late-summer baseflow conditions. Continuous-recording thermographs were installed in the channel at the beginning and end of the reach to monitor surface water temperatures. At zones of interest, transects of two to four 9.5-mm inner diameter polyethylene tubes were inserted into the streambed to a depth of about 10 cm using a steel probe. Tubes were thus installed in both the middle and edge portions of the channel. Shallow subsurface temperatures were measured by inserting a flexible thermistor probe into each tube, equilibrating for 30 seconds, and reading the temperature with an Omega HH-41 digital thermometer (±0.01 ºC). The transects were placed at the beginning, middle, and ends of each habitat unit. Fourteen to eighteen transects and roughly 50 tubes, total, were installed per reach, allowing all tubes to be measured in a sweep lasting about one hour. Three successive sweeps of the tube array were made during the same day. A tape was stretched along the reach for longitudinal stationing of transects, using the 10 m marker posts inserted along the streambank. Surface water temperatures were measured

Final 10/2008

periodically at some of these locations to validate temperature readings from continuous-recording thermographs placed at the upper and lower end of the reach.

*Hydraulic Investigations*

A set of detailed velocity profile measurements was obtained during a peak flow event at each of the three reference cross sections at the 95th Street reaches and at the Knickerbocker treatment reach. Specifically, the longitudinal component of velocity was measured comprising a vertical and lateral array of points (Figure 3). This allows determination of velocity gradients, velocity shadows, and high-velocity cores and construction of an isovel diagram. In addition, discharge and average velocity were calculated and will be used for hydraulic modeling. Measurements were made during flows as close to the top of bank as possible. Since small urban streams exhibit rapidly changing (flashy) hydrology, it was important to complete a given measurement within 1 to 1.5 hours. Therefore, we completed between 60 and 90 point velocity measurements for a given measurement event. We measured five to eight measurements along a vertical transect at 8 to 18 stations (a given 'vertical') along each of three cross-sections (Figure 3). Verticals were spaced close together in transitional areas where steep velocity gradients existed, such as:

- near the streambank
- eddy lines
- edges of obstructions such as large rocks or logs
- velocity shadow zones downstream of obstructions
- turbulent jets (where water was squeezed between walls or obstructions)
- locations where water was directed towards a streambank or obstruction.

In areas between these transitional zones, the verticals were more spread apart and spaced evenly. Verticals were not spaced closer than about 6 cm, since the placement accuracy of a depth reading rod is only about 3 cm.

Final 10/2008

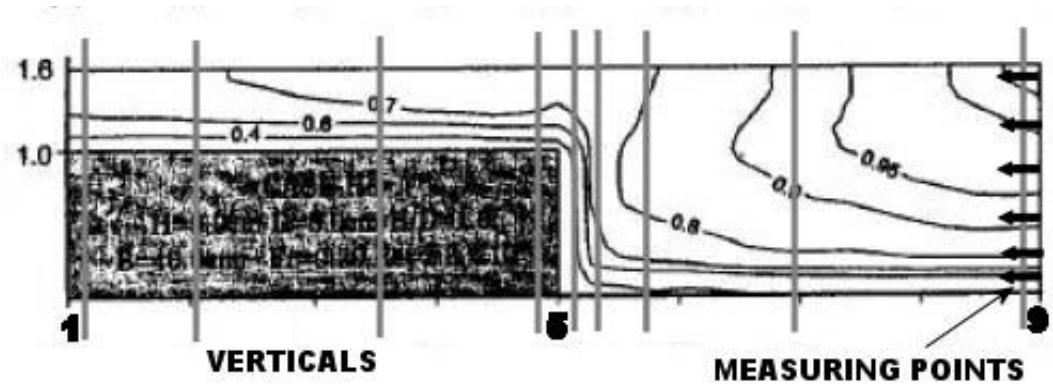


Figure 7. Example of locations where velocity measurements would be obtained during peak flows to determine velocity gradients, velocity shadows, and high-velocity cores, to construct isovel diagrams, and develop hydraulic models. Locations of measuring points and verticals at each of the three reference cross sections at the 95th Street reaches and at the Knickerbocker treatment reach in Thornton Creek were based on isovels (lines of constant velocity) and transition zones.

A measuring tape was a stretched across the cross section. If the cross section was too deep or swift for wading, a scaffold was placed across the stream for access. Vertical arrays of velocity measurements were then taken at stations along the measuring tape, beginning at the left bank using a Marsh-McBirney© model 2000 flow meter. Once the total depth was determined at a vertical, velocity measurements were taken at evenly spaced intervals beginning at 6 cm from the bottom and ending at about 3 cm from the top surface. Spacing was calculated to obtain approximately 6 measurements on a given vertical. Between measurements, the probe was raised to the surface to clear debris.

*Instream Habitat*

Habitat data were collected within a day of fish surveys. Total length (m), average depth (m), maximum depth (m), average wetted width (m), and pool tail out depth (m) were recorded for all habitat types (pools, runs, riffles, glides, cascades) using a hand held tape measure, stadia rod, and/or Laser Tech. Inc©, Impulse LR instrument. Wetted width was measured along three equally spaced transects within the habitat unit. Depth was measured at three equally spaced points along each transect. In addition, a maximum depth was measured and pool tail-out depth was measured for pools. Substrate

Final 10/2008

composition within each habitat was visually estimated as percent fines, gravel, cobble, boulder, rip rap, and bedrock. The level of substrate embeddedness was visually estimated based on the percent of fine sediments (less than 2 mm in diameter) covering stream channel materials. Embeddedness was estimated as none, <25%, 25-50%, 50-75%, and 100%. Instream cover was classified by type (Table 1), complexity (sparse, medium, complex), and measured for surface area. Total area of overhanging vegetation within 0.33 m of the water surface was measured. Overhead and riparian cover was visually estimated as a percent of the total reach length.

Final 10/2008

Table 2. Description and abbreviations of cover types documented within control and treatment reaches in Thornton Creek between August 30 and September 14, (summer) 2005, March 14 and March 21, (winter) 2006, and July 17 and August 1, (summer) 2006.

| Cover Type | Description |
|---|---|
| Rock cover (RC) | Rock of various types, including: |
| Boulder (BLD) | Rock >= 256 mm in diameter |
| Bedrock (BD) | Exposed solid rock |
| Cobble (CB) | Rounded rocks 64-256 mm in diameter |
| Riprap (RR) | Angular, boulder-sized rock placed for bank protection |
| Overhanging vegetation (OHV) | Vegetation overhanging the water, but within 30 cm of the water surface |
| Undercut banks (UB) | Submerged area underneath an overhanging bank |
| Fine Wood (FW) | Woody debris of various types, including: |
| Anchored brush (AB) | Branches of non-tree woody plants hanging in the water |
| Bank roots (BR) | Roots of live trees and/or shrubs in the water |
| Vegetation (VEG) | Submerged, live, non-woody terrestrial vegetation |
| Small wood pile (SWP) | Numerous or single type of wood cover accumulated in a pile or jam |
| Single wood small (SWS) | Woody debris < 20 cm in diameter, not accumulated in debris piles |
| Single wood large(SWL) | Woody debris > 20 cm in diameter, not accumulated in debris piles |
| Complex log jam (CLJ) | Log jam with pool forming key pieces ( >20 cm in diameter) |
| Complex beaver jam (CBJ) | Beaver Dam constructed with small woody debris (< 20 cm in diameter) |
| Hydraulic cover(HC) | Hydraulic conditions which act as cover from current velocities including: |
| Deposition (DE) | Area with slow or no current where sediment deposits; e.g. point bar |
| Eddy (ED) | Back eddy where the current flows in an upstream direction as a result of an obstruction |
| Shelf (SHF) | Shallow, low gradient bank often associated with a steep bank |
| Back Water(BW) | An area with no current velocity |

Final 10/2008

Standard water quality parameters and stream discharge were recorded at each reach following fish sampling. Conductivity (µS) and temperature (°C) were measured using a Hanna© portable waterproof multi-range model HI 9635conductivity /TDS meter. Discharge was determined by establishing a cross section across the stream to determine wetted width. The cross section was then divided into approximately 15 equally spaced intervals. Water depth (0.01 m) and mean current velocity (0.1 cm/s) were recorded in the center of each interval. Velocity was measured using a Marsh-McBirney© model 2000 flowmeter.

*Fish*

Fish were sampled during between 8/30/05 and 9/13/05 (summer), 3/13/06 and 3/21/06 (winter), and 7/17/06 and 8/1/06 (summer) using a Smith-Root LR-24© backpack electrofisher. Population estimates were obtained using standard triple pass depletion methodology, in which 50% or more removal of fish between the 2$^{nd}$ and 3$^{rd}$ passes are recommended to increase accuracy. Time constraints prevented additional passes in several surveys when 50% depletion between the 2$^{nd}$ and 3$^{rd}$ passes was not obtained. Within each reach, habitat units were classified following the methods described in Hawkins et al. (1993). Block nets were placed at the lower and upper ends of each habitat unit to prevent movement of fish. Sampling began at the downstream end of each habitat unit and continued upstream through the entire unit. This upstream sample was considered a single 'pass'. Stunned fish were collected with dip nets and placed in aerated recovery bins, separated by habitat type and pass. All fish were anesthetized with tricaine methanosulfonate (MS-222), identified to species, weighed (0.1 g), measured for fork length (1.0 mm), and released back into the habitat from which they were removed. A sub sample of all unidentifiable species were sacrificed and brought back to the laboratory for taxonomic identification.

Time constraints in summer 2005 prevented weighing and measuring all sculpin captured at the 95th Street control reach. Sculpin that were not sampled were tallied into the following size ranges: 30- 50 mm, 50-75 mm, and 75-100 mm. A minimum of 35 of

Final 10/2008

each species of sculpin were measured during the summer of 2006, which was determined to be an adequate sample size to detect differences based on 2005 data. This sampling regime will also be used during subsequent years. Additional sculpin were tallied and assigned total lengths based on ratios of those recorded during the same sampling period. For example, in summer of 2005, total lengths of tallied sculpin were estimated based on lengths recorded in 2005, whereas lengths not recorded in summer 2006 were estimated based on sculpin surveyed in summer 2006.

Equipment failure prevented collection of weights of all cutthroat trout (n=185 of 382) at the Knickerbocker treatment reach in summer 2006. Weights of cutthroat trout (Lantz et al. 2006), prickly sculpin, and coastrange sculpin were estimated by regression analysis of previously captured fish.

Population estimates were calculated for each species captured in sufficient numbers for each reach and time period using the methods described in Carle and Strub (1978). Density (# of fish/m) of each species was calculated by dividing the population estimate by the reach length. Biomass g/m for each species was calculated by dividing the product of the population estimate and the mean weight by the reach length. Total density and biomass for each reach and time period were calculated in the same manner. Age class structure for species captured in sufficient number was determined by visual analysis of length-frequency distributions (Anderson and Neumann 1996).

*Benthic Invertebrates*

Macroinvertebrates were collected in August 2005 and August 2006 from Knickerbocker and 95$^{th}$ Street control and treatment reaches. Macroinvertebrates were collected from the North and South Fork Confluence control and treatment reaches in August 2006. All samples were collected from one riffle at each study reach using a surber sampler. The surber sampler was placed perpendicular to the flow at the downstream end of the riffle. Larger substrate within the frame was removed and hand scrubbed to displace

Final 10/2008

macroinvertebrates. A common garden weeder was then used to vigorously disturb the creek bed at a depth of approximately 10 cm for a period of 60 seconds. A total of nine sub samples were collected and combined for each reach to determine BIBI scores. All samples were preserved in 70% isopropyl alcohol and sent to Aquatic Biology Associates, Inc. for taxonomic analysis.

The 10-metric BIBI (Karr 1998) was used to determine overall health of each reach. Each of the 10 metric values was assigned scores of 1, 3, or 5. BIBI scores for each reach were determined by summing the scores. The final BIBI scores are associated with stream health, ranging from 10 (very poor) to 50 (excellent)**.** Macroinvertebrates collected in August 2006 are currently being processed by Aquatic Biology Associates, Inc. for taxonomic analysis.

*Periphyton*

Periphyton was sampled at each reach in summer of 2006. Two to three rocks were collected from three to five riffle habitats in each study reach. Riffle habitats were located near reaches where macroinvertebrate samples are taken. Periphyton was scraped and brushed from rocks, using a fine mesh sieve to help remove macroinvertebrates. Remaining periphyton material was pushed through the mesh into an aqueous solution. Subsamples of the aqueous solution were filtered onto Whatman GF/F filters. Periphyton samples are currently being processed. Laboratory processing will include the determination of chlorophyll *a* ($g/m^2$) and ash-free dry mass (AFDM) ($g/m^2$).

Final 10/2008

## Results and Discussion

*Channel morphology, streambank condition, and vegetation*

*95$^{th}$ Street Treatment Reach*

The 95th Street treatment reach was characterized by a gentle slope of 0.0052 and low to moderate vertical diversity (Appendix A: Figure A.1). Prominent pools existed only at two locations: at the upstream culvert outfall and at a log complex between 195 and 230 feet on the profile. The rest of the reach consisted of glide habitat due to the low reach gradient. Most of the channel had a simple trapezoidal morphology (Appendix A: Figures A.2-A.4). The low width to depth and entrenchment ratios (ratio of width at twice the maximum bankfull depth to width at geomorphic bankfull elevation) of 11.1 and 1.78, respectively, indicated incised channel characteristics (Table 2). Although this implied that no active floodplain existed, hydraulic control by the downstream culvert entrance and periodic beaver activity created depositional sediment transport characteristics. Field observations also indicated that water does regularly overtop the narrow terrace on the left bank (Appendix A: Figure A.3).

Streambank condition within this reach indicated generally low to moderate bank erosion potential (Appendix A: Figure A.5). No artificial bank armoring existed except at the culvert openings. Bare surfaces, vertical and near vertical bank angles, and low to moderate rooting density contributed to erosion potential. However, streambank soils appeared to be mostly USC type MH, comprised of fine textured inorganic silts with some clay ("elastic silts") making them somewhat strongly cohesive, and thus somewhat erosion resistant and stable at high bank angles. Soil layering was not observed. Surface erosion was evident in some areas, especially along the right bank in the upper half of the reach, but seemed to be relatively low due to low hydraulic stress (see hydraulics section below). The one exception was the terrace along the right bank at transect 3 (20 meter station, Appendix A: Figure A.5), which was subject to active mass wasting. The streambed in the vicinity of this terrace consisted of unconsolidated fine sand, silt, and clay derived from this mass wasting, another indicator of low sediment transport characteristics. The vegetation at the base of the hill slope adjacent to this station includes Giant horsetail (*Equesetum telmateia*), Skunk cabbage (*Lysichitum americanum*) and Bulrush (*Scirpus microcarpus*), indicating prolonged soil water saturation, which likely contributed to soil instability.

Final 10/2008

A hole augured into the left terrace 30 feet from the streambank consisted of a much coarser composition, including medium and coarse gravels. A hole augured into the right terrace yielded fine silts and sand to the depth of the water table at roughly 3.8 feet.

Vegetation within the 95th Street treatment reach was dominated by native plant species (Appendix A: Table A.2). The reach was well forested, having a mature canopy dominated by black cottonwood and Western red cedar, with a presence of Oregon ash, Bitter cherry and willow species. Mid canopy was dominated by Red osier dogwood, Indian plum, Oregon Crabapple, and Red elderberry. A total of 20 plant species were documented growing in the streambank, of which only two are classified as non-native. Of the four reaches studied, the vegetation in this reach appeared to be in the most natural condition. Communication with local residents revealed that this was due to an ongoing volunteer effort to plant native species and eradicate non-native plants. Most noteworthy was the complete absence of Himalayan blackberry, English ivy and Laurel, which are found in abundance nearly everywhere else in Thornton Creek riparian zones.

A factor influencing channel geomorphic processes in this reach was the presence of beaver. Beaver dams were constructed and destroyed several times at different locations in the reach over the course of summer and fall of 2006. The most common location for dams was the tail out zone for the pool at about 230 feet on the longitudinal profile (Figure 4). Completed dams at this location produced backwater for 50-60 meters. Fine sediment was observed to accumulate copiously on the streambed during these times. Other locations for dam building included the downstream culvert entrance, and the piezometer location in the upstream culvert pool. Each dam was usually destroyed shortly after being completed by unknown persons who threw the dam-making materials onto the bank. The impact of beaver on the riparian vegetation, especially food species such as red osier dogwood, was noticeable, but not beyond the capacity to regrow.

Final 10/2008

Figure 8. Beaver dam constructed in the 95th Street treatment reach on Thornton Creek, July 2006.

*95th Street Control Reach*

The 95th Street control reach was characterized by a moderate slope of 0.0087 and low vertical diversity (Appendix A: Figure A.6). A deep, prominent pool existed at 170-200 ft on the profile, formed as a plunge pool due to a step and lateral constriction at its upstream end. A broad, shallow pool existed at the end of the cascade at the upstream culvert outlet. Cross sectional shapes (Appendix A: Figures A.7 - A.9) were trapezoidal, with the exception of the pool, which was more parabolic. Its low width to depth and entrenchment ratios of 8.8 and 1.67 indicated incised channel characteristics, implying that little or no active floodplain existed (Table 2). No large wood existed within the channel, although several logs spanned the channel above the water at the upstream end of the reach.

Streambanks were mostly steep and the channel incised into the surrounding upland terrace, although a small zone of low elevation streambanks existed along the right bank at about 150 ft on the profile. A small portion of this terrace probably functioned as

Final 10/2008

floodplain, meaning that it is frequently inundated and accretes fine sediment. Small depositional bars occurred here and on the right side of the pool at 170 ft.

Streambank condition within this reach indicated low to very low bank erosion potential on the left bank due to artificial armoring with large rock (Appendix A: Figure A.10). Right bank erosion potential was very low to moderate. Bare surfaces, vertical and near vertical bank angles, and high banks contribute to erosion potential in places where no bank armoring existed. Stream bank soils here were predominantly USC type SM, which was a silt-sand mixture. Such soils were generally not very cohesive, nor resistant to surface erosion.

The vegetation at the 95th Street control reach was dominated by native plant species; however, diversity and density were lower than at the 95th Street treatment reach (Appendix A: Table A.2). The reach was well forested, having a mature canopy dominated by Black cottonwood, Bigleaf maple and Western red cedar with willow present as well. The mid canopy was dominated by immature Bigleaf maple, smaller willows and Himalayan blackberry. Fifteen plant species were identified in the streambank, of which 5 were classified as non-native. Many trees in this reach have been damaged by beaver, including some fairly large Black cottonwoods at the upstream end of the reach. Several of these trees have been felled as safety hazards, and spanned the creek channel above the water.

*Knickerbocker Treatment Reach*

The Knickerbocker treatment reach was characterized by a moderately steep slope that increased from 0.0069 to 0.043 (Appendix A: Figure A.11). Prominent pools existed only at two locations: the upstream end adjacent to the wooden bridge and at the artificially constructed boulder step in the lower boundary of the reach. The entire channel had a simple trapezoidal morphology (Appendix A: Figures A.12-A.14). Its low width to depth ratio of 3.8 was indicative of artificial channelization for flow conveyance. Interestingly, however, the top of bank cross-sectional area (1.79 $m^2$) was remarkably

Final 10/2008

close to the bankfull cross-sectional area predicted by the regional curve (1.85 $m^2$) (Table 2). Thus, although the stream was artificially narrowed, it was technically not incised, and had some regular access to the surrounding upland surface. Overbank flow was observed on one occasion during the winter of 2007. This residual floodplain function may explain how a gravel and cobble streambed persisted even though velocities and near bed shear stresses were high due to the narrow, deep channel morphology. This gravel/cobble bed material was a thin layer over a massive clay formation which was exposed along some of the ravine edges and stream bed farther upstream.

Streambank condition within this reach indicated generally very low bank erosion potential, due to the fact that the entire reach was armored with large boulders (Appendix A: Figure A.15). Streambank soils were difficult to assess because they were covered by rock armoring and thick turf. A few bare spots appeared to be mostly USC type SC, comprised of sand with some clay content. Water seepage and wet-site vegetation at the base of the hill slope adjacent to this station indicated soil water saturation, but any instability was prevented by the rock armor.

Two holes were augured into the left terrace about 6 feet (2 m) from the streambank near transect 10. This substrate was a uniform mixture of fine to medium gravel with coarse sand and small amounts of silt but little or no clay (USC type GM), to a depth of about 2.6 ft (0.8 m). Below that depth, saturated conditions were encountered.

Vegetation within the Knickerbocker treatment reach was dominated by turf-forming grasses, which appeared to be derived from a commercial erosion control mixture (Appendix A: Table A.2). Native plant species occurred only sporadically in this reach. The reach was open, having no substantial tree canopy. Mid-canopy-sized trees and shrubs included laurel, red alder, orange eye butterfly bush, ornamental cherry, and salmonberry. Himalayan blackberry and giant knotweed occurred in abundance. The invasive Jewelweed (*Impatiens glandulifera*) was observed in the reach but not detected at the 10-m monitoring stations. In total, 19 plant species were documented of which 12 were non-native.

Final 10/2008

Table 3. Summary of channel morphology at Knickerbocker and 95th Street control and treatment reaches, Thornton Creek. Within each reach, transects were arranged from upstream to downstream. Regional curve estimates of bankfull cross sectional area are from Castro and Jackson (2001). Bankfull dimensions, width, depth, and cross sectional area refer to the elevation of the top of bank, i.e., the slope break where the near vertical and usually un-vegetated streambank transitions into the adjoining upland surface. In cases where slope or morphology changed noticeably within the reach, average slopes were computed for the upstream and downstream portions separately (in order from top to bottom in the table).

| | | | Bankfull Cross sectional Area, $m^2$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Site | Transect No. | Habitat Unit | From Survey | Regional Curve - Low | Regional Curve - High | Bankfull Average Depth, m | Bankfull Width, m | Width/Depth | Average Slope |
| Knickerbocker Control | 7 | Pool Tailout/Depositional | 1.65 | | | 0.251 | 6.55 | 26.1 | 0.019 |
| | 8 | Pool | 3.88 | | | 0.563 | 6.90 | 12.3 | 0.018 |
| | 9 | Riffle | 2.50 | 1.85 | 2.65 | 0.416 | 6.00 | 14.4 | |
| Knickerbocker Treatment | 11 | Pool Tailout/Depositional | 1.33 | | | 0.565 | 2.36 | 4.2 | 0.0069 |
| | 10 | Riffle | 1.79 | 1.85 | 2.65 | 0.684 | 2.61 | 3.8 | 0.043 |
| | 12 | Pool | 2.32 | | | 0.981 | 2.36 | 2.4 | |
| 95th Street Control | 4 | Pool Tailout/Depositional | 4.20 | | | 0.576 | 7.28 | 12.6 | 0.0087 |
| | 5 | Pool | 3.24 | | | 0.674 | 4.80 | 7.1 | |
| | 6 | Riffle | 3.03 | 4.72 | 7.78 | 0.586 | 5.17 | 8.8 | |
| 95th Street Treatment | 1 | Riffle | 2.57 | 4.72 | 7.78 | 0.481 | 5.34 | 11.1 | 0.0052 |
| | 2 | Pool | 4.32 | | | 0.946 | 4.57 | 4.8 | |
| | 3 | Pool Tailout/Depositional | 3.58 | | | 0.691 | 5.19 | 7.5 | |

Final 10/2002

*Knickerbocker Control Reach*

The Knickerbocker control reach was characterized by a moderate slope of 0.019 (upstream third) to 0.018 (lower third), with the highest vertical streambed diversity of all of the reaches (Appendix A: Figure A.16). A deep, prominent pool existed at 80-120 ft on the profile, formed by scour beneath logs comprising the largest and most stable wood complex observed. Other prominent pools were associated with single logs that acted as steps. Over all, the channel had meandering pool-riffle morphology, interrupted by forced pools and steps due to large wood. This meandering morphology was more readily observable at the upper end of the reach, between 0 ft and 80 ft on the profile. Cross sectional shapes were complex (Appendix A, Figures A.17- A.19). Width-to-depth and entrenchment ratios of 14.4 and >1.61 indicated borderline unconfined channel characteristics, implying that some active floodplain function existed (Table 2). Indeed, the pool and the riffle transects showed expression of the geomorphic floodplain along the right bank (Appendix A, Figures A.18-A.19). The top-of-bank cross-sectional area of 1.65 $m^2$ corresponded remarkably well with the regional curve prediction of 1.85 $m^2$. Substantial amounts of sediment appeared to be regularly mobilized and deposited in this reach, and recent overbank deposits of sand have been observed on channel-adjacent surfaces. The gravel bars appeared active, with visible changes in morphology and surface texture after peak runoff events.

The logjam located between 100 and 130 ft on the profile was associated with active mass wasting from the left (east) edge of the ravine. This mass wasting appeared to be controlled by geotechnical instability rather than hydraulic erosion. Soil stratification occurred in the ravine walls, which may have lead to water saturation and consequent loss of soil strength during storm events. A typical layering sequence observed was silty sand (USC type SM) over mixed gravels (type GP) over massive clay (type CH or CL). Lower portions of the slope in the most active failure zone were covered with recent slide deposition, obscuring the soil structure. As this slope failed, large trees were added to the logjam. The channel thalweg was pushed towards the right terrace by the encroaching slide deposits. Mass wasting on a lesser scale was evident just upstream of the reach, where near-vertical ravine walls confined the stream channel.

Final 10/2008

Streambank condition within this reach indicated a variety of bank erosion potential, ranging from very low to extreme (Appendix A: Figure A.20). The highest stream bank erosion potential occurs on the right (eastern) side in places where the channel abutted a near-vertical high terrace. Here, soil stratification, vertical bank angles, and lack of rooted vegetation contributed to very high and extreme BEHI scores. Elsewhere in the reach, erosion hazard was predominantly low to moderate. Soil types were predominantly clayey sand (SC) or clayey sand over mixed gravel (SC/GP). Such soils are generally not cohesive nor resistant to surface erosion.

The Knickerbocker control reach was well forested. The dominant canopy consisted of Bigleaf maple and Red alder (Appendix A: Table A.2). The mid canopy was dense and consisted of Holly, laurel, Himalayan blackberry, salmonberry, and copious amounts of English ivy and climbing nightshade. Also notable in the mid canopy were giant knotweed and Indian plum. Sixteen species of vascular plants were documented, of which ten were native species.

A small tributary entered the study reach at approximately160 ft. (Appendix A: Figure A.16). This tributary appeared to have contributed to enhanced sediment deposition due to the presence of a low-relief fan over the pool tail out zone.

It seems like the Knickerbocker reaches are very different in terms of gradient, overhead vegetation, confinement, substrate and erodibility. Are the two Knickerbocker reaches similar enough to determine changes to physical and biological influence from the actual restoration projects?

*Hyporheic Investigations*

*95th Street Treatment Reach*

Final 10/2008

In general, surface water and ground water temperature interactions observed at the 95th Street treatment reach between August 29, 2006 and October 8, 2006, included strong diurnal temperature cycling of the surface water, dampened cycling of the top stratum of the streambed , and predominantly stable temperatures in the middle and bottom strata (Appendix B: Figures B.1 and B.2).

An intensive hyporheic temperature survey at the 95th Street treatment reach was conducted on September 7, 2006(Appendix B: Figure B. 3). This was generally a period of stable, late summer base flow, during clear, sunny weather. Diurnal air temperatures varied by approximately 5.8 ºC, averaging 14.4 ºC. Stream discharges were 0.0849 $m^3/s$ (3.00 $ft^3/s$) at the upstream end of the reach and 0.0911 $m^3/s$ (3.22 $ft^3/s$) at the downstream end. Surface water diurnal temperatures varied by approximately 1.9 ºC, averaging 15.3 ºC. During this time, temperatures in the lower and middle subsurface levels were nearly constant at 13.6 ºC and 14.6 ºC, respectively, while the uppermost subsurface probe registered diurnal variations of about 1.3 ºC, centered about an average of 15.3 ºC. These probes were, respectively, 140 cm, 75 cm, and 13 cm below the streambed.

Generally, spatial differences in local upwelling and downwelling were detected at the 95th Street treatment reach (Appendix B: Figure B.3). Upwelling occurred mainly at heads of pools and glides. Downwelling occurred at pool and glide tail out zones, and some mid riffle locations. The most significant upwelling zones occurred at the head of the broad pool at station 4, the large pool encompassing transect No. 2 (stations 8 and 9), and a scour pool on the right (west) side just downstream from the tributary confluence, at station 13. Prominent downwelling zones were pool/glide tail out zones and riffles, particularly at station 6 and riffles at stations 12 and 14.

Pieziometric head was variable during this time, ranging from a high of 15 cm to a low of zero, with multi-day stable periods centered at around 10 cm, for a gradient of 0.074 m/m. On the day of the intensive study, a head of about 3 cm was recorded (Appendix B: Figures B.13 and B.14).

Final 10/2008

*95th Street Control Reach*

Surface water and ground water temperature (ºC) interactions observed at the 95th Street control reach were similar to those observed at the treatment reach except that deep groundwater temperatures were significantly warmer than those at 95th Street treatment reach (Appendix B: Figures B.4 and B.5). Temperatures at the control reach were surveyed intensively on September 8, 2006, during weather and hydrologic conditions similar to those during treatment reach measurements (Appendix B: Figure B.6). Stream discharge was 0.0816 $m^3/s$ (2.88 $ft^3/s$) at the upstream end of the reach and 0.0884 $m^3/s$ (3.12 $ft^3/s$) at the downstream end. Diurnal air temperature varied by approximately 5.2 ºC, averaging 14.2 ºC (Appendix B: Figure B.5). Surface water diurnal variation in the control reach was about 0.9 ºC, with an average for the day of 15.3 ºC. During this time, temperatures in the lower and middle subsurface levels were nearly constant and 14.3 ºC and 15.1 ºC, respectively, while the uppermost subsurface probe registered diurnal variations of about 1.0 ºC, centered about an average of 14.9 ºC. These probes were, respectively, 136 cm, 76 cm, and 18 cm below the streambed. Piezometric head was nearly constant during this time centered at around 55 cm, which represents a large piezometric gradient of 0.40 m/m (Appendix B: Figures B.15 and B.46). At this reach, the survey happened to occur during the time of day when the shallow inter-gravel temperatures were actually higher than the surface water temperature, due to lag in diurnal response time. Thus, relatively warmer temperatures indicated upwelling, and cooler temperatures indicated downwelling. Significant downwelling was indicated along the left side of the mid pool and tail out zones at station 9 and 10, and pool tail out zone of station 5. Upwelling occurred in the pools located at stations 4 and 10.

*Knickerbocker Treatment Reach*

Final 10/2008

Overall surface and ground water piezometric water temperature (ºC) patterns at the Knickerbocker treatment reach were similar to those observed at the 95th Street reaches (Appendix B: Figures B.7 and B.8). This reach had the coldest deep groundwater temperatures recorded. Middle stratum subsurface temperatures were less constant here than at 95th Street. This could possibly indicate lower vertical groundwater influx rates (Appendix B: Figure B.7).

Inter-gravel temperatures at the Knickerbocker treatment reach were surveyed intensively on September 27, 2006 (Appendix B: Figure B.9). This was also generally a period of stable, late summer base flow, during clear, sunny weather. Stream discharge was 0.019 $m^3/s$ (0.69 $ft^3/s$) at the upstream end of the reach, and 0.027 $m^3/s$ (0.97 $ft^3/s$) at the downstream end. Diurnal air temperature varied by approximately 6.4 ºC, averaging 14.9 ºC. Surface water diurnal temperatures in the treatment reach varied by approximately 1.7 ºC, averaging 14.5 ºC. During this time, temperatures in the lower subsurface level were nearly constant at13.1 ºC, while the middle subsurface level initially measured 13.6 ºC, slowly rising by 0.07 ºC per day. The uppermost subsurface probe registered diurnal variations of approximately 1.4 ºC, averaging 14.1 ºC. These probes were, respectively, 143 cm, 75 cm, and 11 cm below the streambed. Piezometric head was steady during this time at about 39 cm, for a gradient of 0.28 m/m. Piezometric head in the Knickerbocker treatment reach was observed to respond very slowly to changing hydraulic conditions, which likely reflects the relatively impermeable clay substrate underlying the streambed (Appendix B: Figures B.17 and B.18).

Downwelling was evident in the pool and tail out at stations 2 and 1, respectively, and in the pool/glide tail out zones at stations 8 and 12 (Appendix B: Figure B.9). Cooler inter-gravel temperatures were recorded on the right side of the channel than on the left, supporting the observation that groundwater emerged from the valley wall on the right (south) side of the creek (Appendix B: Figure B.9). It is likely that this lateral groundwater movement had a greater influence on temperature than vertical movement. Middle and lower stratum subsurface temperatures were closer together than at the treatment reach (Appendix B: Figures B.10 and

Final 10/2008

B.11). Considering that the treatment reach also had colder groundwater, it is likely that groundwater influx in the control reach is smaller relative to the treatment reach.

*Knickerbocker Control Reach*

Inter-gravel temperatures at the Knickerbocker control reach were surveyed intensively on September 28, 2006, under base flow and weather conditions similar to the previous day when the treatment reach was surveyed (Appendix B: Figure B.12). Stream discharge was 0.027 $m^3/s$ (0.94 $ft^3/s$) at the upstream end of the reach and 0.024 $m^3/s$ (0.83 $ft^3/s$) at the downstream end. Diurnal air temperature varied by approximately 6.9 ºC, averaging 15.3 ºC. Diurnal surface water temperatures varied in the treatment reach by 1.6 ºC, averaging 14.8 ºC. During this time, temperatures in the lower subsurface level were nearly constant, at 14.1 ºC, while the middle subsurface level initially measured 14.2 ºC, slowly rising by 0.1 ºC per day. The uppermost subsurface probe registered diurnal variations of about 1.2 ºC, averaging 14.6 ºC. These probes were, respectively, 127 cm, 66 cm, and 11 cm below the streambed. Piezometric head was steady during this time at about 32 cm, for a gradient of 0.25 m/m. Pieziometric head in the Knickerbocker control reach also was observed to respond very slowly to changing hydraulic conditions, since dense clay also underlies the streambed here (Appendix B: Figures B.19 and B.20).

The Knickerbocker control reach seemed to have a regular pattern of alternate upwelling and downwelling, mostly following expected habitat unit features (Appendix B: Figure 12). Upwelling occurred in pool head zones such as station 3, 7, and 16, while downwelling was evident at riffles and tail out zones at stations 4, 5, 10, and 12. A very prominent zone of upwelling was evident at station 11, which is a pool situated adjacent to the tributary confluence and its depositional fan. This zone displayed the largest surface water/subsurface water temperature differences documented anywhere in the survey.

Final 10/2008

A statistical portrayal of the surface/subsurface water temperature differences by site could shed some light on the relative degree of local hyporheic exchange. Small average temperature differences and small total spread of measurements would tend to indicate smaller amounts of hyporheic exchange. Figure 5 could then support the hypothesis that the 95th Street control reach had relatively greater exchange than the 95th Street treatment reach, and conversely the Knickerbocker treatment reach seemed to have greater hyporheic exchange than the corresponding control reach. The latter result was unexpected, and could be attributed to confounding factors such as the relative shallowness of the gravel/cobble substrate in the treatment reach, and the large amounts of groundwater seepage that emerged from the adjacent hill slope on the right side.

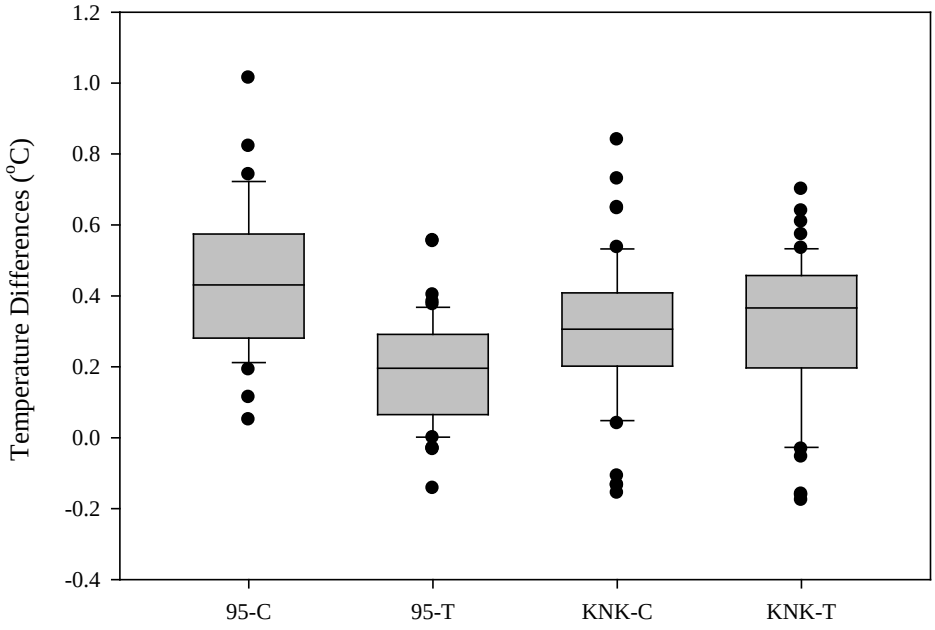


Figure 9. Temperature (ºC) differences between surface water and shallow (10 cm deep) inter-gravel water recorded at 95th Street (95) and Knickerbocker (KNK) control (C) and treatment (T) reaches, on Thornton Creek. Inter-gravel temperatures were recorded during summer base flow conditions on September 7, 8, (95th Street reaches) and 28, (Knickerbocker reaches) 2006. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles.

At all reaches, surface water temperatures began to consistently dip below the deep subsurface water temperatures during the period between September 29 and October 3, 2006. As surface water temperatures dip, the temperatures at the top and middle locations in the piezometer wells respond, developing a diurnal dip. Eventually, this leads to a reversal in the direction of heat flux, from predominantly downward to upward, as the deeper groundwater (bottom of the piezometer well) cools towards winter conditions.

The prodigious amount of time-series subsurface temperature and piezometric head data will be used in the near future to develop and calibrate a one-dimensional transient conduction advection model to determine groundwater influx. To examine these data qualitatively, a date was sought during which hydrologic conditions (surface water level and piezometric head) were steady, deep subsurface temperatures were constant, and a fairly uniform thermal gradient existed (i.e., surface water temperatures did not drop below subsurface temperatures during the diurnal cycle). The date selected, September 4, 2006, satisfied most of these conditions at all sites, with the exception of surface water temperatures dipping slightly below middle peizometer temperatures at the Knickerbocker control site, and rather unsteady (rising) piezometric head at the 95$^{th}$ Street treatment site. Average thermal gradients and piezometric heads for September 4 are shown in Figure 6. The highest overall (surface water to well bottom) thermal gradients occurred at the Knickerbocker treatment site. No correlation of gradient to piezometric head is apparent. Figure 6 shows that thermal gradient within the subsurface (middle to well bottom) correlates inversely with well bottom temperature. Better physical interpretation of these observations awaits development of the quantitative model.

Final 10/2008

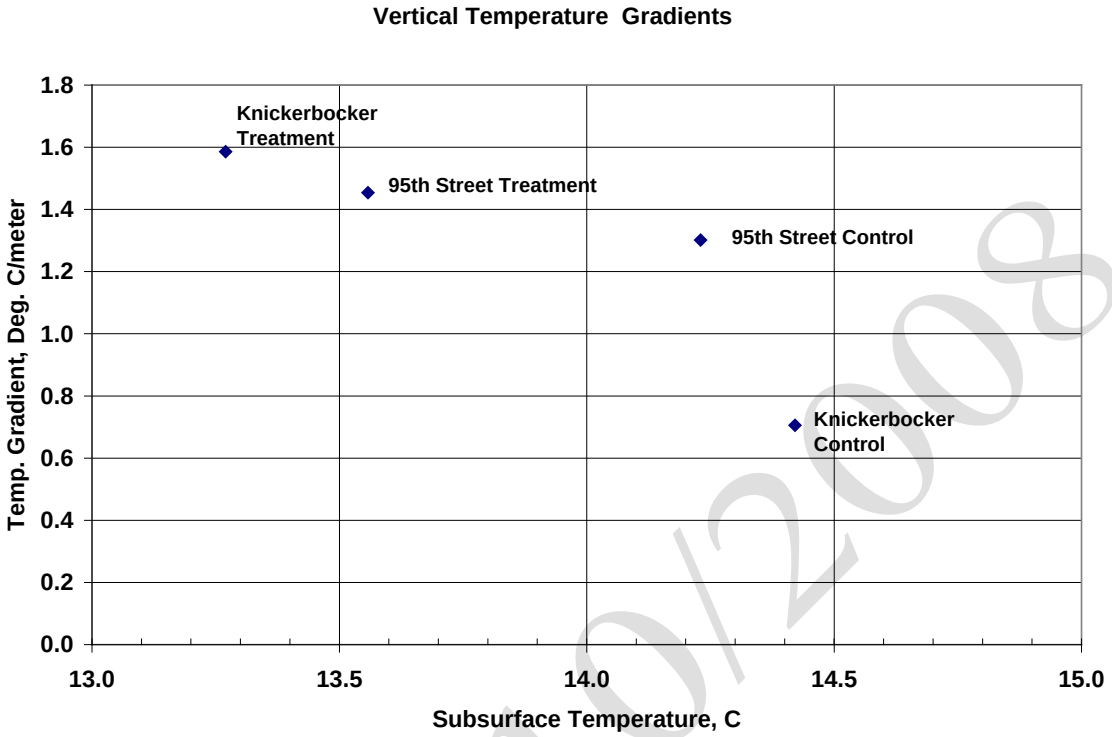


Figure 10. Vertical temperature gradient in the streambed substrate, as a function of bottom level piezometer temperature on September 4, 2006.

*Hydraulic Investigations*

During storm events, hydraulic conditions in Thornton Creek change rapidly, making it difficult to time fieldwork to catch peak flow conditions. Nevertheless, high flow velocity profiles were measured on two transects at the Knickerbocker treatment reach on December 14, 2006, and at all transects at the 95$^{th}$ Street control and treatment reaches on November 15 and 21, 2006. Isovel diagrams, showing lines of constant average downstream velocity, are shown in Appendix C (Figures C.1 - C.8).

Highest overall velocities, up to 2.44 m/s, were observed at the pool transect of the Knickerbocker treatment reach (Appendix C: Figure C.1). Velocities of nearly 1 m/s were

Final 10/2008

recorded adjacent to the left bank. Low velocity zones were confined to the extreme right bank. The water level during the December 14 storm rose about 0.3 meters in 30 minutes, falling just as swiftly as the rain abated. Thus, the discharge declined from 2.33 $m^3/s$ (82.4 $ft^3/s$) to 1.37 $m^3/s$ (48.3 $ft^3/s$) during the 80 minutes between when the pool transect (Appendix C: Figure C.1) and the riffle transect (Appendix C: Figure C.2) were measured. Water levels were overbank during the peak of this storm. Extreme velocity gradients were recorded at the stream bottom and channel sides (Appendix C: Figures C.2 and C.3).

Velocities at the 95th Street treatment reach were surprisingly low for the overbank event that occurred on November 21, 2006, most likely due to backwater effects from the downstream culvert entrance. Maximum velocity was 0.76 m/s at the riffle transect (Appendix C: Figure C.4), at a discharge of 0.841 $m^3/s$ (29.7 $ft^3/s$). Note the relatively low velocity gradient at the channel sides within this reach compared to the Knickerbocker treatment reach (Appendix C: Figures C.4 C.2). The pool transect (Appendix C: Figure C.5) had very low velocities overall, with a maximum of only 0.34 m/s, and very low velocity gradients at a discharge of 0.765 $m^3/s$ (27.0 $ft^3/s$). The pool tail-out transect (Appendix C: Figure C.6) was characterized by flow divergence, with an extensive zone of low, uniform velocity in the middle third, at 0.787 $m^3/s$ (27.8 $ft^3/s$).

Perhaps the most complex pattern of velocities was measured at the pool transect in the 95th Street control reach (Appendix C: Figure C.7). This cross section exhibited both zones of high and low velocity gradients, a split high-velocity core, and a back eddy zone (on the right side). Maximum overall velocity observed was 1.61 m/s in the pool transect at a discharge of 1.25 $m^3/s$ (44.2 $ft^3/s$).

In general, the 95th Street control reach showed the greatest diversity of velocity than the 95th Street treatment reach, and pools showed much greater velocity diversity than riffles or tail-out zones (Appendix C: Figure C.8). The Knickerbocker treatment reach had very high median, average and maximum velocities with few low velocity zones.

Final 10/2008

High flow velocities at the 95th control and treatment sites were similar, but varied from those measured at the Knickerbocker treatment site (Appendix C: Figure C.9). Velocities at the 95th control and treatment site were similar among the different habitats; however, they were generally more variable at the 95th control site. In contrast, velocities were greater and more variable at the two cross-sections at the Knickerbocker treatment reach than at any of the 95th treatment and control reach cross sections.

*Habitat and Cover*

Total habitat area and types available to aquatic biota differed temporally and spatially between control and treatment reaches at 95th Street and Knickerbocker (Figure 10). Total habitat available decreased over time in both reaches at 95th Street. Pools and runs composed > 80% of the habitat available in the control reach during summer surveys. Riffles were more available in winter in both reaches. Pool habitat varied over time in the treatment reach and decreased substantially in winter, 30%.

Total habitat available at Knickerbocker was greater during the winter survey than both summer surveys. Both Knickerbocker reaches exhibited the greatest habitat diversity than all the other reaches examined. Pools and riffles were the dominant habitat type, composing 71% to 78% of the habitat available in the control reach and 57% to 74% in the treatment reach. Pool habitat was more available in the control reach than the treatment reach during all surveys.

The North Fork control and treatment reaches differed in type of available habitat during summer 2006. Both reaches were composed of roughly 50% runs. Pool habitat was lacking in the treatment reach and accounted for < 30% of the total area in the control reach.

Final 10/2008

Habitat type at the South Fork Confluence treatment and control reaches were similar. Control and treatment reaches were composed of riffle, pool, and run habitats. Riffles accounted for roughly 60% of the total area in both reaches. Pool habitat was greater in the control reach than the treatment reach.

Final 10/2008

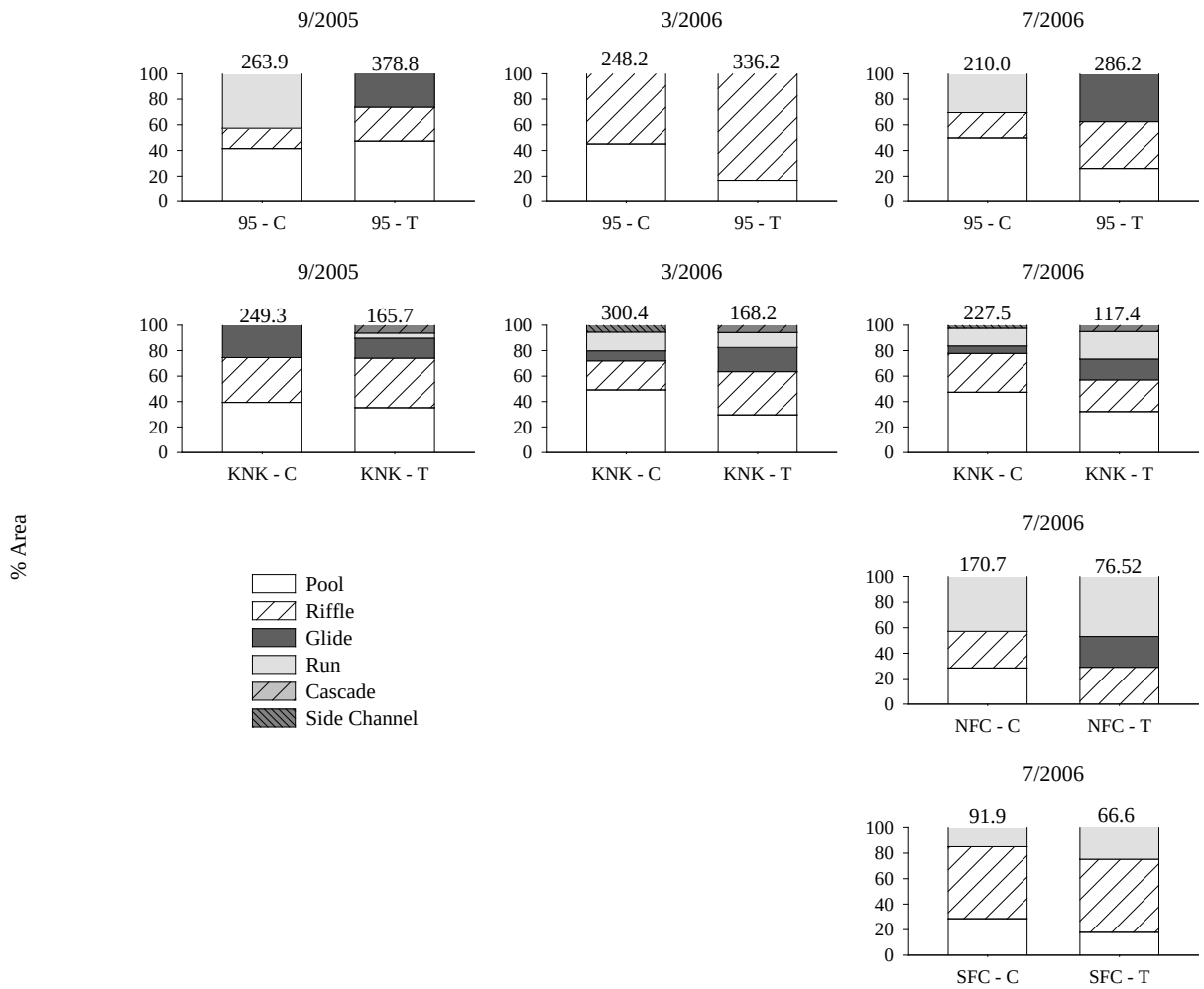


Figure 11. Percent habitat available at 95th Street (95), Knickerbocker (KNK), and North (NFC) and South (SFC) Fork Confluence control (C) and treatment (T) reaches in Thornton Creek between August 30 and September 14, (summer) 2005, March 14 and March 21, (winter) 2006, and July 17 and August 1, (summer) 2006. Numbers above the bars represent total surface area ($m^2$)

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Generally, streams providing optimum rearing and spawning habitat in the Pacific Northwest are composed of 50% pool and 50% riffle habitat (Peterson et al. 1992). Overall, pool and riffle habitat was < 50% in thirteen of sixteen surveys. In heavily urbanized Puget Sound lowland streams like Thornton Creek, complex pool and riffle habitats are reduced and replaced with glide habitat (May 1996). The control reach at 95th Street was the only reach in which 50% of the total area was pool habitat. However, pools in this reach lacked the complex woody cover preferred by rearing coho salmon (Bisson et al. 1982) and age 1 and older cutthroat trout (Voight and Hayden 1997). Only three reaches contained complex log jams that were actively forming pools (Appendix D: Table D.5), Knickerbocker control (Figure 11), 95th Street treatment (Figure 12), and North Fork Confluence control (Figure 13). In addition, beaver dams were prevalent at 95th Street treatment reach on several surveys (Figure 4). However, residents have reported their periodic removal by park personnel. Habitat complexity within the stream is also important to both salmonid species. In addition to complex pool habitat, juvenile coho salmon use side channels and other areas with low velocities (TCWMC 2000). Age 0 cutthroat trout have been reported to use a variety of habitats. Moore and Gregory (1988) found age 0 cutthroat preferred lateral margins whereas higher densities of age 0 trout were observed by others in riffles, glides, scour pools, and pool tailouts (June 1981; Solazzi et al. 1997). However, Trotter (1997) suggested their use of riffles and tailouts may have been influenced by competitive interactions with juvenile coho salmon and steelhead.

Final 10/2008

Figure 12. Photo of complex pool habitat formed by a log jam in the Knickerbocker control reach, Thornton Creek, September 2006.

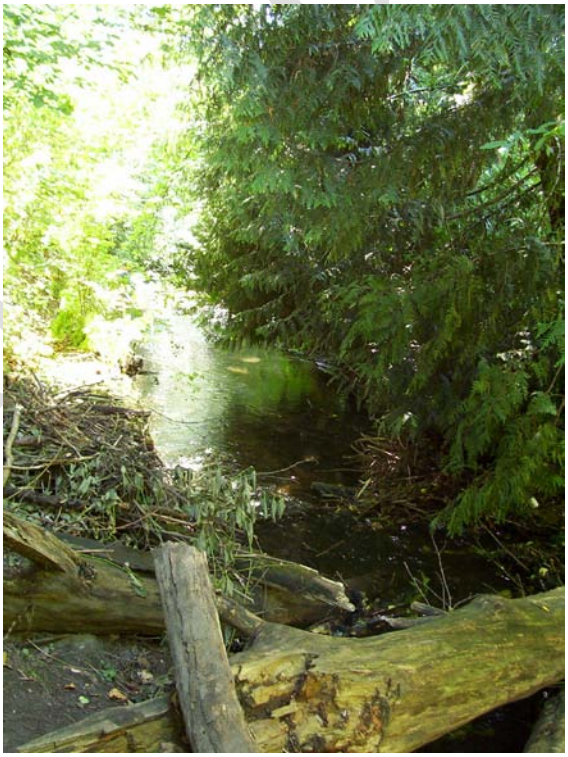

Figure 13. Photo of complex pool habitat formed by large wood at the 95th Street treatment reach, Thornton Creek, September 2005.

Figure 14. Photo of complex pool habitat formed by large wood in the North Fork Confluence control reach in Thornton Creek, September 2006.

The total amount of cover varied considerably in some cases within control and treatment reaches at 95th Street and Knickerbocker over the course of the surveys (Figure 14). The total amount of cover at 95th Street control reach increased two-fold from summer 2005 to winter and summer of 2006. The total amount of instream cover also increased at the Knickerbocker control reach from the summer of 2005 to the winter and summer of 2006. In contrast, total cover decreased at the Knickerbocker treatment reach from the summer of 2005 to the winter and summer of 2006.

The type and diversity of cover available to fish also differed between control and treatment reaches over the surveys. In general, hydraulic cover, undercut banks, and rock cover were the most abundant cover elements at 95th Street although the availability of each element differed over time between reaches.

Available cover type was considerably different between Knickerbocker control and treatment reaches. Instream cover available at Knickerbocker treatment reach consisted of rip rap and overhanging vegetation, primarily Himalayan blackberry, whereas complex

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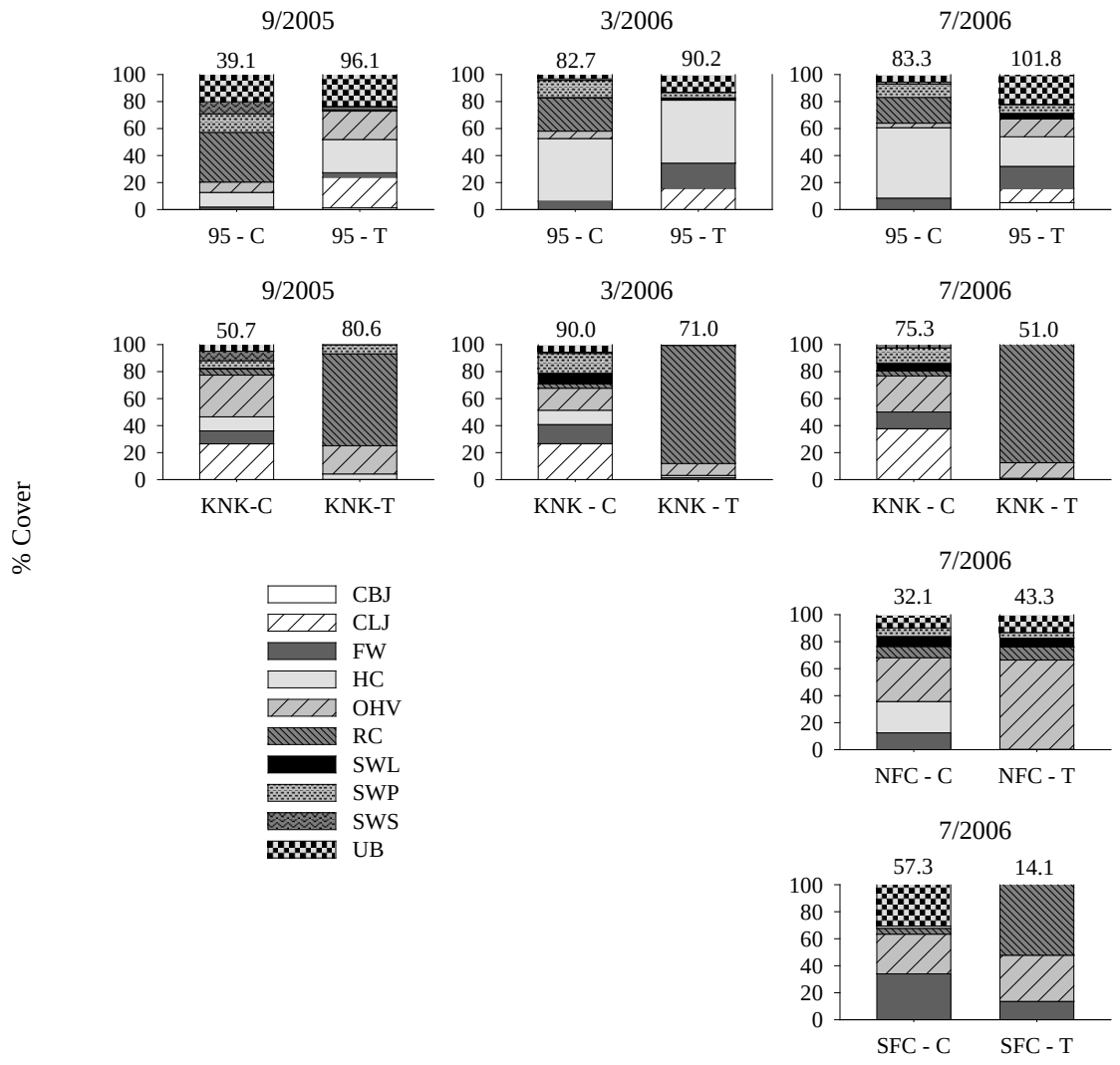


Figure 15. Percent cover type ($m^2$) available at 95th St (95), Knickerbocker (KNK), and North (NFC) and South (SFC) Fork Confluence control (C) and treatment (T) reaches in Thornton Creek during between August 30 and September 14, (summer) 2005, March 14 and March 21, (winter) 2006, and July 17 and August 1, (summer) 2006. Cover types are as follows: CBJ = complex beaver jam, CLJ = complex log jam, FW = fine wood, HC = hydraulic cover, OHV = overhanging vegetation, RC = rock cover, SWL = single wood large, SWP = simple wood pile, SWS = single wood small, and UB = undercut bank. Total cover surface area ($m^2$) is listed above each bar.

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logjams, overhanging vegetation, predominantly Himalayan blackberry, and small wood piles were most abundant in the control reach over all surveys.

During the summer 2006 survey, overhanging vegetation, predominantly Himalayan blackberry, composed > 60% of cover at the North Fork Confluence treatment reach. Cover type was more diverse in the control reach with overhanging vegetation, hydraulic cover, and fine wood composing > 60%. Similarly, cover type available at both reaches of the South Fork Confluence differed in composition. Riprap was the most abundant element in the treatment reach, whereas overhanging vegetation, undercut banks, and fine wood were more abundant in the control reach in summer 2006.

Complex cover is an important component for salmonid rearing habitat. Urbanized streams typically lack the habitat complexity needed to sustain abundant and diverse salmonid communities as a result of watershed development (May 1996). The lack of recruitment of suitable-sized LWD due to loss of coniferous riparian species has reduced the quality and quantity of habitat and appropriate cover in Thornton Creek as evident in the study reaches. In addition, a large portion of Thornton Creek has been heavily armored with concrete and or rip rap, including Knickerbocker treatment, North Fork Confluence control, and South Fork Confluence treatment reaches. Although rip rap does provide cover for fish, it does not provide complex habitat required for certain age classes (Peters et al. 1998). The lack of instream and riparian cover also causes temperatures to exceed water quality standards. Washington State standards for instream temperatures in Thornton Creek are <16 ºC (TCWMC 2000). Summer temperatures exceeding this standard were observed in one reach in 2005 and three reaches in 2006 (Appendix A: Table A.1). Preferred temperatures for rearing Chinook and coho salmon are between 12 and 14 ºC, 10 and 13 ºC for rearing steelhead, and 14 and 16 ºC for rearing cutthroat trout (Bjornn and Reiser 1991). Thus, the addition of large wood structures and reconnection of the floodplain may in part increase overall health of the reaches by improving the quality and quantity of instream habitat for fish. However, protection of existing riparian and restoration of degraded riparian zones should be implemented along with habitat complexity projects to improve the long term health of Thornton Creek.

Final 10/2008

*Fish*

A total of 3,317 fish, representing 11 species and 7 families (Appendix D: Table D.1), were captured over the three surveys; 1,125 between August 30 and September 14, 2005 (summer), 590 between March 14 and March 21, (winter) 2006, and 1,602 between July 17 and August 1, (summer) 2006. Four of the eleven species, three within Centrarchidae and oriental weatherfish, *Misgurnus anguillicaudatus*, are non-native and were present in low numbers. In general, species composition differed between lower and upper reaches of Thornton Creek (Appendix D: Table D.2). Cutthroat trout were the dominant species collected at all reaches and time periods (70% to 100%), except at 95$^{th}$ Street control, where cutthroat trout comprised only 3% to 5% of the population estimates. This change in community structure may have been influenced by Lake Washington species and was reflected in the overall increase in community diversity and abundance of sculpin**.** Serl (1999) also observed low abundances of cutthroat trout in lower reaches of Thornton Creek where sculpin were abundant.

Diversity was greater at the control reaches for all surveys, except at the South Fork Confluence where diversity was greater in the treatment reach (Appendix D: Table D.3). The 95$^{th}$ Street control reach exhibited the greatest diversity of fish species (n = 7). Juvenile coastrange sculpin, juvenile and adult prickly sculpin and lamprey ammocoetes were collected only in this reach. Coastrange sculpin comprised 64% to 74% of the population estimates and prickly sculpin comprised 19% to 26% of the population estimates over the three surveys. Both species of sculpin generally inhabit lower reaches of Puget Sound lowland streams and rivers and tend to be segregated spatially by habitat types. Prickly sculpin are commonly found in pools and areas with lower velocities. In contrast, coastrange sculpin tend to occupy faster currents in riffles (Taylor 1963; Tabor et al. 2006). Both species have planktonic larvae and migrate downstream to spawn in the spring. During the fall juveniles and adults migrate upstream (Morrow 1980). The absence of both species of juvenile sculpin and adult prickly sculpin in the 95$^{th}$ Street treatment reach may indicate that one or both of the culverts located between the two reaches acts as a migratory barrier. Further assessment of fish passage at the culverts is

Final 10/2008

recommended since reconnecting isolated habitats is generally considered a priority for stream restoration (Roni et al. 2002). Three species of lamprey, western brook lamprey, *Lampetra richardsoni*, Pacific lamprey, *Entosphenus tridentatus*, and river lamprey, *Lampetra ayresi*, are reported to inhabit Washington's rivers and streams. However, due to the difficulty in identifying lamprey ammocoetes to species level as a result of their overlapping morphological characteristics, all lamprey were combined and classified as unidentified lamprey (Wydoski and Whitney 2003).

Similarly, species diversity was greater in the Knickerbocker control (n = 3) reach than the treatment reach, in which cutthroat trout was the only species captured during all three surveys. Threespined stickleback, *Gasterosteus aculeatus* and coho salmon, *Oncorhynchus kisutch*, comprised < 5% of the population while cutthroat trout dominated the Knickerbocker control reach (Appendix D: Table D.2).

Species diversity was greater in the North Fork Confluence control (n = 4) and South Fork Confluence treatment reaches (n = 2) compared to the North Fork treatment and South Fork control reaches (100% cutthroat trout) in summer 2006. However, > 93% of the population in the North Fork control and South Fork treatment reaches were comprised of cutthroat trout (Appendix D: Table D.2).

Generally, juvenile coho salmon were absent or captured in low abundance (Appendix D: Table D.2). The highest population of coho salmon (n = 19) was estimated in the North Fork Confluence control reach in summer 2006. The ratio of coho to cutthroat abundance is often used as an indication of biological integrity in streams in the Pacific Northwest (May 1996). Cutthroat trout are more adaptable to degraded habitat conditions than other sensitive species (TCWMC 2000; Serl 1999). Reconnecting the floodplain and structure addition may increase abundance of coho and sensitive species in the study reaches by reducing the intensity of storm flows, thus reducing redd scouring, increasing habitat heterogeneity, (i.e., pool, backwater, and side channel areas to increase rearing, overwintering, and spawning habitat), and creating refugia from high flows.

Final 10/2008

*Density*

Total density for all reaches ranged from 2.3 fish/m to 9.0 fish/m in summer 2005, 1.0 fish/m to 6.3 fish/m in winter 2006, and 2.0 fish/m to 7.7 fish/m in summer 2006 (Appendix D: Table D.3). Total densities at 95$^{th}$ Street control and treatment reaches ranged from 1.5 to 9.29 fish/m during summer 2005, and winter and summer 2006. Densities were consistently greater, three to five fold, at the 95$^{th}$ Street control reach than the 95$^{th}$ Street treatment reach for all surveys. Coastrange and prickly sculpin accounted for 91% to 94% of the total density estimates at the control reach. Cutthroat trout accounted for 68% to 93% of the total density in the treatment reach. Serl (1999) also reported greater densities, 8.5 to 12.0 fish/m, of sculpin and lower densities of cutthroat trout, 0.1 to 0.2 fish/m, where sculpin were abundant. Total density at both 95$^{th}$ Street control and treatment reaches decreased considerably over the winter survey and in summer 2006 remained similar to those observed in winter 2006.

Cutthroat trout accounted for 96% to 100% of the total density in both control and treatment reaches at Knickerbocker; however, no consistent trends were observed among surveys (Appendix D: Table D.3). Greater densities were estimated at the control reach than the treatment reach in both summer 2005, 3.81 and 2.63 fish/m, and winter 2006 surveys, 1.27 and 0.98 fish/m, respectively. The opposite was observed in summer 2006 where density of cutthroat trout at the treatment reach was two fold the density of the control reach.

Total density at both the North and South Fork Confluence control reaches were greater than treatment reaches in summer 2006 (Appendix D: Table D.3). Cutthroat trout accounted for 93% to 100% of the total density.

*Biomass*

Total biomass estimates for all reaches ranged from 26.7 to 40.1 g/m in summer 2005, 16.1 to 24.0 g/m in winter 2006, and 11.5 to 32.9 g/m in summer 2006 (Appendix D:

Final 10/2008

Table D.4). Total biomass at 95th Street control and treatment reaches ranged from 16.1 to 30.3 g/m during summer 2005 and winter and summer 2006 surveys. Total biomass at both 95th Street control and treatment reaches decreased considerably over the winter survey, however no consistent temporal trend was observed between summer surveys. Total biomass was greater at the 95th Street treatment reach during summer 2005 and winter 2006 but less than the control reach in summer 2006.

Total biomass ranged from 13.3 to 40.1 g/m at Knickerbocker control and treatment reaches during summer 2005, and winter and summer 2006 (Appendix D: Table D.4). Total biomass was considerably lower in both reaches in the winter 2006; however, no consistent temporal trends were observed between summer surveys. Biomass was greater in the Knickerbocker control reach than in the treatment reach during summer 2005 and winter 2006 but lower than the treatment reach in summer 2006.

Total biomass at both the North and South Fork Confluence control reaches were greater than treatment reaches in summer 2006 (Appendix D: Table D.4). Total biomass ranged from 11.5 to 32.9 g/m.

*Age Class Structure*

Length-frequency distributions of cutthroat trout collected in Thornton Creek between August 30 and September 14, (summer) 2005, March 14 and March 21, (winter) 2006, and July 17 and August 1, (summer) 2006, indicated the presence of three or more age groups (Figure 7). Age 0 fish dominated the reaches in summer surveys. Length of age 0 cutthroat ranged from 30 mm to 80 mm which is similar to average fork lengths, 52.1 mm to 77.1 mm for age 0 cutthroat reported in Serl (1999). Age 1 trout were captured in all surveys and age 2 and older trout were most likely absent or present in low numbers for all reaches. It was difficult to distinguish between age 1 and older trout for most surveys based on length-frequency distributions alone. Age 1 trout ranged from 80 mm to 160 mm and age 2 or older trout ranged from 170 mm to 210 mm. Serl (1999) reported age 1

Final 10/2008

cutthroat trout average lengths ranged from 110.7 mm to 157.1 mm and average lengths of age 2 cutthroat trout ranged from 152.2 mm to 234.0 mm in Thornton Creek.

Final 10/2008

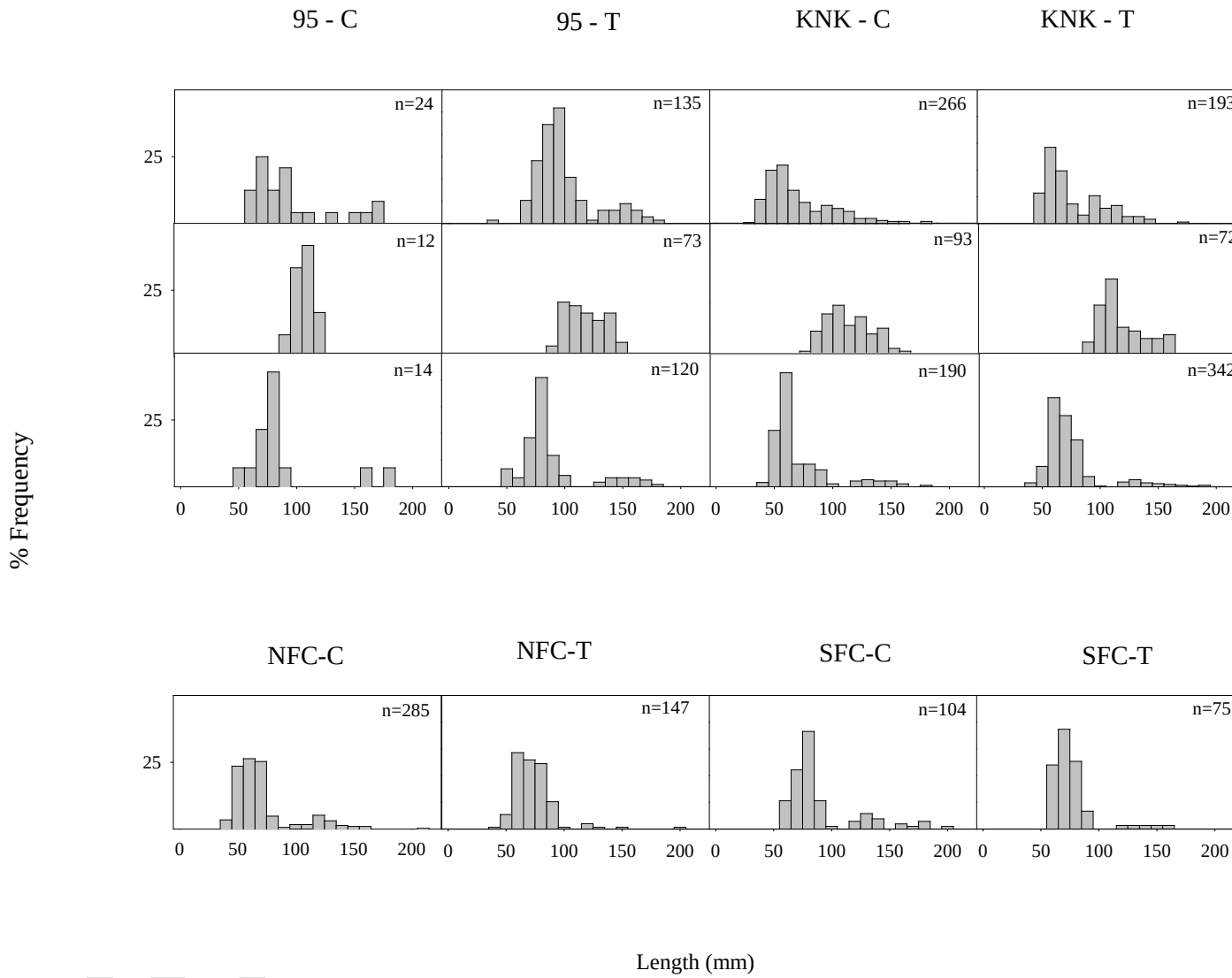


Figure 16. Length-frequency histograms of cutthroat trout captured between August 30 and September 14, (summer) 2005, March 14 and March 21, (winter) 2006 from 95th St (95), Knickerbocker (KNK), North (NFC) and South Fork Confluence (SFC) control (C) and treatment (T) reaches on Thornton Creek.

Length-frequency distributions of coho salmon were examined only for North Fork confluence control and 95th Street treatment reaches because of low abundance or absence from the survey reaches (Figure 8). Age 0 coho salmon fork lengths ranged from 65 mm to 94 mm which are similar to those reported in Serl (1999), 67.1 mm to 102.0 mm.

Length-frequency histograms indicated three or more age classes of prickly sculpin and two or more age classes of coastrange sculpin (Figure 8). Total lengths of prickly sculpin ranged from 27 mm to 159 mm in summer 2005, 45 mm to 109 mm in winter 2006, and 28 mm to 138 mm in summer 2006. Age 0 prickly sculpin ranged from 30 mm to 50 mm and age 1 from 50 mm to 100 mm in summer 2005 and 2006 surveys. Age 2 fish ranged from 100 mm to 120 mm, and a possible age class 3 or older ranged from 140 mm to 160 mm. In winter 2006, age 1 fish ranged from 50 to 70 mm. Age 2 and older sculpin were difficult to distinguish by length-frequency analysis alone; however, it appeared that age 2 fish ranged from 80 mm to 90 mm and age 3 or older sculpin ranged from 100 mm to 110 mm. Average total lengths at the end of each year for prickly sculpin from Lake Washington were reported as 48.3 mm, 86.4 mm, 109.2 mm, 127.0 mm, 147.3 mm, and 165.1 mm for age classes 0, 1, 2 and 3 , 4 and 5, respectively (Wydoski and Whitney 2003). Based on these reported lengths, it is possible that one or more age classes were not detected by visual examination of length-frequency histograms.

Total length of coastrange sculpin ranged from 30 mm to 94 mm in summer 2005, 35 mm to 99 mm in winter 2006, and 33 mm to 84 mm in summer 2006. Age classes were not clearly distinguishable for coastrange sculpin in summer 2005 and winter 2006 based on analysis of length-frequency histograms; however, there appears to be two age classes present in the summer 2006 survey. Total lengths of age 0 coastrange ranged from 30 mm to 70 mm. Age 1 or older sculpin ranging from 80 mm to 90 mm may have been captured in summer 2006. Average total lengths at the end of each year for coastrange sculpin in Oregon were reported as 45.7 mm, 55.9 mm, 71.1 mm, and 76.2 mm for age classes 0 , 1, 2, and 3, respectively (Wydoski and Whitney 2003)

Final 10/2008

# 95-C

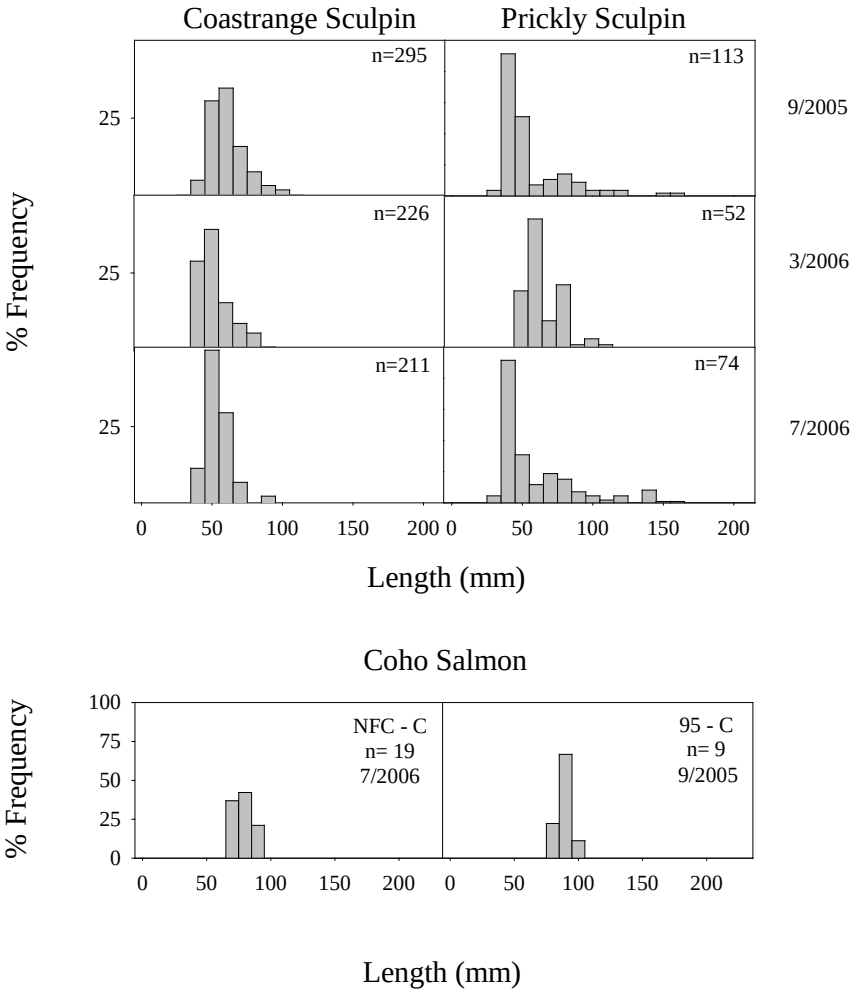


Figure 17. Length-frequency histograms of coastrange sculpin, prickly sculpin, and coho salmon captured between August 30 and September 14, (summer) 2005, March 14 and March 21, (winter) 2006 from 95th Street (95) and North Fork Confluence (NFC) control (C) and treatment (T) reaches on Thornton Creek.

*Benthic Invertebrates*

Based on BIBI scores, 95th Street and Knickerbocker control and treatment reaches were in very poor condition (Figure 9). Thornton creek is heavily urbanized and low BIBI scores have frequently been reported (Kleindl 1995; Morley and Karr 2002). SPU has been monitoring the health of Thornton Creek since 1994. BIBI scores have ranged from 10 – 20, i. e., very poor to poor (Laura Reed, SPU, personal communication). Isopods, amphipods, and sediment-tolerant oligochaets comprised the three dominant taxa at 95th Street control and treatment reaches (Appendix D: Table D.5). The number of oligochaets collected was roughly half (47%) of the taxa at the control reach. Isopods and amphipods comprised 36% of individuals collected. The following three groups comprised 70% of the taxa at 95th Street treatment reach: oligochaets, 34%; isopods, 32%; and amphipods, 8%. Knickerbocker control reach consisted primarily of Simuliidae, *Simulium* sp (39%), amphipods (21%), and *Baetis tricaudatus* (15%), a tolerant mayfly. Roughly half of the taxa collected at Knickerbocker treatment reach consisted of *Baetis tricaudatus* (28%) and amphipods (26%). Oligochaets were the third dominant taxa collected at this reach and comprised 8% of the total taxa.

Aquatic invertebrates are an essential component of coho and cutthroat diets. In streams, juvenile coho salmon primarily feed on aquatic insects within Emphemeroptera, Diptera, and Plecoptera (Wydoski and Whitney 2003). Johnson and Johnson (1981) reported roughly 75% of the diet of juvenile coho salmon consisted of aquatic invertebrates. Likewise, Dipteran, Plecoptera, and Tricoptera are important food sources for juvenile cutthroat trout in coastal streams (Lowry 1966). However, cutthroat trout are reported as being more of a generalist species than coho salmon and their diet often reflects the available food source (Glova 1984; Martin 1984). The cutthroat population in Thornton Creek has managed to persist despite low BIBI scores. McMillan (2006) suggests the large population of juvenile cutthroat trout in Thornton Creek may be sustained by cannibalism or predation on sucker fry.

Final 10/2008

Stream health, determined by BIBI scores, is correlated with instream habitat conditions (May 1996). Thus, the proposed floodplain connectivity and structure addition projects may improve the overall health of the system by increasing the quality and quantity of habitat and food for the macroinvertebrate community. Large wood provides food and habitat for aquatic invertebrates directly and indirectly, by retaining salmon carcasses and coarse particulate organic matter. In addition, the proposed projects may increase habitat available for macroinvertebrates and reduce streambed scour during storm flows.

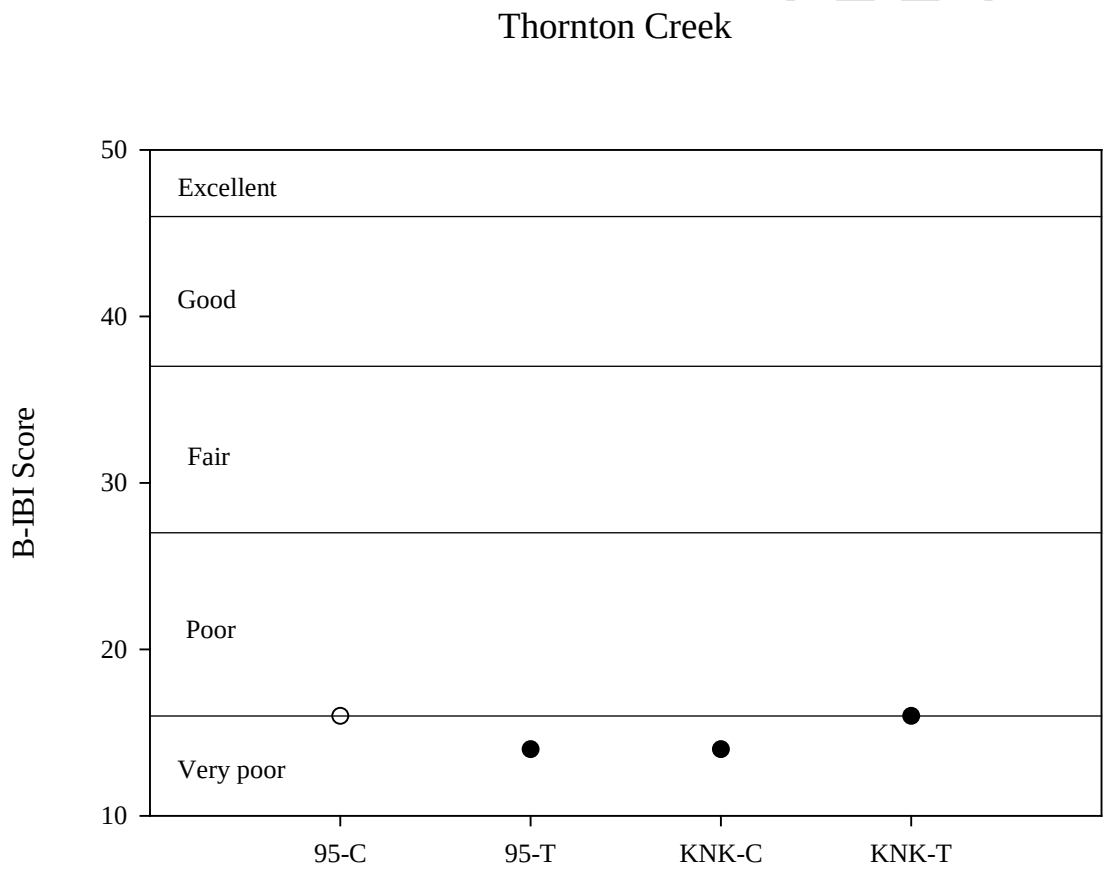


Figure 18. BIBI scores measured at 95th Street (95) and Knickerbocker (KNK) control (C) and treatment (T) reaches in Thornton Creek, August 2005.

Final 10/2008

## Summary

*Physical*

In natural settings in humid landscapes, channel morphology is determined by the long-term sediment load and the hydrologic patterns, as these interact with bio-physical factors such as large wood input and riparian vegetation. In heavily urbanized watersheds, sediment sources become disrupted. Typically, sediment availability becomes linked to soil and streambank disruption due to human activities, which are discontinuous in space and time. Thus, the paradigm of the "self-formed channel" with its associated channel forming or geomorphic bankfull discharge becomes less useful, and regional hydraulic geometry relationships developed outside of urban areas would not be expected to apply. Certainly, such is expected to be the case for the 95$^{th}$ Street reaches. Although observations during high discharge indicate that the 95$^{th}$ Street treatment reach is depositional in nature, as would be expected due to its geomorphic setting at the downstream end of watershed, natural sediment loading and fluvial transport are precluded by the sediment detention facility and peak flow bypass located upstream at the North and South Fork confluence area. Without natural sediment levels and peak flow hydrology magnitudes, a predictable self-formed channel geometry is not anticipated to exist here.

However, the Knickerbocker reach lies at the end of a ravine that receives regular sediment input. Thus, the observation that channel top-of-bank cross sectional area at the Knickerbocker control is within 11 percent of that predicted by regional hydraulic geometry relationships is not all that surprising. What is surprising is that the top-of-bank cross sectional area at the highly-modified Knickerbocker treatment reach also matches this regional prediction, being only 3 percent lower.

*Biological*

Final 10/2008

Cutthroat trout dominated (70% to 100%) all but one reach, 95th Street control, in Thornton Creek during summer 2005 and winter and summer 2006 surveys. At 95th Street control, coastrange and prickly sculpin composed 91% to 94% of the population. Age 0 fish dominated the cutthroat population. Ages 1 and 2 and older were also present but in lower abundance. Coho salmon were absent or captured in low abundance in all reaches. Based on fish IBI's, coho salmon-to-cutthroat trout ratios, the study reaches are impaired.

BIBI scores (14 to 16) indicated the study reaches sampled in Thornton Creek are in very poor condition. BIBI scores from Thornton Creek have consistently rated poor to very poor since 1994 (SOTW 2007).

Habitat available to aquatic organisms in the reaches differed among surveys. Pool to riffle ratios were generally below what are considered optimal, 1:1, for Puget Sound lowland streams. Only three reaches contained pool-forming complex logjams, the Knickerbocker control, 95th Street treatment, and North Fork Confluence control reaches, that provided the complex cover generally preferred by coho salmon and larger cutthroat trout.

## Problems

Large variation in physical and biological metrics, which are exacerbated by stream management or other human related activities, poses the greatest threat to the success of this monitoring activity. Stream management activities occurring within or near our study reaches include removal of beaver dams and logjams, and potential dredging. Other human-induced activities include a gasoline spill. A beaver has repeatedly built a dam in the 95th street treatment reach, which results in the formation of a dam pool extending up to 50 m upstream. The dam has been removed within a short period, apparently by the Seattle Parks Department, which changes the habitat conditions back to the pre-dam condition. Thus, depending on the timing of our sampling, we may have a

Final 10/2008

reach dominated by a dam pool (with beaver dam) or by glides and riffles (no beaver dam).

In addition, we discovered that the Parks Department was considering removing the large debris jam within our Knickerbocker study reach. It was purely by chance that we were both in the field on the same day. Had this not occurred, and the Parks Department had decided to remove the dam, we would have considered this a natural event and the resulting habitat changes would have been attributed to natural variation. Removal of this dam will result in a significant decrease in cover, pool habitat, and likely a reduction in fish densities. Thus, the variation observed in these metrics would have been artificially increased.

A 40-to-100 gallon gasoline spill occurred on the south fork of Thornton Creek, apparently reaching the Knickerbocker study reaches. Fortunately, the summer 2006 fish survey was completed two days prior to this spill. However, these types of events can significantly increase variation in biological parameters. Two days after the spill, another crew surveyed the Maple Leaf reach which is located downstream from Knickerbocker on the south branch of Thornton Creek (Lantz et al. 2007). The number of fish observed in the reach was considerably higher from the previous year's survey (Dan Lantz, USFWS, personal communication). This may or may not have been due to avoidance of gasoline which extended down to the Knickerbocker site. However, this does show the potential impacts to variation in the data that may occur from these types of events.

In addition, we have become aware of proposed dredging within Thornton Creek which may impact our 95$^{th}$ Street sites. Dredging can significantly alter the physical environment, resulting in large changes in aquatic biotic communities. Therefore, dredging within or near our study reaches prior to the completion of this monitoring activity will reduce the likelihood of detecting statistically significant changes as a result of the proposed restoration activities.

Final 10/2008

The likelihood of observing statistically significant results from comparisons of pre- and post-restoration projects is greatly influenced by the observed variation. The physical and biological metrics proposed for this monitoring activity are inherently variable under natural conditions. This variation will likely increase as a result of stream management activities described above, reducing the likelihood that statistically significant results will be obtained from this study.

Another concern is the stability of unanchored LWD structures. Larson et al. (2001) reported movement of unanchored LWD in Puget Sound lowland urban streams and recommended anchoring structures in areas where LWD is sparse. On Madsen Creek, a tributary to the Cedar River, 68% of the LWD moved during a five year monitoring period (Bethel and Neal 2003).

## Recommendations

We recommend discontinuing winter habitat and fish electrofishing surveys due to the potential of disturbing the large number of cutthroat and listed fish species redds. We also recommend eliminating diversity indices as a metric of integrity for fish, since all but one reach is predominately composed of cutthroat trout.

We recommend elimination of piezometer and intensive temperature winter surveys. High flows overtop wells, biasing the winter temperature data. In addition, there is a potential for equipment damage due to LWD movement within the channel and sediment deposition within the wells from storm flows. Monitoring interactions between surface and groundwater is more important during the summer when maintaining cooler temperatures is important for aquatic biota.

We would like to discuss the potential of collaborating with Washington Trout to determine if the habitat complexity projects result in a redistribution of spawning salmonids among the treatment and control reaches.

Final 10/2008

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Final 10/2008

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Final 10/2008

# Appendices

Final 10/2008

**Appendix A:**

Channel Morphological, Streambank, and Vegetative Characteristics

Table A.1. Reach conditions measured at 95th Street (95), Knickerbocker (KNK), and North (NFC) and South (SFC) Fork Confluence control (C) and treatment (T) reaches in Thornton Creek during summer 2005 and summer and winter 2006. Key wood pieces are pool forming wood pieces > 20 cm in diameter. Key pieces were not counted in 2005, asterisks indicate estimates based on photographs.

| Reach | Survey Date | Reach Length (m) | Average Depth (m) | Average Wetted Width (m) | Maximum Depth (m) | # Key Wood Pieces | % Riparian Cover | Temp (ºC) | Conductivity (*us*) |
|---|---|---|---|---|---|---|---|---|---|
| 95-C | 8/30/05 | 51.0 | 0.2 | 5.2 | 0.7 | 0 | 90 | 14.8 | 233.0 |
| 95-T | 8/31/05 | 88.2 | 0.2 | 4.3 | 0.3 | 6-8* | 50 | 17.8 | 225.1 |
| KNK-C | 9/14/05 | 75.9 | 0.1 | 3.3 | 0.8 | 9-11* | 100 | 14.1 | 256.0 |
| KNK-T | 9/13/05 | 76.3 | 0.2 | 2.2 | 0.5 | 1 | 5 | 14.6 | 254.1 |

| Reach | Survey Date | Reach Length (m) | Average Depth (m) | Average Wetted Width (m) | Maximum Depth (m) | # Key Wood Pieces | % Riparian Cover | Temp (ºC) | Conductivity (*us*) |
|---|---|---|---|---|---|---|---|---|---|
| 95-C | 3/14/06 | 49.6 | 0.2 | 5.1 | 0.7 | 0 | 50 | 9.4 | 202.6 |
| 95-T | 3/13/06 | 73.9 | 0.4 | 4.6 | 1.6 | 8 | 50 | 8.8 | 211.3 |
| KNK-C | 3/21/06 | 80.8 | 0.1 | 3.4 | 0.6 | 10 | 95 | 9.9 | 253.8 |
| KNK-T | 3/20/06 | 73.5 | 0.2 | 2.2 | 0.6 | 0 | 5 | 10.0 | 251.8 |

Final 10/2008

Table A.1. Continued.

| Reach | Survey Date | Reach Length (m) | Average Depth (m) | Average Wetted Width (m) | Maximum Depth (m) | # Key Wood Pieces | % Riparian Cover | Temp (ºC) | Conductivity (*us*) |
|---|---|---|---|---|---|---|---|---|---|
| 95-C | 7/17/06 | 48.0 | 0.1 | 4.5 | 0.4 | 0 | 80 | 15.6 | 230.7 |
| 95-T | 7/18/06 | 66.6 | 0.4 | 4.3 | 1.0 | 3 | 70 | 14.8 | 235.9 |
| KNK-C | 7/19/06 | 79.9 | 0.1 | 2.9 | 0.6 | 7 | 100 | 14.7 | 257.0 |
| KNK-T | 7/20/06 | 73.0 | 0.2 | 1.6 | 0.5 | 0 | 10 | 16.4 | 261.8 |
| NFC-C | 8/1/06 | 52.0 | 0.2 | 3.3 | 0.8 | 1 | 100 | 14.0 | 231.2 |
| NFC-T | 7/31/06 | 34.2 | 0.1 | 2.2 | 0.3 | 0 | 30 | 14.6 | 234.0 |
| SFC-C | 7/25/06 | 42.2 | 0.3 | 2.03 | 0.8 | 0 | 100 | 16.8 | 243.2 |
| SFC-T | 7/24/06 | 40.0 | 0.2 | 1.6 | 0.4 | 0 | 30 | 19.8 | 242.1 |

Final 10/2008

Table A.2. Summary of vascular plant species found rooted in the streambank or comprising the dominant (C) and mid (M) canopy ecological strata at 95th Street and Knickerbocker control and treatment reaches in Thornton Creek, July 2006. Green color indicates a native species, while yellow indicates an introduced species. The black dots indicate the number of streambank stations in the reach where that species was observed.

| Master Plant list: | Code | Genus/Species | Common Name | 95th Street Treatment | 95th Street Control | Knickerbocker Treatment | Knickerbocker Control |
|---|---|---|---|---|---|---|---|
| 1 | ACMA3 | Acer Macrophyllum | Bigleaf Maple | | CM | | C |
| 2 | ALRU2 | Alnus rubra | Red alder | | | M | C? |
| 3 | ATFI | Athyrium filix-femina | Lady fern | ???? | ???? | ?? | ???? |
| 4 | BUDA2 | Buddleja davidii | orange eye butterflybush | | | M? | |
| 5 | CABU2 | Capsella bursa-pastoris | Shepherd's purse | ? | | | |
| 6 | COAR4 | Convolvulus arvensis | Field morning-glory | | ? | | |
| 7 | COST4 | Cornus stolonifera | Red osier dogwood | MP???? | | | |
| 8 | EQTE | Equisetum telmateia | Giant horsetail | ?? | | ???? | ???? |
| 9 | EPAN2 | Epilobium angustifolium | Fireweed | ? | | ?? | |
| 10 | FRLA | Fraxinus latifolius | Oregon ash | C | | | |
| 11 | GEPU2 | Geranium pusillum | small geranium | | ?? | ? | |
| 12 | GRASS | | Unident. Grass spp. | ????? | ??? | ??????? ???? | |
| 13 | HEHE | Hedera helix | English ivy | | ? | ? | ??????? ???? |
| 14 | HYRA3 | Hypochaeris radicata | hairy cat's ear | | | ?? | |
| 15 | ILEX | Ilex sp. | Holly | | | | M ?? |
| 16 | LACA | Lactuca canadensis | Wild lettuce | | ?? | | |
| 17 | LAURU | Laurus sp. | Laurel | | | M | M? |
| 18 | OSCE2 | Osmaronia cerasiformis | Indian plum | M ?? | | | M?? |
| 19 | PHCA11 | Physocarpus capitatus | Pacific ninebark | ? | | | |
| 20 | PISI | Picea sitchensis | Sitka spruce | ? | | | |
| 21 | POMU | Polystichum munitum | Sword fern | ? | | | ????? |
| 22 | POSA4 | Polygonum sachalinense | Giant knotweed | | | ???? | MP?? |
| 23 | POTR15 | Populus trichocarpa | Black cottonwood | C | C?? | | |
| 24 | PRUNUS | Prunus sp. | Ornamental cherry | | | M | |
| 25 | PREM | Prunus emarginata | Bitter cherry | C | | | |
| 26 | MAFU | Malus fusca | Oregon crabapple | M | | | |
| 27 | RAOC | Ranunculus occidentalis | western buttercup | ?? | ?? | ??????? ? | |
| 28 | RUCR | Rumex crispus | curly dock | | | ? | |
| 29 | RUDI2 | Rubus discolor | Himalayan blackberry | | M? | ?????? | MP ?? |
| 30 | RUSP | Rubus spectabilis | Salmonberry | ? | | M? | MP? ?? |
| 31 | SALIX | Salix sp. | Willow sp. | | M? | | |
| 32 | SARA2 | Sambucus racemosa | Red elderberry | M | | | ? |
| 33 | SCMI2 | Scirpus microcarpus | Panicled bullrush | ? | | | |
| 34 | SODU | Solanum dulcamara | Climbing nightshade | | | ? | M |
| 35 | TAOF | Taraxacum officinale | common dandelion | | ? | ?? | |
| 36 | THPL | Thuja plicata | Western redcedar | C ?? | ????? | | ? |
| 37 | TOME | Tolmiea menziesii | Youth-on-age | | ? | | ??? |
| 38 | URDI | Urtica dioica | Stinging nettle | ? | ? | | |
| 39 | VIMI2 | Vinca minor | Common periwinkle | | | ? | |

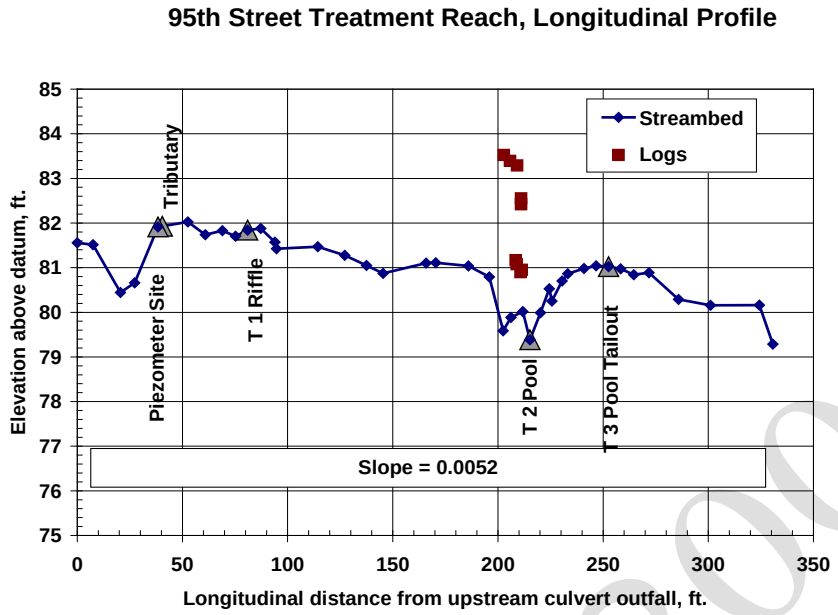


Figure A.1. Streambed longitudinal channel profile at 95th Street treatment reach in Thornton Creek, February 2006. Survey points along the thalweg and at dominant features were measured using a Nikon Total Station DTM-500 series.

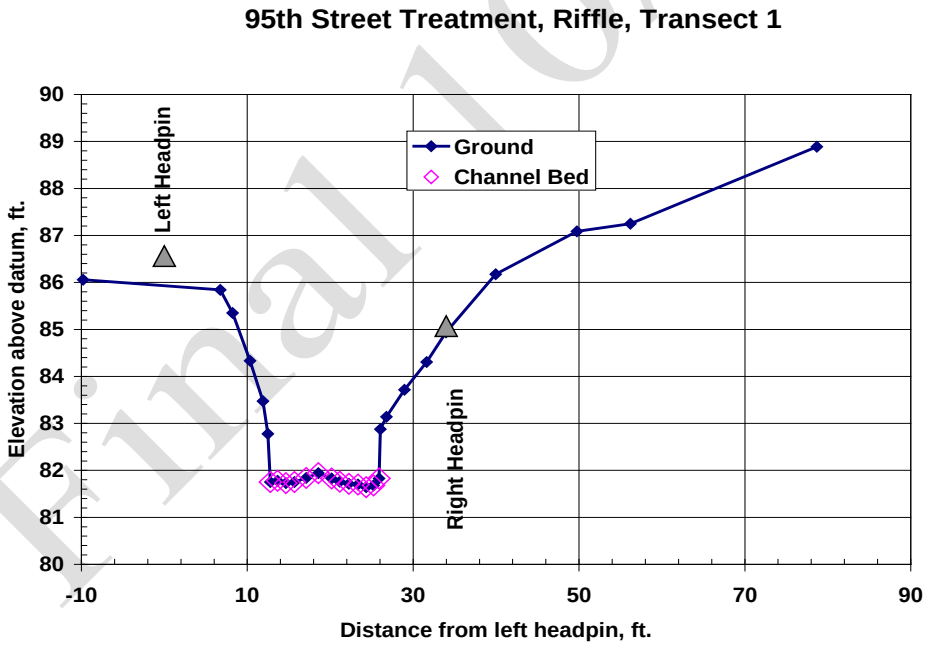


Figure A.2. Stream channel profile of the riffle cross section, transect No. 1, looking downstream at 95th Street treatment reach, Thornton Creek, February 2006. All measurements were recorded using a Nikon Total Station DTM-500 series.

Final 10/2008

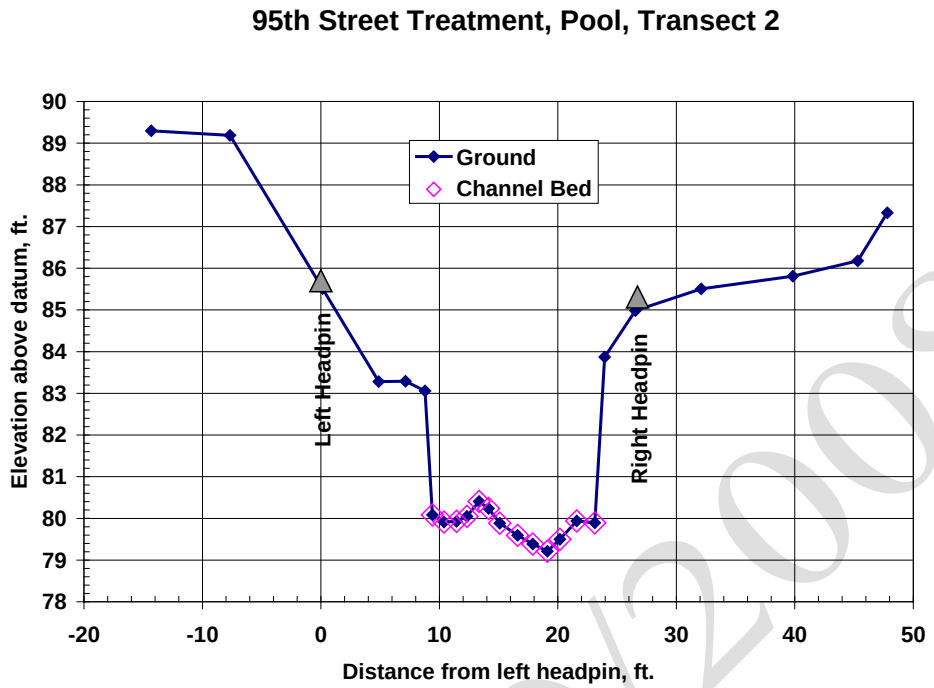


Figure A.3. Stream channel profile of the poolcross section, transect No. 2, looking downstream at 95th Street treatment reach, Thornton Creek, February 2006. All measurements were recorded using a Nikon Total Station DTM-500 series.

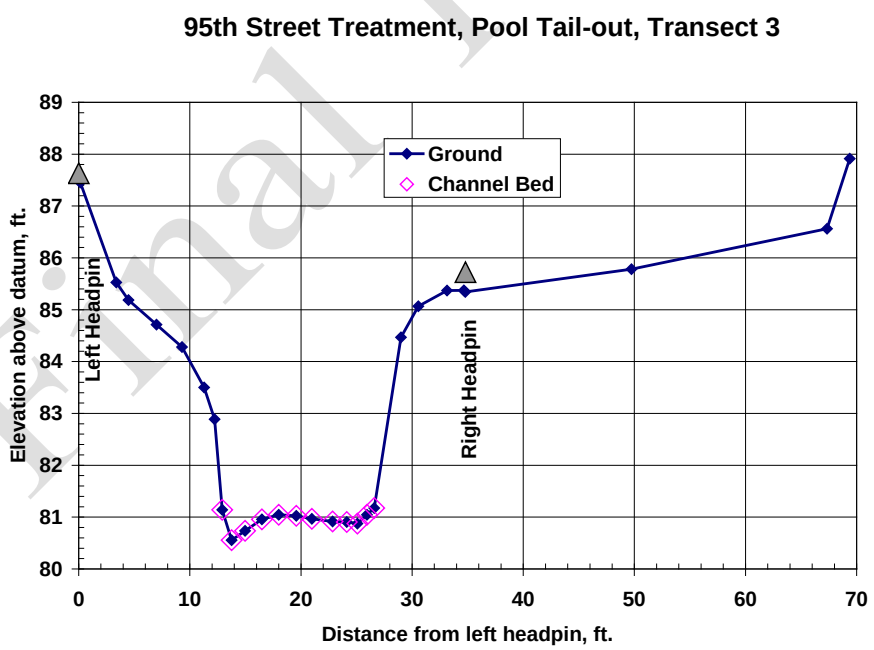


Figure A.4. Stream channel profile of the pool tailout/depositional zone cross section, transect No. 3, looking downstream at 95th Street treatment reach, Thornton Creek, February 2006. All measurements were recorded using a Nikon Total Station DTM-500 series.

Final 10/2008

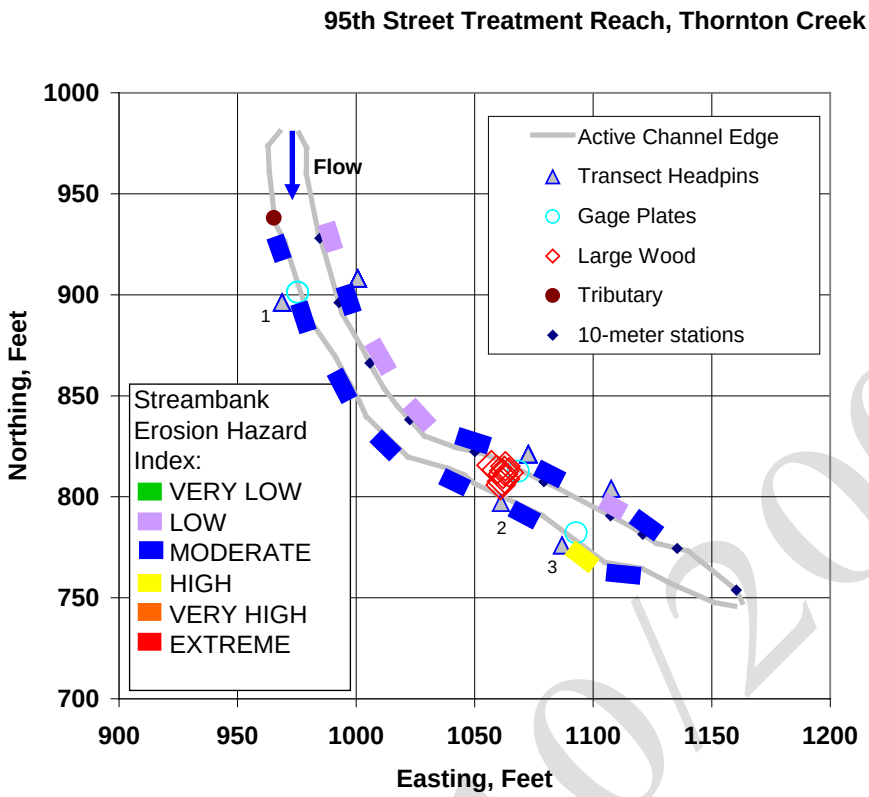


Figure A.5. Planview of 95th Street treatment reach showing Streambank Erosion Hazard Index (BEHI) scores determined in August 2006. 10-meter stations are marked along the left bank (upper, in the graph), which began at 0 m at the downstream end and continued to 80 m at the upstream end. An additional station was assessed at 15 m. Streambanks were not evaluated at 0 m or 10 m due to influences of the downstream culvert.

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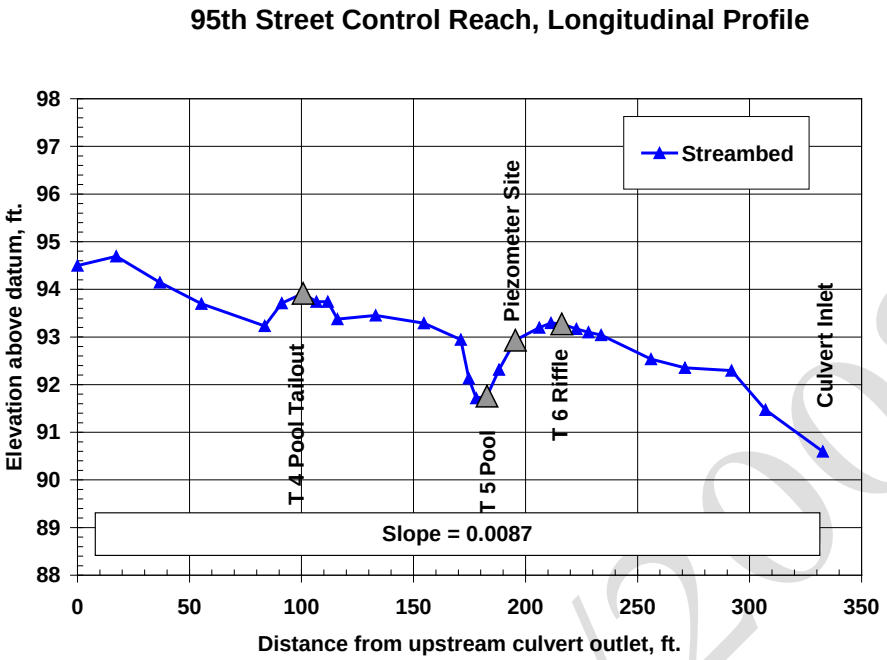


Figure A.6. Streambed longitudinal channel profile at 95th Street control reach in Thornton Creek, February 2006. Survey points along the thalweg and at dominant features were measured using a Nikon Total Station DTM-500 series.

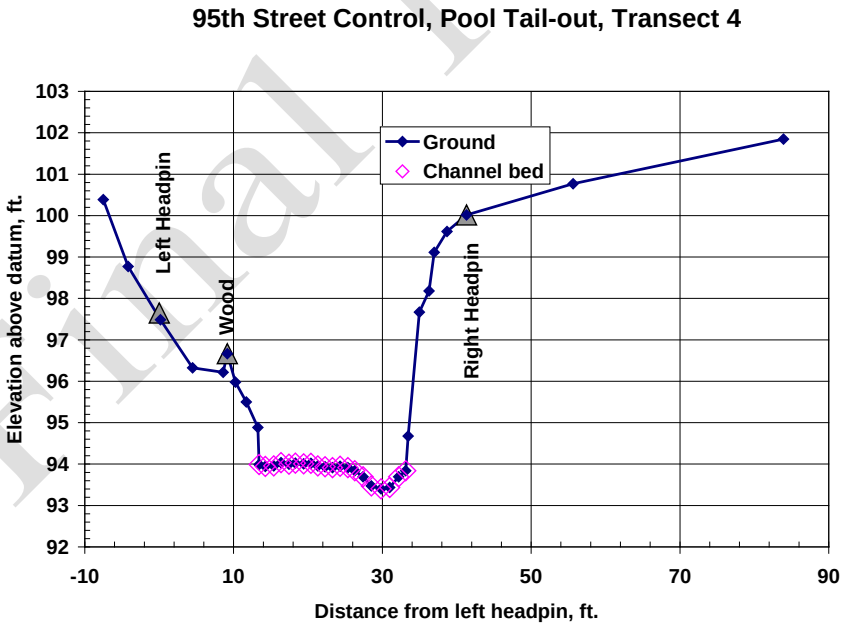


Figure A.7. Stream channel profile of the pool tailout/depositional zone cross section, transect No. 4, looking downstream at 95th Street control reach, Thornton Creek, February 2006. All measurements were recorded using a Nikon Total Station DTM-500.

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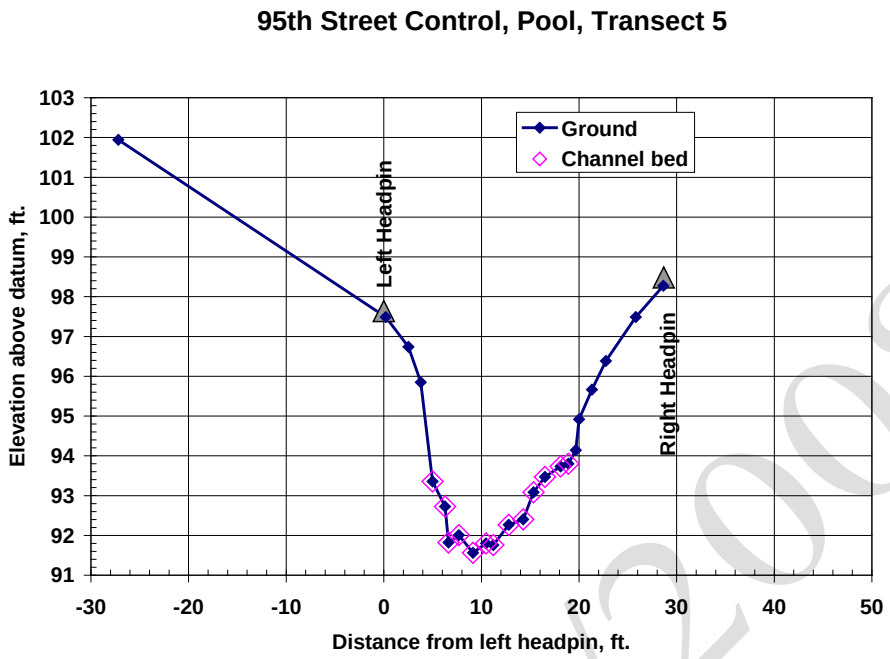


Figure A.8. Stream channel profile of the pool cross section, transect No. 5, looking downstream at 95th Street control reach, Thornton Creek, February 2006. All measurements were recorded using a Nikon Total Station DTM-500.

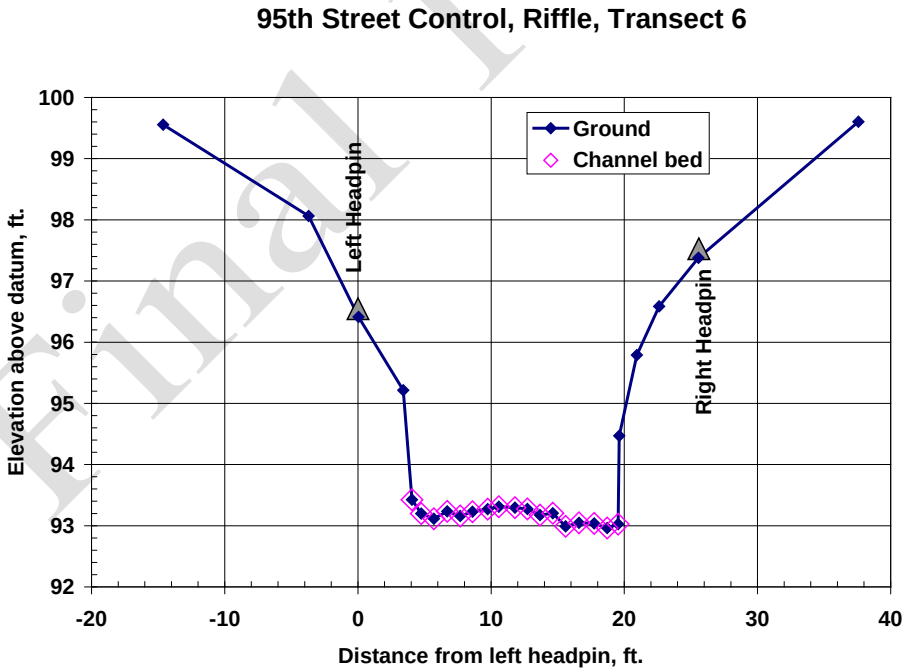


Figure A.9. Stream channel profile of the riffle cross section, transect No. 6, looking downstream at 95th Street control reach, Thornton Creek, February 2006. All measurements were recorded using a Nikon Total Station DTM-500.

Final 10/2008

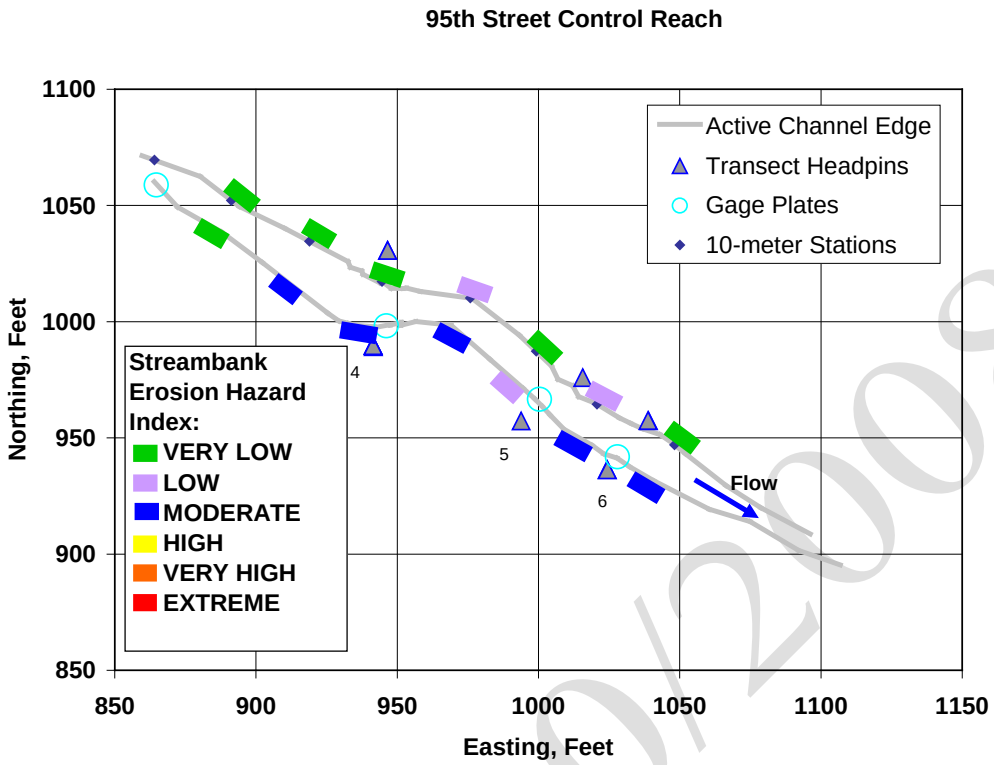


Figure A.10. Planview of 95th Street control reach showing Streambank Erosion Hazard Index (BEHI) scores determined in August 2006. 10-meter stations are marked along the left bank (upper, in the graph), which begins downstream at 0 m and continuing to the upstream end at 70 m .with 0 m on the downstream end and 70 m at the upstream end.

Final 10/2008

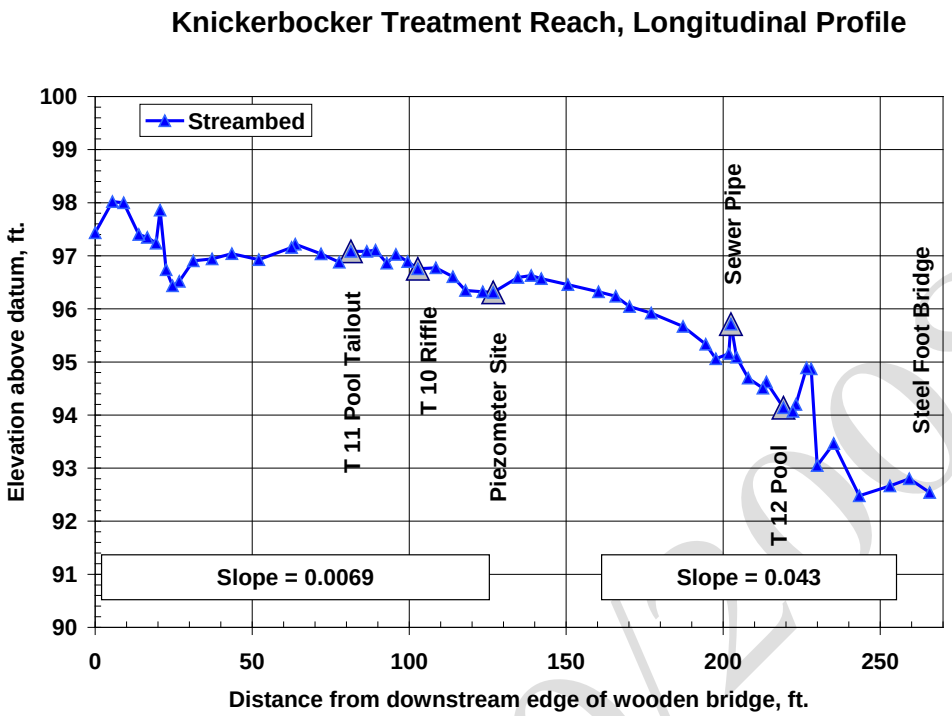


Figure A.11. Streambed longitudinal channel profile at the Knickerbocker treatment reach in Thornton Creek, January 2007. Survey points along the thalweg and at dominant features were measured using a Nikon Total Station DTM-500 series.

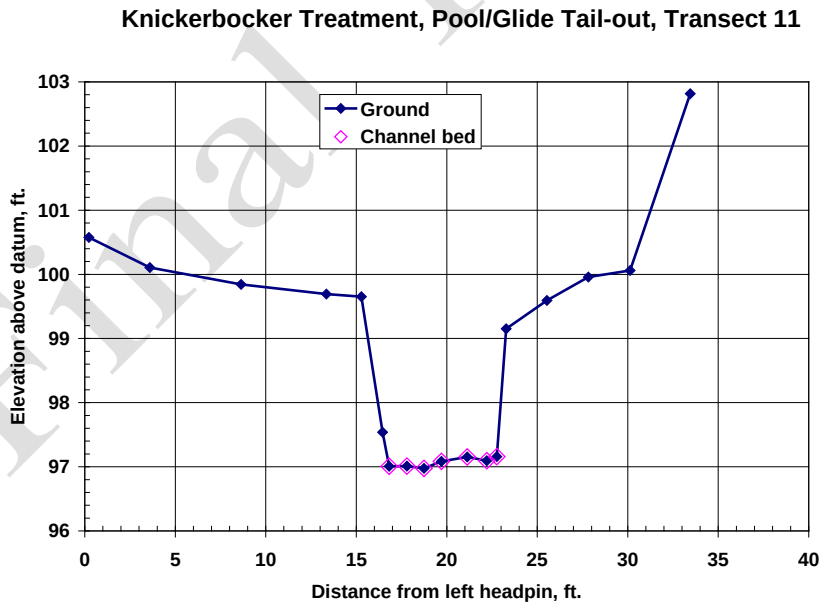


Figure A.12. Stream channel profile of the pool tailout/depositional zone cross section, transect No. 11, looking downstream, at Knickerbocker treatment reach in Thornton Creek, January 2007. All measurements were recorded using a Nikon Total Station DTM-500.

Final 10/2008

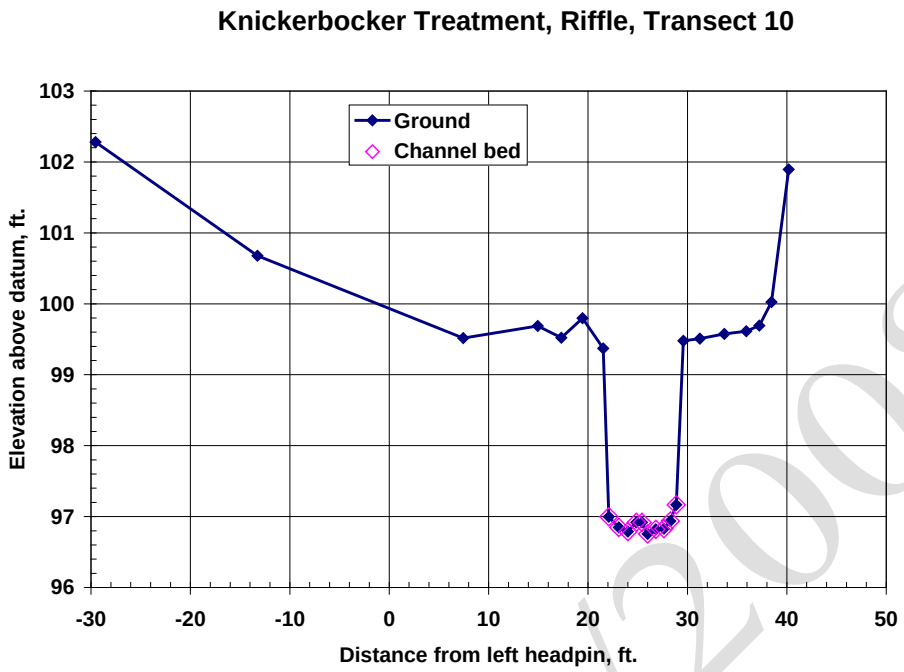


Figure A.13. Stream channel profile of the riffle cross section, transect No. 10, looking downstream, at Knickerbocker treatment reach in Thornton Creek, January 2007. All measurements were recorded using a Nikon Total Station DTM-500.

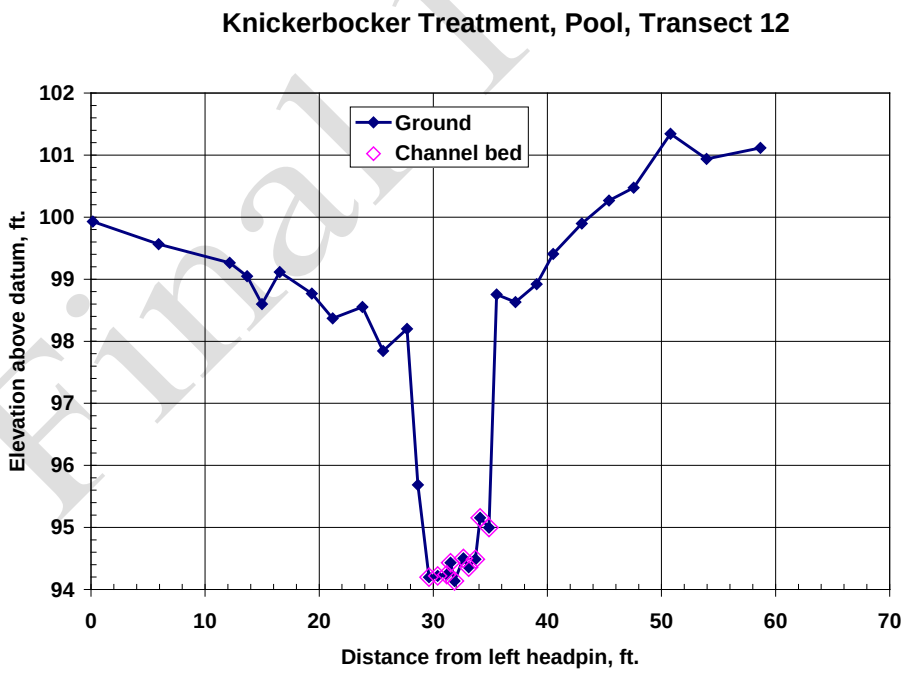


Figure A.14. Stream channel profile of the pool cross section, transect No. 12, looking downstream, at Knickerbocker treatment reach in Thornton Creek, January 2007. All measurements were recorded using a Nikon Total Station DTM-500.

Final 10/2008

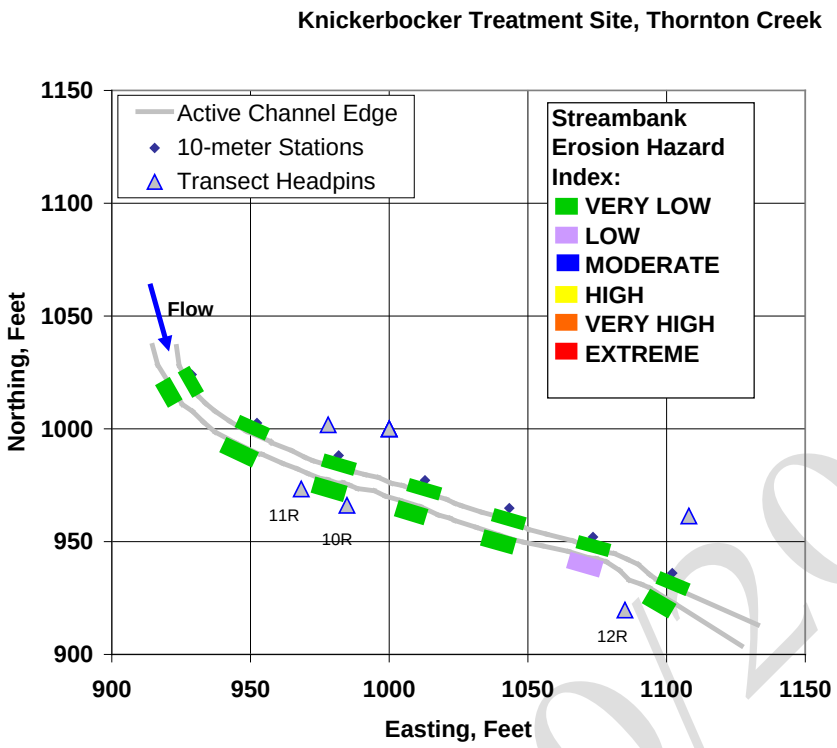


Figure A.15. Planview of Knickerbocker treatment reach showing Streambank Erosion Hazard Index (BEHI) scores determined in August 2006. 10-meter stations are marked along the left bank (upper, in the graph), which begins downstream at h 0 m on and continues to 60 m at the upstream end.

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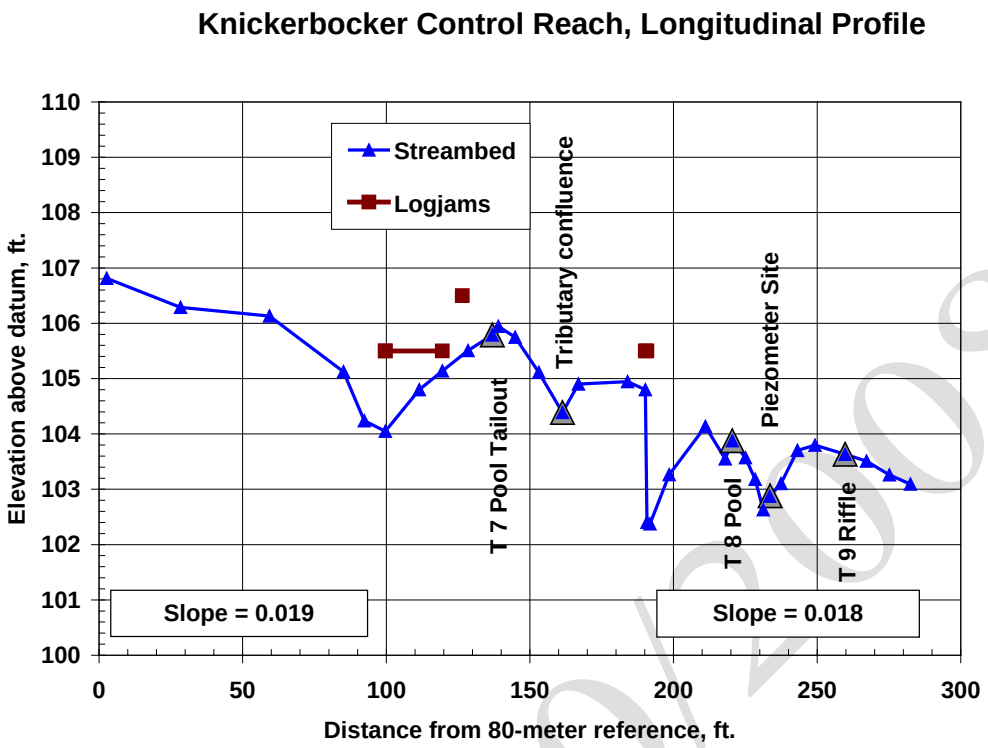


Figure A.16. Streambed longitudinal channel profile at Knickerbocker control reach in Thornton Creek, January 2007. Survey points along the thalweg and at dominant features were measured using a Nikon Total Station DTM-500 series.

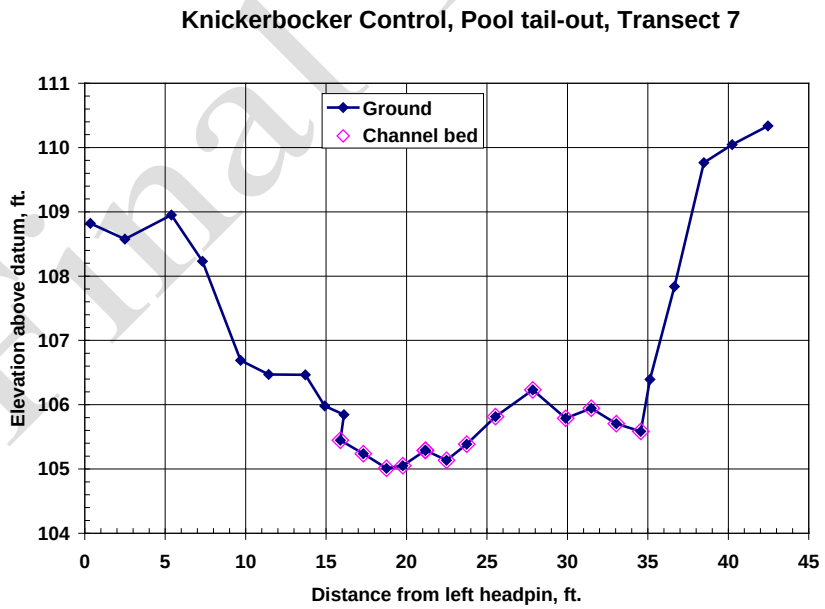


Figure A.17. Stream channel profile of the pool tailout/depositional zone cross section, transect No. 7, looking downstream, at Knickerbocker control reach in Thornton Creek, January 2007. All measurements were recorded using a Nikon Total Station DTM-500.

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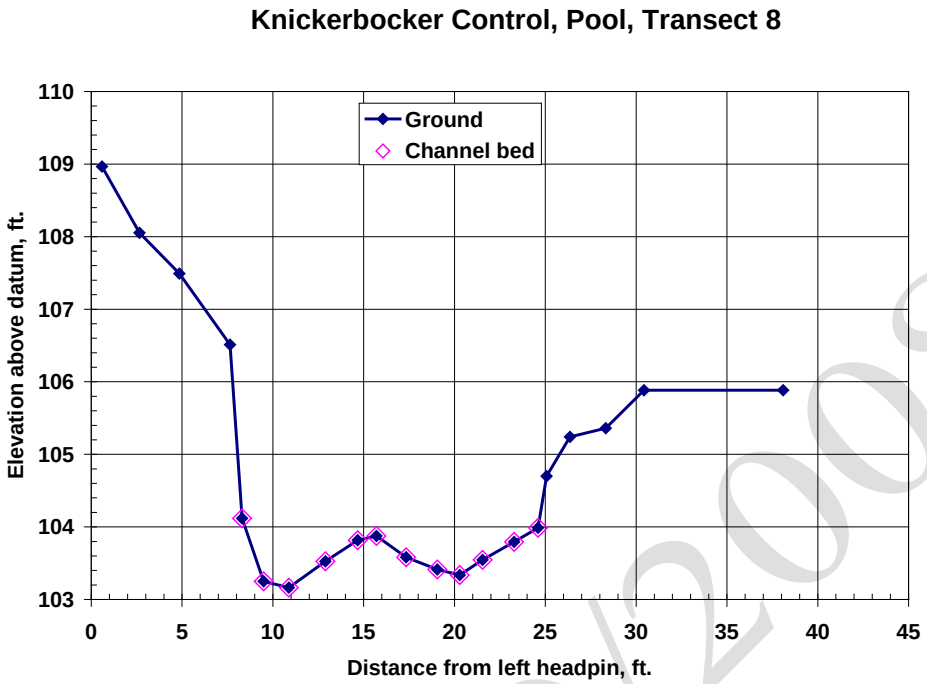


Figure A.18. Stream channel profile of the pool cross section, transect No. 8, looking downstream, at Knickerbocker control reach in Thornton Creek, January 2007. All measurements were recorded using a Nikon Total Station DTM-500.

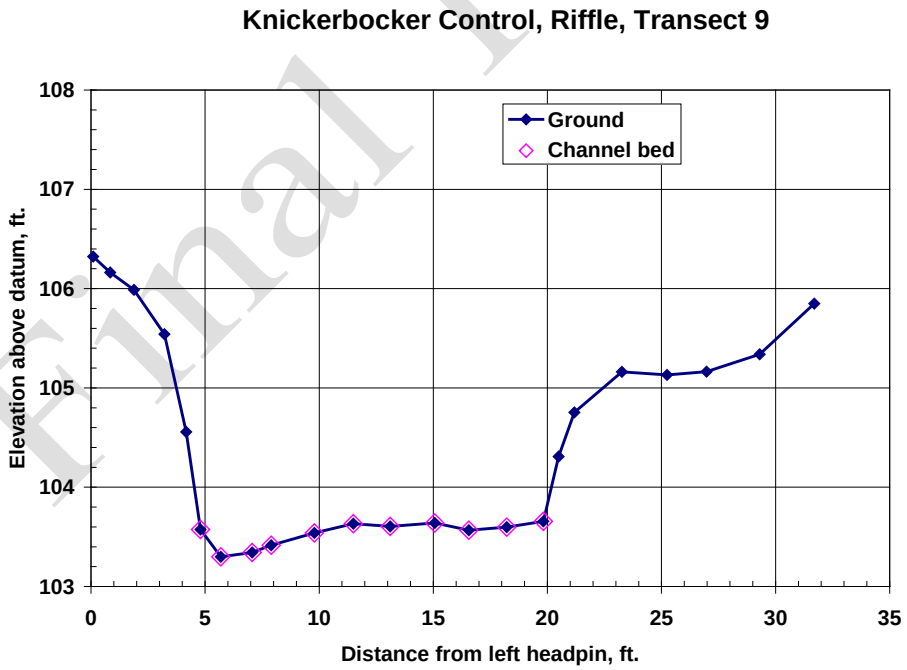


Figure A.19. Stream channel profile of the riffle cross section, transect No. 4, looking downstream, at Knickerbocker control reach in Thornton Creek, January 2007. All measurements were recorded using a Nikon Total Station DTM-500.

Final 10/2008

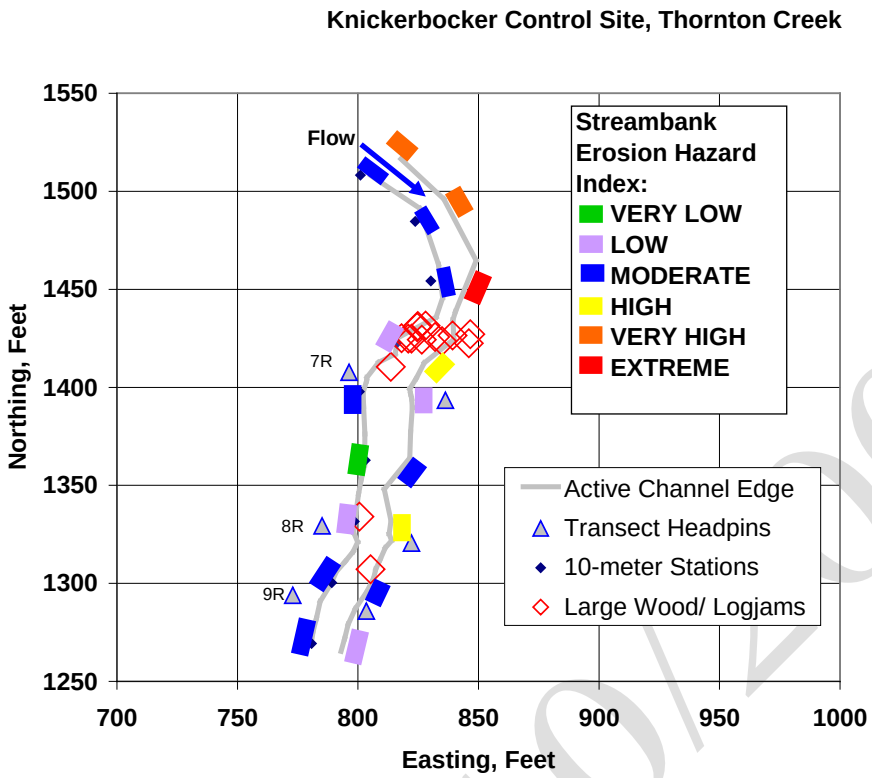


Figure A.20. Planview of Knickerbocker Control Reach showing Streambank Erosion Hazard Index (BEHI) scores determined in August 2006. 10-meter stations are marked along the right bank (left side in the graph), beginning with 0 m on the downstream end and continuing to 80 m at the upstream end.

Final 10/2008

**Appendix B:**
Hyporheic Investigations

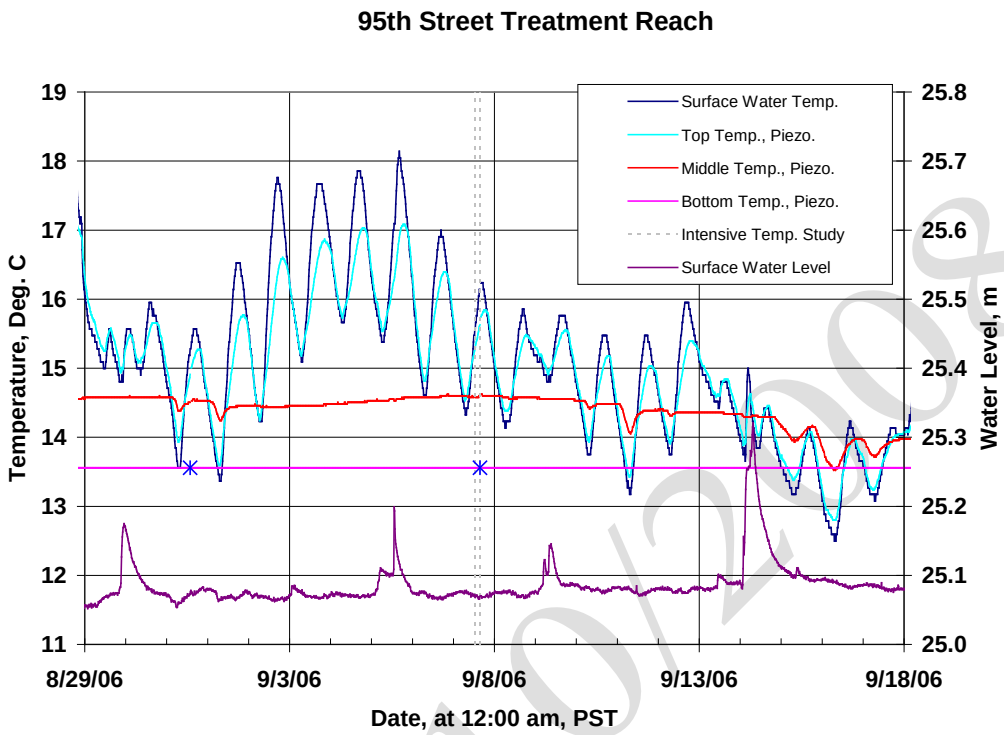


Figure B.1. Surface and subsurface water temperatures (ºC) and surface water levels (m) recorded within the stilling and piezometer wells located at the 95th Street treatment reach between 8/29/06 and 9/18/06. All readings were recorded in 15 minute intervals by pressure transducers, (Onset computers, Hobo Water Level Logger model U20-001-01) and thermographs (Onset computers, Hobo Water Temp pro v2) installed in the wells. This set of temperature readings center around the intensive hyporheic temperature study conducted in this reach on September 7, 2006. Asterisks denote times when instruments were removed from the piezometer and stilling wells for servicing. Bottom, middle and top piezometer temperature measurements were recorded at 140 cm, 75 cm, and 13 cm below the streambed, respectively.

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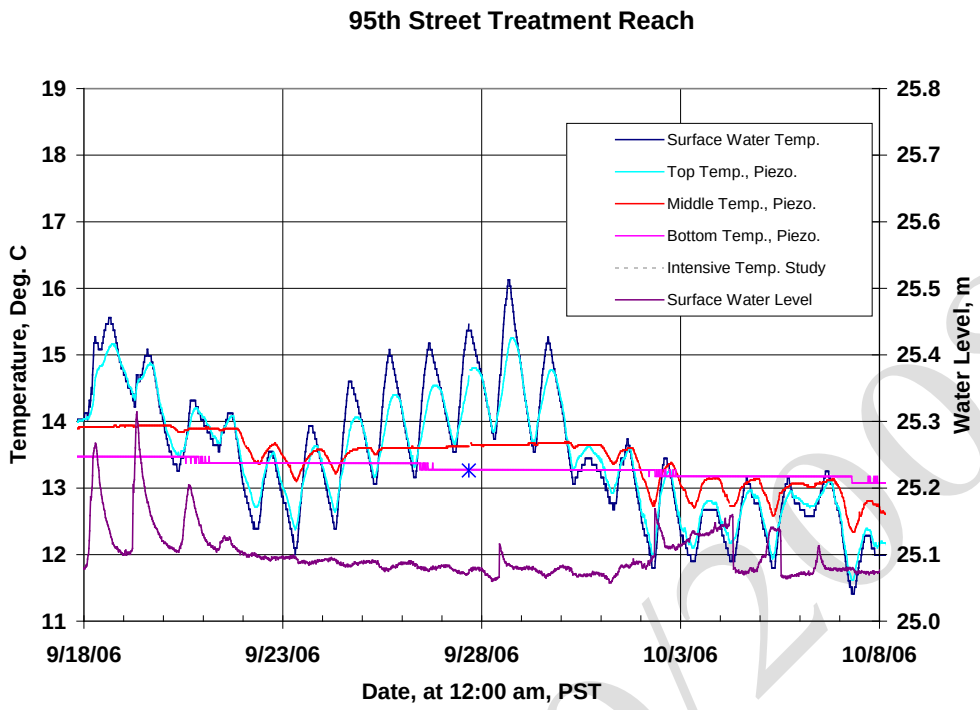


Figure B.2. Surface and subsurface water temperatures (ºC) and surface water levels (m) recorded within the stilling and piezometer wells located at the 95th Street treatment reach between 9/18/06 and 10/8/06. All readings were recorded in 15 minute intervals by pressure transducers, (Onset computers, Hobo Water Level Logger model U20-001-01) and thermographs (Onset computers, Hobo Water Temp pro v2) installed in the wells. This set of temperature readings center around the intensive hyporheic temperature study conducted at the Knickerbocker reaches. Asterisks denote times when instruments were removed from the piezometer and stilling wells for servicing. Bottom, middle and top piezometer temperature measurements were recorded at 140 cm, 75 cm, and 13 cm below the streambed, respectively.

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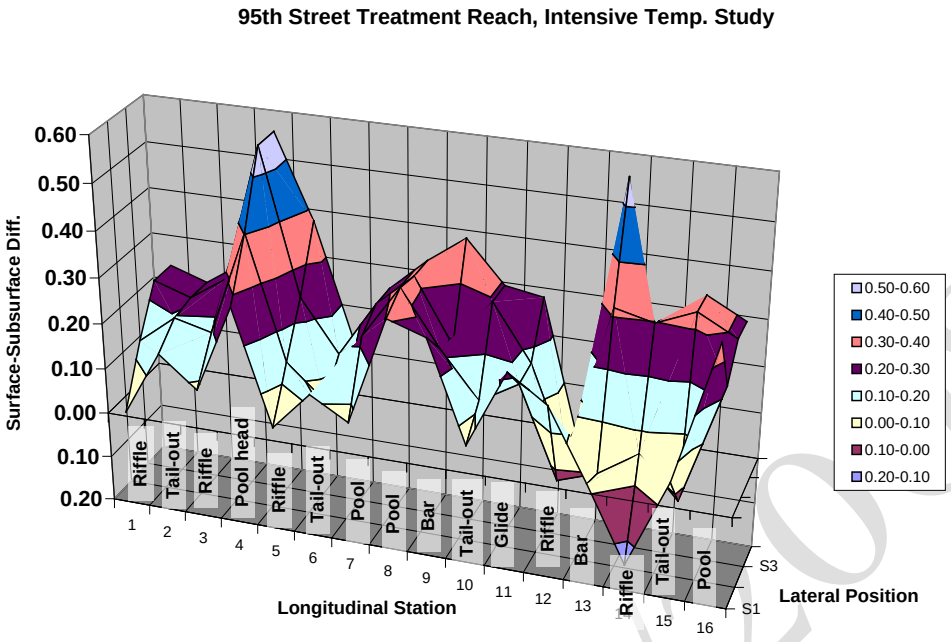


Figure B.3. Intensive subsurface temperature study at the 95th Street treatment reach conducted between 12:51 and 15:26 PST on September 7, 2006. Values are differences between surface water temperature and inter-gravel temperature measured within the streambed at a depth of 10 cm. Peaks and troughs represent zones of relative upwelling and downwelling, respectively. The numbers plotted are the averages of three measurement runs. Flow is from right to left.

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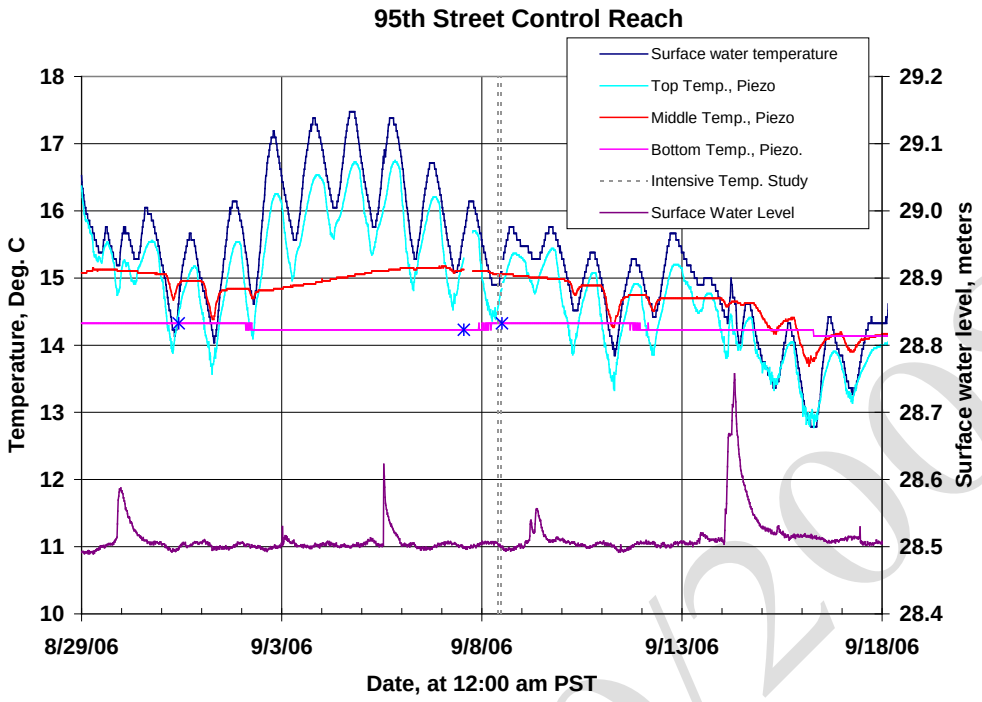


Figure B.4. Surface and subsurface water temperatures (ºC) and surface water levels (m) recorded within the stilling and piezometer wells located at the 95th Street control reach between 8/29/06 and 9/18/06. All readings were recorded in 15 minute intervals by pressure transducers, (Onset computers, Hobo Water Level Logger model U20-001-01) and thermographs (Onset computers, Hobo Water Temp pro v2) installed in the wells. This set of temperature readings center around the intensive hyporheic temperature study conducted in this reach on September 8, 2006. Asterisks denote when the instruments were removed from the piezometer and stilling wells for servicing. Bottom, middle and top piezometer temperature measurements were recorded at 136 cm, 76 cm, and 18 cm below the streambed, respectively.

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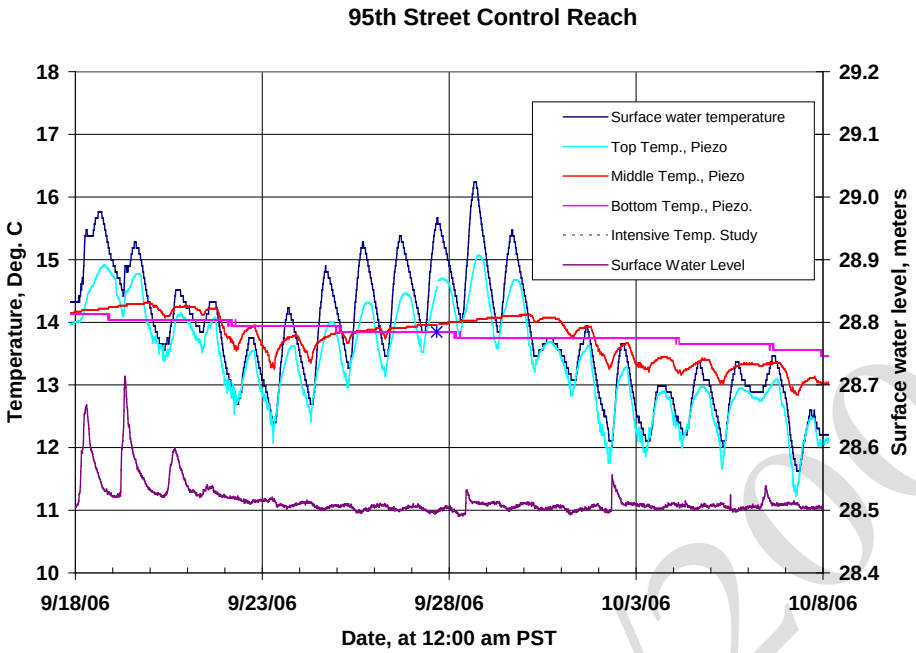


Figure B.5. Surface and subsurface water temperatures (ºC) and surface water levels (m) recorded within the stilling and piezometer wells located at the 95th Street control reach between 9/18/06 and 10/8/06. All readings were recorded in 15 minute intervals by pressure transducers (Onset computers, Hobo Water Level Logger model U20-001-01) and thermographs (Onset computers, Hobo Water Temp pro v2) installed in the wells. This set of temperature readings center around the intensive hyporheic temperature study conducted in the Knickerbocker reaches. Asterisks denote when instruments were removed from the piezometer and stilling wells for servicing. Bottom, middle and top piezometer temperature measurements were recorded at 136 cm, 76 cm, and 18 cm below the streambed, respectively.

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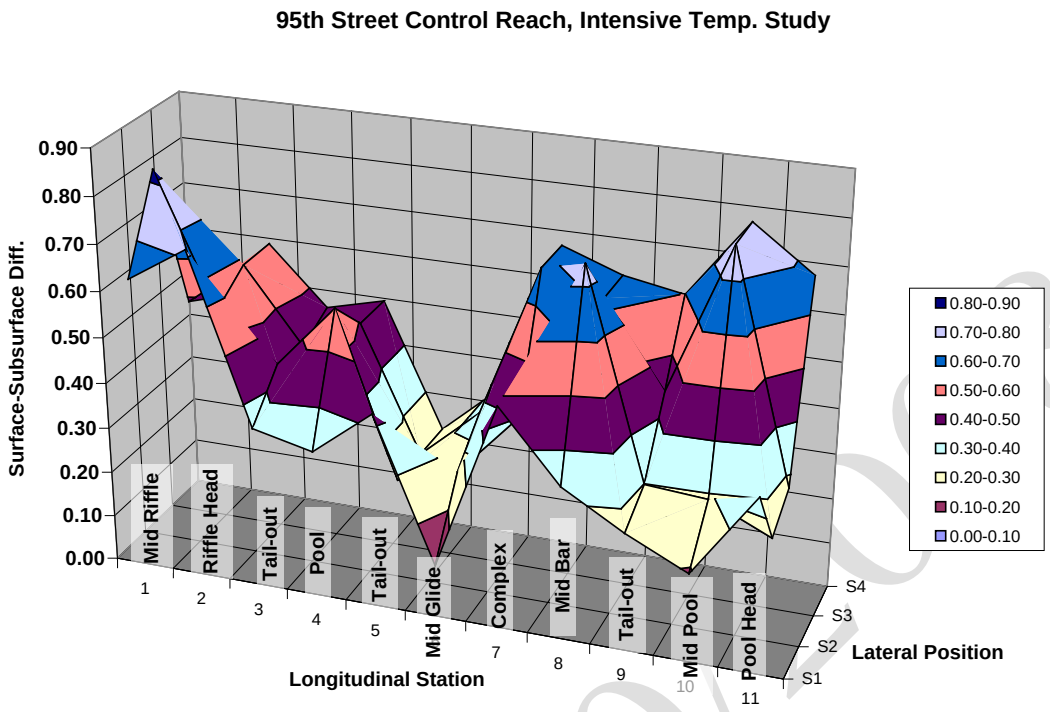


Figure B.6. Intensive subsurface temperature study at the 95th Street control reach, conducted between 9:28 and 11:22 PST on September 8, 2006. Values are differences between surface water temperature and inter-gravel temperature measured within the streambed at a depth of 10 cm. Peaks and troughs represent zones of relative upwelling and downwelling, respectively. The numbers plotted are the averages of three measurement runs. Flow is from right to left.

Final 10/2008

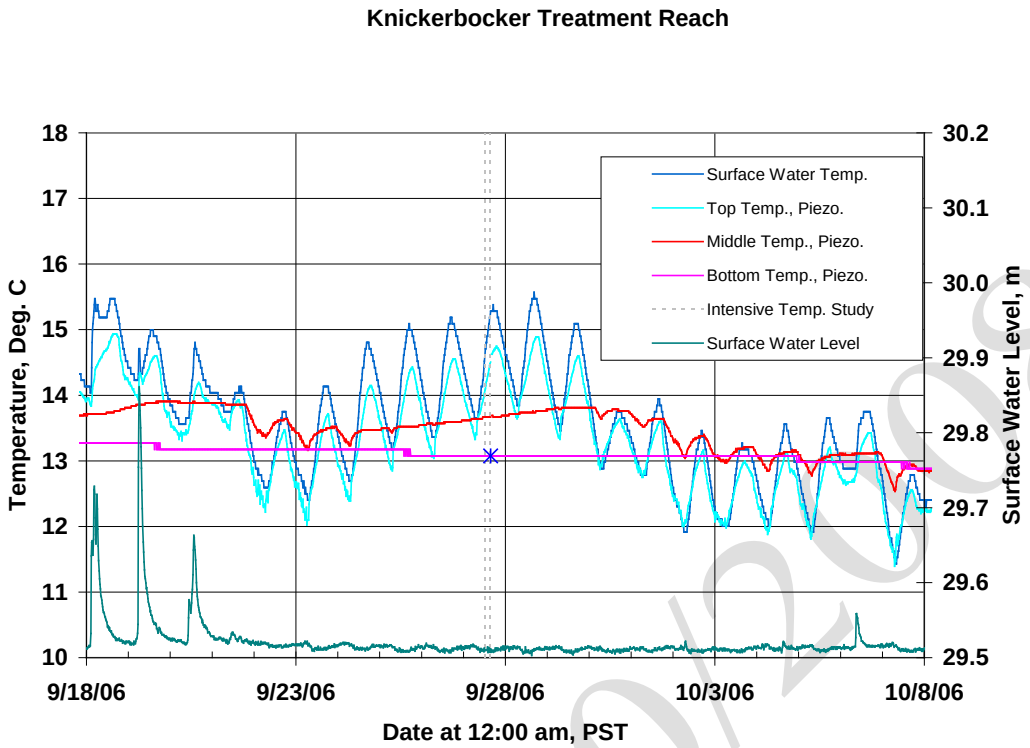


Figure B.7. Surface and subsurface water temperatures (ºC) and surface water levels (m) recorded within the stilling and piezometer wells located at the Knickerbocker treatment reach between 9/18/06 and 10/8/06. All readings were recorded in 15 minute intervals by pressure transducers (Onset computers, Hobo Water Level Logger model U20-001-01) and thermographs (Onset computers, Hobo Water Temp pro v2) installed in the wells. This set of temperature readings center around the intensive hyporheic temperature study conducted on September 27, 2006. Asterisks denote times when instruments were removed from the piezometer for servicing. Bottom, middle and top piezometer measurement locations were 143 cm, 75 cm, and 11 cm below the streambed, respectively.

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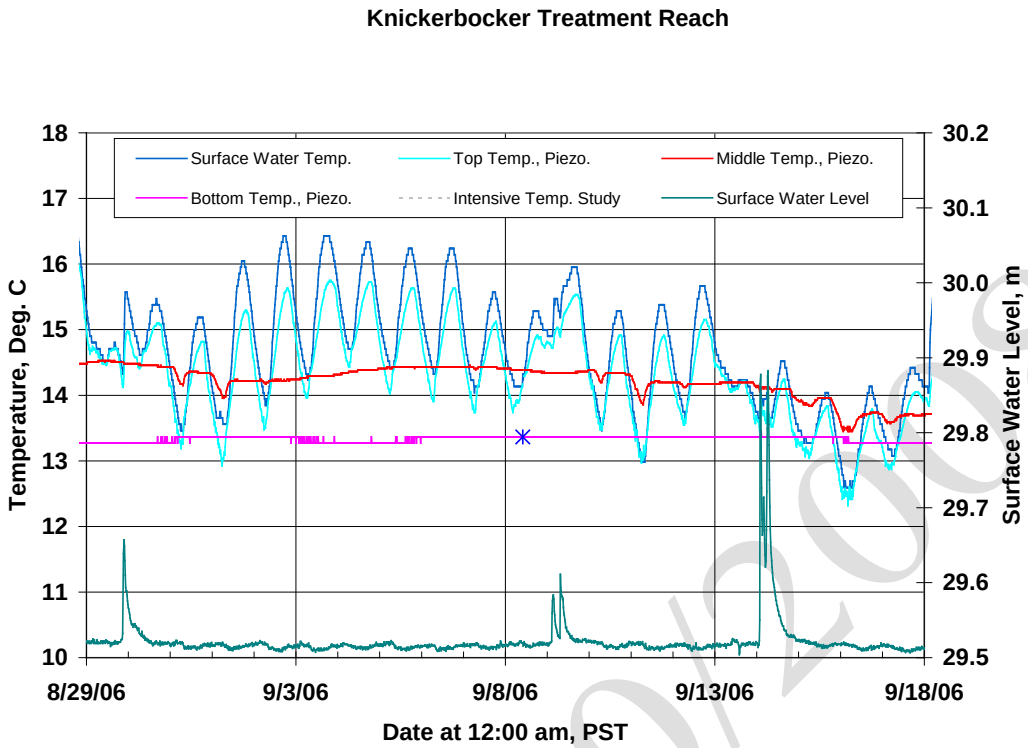


Figure B.8. Surface and subsurface water temperatures (ºC) and surface water levels (m) recorded within the stilling and piezometer wells located at the Knickerbocker treatment reach between 8/29/06 and 9/18/06. All readings were recorded in 15 minute intervals by pressure transducers (Onset computers, Hobo Water Level Logger model U20-001-01) and thermographs (Onset computers, Hobo Water Temp pro v2) installed in the wells. This set of temperature readings center around the intensive hyporheic temperature study conducted at the 95th Street reaches. Asterisks denote times when instruments were removed from the piezometer for servicing. Bottom, middle and top piezometer measurement locations were 143 cm, 75 cm, and 11 cm below the streambed, respectively.

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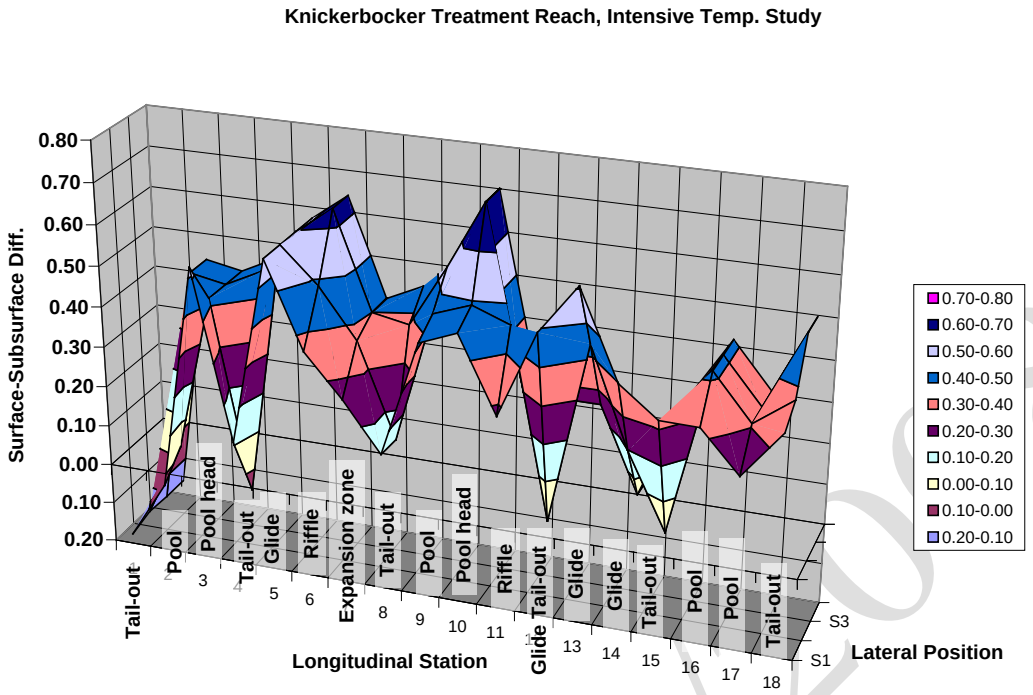


Figure B.9. Intensive subsurface temperature study at the Knickerbocker treatment reach, conducted between 12:03 and 15:07 PST on September 27, 2006. Values are differences between surface water temperature and inter-gravel temperature measured at a depth of 10 cm within the streambed. Peaks and troughs represent zones of relative upwelling and downwelling, respectively. The numbers plotted are the averages of three measurement runs. Flow is from right to left.

Final 10/2008

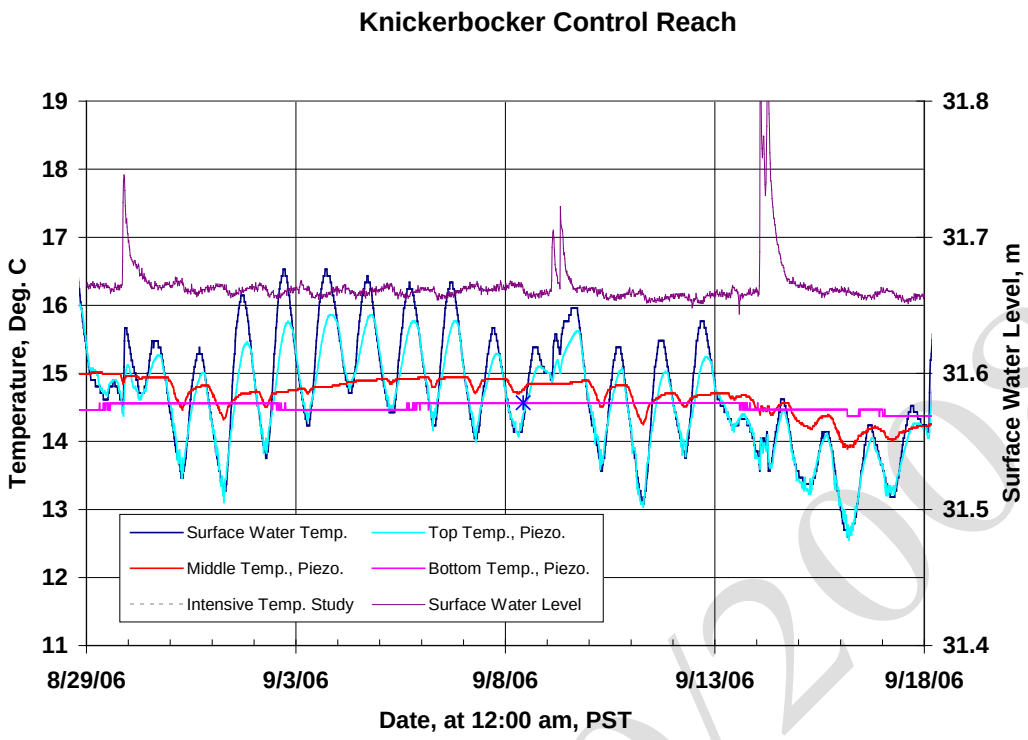


Figure B.10. Surface and subsurface water temperatures (ºC) and surface water levels (m) recorded within the stilling and piezometer wells located at the Knickerbocker control reach between 8/29/06 and 9/18/06. All readings were recorded in 15 minute intervals by pressure transducers (Onset computers, Hobo Water Level Logger model U20-001-01) and thermographs (Onset computers, Hobo Water Temp pro v2) installed in the wells. This set of temperature readings center around the intensive hyporheic temperature study conducted in the 95th Street reaches. Asterisks denote times when instruments were removed from the piezometer for servicing. Bottom, middle and top piezometer measurement locations were 127 cm, 66 cm, and 11 cm below the streambed, respectively.

Final 10/2008

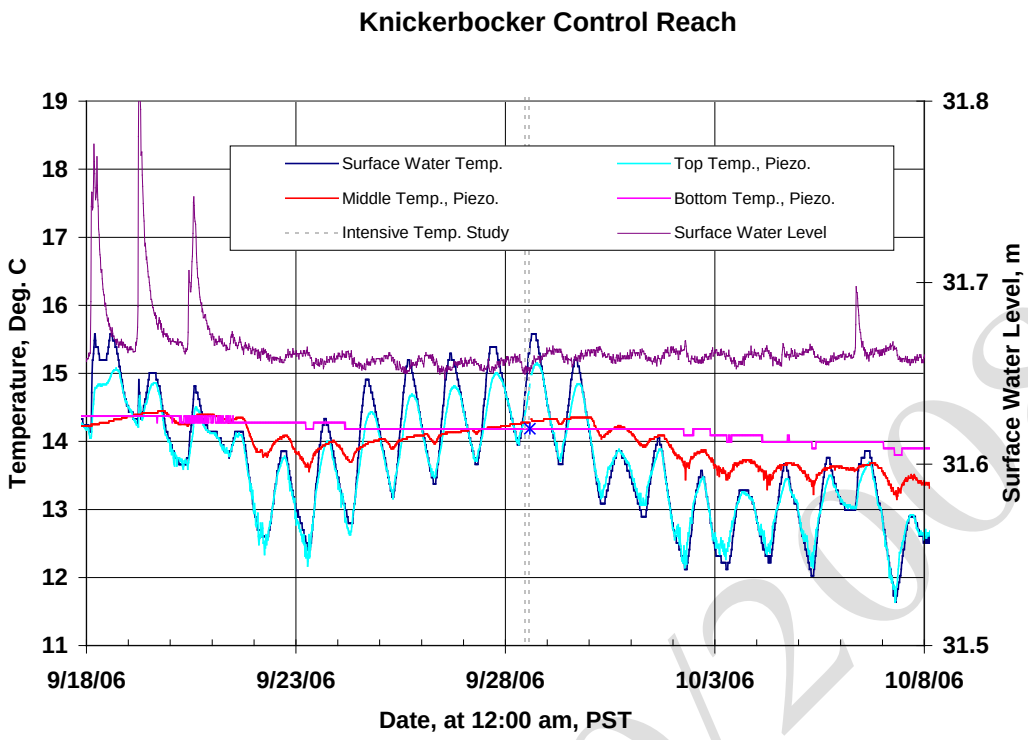


Figure B.11. Surface and subsurface water temperatures (ºC) and surface water levels (m) recorded within the stilling and piezometer wells located at the Knickerbocker control reach between 9/18/06 and 10/8/06. All readings were recorded in 15 minute intervals by pressure transducers (Onset computers, Hobo Water Level Logger model U20-001-01) and thermographs (Onset computers, Hobo Water Temp pro v2) installed in the wells. This set of temperature readings center around the intensive hyporheic temperature study conducted in this reach on September 28, 2006. Asterisks denote times when instruments were removed from the piezometer for servicing. Bottom, middle and top piezometer measurement locations were 127 cm, 66 cm, and 11 cm below the streambed, respectively.

Final 10/2008

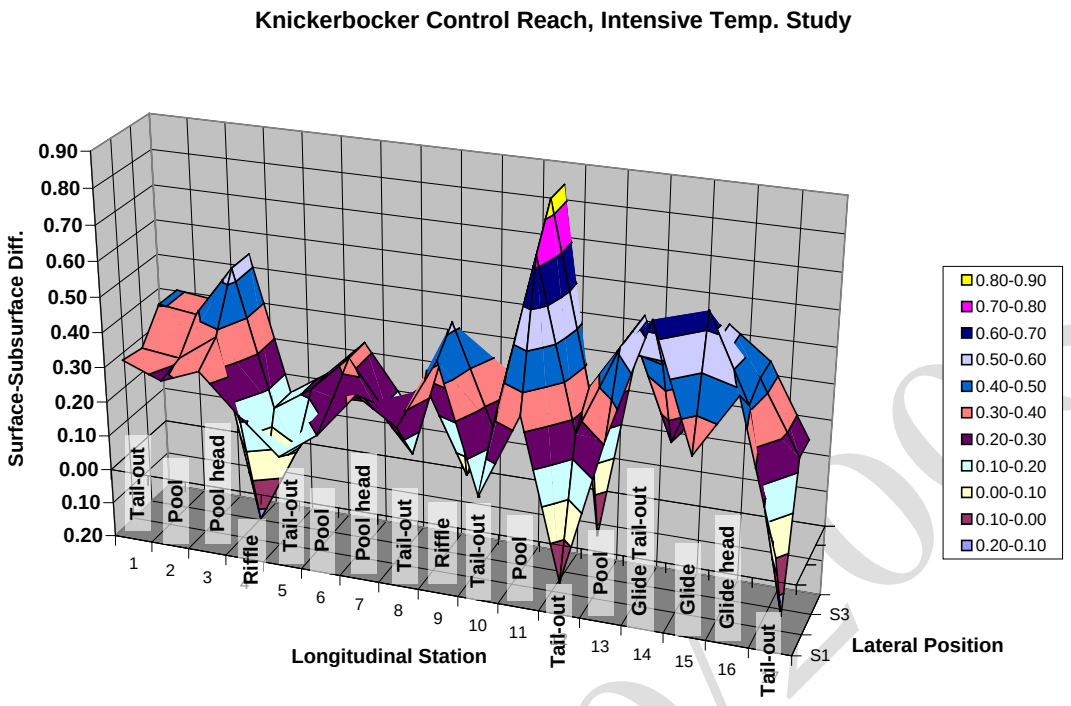


Figure B.12. Intensive subsurface temperature study at the Knickerbocker control reach, conducted between 11:19 and 13:48 PST on September 28, 2006. Values are differences between surface water temperature and inter-gravel temperature measured at a depth of 10 cm within the streambed. Peaks and troughs represent zones of relative upwelling and downwelling, respectively. The numbers plotted are the averages of three measurement runs. Flow is from right to left.

Final 10/2006

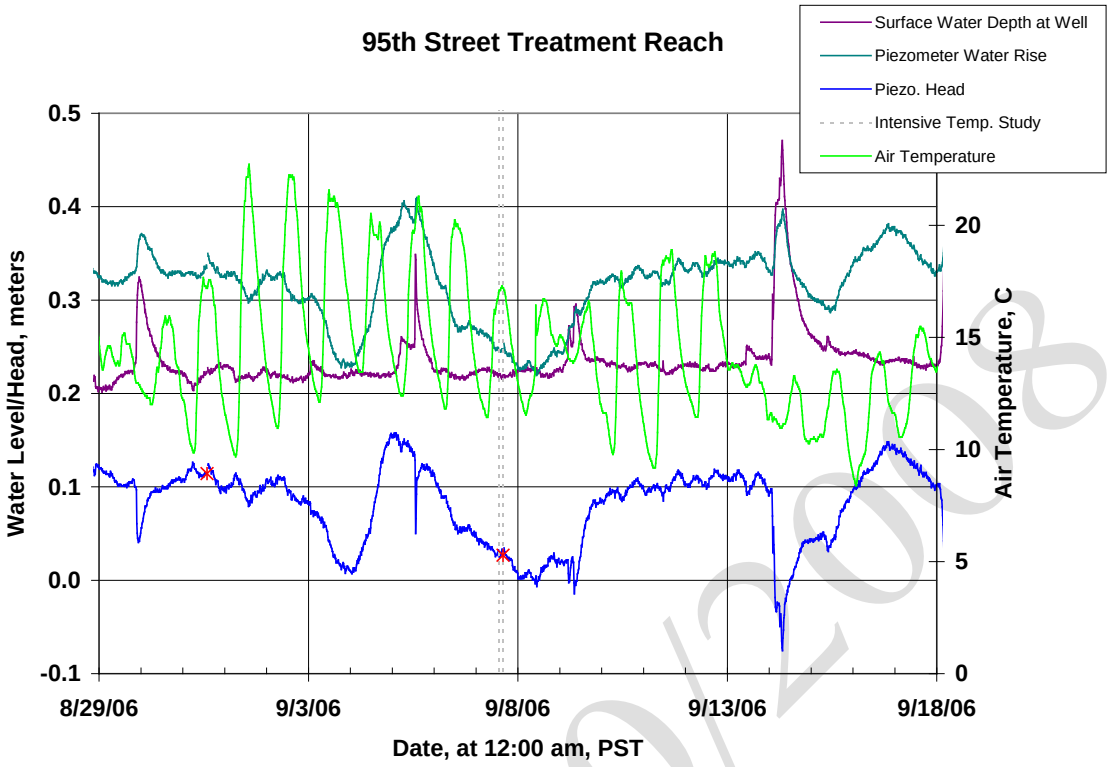


Figure B.13. Surface and subsurface water levels (m) in the stream and piezometer, measured as depth or rise relative to the streambed elevation, at the 95th Street treatment reach between 8/29/06 and 9/18/06. Air temperature (ºC) was also recorded for this 20-day period which centered on the date, September 7, 2006, of the intensive hyporheic temperature study conducted in this reach. Piezometric head was computed as the differences between the surface water depth and piezometric water rise. Asterisks denote times when the pressure transducers and thermographs were removed from the piezometer for servicing.

Final 10/2008

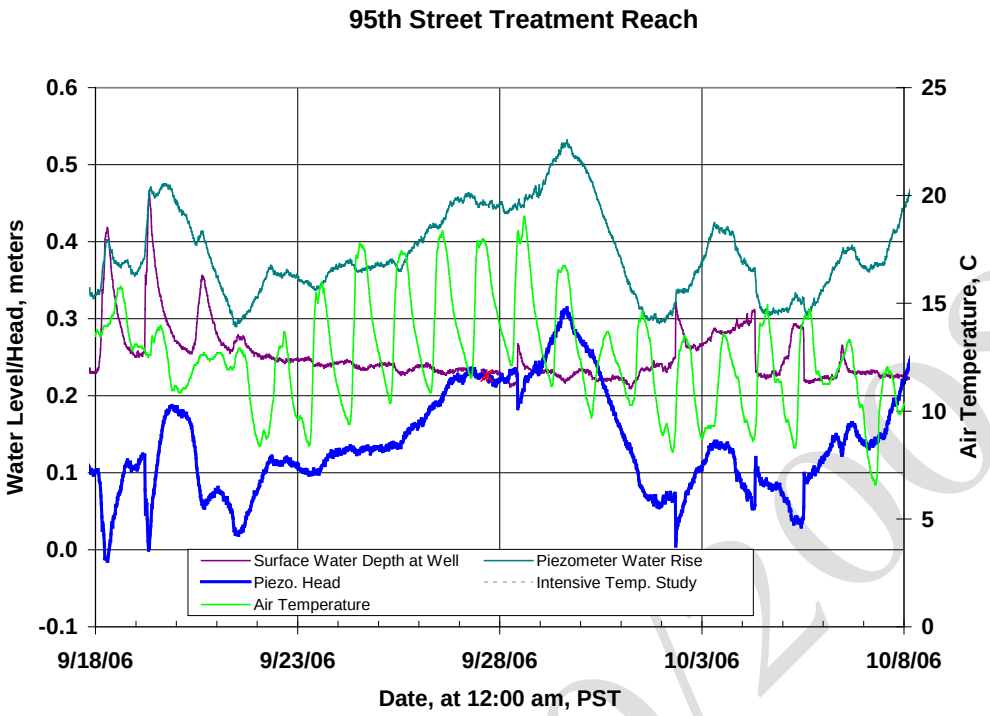


Figure B.14. Surface and subsurface water levels (m) in the stream and piezometer, measured as depth or rise relative to the streambed elevation, at the 95th Street treatment reach between 9/18/06 and 10/8/06. Air temperature (ºC) was also recorded for this 20-day period which centered on the dates of the intensive hyporheic temperature study conducted at the Knickerbocker reaches. Piezometric head was computed as the differences between the surface water depth and piezometric water rise. Asterisks denote times when instruments were removed from the piezometer for servicing.

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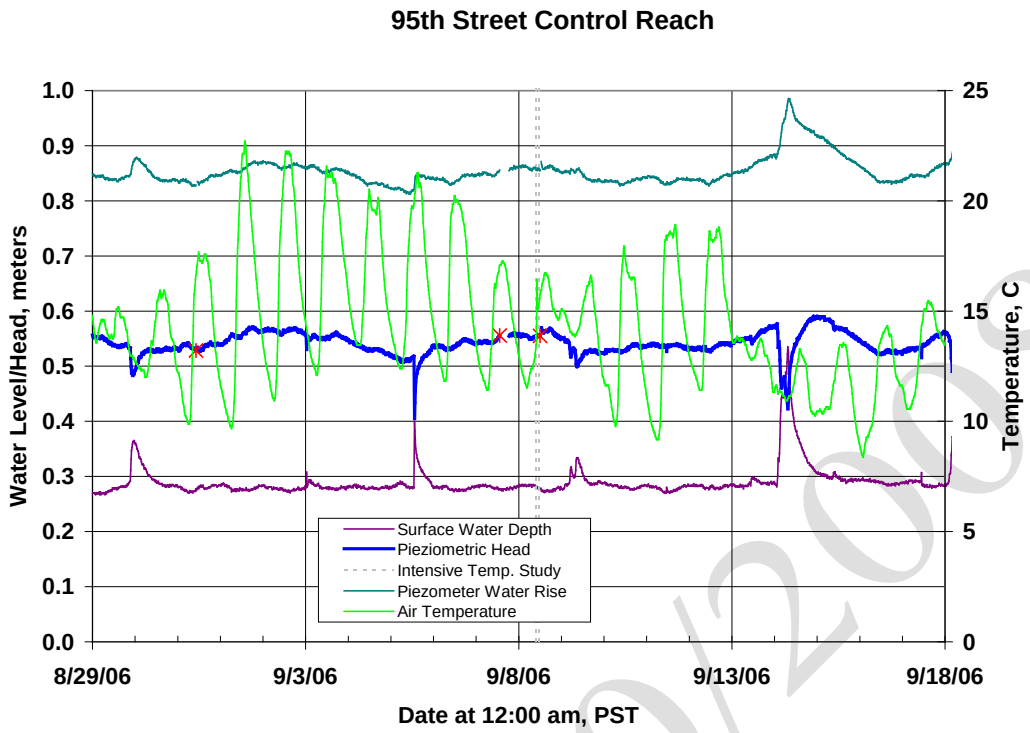


Figure B.15. Surface and subsurface water levels at the 95th Street control reach between 8/29/06 and 9/18/06, the 20-day period centered around September 8, 2006, the date of the intensive hyporheic temperature study conducted at this reach. Asterisks denote times when instruments were removed from the piezometer for servicing. Surface water level and piezometric water rise are computed relative to the streambed elevation at the piezometer well. Piezometric head is the difference between these levels.

Final 10/2008

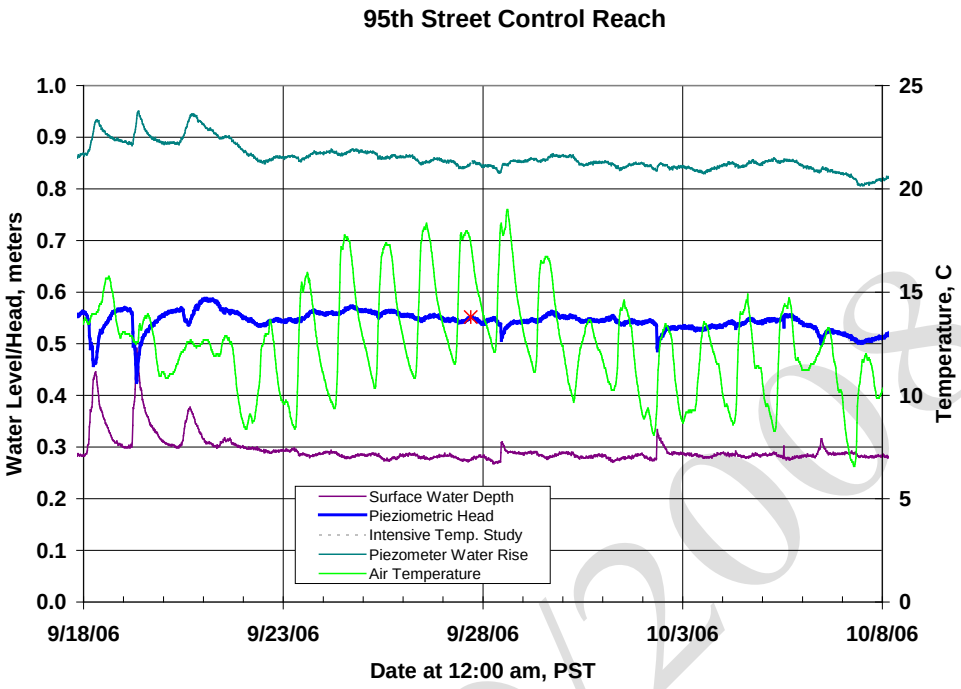


Figure B.16. Surface and subsurface water levels at the 95th Street control reach during the 20-day period centered on September 28, 2006, the date of the intensive hyporheic temperature study at the Knickerbocker reaches. Asterisks denote times when instruments were removed from the piezometer for servicing. Surface water level and piezometric water rise are computed relative to the streambed elevation at the piezometer well. Piezometric head is the difference between these levels.

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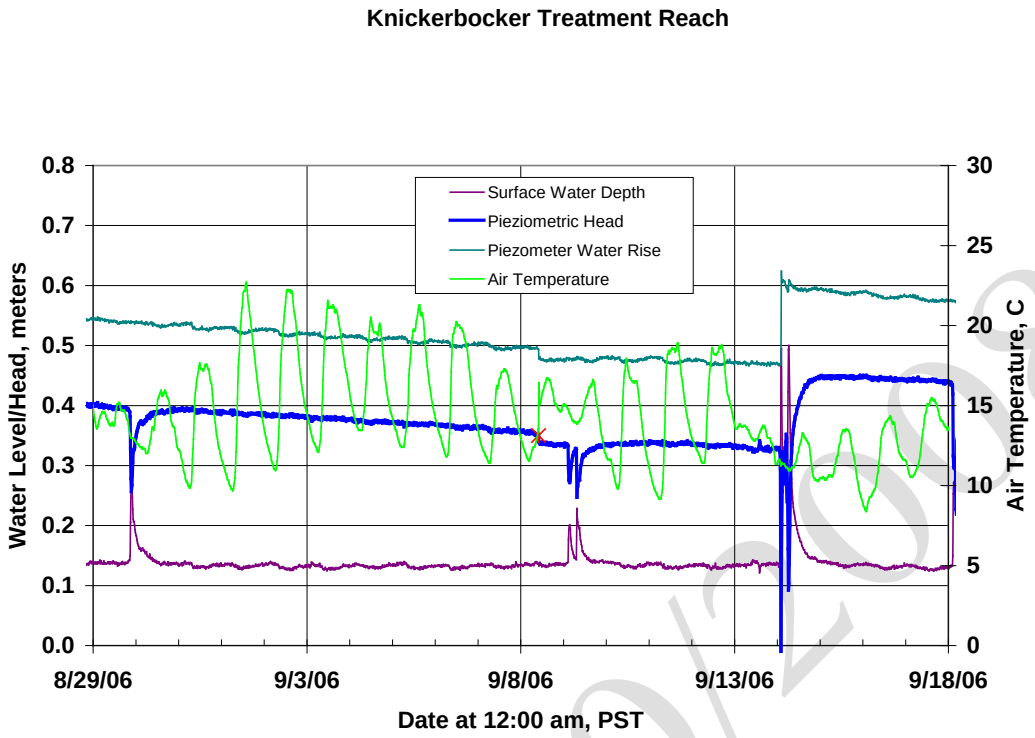


Figure B.17. Surface and subsurface water levels at the Knickerbocker treatment reach during the 20-day period centered on September 7, 2006, the date of the intensive hyporheic temperature study at the 95th Street site. Asterisks denote times when instruments were removed from the piezometer for servicing. Surface water level and piezometric water rise are computed relative to the streambed elevation at the piezometer well. Piezometric head is the difference between these levels.

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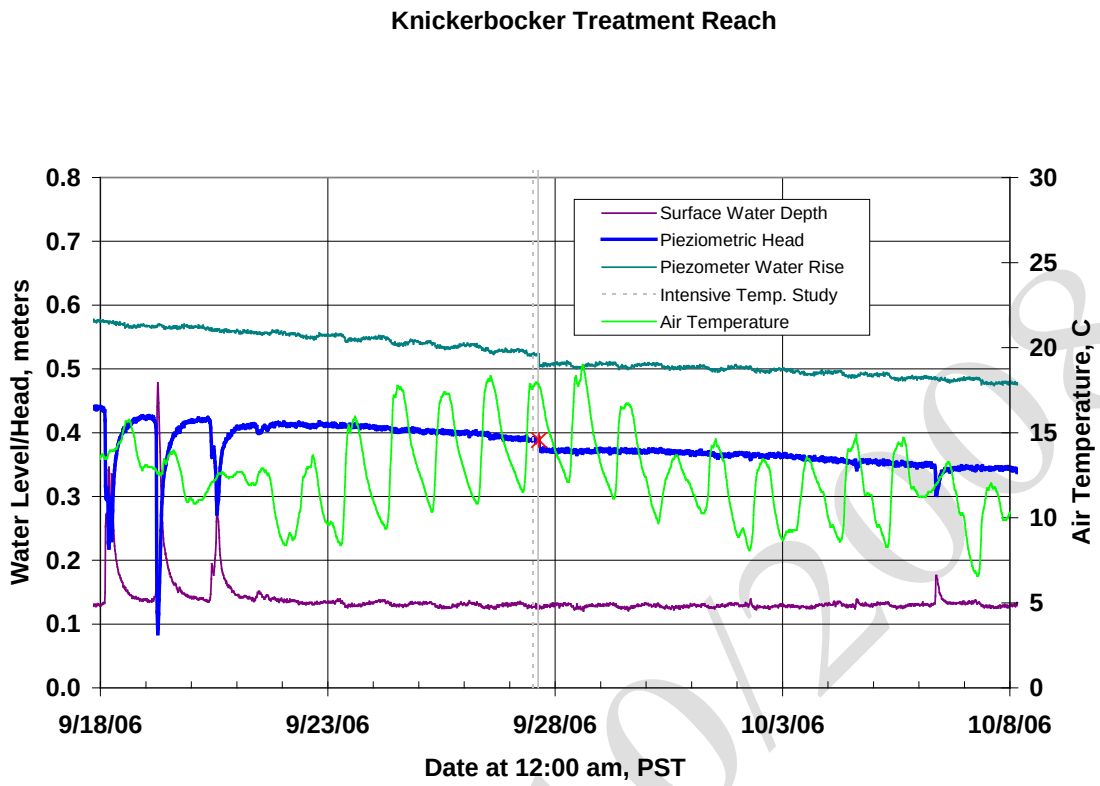


Figure B.18. Surface and subsurface water levels at the Knickerbocker treatment reach during the 20-day period centered on the intensive hyporheic temperature study. Asterisks denote times when instruments were removed from the piezometer for servicing. Surface water level and piezometric water rise are computed relative to the streambed elevation at the piezometer well. Piezometric head is the difference between these levels.

Final 10/2008

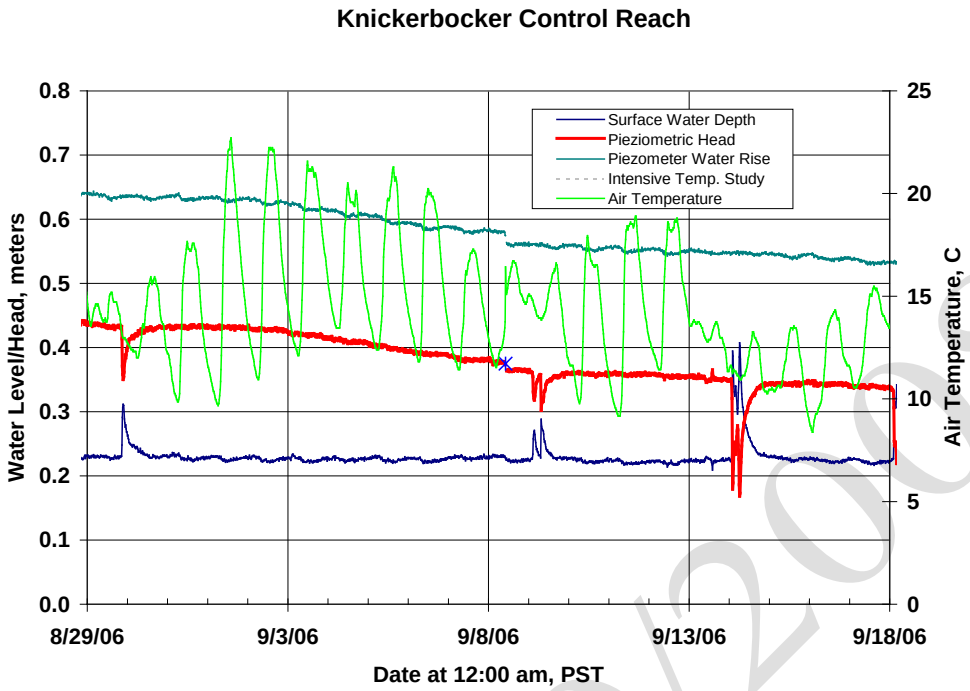


Figure B.19. Surface and subsurface water levels at the Knickerbocker Control Reach during the 20-day period centered on September 7, 2006, the date of the intensive hyporheic temperature study at the 95th Street reaches. Asterisks denote times when instruments were removed from the piezometer for servicing. Surface water level and piezometric water rise are computed relative to the streambed elevation at the piezometer well. Piezometric head is the difference between these levels.

Final 10/2008

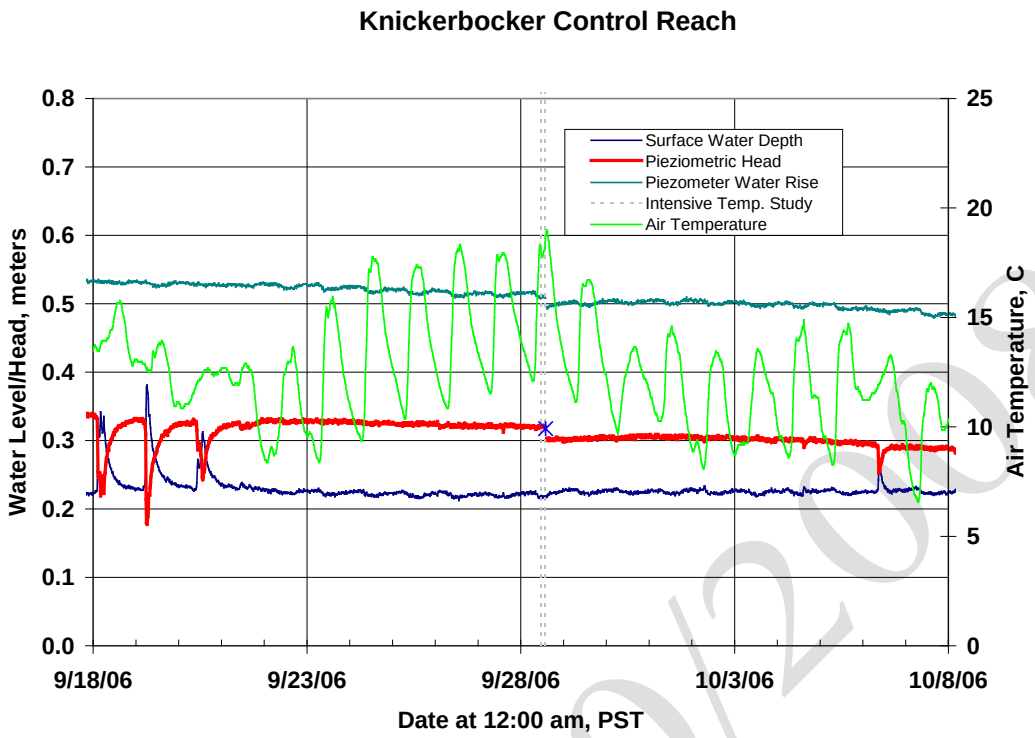


Figure B.20. Surface and subsurface water levels at the Knickerbocker Control Reach during the 20-day period centered on the intensive hyporheic temperature study. Asterisks denote times when instruments were removed from the piezometer for servicing. Surface water level and piezometric water rise are computed relative to the streambed elevation at the piezometer well. Piezometric head is the difference between these levels.

Final 10/2008

**Appendix C:**
Hydraulic Investigations

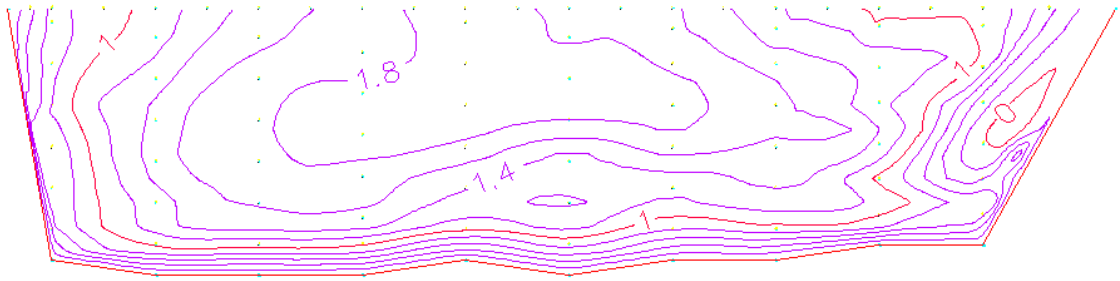


Figure C.1. Isovel diagram of the riffle cross section at Knickerbocker treatment reach (Transect 10) measured during a storm event on December 14, 2006. Lines of constant average velocity are in m/s and contour intervals are 0.2 m/s. Blue colored dots represent measurement points. Total discharge measured 48.3 $ft^3/s$.

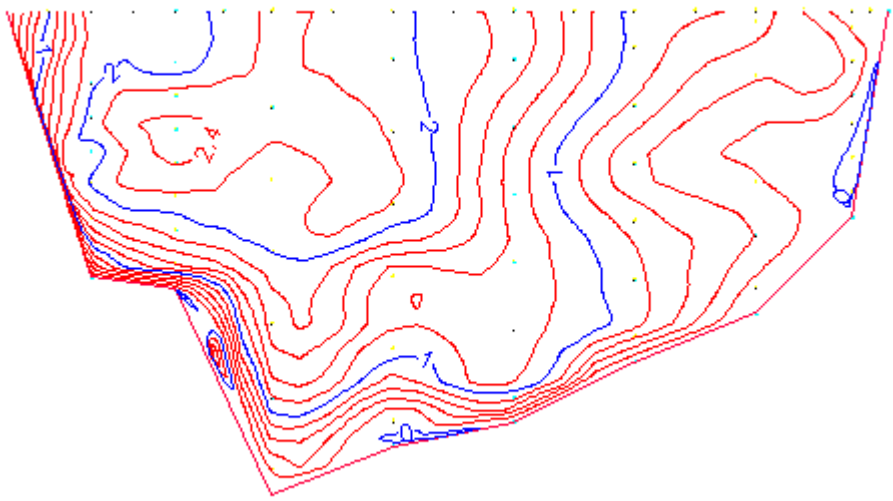

Figure C.2. Isovel diagram of the pool cross section at Knickerbocker treatment reach (Transect 12) measured during a storm event on December 14, 2006. Lines of constant average velocity are in m/s and contour intervals are 0.2 m/s. Blue colored dots represent measurement points. Total discharge measured 82.4 $ft^3/s$.

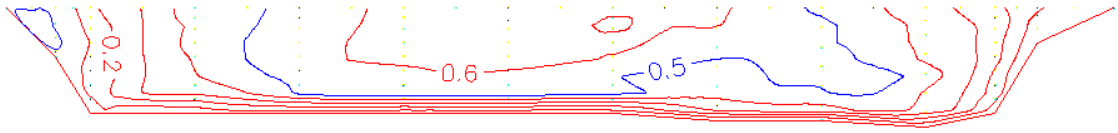


Figure C.3. Isovel diagram of the riffle cross section at the 95th Street treatment reach (Transect 1) measured during a storm event on November 21, 2006. Lines of constant average velocity are in m/s and contour intervals are 0.2 m/s. Blue colored dots represent measurement points. Total discharge measured 29.7 $ft^3/s$.

Figure C.4. Isovel diagram of the pool cross section at the 95th Street treatment reach (Transect 2) measured during a storm event on November 21, 2006. Lines of constant average velocity are in m/s and contour intervals are 0.2 m/s. Blue colored dots represent measurement locations. Total discharge measured 27.0 $ft^3/s$.

Figure C.5. Isovel diagram of the pool tail-out cross section at the 95th Street treatment reach (Transect 3) measured during a storm event on November 21, 2006. Lines of constant average velocity are in m/s and contour intervals are 0.2 m/s. Blue colored dots represent measurement locations. Total discharge measured 27.8 $ft^3/s$.

Figure C.6. Isovel diagram of the pool cross section at the 95th Street control reach (Transect 5) measured during a storm event on November 15, 2006. Lines of constant average velocity are in m/s and contour intervals are 0.2 m/s. Blue colored dots represent measurement locations. Total discharge measured 44.2 $ft^3/s$.

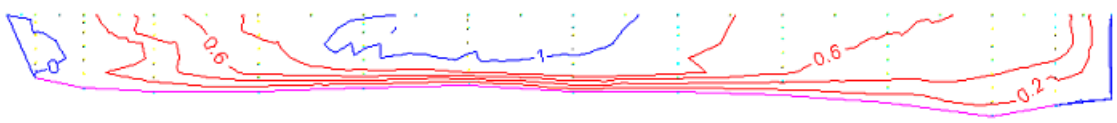


Figure C.7. Isovel diagram of the riffle cross section at the 95th Street control reach (Transect 6) measured during a storm event on November 15, 2006. Lines of constant average velocity are in m/s and contour intervals are 0.2 m/s. Blue colored dots represent measurement locations. Total discharge measured 32.4 $ft^3/s$.

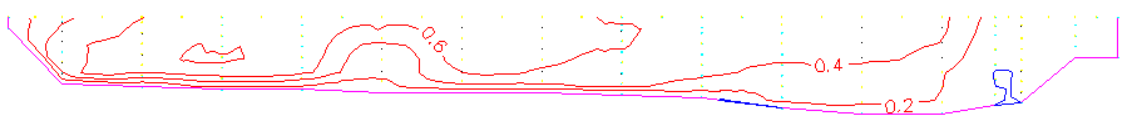


Figure C.8. Isovel diagram of the pool tail-out cross section at the 95th Street control reach (Transect 4) measured during a storm event on November 15, 2006. Lines of constant average velocity are in m/s and contour intervals are 0.2 m/s. Blue colored dots represent measurement locations. Total discharge measured 40.2 $ft^3/s$.

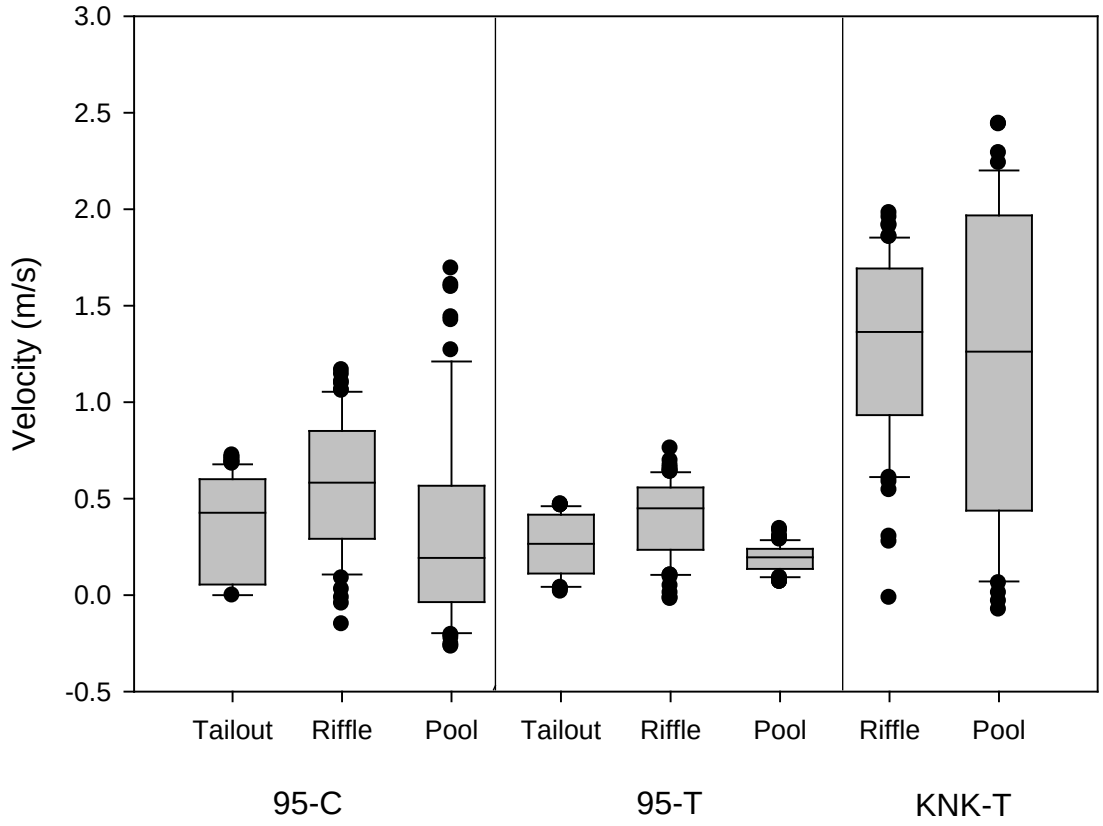


Figure C.9. Velocity measurements during peak discharges at 95th Street (95) control (C) and treatment (T) reaches and Knickerbocker (KNK) treatment reach, Thornton Creek in November and December 2006. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles.

Final

**Appendix D:**
Biological Data

Table D.1. Population estimates (± SE where calculated) at 95th St. (95), Knickerbocker (KNK), and North (NFC) and South (SFC) Fork Confluence control (C) and treatment (T) reaches during summer 2005 and winter and summer 2006 surveys on Thornton Creek. Sampling dates are listed under the reach names. Estimates were calculated using 3 pass depletion methodology (Carle and Strub 1978). Asterisks indicate non-native species.

| **Species** | **95-C** | **95-T** | **KNK-C** | **KNK-T** |
|---|---|---|---|---|
| | **8/30/2005** | **8/31/2005** | **9/14/2005** | **9/13/2005** |
| **Petromyzontidae** | | | | |
| Lamprey unidentified | 14 (-) | | | |
| **Salmonidae** | | | | |
| *Oncorhynchus kisutch*,Coho salmon | 1 (-) | 9 (-) | | |
| *Oncorhynchus clarki*, Cutthroat trout | 24 (-) | 179 (16.6) | 281 (5.7) | 201 (3.9) |
| **Cobitidae** | | | | |
| *Misgurnus anguillicaudatus****,** Oriental Weatherfish | 2 (-) | | | |
| **Gasterosteidae** | | | | |
| *Gasterosteus aculeatus*, Threespined stickleback | | 46 (2.5) | 8 (-) | |
| **Centrarchidae** | | | | |
| *Micropterus salmoides****,** Largemouth bass | 1 (-) | | | |
| *Lepomis gibbosus**, Pumpkinseed sunfish | | 5 (-) | | |
| **Cottidae** | | | | |
| *Cottus aleuticus*, Coastrange sculpin | 308 (7.0) | 7 (-) | | |
| *Cottus asper*, Prickly sculpin | 124 (5.5) | | | |
| **Total Population** | **475 (8.9)** | **248 (16.0)** | **290 (6.0)** | **201 (3.9)** |

Final 10/2008

Table D.1. Continued.

| **Species** | **95-C** | **95-T** | **KNK-C** | **KNK-T** |
|---|---|---|---|---|
| | **3/14/2006** | **3/13/2006** | **3/21/2006** | **3/20/2006** |
| **Petromyzontidae** | | | | |
| Lamprey unidentified | 19 (3.8) | | | |
| **Salmonidae** | | | | |
| *Oncorhynchus kisutch*, Coho salmon | | 2 (-) | | |
| *Oncorhynchus clarki*, Cutthroat trout | 12 (-) | 75 (1.7) | 99 (3.6) | 72 (-) |
| **Cyprinidae** | | | | |
| *Rhinichthys osculus*, Speckled dace | 1 (-) | 22 (3.6) | | |
| **Gasterosteidae** | | | | |
| *Gasterosteus aculeatus*, Threespined stickleback | 4 (-) | 7 (1.4) | 3 (-) | |
| **Centrarchidae** | | | | |
| Sunfish unidentified | | 1 (-) | | |
| **Cottidae** | | | | |
| *Cottus aleuticus*, Coastrange sculpin | 272 (14.6) | 4 (-) | | |
| *Cottus asper*, Prickly sculpin | 73 (11.4) | | | |
| **Total Population** | **387 (20.5)** | **117 (3.9)** | **104 (4.0)** | **72 (-)** |

Final 10/2008

Table D.1. Continued.

| **Species** | **95-C** | **95-T** | **NFC-C** | **NFC-T** | **SFC-C** | **SFC-T** | **KNK-C** | **KNK-T** |
|---|---|---|---|---|---|---|---|---|
| | **7/17/06** | **7/18/06** | **8/1/06** | **7/31/06** | **7/25/06** | **7/24/06** | **7/19/06** | **7/20/06** |
| **Petromyzontidae** | | | | | | | | |
| Lamprey unidentified | 2 (-) | | | | | | | |
| **Salmonidae** | | | | | | | | |
| *Oncorhynchus kisutch,* Coho salmon | | 2 (-) | 19 (-) | | | | | |
| *Oncorhynchus clarki,* Cutthroat trout | 18 (3.7) | 124 (2.6) | 300 (5.7) | 180 (12.6) | 127 (10.3) | 80 (3.7) | 210 (7.7) | 385 (12.1) |
| **Cyprinidae** | | | | | | | | |
| *Rhinichthys osculus,* Speckled dace | 1 (-) | | | | | | | |
| **Cobitidae** | | | | | | | | |
| *Misgurnus anguillicaudatus,**** Oriental weatherfish | 1 (-) | | | | | | | |
| **Gasterosteidae** | | | | | | | | |
| *Gasterosteus aculeatus,* Threespined stickleback | | 6 (-) | | | | | 2 (-) | |
| **Centrarchidae** | | | | | | | | |
| *Ambloplites rupestris*,* Rock bass | | | 1 (-) | | | | | |

Final 10/2008

| Species | 95-C | 95-T | NFC-C | NFC-T | SFC-C | SFC-T | KNK-C | KNK-T |
|---|---|---|---|---|---|---|---|---|
| | **7/17/06** | **7/18/06** | **8/1/06** | **7/31/06** | **7/25/06** | **7/24/06** | **7/19/06** | **7/20/06** |
| *Lepomis gibbosus**, Pumpkinseed sunfish | | | 3 (-) | | | | | |
| **Cottidae** | | | | | | | | |
| *Cottus aleuticus*, Coastrange sculpin | 285 (22.5) | 1 (-) | | | | | | |
| *Cottus asper*, Prickly sculpin | 96 (11.0) | | | | | | | |
| **Total Population** | **415 (28.4)** | **133 (2.6)** | **323(5.5)** | **180 (12.6)** | **127 (10.3)** | **80 (3.7)** | **212 (7.7)** | **385 (12.1)** |

Final 10/2008

Table D.2. Density estimates fish/m at 95th St. (95), Knickerbocker (KNK), North Fork Confluence (NFC) and South Fork Confluence (SFC) control (C) and treatment (T) reaches on Thornton Creek during summer 2005 and winter and summer 2006 surveys. Sampling dates are listed under the reach names. Asterisks indicate non-native species.

| **Species** | **95-C** | **95-T** | **KNK-C** | **KNK-T** |
|---|---|---|---|---|
| | **8/30/2005** | **8/31/2005** | **9/14/2005** | **9/13/2005** |
| **Petromyzontidae** | | | | |
| Lamprey unidentified | 0.04 | | | |
| | | | | |
| **Salmonidae** | | | | |
| *Oncorhynchus kisutch*, Coho Salmon | 0.02 | 0.1 | | |
| *Oncorhynchus clarki*, Cutthroat trout | 0.5 | 1.5 | 3.5 | 2.5 |
| | | | | |
| **Cobitidae** | | | | |
| *Misgurnus anguillicaudatus*,* Oriental weatherfish | 0.04 | | | |
| | | | | |
| **Gasterosteidae** | | | | |
| *Gasterosteus aculeatus* | | 0.5 | 0.1 | |
| | | | | |
| **Centrarchidae** | | | | |
| *Micropterus salmoides** | 0.02 | | | |
| *Lepomis gibbosus** | | 0.1 | | |
| | | | | |
| **Cottidae** | | | | |
| *Cottus aleuticus*, Coastrange sculpin | 6.0 | 0.1 | | |
| *Cottus asper*, Prickly sculpin | 2.2 | | | |
| | | | | |
| **Total Density** | **9.0** | **2.3** | **3.6** | **2.5** |

Final 10/2008

Table D.2. Continued.

| **Species** | **95-C** | **95-T** | **KNK-C** | **KNK-T** |
|---|---|---|---|---|
| | **3/14/2006** | **3/13/2006** | **3/21/2006** | **3/20/2006** |
| **Petromyzontidae** | | | | |
| Lamprey unidentified | 0.3 | | | |
| **Salmonidae** | | | | |
| *Oncorhynchus kisutch*, Coho salmon | | | 0.01 | |
| *Oncorhynchus clarki*, Cuttroat trout | 0.2 | 2.5 | 1.2 | 1.0 |
| **Cyprinidae** | | | | |
| *Rhinichthys osculus*, Speckled dace | 0.02 | | | |
| **Gasterosteidae** | | | | |
| *Gasterosteus aculeatus*, Threespined stickleback | 0.1 | | 0.04 | |
| **Centrarchidae** | | | | |
| Sunfish unidentified* | | 0.01 | | |
| **Cottidae** | | | | |
| *Cottus aleuticus*, Coastrange sculpin | 4.6 | | | |
| *Cottus asper*, Prickly Sculpin | 1.1 | | | |
| **Total Density** | **6.3** | **2.5** | **1.2** | **1.0** |

Final 10/2008

Table D.2. Continued.

| Species | 95-C | 95-T | NFC-C | NFC-T | SFC-C | SFC-T | KNK-C | KNK-T |
|---|---|---|---|---|---|---|---|---|
| | 7/17/2006 | 7/18/2006 | 8/1/2006 | 7/31/2006 | 7/25/2006 | 7/24/2006 | 7/19/2006 | 7/20/2006 |
| **Petromyzontidae** | | | | | | | | |
| Lamprey unidentified | 0.04 | | | | | | | |
| **Salmonidae** | | | | | | | | |
| *Oncorhynchus kisutch,* | | | | | | | | |
| Coho salmon | | 0.03 | 0.4 | | | | | |
| *Oncorhynchus clarki,* | | | | | | | | |
| Cuttroat trout | 0.4 | 1.9 | 5.5 | 4.6 | 2.8 | 1.9 | 2.5 | 5.3 |
| **Cyprinidae** | | | | | | | | |
| *Rhinichthys osculus,* | | | | | | | | |
| Speckled dace | 0.02 | | | | | | | |
| **Cobitidae** | | | | | | | | |
| *Misgurnus anguillicaudatus,**** | | | | | | | | |
| Oriental weatherfish | 0.02 | | | | | | | |
| **Gasterosteidae** | | | | | | | | |
| *Gasterosteus aculeatus,* | | | | | | | | |
| Threespined stickleback | | | | | | | 0.02 | |
| **Centrarchidae** | | | | | | | | |
| *Ambloplites rupestris,** | | | | | | | | |
| Rock bass | | | 0.02 | | | | | |
| *Lepomis gibbosus,** | | | | | | | | |
| Pumpkinseed sunfish | | | 0.1 | | | | | |

Final 10/2008

| Species | 95-C | 95-T | NFC-C | NFC-T | SFC-C | SFC-T | KNK-C | KNK-T |
|---|---|---|---|---|---|---|---|---|
| | **7/17/2006** | **7/18/2006** | **8/1/2006** | **7/31/2006** | **7/25/2006** | **7/24/2006** | **7/19/2006** | **7/20/2006** |
| **Cottidae** | | | | | | | | |
| *Cottus aleuticus,* Coastrange sculpin | 5.7 | 0.02 | | | | 0.1 | | |
| *Cottus asper,* Prickly Sculpin | 1.5 | | | | | | | |
| **Total Density** | **7.7** | **2.0** | **5.9** | **4.6** | **2.8** | **2.0** | **2.6** | **5.3** |

Final 10/2008

Table D.3. Biomass g/m estimates at 95th St (95), Knickerbocker (KNK), and North (NFC) and South (SFC) Fork Confluence control (C) and treatment (T) reaches during summer 2005 and winter and summer 2006 surveys in Thornton Creek. Asterisks indicate non-native species.

| **Species** | **95-C** | **95-T** | **KNK-C** | **KNK-T** |
|---|---|---|---|---|
| | **8/30/2005** | **8/31/2005** | **9/14/2005** | **9/13/2005** |
| **Petromyzontidae** | | | | |
| Lamprey unidentified | 1.3 | | | |
| **Salmonidae** | | | | |
| *Oncorhynchus kisutch,* Coho Salmon | 0.2 | 0.8 | | |
| *Oncorhynchus clarki,* Cutthroat trout | 5.4 | 27.8 | 40.0 | 31.0 |
| **Cobitidae** | | | | |
| *Misgurnus anguillicaudatus,**  Oriental weatherfish | 0.6 | | 0.1 | |
| **Gasterosteidae** | | | | |
| *Gasterosteus aculeatus,* Threespined stickleback | | 0.5 | | |
| **Centrarchidae** | | | | |
| *Micropterus salmoides,** Largemouth bass | 0.1 | | | |
| *Lepomis gibbosus,** Pumpkinseed sunfish | | 0.2 | | |
| **Cottidae** | | | | |
| *Cottus aleuticus,* Coastrange sculpin | 12.1 | 1.0 | | |
| *Cottus asper,* Prickly sculpin | 7.1 | | | |
| **Total Biomass** | **26.7** | **30.3** | **40.1** | **31.0** |

Final 10/2008

Table D.3. Continued.

| Species | 95-C | 95-T | KNK-C | KNK-T |
|---|---|---|---|---|
| | **3/14/2006** | **3/13/2006** | **3/21/2006** | **3/20/2006** |
| **Petromyzontidae** | | | | |
| Lamprey unidentified | 4.5 | | | |
| **Salmonidae** | | | | |
| *Oncorhynchus kisutch,* Coho Salmon | | 0.3 | 0.2 | |
| *Oncorhynchus clarki,* Cutthroat trout | 2.8 | 19.0 | 23.6 | 17.4 |
| **Cyprinidae** | | | | |
| *Rhinichthys osculus,* Speckled dace | 0.1 | | 0.1 | |
| **Cobitidae** | | | | |
| *Misgurnus anguillicaudatus,**  Oriental weatherfish | 0.02 | | | |
| **Gasterosteidae** | | | | |
| *Gasterosteus aculeatus,* Threespined stickleback | 0.3 | 0.3 | | |
| **Centrarchidae** | | | | |
| Sunfish unidentified | | 0.03 | | |
| **Cottidae** | | | | |
| *Cottus aleuticus,* Coastrange sculpin | 8.3 | 0.8 | | |
| *Cottus asper,* Prickly sculpin | 4.5 | | | |
| **Total Biomass** | **16.1** | **22.8** | **24.0** | **17.4** |

Final 10/2008

Table D.3. Continued.

| Species | 95-C | 95-T | NFC-C | NFC-T | SFC-C | SFC-T | KNK-C | KNK-T |
|---|---|---|---|---|---|---|---|---|
| | 7/17/2006 | 7/18/2006 | 8/1/2006 | 7/31/2006 | 7/25/2006 | 7/24/2006 | 7/19/2006 | 7/20/2006 |
| **Petromyzontidae** | | | | | | | | |
| Lamprey unidentified | 0.3 | | | | | | | |
| **Salmonidae** | | | | | | | | |
| *Oncorhynchus kisutch,* Coho salmon | | 0.2 | 1.9 | | | | | |
| *Oncorhynchus clarki,* Cuttroat trout | 3.8 | 17.8 | 30.0 | 25.1 | 29.2 | 10.6 | 13.2 | 28.9 |
| **Cyprinidae** | | | | | | | | |
| *Rhinichthys osculus,* Speckled dace | 0.04 | | | | | | | |
| **Cobitidae** | | | | | | | | |
| *Misgurnus anguillicaudatus,**** Oriental weatherfish | 0.3 | | | | | | | |
| **Gasterosteidae** | | | | | | | | |
| *Gasterosteus aculeatus,* Threespined stickleback | | | | | | | 0.04 | |
| **Centrarchidae** | | | | | | | | |
| *Ambloplites rupestris,** Rock bass | 0.9 | | | | | | | |
| *Lepomis gibbosus,** Pumpkinseed sunfish | | | 0.1 | | | | | |

Final 10/2008

| Species | 95-C | 95-T | NFC-C | NFC-T | SFC-C | SFC-T | KNK-C | KNK-T |
|---|---|---|---|---|---|---|---|---|
| | 7/17/2006 | 7/18/2006 | 8/1/2006 | 7/31/2006 | 7/25/2006 | 7/24/2006 | 7/19/2006 | 7/20/2006 |
| **Cottidae** | | | | | | | | |
| *Cottus aleuticus,* Coastrange sculpin | 9.0 | | | | | 0.8 | | |
| *Cottus asper,* Prickly Sculpin | 7.6 | | | | | | | |
| **Total Biomass** | **21.0** | **18.0** | **32.9** | **25.1** | **29.2** | **11.5** | **13.3** | **28.9** |

Final 10/2008

Table D.4. Macroinvertebrate taxonomic composition collected between September 19 and 21, 2005 from 95th St (95) and Knickerbocker (KNK) control (C) and treatment (T) reaches on Thornton Creek. Asterisks indicate tolerant taxa. Bold taxa indicate long lived species.

| **Taxon** | **95-C 9/21/2005** | **95-T 9/19/2005** | **KNK-C 9/21/2005** | **KNK-T 9/21/2005** |
|---|---|---|---|---|
| Cnidaria | | | | |
| Hydridae | | | | |
| *Hydra* sp.* | 2 | 3 | | |
| Turbellaria | 5 | 74 | 48 | 20 |
| Nematoda | 4 | 3 | 7 | 23 |
| Oligochaeta | 393 | 423 | 97 | 94 |
| Hirudinea* | 1 | 11 | | |
| Glossiphoniidae | | | | |
| *Helobdella* sp.* | | 5 | | |
| Pelecypoda | | | | |
| Sphaeriidae | | | | |
| *Pisidium* sp. | 31 | 59 | 3 | 4 |
| Gastropoda | | | | |
| Planorbidae* | 1 | | | |
| Crustacea | | | | |
| Gammaridae | | | | |
| *Crangonyx* sp.* | 144 | 104 | 232 | 293 |
| Asellidae | | | | |
| *Caecidotea* sp.* | 156 | 455 | 1 | |
| Acari | 1 | 3 | | |
| Ephemeroptera | | | | |
| Baetidae | | | | |
| *Baetis tricaudatus** | 45 | 91 | 165 | 317 |

Final 10/2008

Table D.4. Continued.

| **Taxon** | **95-C 9/21/2005** | **95-T 9/19/2005** | **KNK-C 9/21/2005** | **KNK-T 9/21/2005** |
|---|---|---|---|---|
| Trichoptera | | | | |
| Hydropsychidae | | | | |
| ***Parapsyche almota*** | | | 15 | 1 |
| Hydroptilidae | | | | |
| *Hydroptila* sp.* | | 1 | | 11 |
| *Oxyethira* sp. | | 1 | | |
| Coleoptera | | | | |
| Elmidae | | | | |
| ***Narpus* sp.** | 2 | | | |
| Diptera | | | | |
| Dixidae | | | | |
| *Dixa* sp. | | | 1 | |
| Empididae | | | | |
| *Chelifera/Metachela* sp. | 2 | | 2 | |
| *Hemerodromia* sp.* | 5 | 1 | | |
| Simuliidae | | | | |
| *Simulium* sp. | 3 | | 428 | 64 |
| Tipulidae | | | | |
| *Antocha* sp. | | 4 | 3 | 45 |
| ***Tipula* sp**. | 1 | | | 1 |
| Chironomidae | | | | |
| Chironomidae- pupae | 3 | 1 | 2 | 11 |
| *Apedilum* sp. | | | | 7 |
| *Brillia* sp. | | | 7 | 1 |
| *Cricotopus* sp. | | | | 20 |
| *Cricotopus Bicinctus Group** | 1 | | 2 | 45 |
| *Cryptochironomus* sp.* | | 9 | | |

Final 10/2008

Table D.4. Continued.

| **Taxon** | **95-C** | **95-T** | **KNK-C** | **KNK-T** |
|---|---|---|---|---|
| *Eukiefferiella* sp. | 3 | | 29 | 12 |
| *Eukiefferiella Devonica Group* | 1 | | | 30 |
| *Micropsectra* sp. | | | 1 | 7 |
| *Orthocladius Complex* | | 1 | 1 | 13 |
| *Pagastia* sp. | 3 | | 13 | 42 |
| *Parametriocnemus* sp. | 2 | | 1 | 2 |
| *Polypedilum* sp. | 7 | 77 | 2 | 1 |
| *Rheocricotopus* sp. | | | 2 | |
| *Rheotanytarsus* sp. | | | | 1 |
| *Synothocladius* sp. | | | | 3 |
| *Thienemanniella* sp. | 12 | 2 | 3 | 8 |
| *Thienemannimyia Complex* | 6 | 1 | 4 | 9 |
| *Tvetenia Bavarica Group* | 4 | | 25 | 28 |
| **Total Counts** | **838** | **1329** | **1094** | **1113** |

Final 10/2008

Final 10/2008