MORSE CREEK REMEANDER RESTORATION: MONITORING REPORT YEAR THREE

North Olympic Salmon Coalition and Mike Haggerty Consulting

October 2012

NORTH OLYMPIC SALMON COALITION

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ACRONYMS/ABBREVIATIONS USED

BFD	bankfull depth
BFW	bankfull width
cfs	cubic feet per second
CMZ	channel migration zone
CW	channel width
DEPU	Dungeness and Elwha Planning Unit
DEPU	Washington Department of Fish and Wildlife
DBH	diameter at breast height
DOE	Washington State Department of Ecology
ELJ	engineered logjam
FAF	Fish America Foundation
JST	Jamestown S'Klallam Tribe
LEKT	Lower Elwha Klallam Tribe
LWD	large woody debris
NACO	National Association of Counties
NOAA	National Oceanic and Atmospheric Administration
NOSC	North Olympic Salmon Coalition
NOPLE	North Olympic Peninsula Lead Entity for Salmon
RBT	right bank tributary
RCO	Recreation and Conservation Funding Board
RM	river mile
SRFB	Salmon Recovery Funding Board
WDFW	Washington Department of Fish and Wildlife.
WRIA	water resource inventory area

1 INTRODUCTION

1.1 Project Background

During the summer of 2010 the North Olympic Salmon Coalition (NOSC) constructed the Morse Creek Riverine Restoration Project. The project re-activated 1,510 feet of main channel, 1,125 feet of side channel, 740 feet of off-channel habitat, 885 feet of overflow channel, and 12.4 acres of floodplain as it existed circa 1939. Sometime after 1939 a dike was installed and the stream was rerouted between the dike and the west valley wall. Prior to restoration the project reach was channelized, confined, over-steepened, diked, and depleted of large wood resulting in severe channel simplification. Restoration included moving the main channel back to its 1939 alignment, constructing 19 engineered log jams (ELJ's), and adding of 1,125 feet of side channels. This report summarizes habitat monitoring data collected before and after the restoration project was implemented. In total the report summarizes three years of data collected at or near the restoration site.

1.2 Morse Creek Watershed

Morse Creek is the largest independent drainage between the Dungeness River and Elwha River and enters the Strait of Juan de Fuca approximately 2 miles east of Port Angeles. The stream extends 16.3 miles from its headwaters in the Olympic National Park (Elwha-Dungeness Planning Unit [EDPU] 2005). The moderate sized watershed drains steep headwaters, including Hurricane Ridge, Mount Angeles, and Deer Park. A natural waterfall at river mile 4.9 acts as an impassable barrier to anadromous fish (Haring 1999).

Figure 1.1. Morse Creek Watershed Map (source: EDPU 2005).

The high elevation headwaters accumulate significant snow pack, causing Morse Creek to exhibit two peaks in annual discharge – one associated with winter rainstorms and the other resulting from spring snowmelt. As a consequence of this hydrology, Morse

Creek historically produced a greater number of salmonid stocks than would normally be expected of a stream this size. Salmonid stocks that occurred in this watershed include: spring/summer Chinook (now extirpated), fall coho salmon, fall chum salmon, pink salmon, winter/summer steelhead trout (ESA-listed), sea-run cutthroat trout, and bull trout (ESA-listed).

1.3 Morse Creek Riparian Restoration Area

The project is located within a 133-acre wildlife area owned by the Washington Department of Fish and Wildlife. It was purchased to protect important wildlife habitat adjacent to an urban setting and for restoration of the riverine system. The project reach was channelized and diked. This caused channel incision and resulted in a channel dominated by large cobbles, boulders, and bedrock. Pre-project habitat conditions were extremely poor for fish at all life stages. The project re-activated the 1939 channel, resulting in 1,510 feet of new main channel, 1,150 feet of side channel, 740 feet of off-channel habitat, and 885 feet of overflow channel. The project also treated 840 feet of channel with large woody debris jams. The project reconnected 12.4 acres of floodplain previously isolated behind dikes. In total the project treated almost 0.5 miles of the mainstem Morse Creek; representing nearly 10 percent of the historical mainstem anadromous length. Figure 1.2 depicts differences in channel characteristics between the old channel and the newly constructed channel.

Figure 1.2. Morse Restoration Project before (old channel on left) and after (new channel on right).

1.4 Project Need

The lower Morse Creek channel has been severely impacted by human activity. From its mouth to the project site at river mile 1.2 Morse Creek has been straightened and diked for the majority of its length. Previously this reach had abundant spawning gravels, LWD, and off channel habitat. The habitat had been transformed into a scoured and simplified channel with little LWD. The project area was purchased by WDFW to address habitat conditions. In the past a dike was built that moved the creek from its meandering path, straightening it and forcing the creek against the steep west valley wall. This action reduced the stream length and sinuosity resulting in higher velocities through the reach. Bed scour resulted in exposure and deposition of large cobble and boulders, removal of gravels suitable for spawning, and scouring to bedrock. Increased velocities and the changing bed flushed LWD downstream and didn’t allow new LWD to be retained in the reach. The dike and steep valley wall created conditions with almost no connected floodplain in the reach.

The project is located in the Watershed Resource Inventory Area (WRIA) 18. WRIA 18 has produced a Limiting Factors Analysis (LFA) to address habitat conditions limiting fish productivity. The WRIA 18 LFA (Haring 1999) lists the following actions as important to the restoration of Morse Creek, all of which the project addressed.

- “Restore floodplain function downstream of RM 1.7, including the removal of portions of dikes, elimination of floodplain constrictions, and restoration of natural banks”

- "Restore large woody debris (LWD) presence throughout the channel downstream of the natural falls at RM 4.9; develop and implement a short-term LWD strategy to provide LWD presence and habitat diversity until full riparian function is restored;”

- “Restore riparian function by encouraging conifer regeneration in deciduous stands that historically had a conifer component”

1.5 Project Partners and Collaborators

Below is a list of project partners and collaborators.

- Salmon Recovery Funding Board (SRFB)
- Recreation and Conservation Funding Board (RCO)
- Lower Elwha Klallam Tribe (LEKT)
- Jamestown S'Klallam Tribe (JST)
- National Oceanic and Atmospheric Administration (NOAA)
- Fish America Foundation (FAF)
- National Association of Counties (NACO)
- Washington Department of Fish and Wildlife (WDFW)
- Department of Ecology (DOE)
- North Olympic Peninsula Lead Entity (NOPLE)

1.6 Report Organization

This report summarizes monitoring data for the three-year period from 2010 through 2012. The report is divided into six main chapters:

- Introduction (Chapter 1)
- Monitoring (Chapter 2)
- Methods (Chapter 3)
- Results (Chapter 4)
- Discussion (Chapter 5)
- Citations (Chapter 6)

Chapter 1 includes general project background, a brief watershed description, and discussion on the project need, and the Morse Creek Restoration Area. Chapter 2 includes an overview discussion on monitoring and the approach used to monitor the Morse Creek restoration project. Field survey methods are described in Chapter 3. The results are presented in Chapter 4. A brief discussion of results in presented in Chapter 5. A list of referenced citations is included in Chapter 6.

2 MONITORING

2.1 Introduction

This report provides data and analysis of the baseline and first two years of post-project monitoring efforts to demonstrate changes in pre-and-post-restoration habitat conditions. This chapter includes two subsections: The Importance of Monitoring (Section 2.2) and Monitoring Approach (Section 2.3)

2.2 The Importance of Monitoring

The importance of appropriate pre-project and post-project monitoring has been advocated repeatedly (Kondolf 1998; Jungwirth and others 2002; Downs & Kondolf 2002), and a few studies have documented improvements in stream condition by evaluating completed restoration projects with pre-project and post-project data or using comparison sites. Post-project monitoring will help determine whether additional actions or adjustments are needed, as well as, demonstrate the project's successes and/or failures. In addition, Morse Creek post project monitoring can provide useful information for future restoration efforts. The process of monitoring and adjustment is known as adaptive management (see Figure 2.1). Monitoring plans should be feasible in terms of costs and technology, and should always provide information relevant to meeting the project goals.

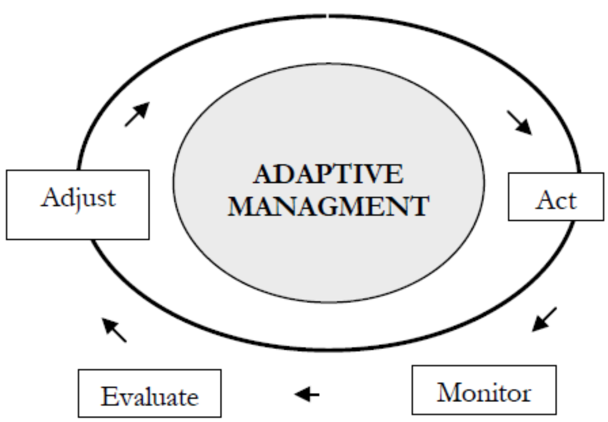

Figure 2.1. Diagram depicting the adaptive management process (from Shreffler 2007; modified from Thom and Wellman 1996)

2.3 Monitoring Approach

Three intensive monitoring reaches were identified during the monitoring scoping phase: the abandoned channel reach, the new channel reach (and side channels), and the upstream control reach (see Table 2.1 and Figure 2.2). Other channel segments had less intensive or no monitoring.

Additional stream segments influenced by the project and monitored less intensively include impact reach #1 and impact reach #2 (Figure 2.2). The downstream end of impact reach #1 corresponds to a point just downstream of the restoration project boundaries; the upstream end is at the intersection of the abandoned channel reach and the new channel reach. The downstream end of impact reach #2 corresponds to the upstream end of the new channel reach and the upstream boundary corresponds to the downstream end of the control reach. Table 2.1 includes the measured lengths for constructed/treated and monitored reaches.

Table 2.1. Morse Creek constructed or treated channel lengths and 2010 through 2012 monitoring reach lengths.

Project Reach	Constructed or Treated Length (m)	2010 Monitoring Length (m)	2011 Monitoring Length (m)	2012 Monitoring Length (m)
Abandoned Channel	385	385	na	na
New Off-Channel Habitat (wetted area of abandoned channel)	NA	NA	225	237
New Main Channel	471	471	460	460
Side Channel 1 & 3	255	NA	255	245
Side Channel 2	110	NA	NA	98
Overflow Channel 1/2	215	215	NA	NA
Control Reach	500	500	415	400

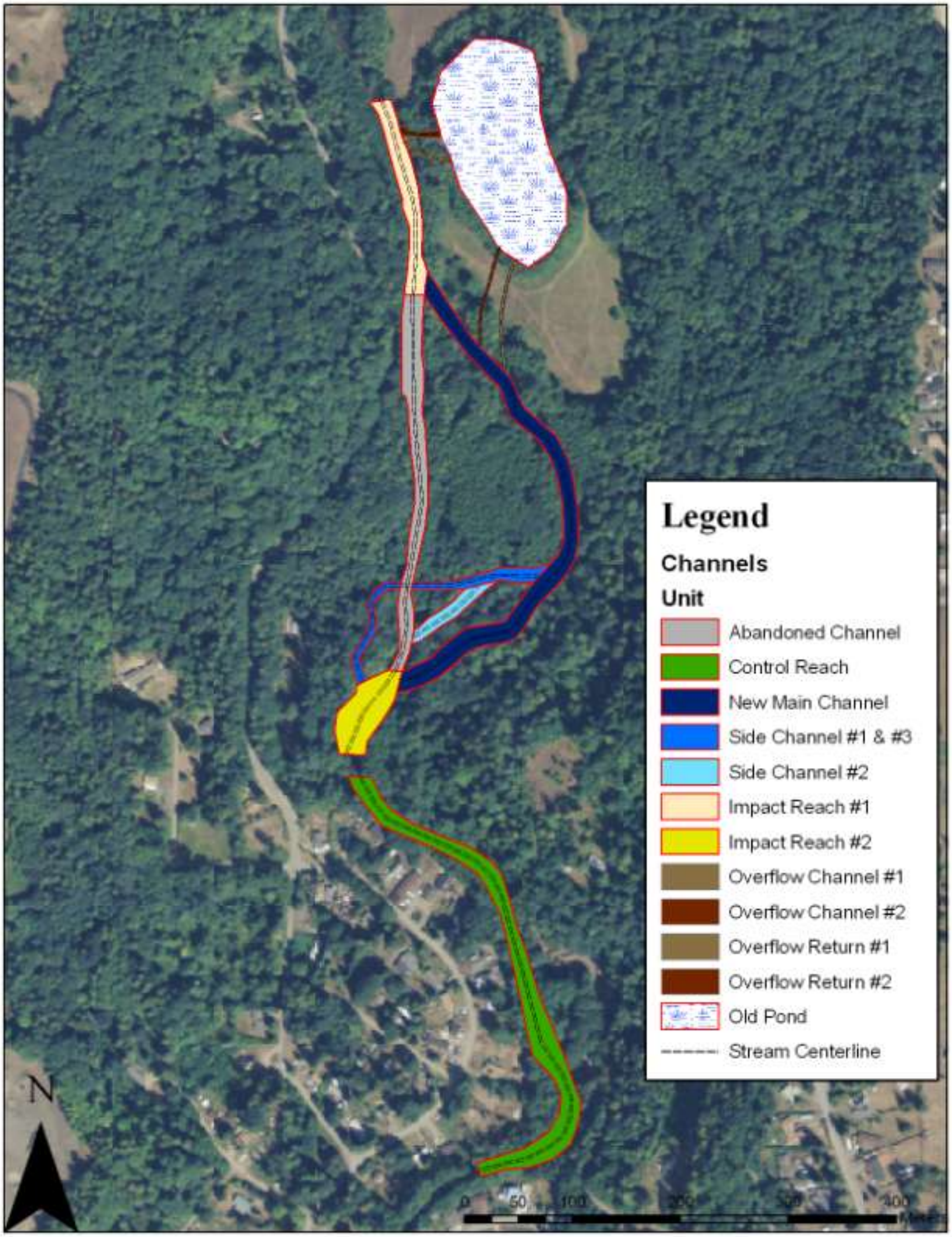

Figure 2.2. Morse Creek site map.

3 METHODS

This chapter describes the methods used to collect field data. The chapter is divided into six main subsections:

- Channel Thalweg Survey (Section 3.1)
- LWD Survey (Section 3.3)
- Habitat Unit Surveys (Section 3.2)
- Channel Profile and Cross-Sections (Section 3.4)
- Snorkel Surveys (Section 3.5)
- Macroinvertebrate Monitoring (Section 3.6)

3.1 Channel Thalweg Survey

Measurement stations were established at distances equal to 1/100th of the surveyed reach length. Transects (both primary and secondary) were established at distances equal to 1/20th of the surveyed reach length. Primary transects were located every 25 meters along the channel thalweg length, and the secondary transects were located every 5 meters along the channel thalweg length. Permanent reference points were established at long-term monitoring channel cross-sections where channel cross- sections and complete pebble counts were surveyed (see Section 3.4).

Figure 3.1. Channel thalweg depth and wetted width measurements.

For primary transects the following parameters were measured: thalweg depth (to nearest 0.01 meter), wetted width (to nearest 0.1 meter), bankfull width (to nearest 0.1 meter), bar width (to nearest 0.1 meter), thalweg soft sediment (Yes or No, sediment less than 16 mm), habitat unit ID (from habitat survey), particle size and depth at left edge of water, 25, 50, 75, and 100 percent wetted width, GPS location, and a minimum of two photos (one looking downstream and one looking upstream). For secondary transects the same parameters were measured as in the primary transect except no bankfull width, GPS, photo, or riparian/canopy cover data were collected.

Pebble Counts

Particle size was determined by measuring the b-axis of the particle. The first step in determining the length of the b-axis is to determine the orientation of the a-axis. The a-axis was defined as the longest axis across the particle. The b-axis was defined as the longest intermediate axis perpendicular to the a-axis. Five pebbles were inventoried at each of the primary and secondary transects.

Detailed pebble counts were made at each channel cross-section. The methods used were adapted from Wolman (1954) and involved collecting and measuring the b-axis of 100 streambed particles. The measurer started at the right or left bank edge of channel and took one pace along the cross-section. While facing away from the stream bottom the observer used a pointer to randomly select a particle for measurement. The particle was picked up and the b-axis was measured and recorded. The measurer then proceeded taking one-pace across the channel in a random, zigzag manner staying within +/- 2 meters of the cross-section center line, and collect a sample at each position.

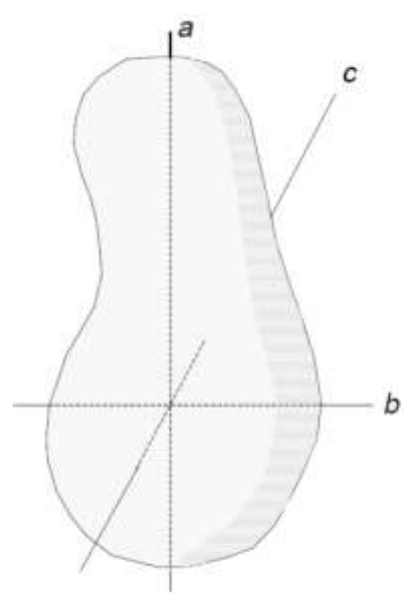

Figure 3.2. Diagram depicting a-, b-, and c-axis for an irregularly shaped particle (from: Yuzyk and Winkler 1991 in Brunte and Abt 2001.)

Riparian Condition/Canopy Cover

Riparian condition and canopy cover data were collected at each primary transect. Instream canopy cover was measured using a Model-A convex spherical densitometer. The instrument was held level, approximately 30 cm in front of the operator at elbow height, so that the operator's head was just outside of the grid area. The densitometer was modified from the manufacturer; it included four equally spaced dots in each of the 24 grid squares. The number of dots covered by canopy were counted and summed. To find percent canopy closure the sum was multiplied by 1.04167 (100/96).

Riparian condition was evaluated at each primary transect. Riparian conditions were classified using the methods generally outlined in Washington Forest Practice Board standard methodology for conducting watershed analysis (WFPB 1997). An area 15 meters upstream and downstream and 30 meters deep was assessed and classified using the criteria in Table 3.1

Table 3.1. Summary of riparian habitat classifications (source: WFPB 1997).

Dominant Riparian Condition	Dom. Veg. Type	C > 70%Conifer Dominated	First letter code used in series of three
	Dom. Veg. Type	D > 70% Deciduous	
	Dom. Veg. Type	M = all other cases	
	Average tree size	(S) small < 12 inches DBH	Second letter code used in series of three
	Average tree size	(M) medium >12 in. DBH < 20 in. DBH	
	Average tree size	(L) large > 20 inches DBH	
	Stand density	(D) dense > two-thirds canopy closure	Third letter
	Stand density	(S) Sparse < two-thirds canopy closure	

3.2 Habitat Unit Survey

These data were collected at the same time as the thalweg survey data. The downstream end of each habitat unit was recorded based on the distance from the start of survey. The upstream end of each unit corresponded to the downstream end of the next upstream habitat unit. The following parameters were inventoried and recorded: cumulative distance, habitat unit ID, habitat type [plunge pool (PP); step pool (STP); pools behind boulders (POB); mixed pocket water (POWC); glide (G); run (RUN); rapid (R); cascade (CS); low gradient riffle (LGR); low gradient riffle w/ pockets (LGRP); high gradient riffle (HGR)], pool forming agent (LWD, LWD jam, bed, bank, boulders, bedrock, roots, etc…), maximum depth, pocket depth, residual depth, unit length, and notes.

Habitat unit area was calculated using wetted width data from the thalweg survey. Where habitat unit boundaries were irregular or complex wetted width measurements were made at either 3 or 5 meter intervals depending upon the length of the habitat unit. Secondary habitat unit wetted widths were measured at equal intervals so at least 4 wetted width measurements were obtained.

3.3 LWD Survey

For the abandoned channel and control reach LWD survey data were collected during the thalweg survey. Each piece of LWD was inventoried and recorded based on the thalweg distance from the start of survey. The following parameters were also measured and recorded: piece ID, diameter at large end, diameter at small end, rootwad attached (yes/no), length, species class (conifer/deciduous/unknown), jam ID (each piece of LWD was classified as either in a jam or not in a jam; jam ID was recorded for all pieces within a jam), channel position (e.g., LBM-left bank margin), habitat unit forming (Yes/No, and habitat unit ID), and notes. In 2011 and 2012, wood in ELJs were not inventoried again, but wood recruited within the bankfull width was recorded and measured.

3.3.1 Engineered Logjam LWD Survey

2010 Survey Methods

Nearly every piece of LWD placed within the bankfull width was part of an engineered logjam (ELJ). Many of these pieces were buried and therefore it was not possible to inventory all pieces of project placed LWD. Each ELJ or combination of ELJs was inventoried. The following data were measured and recorded for each ELJ: jam ID (including design ID), stream reach (e.g., new channel), upstream end (distance from start of survey), downstream end, jam length, average width, average maximum height, average minimum height, channel location, and notes. A minimum of one photo was taken of each jam.

All clearly visible LWD pieces were inventoried, and subset was tagged with a unique numbered aluminum tag. Each LWD piece had the following parameters measured and recorded: approximate distance from new channel start of survey, piece number, tag number (when tagged), diameter within +/- 1 meter of tag, rootwad attached (y/n), piece size (S/M/L), species type (conifer, deciduous, unknown), jam ID, channel position, and notes. Size classes were defined based on the diameter at the mid-point of the piece. Sizes were small (10-20 cm), medium (20-50 cm), or large (>50 cm).

3.4 Channel Profile and Cross-Sections

A channel profile was run upstream from the start of each surveyed reach. Water surface and substrate elevations were measured and recorded at all primary and secondary transects. Additional profile measurements between transects were also made, in some cases at intervals as small as five meters. Standard survey methods were employed using an auto level, tripod, and stadia rod (Figure 3.3). Reference elevations were established at a minimum of two points at each of the permanent cross-sections. All reference elevations were surveyed within a common datum.

Figure 3.3. Channel profile survey on Morse Creek.

Cross-sections were established within each reach. Cross-sections were typically established at representative sites or in areas where significant change was likely to occur. Cross-section elevation measurements were typically measured at 1 meter intervals along each cross-section. However, these measurement intervals varied depending upon topography, in some cases measurements were made at less than or greater than 1 meter intervals. Detailed pebble counts were conducted at each cross-section following methods outlined above for detailed pebble counts (see Section 3.1). Figure 3.4 depicts the location of each cross-section within the project area.

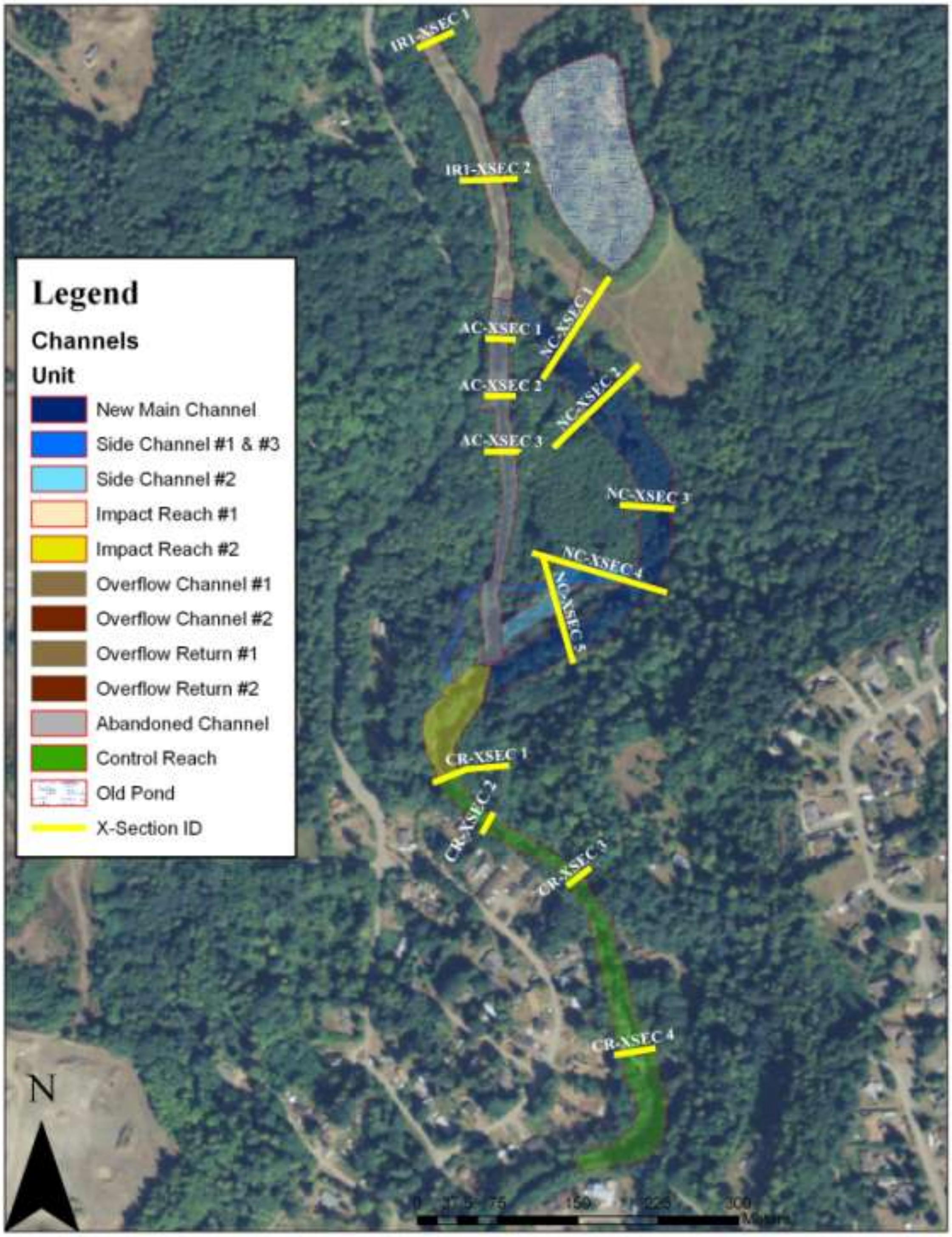

Figure 3.4. Morse Creek cross-section location map.

3.5 Snorkel Surveys

Figure 3.5. Snorkel surveys on Morse Creek.

Snorkel surveys were conducted on August 16, 2010, September 19, 2011, and September 13, 2012. Two stream segments were surveyed each year including the control reach and the abandoned channel (2010) or the new channel (2011 and 2012). Habitat unit boundaries were delineated in the field prior to the survey. Length and area measurements were made based on the previously conducted habitat and thalweg surveys. Three snorkelers entered each habitat unit from the downstream end, surveying in the upstream direction. Within each habitat unit each snorkeler was assigned a lane within the habitat unit to reduce a potential double counting of fish. One recorder was stationed on the bank and recorded the observations called out by the snorkelers.

Juvenile salmonids were recorded based on species and age class. Age class was based on size. Age 0+ coho were less than 70 mm length and age 1+ coho were 70-140 mm length. Age 0+ trout were less than 60 mm, age 1+ trout were 60-100 mm, and age 2+ trout were greater than 100 mm. No other juvenile salmonid species were observed within stream segments surveyed. Adult salmonid species were observed and recorded.

Side and off-channel habitats could not surveyed using the snorkel survey techniques described above. In these cases two surveyors walked from the top of the habitat unit downstream, one on either side of the habitat unit. Each juvenile salmonid was counted and recorded; totals were summed for each habitat unit.

3.6 Macroinvertebrate Monitoring

Macroinvertebrate sampling was conducted on September 22, 2010 and October 10, 2011 by Streamkeepers of Clallam County. Sampling was also conducted in early September 2012. Streamkeepers currently uses the 10-metric genus-level Benthic Index of Biological Integrity for the Puget Sound Lowlands to analyze its benthic macroinvertebrate samples. This index is based on three replicate samples taken at the same time and site; metrics are based on total and average counts for those replicates.

The BIBI approach involves statistical analysis using metrics that have a predictable response to water quality and/or habitat impairment. The selected metrics fall into five major groups including taxa-richness, taxa composition, tolerance to perturbation, trophic classification and taxa habit. Raw values from each metric are given a score of 1, 3 or 5 based on ranges of values developed for each metric. The results are combined into a scaled BIBI score from 1.0 to 5.0 and a narrative rating is applied (for complete method details please see- http://www.clallam.net/streamkeepers/html/biological_monitoring.html).

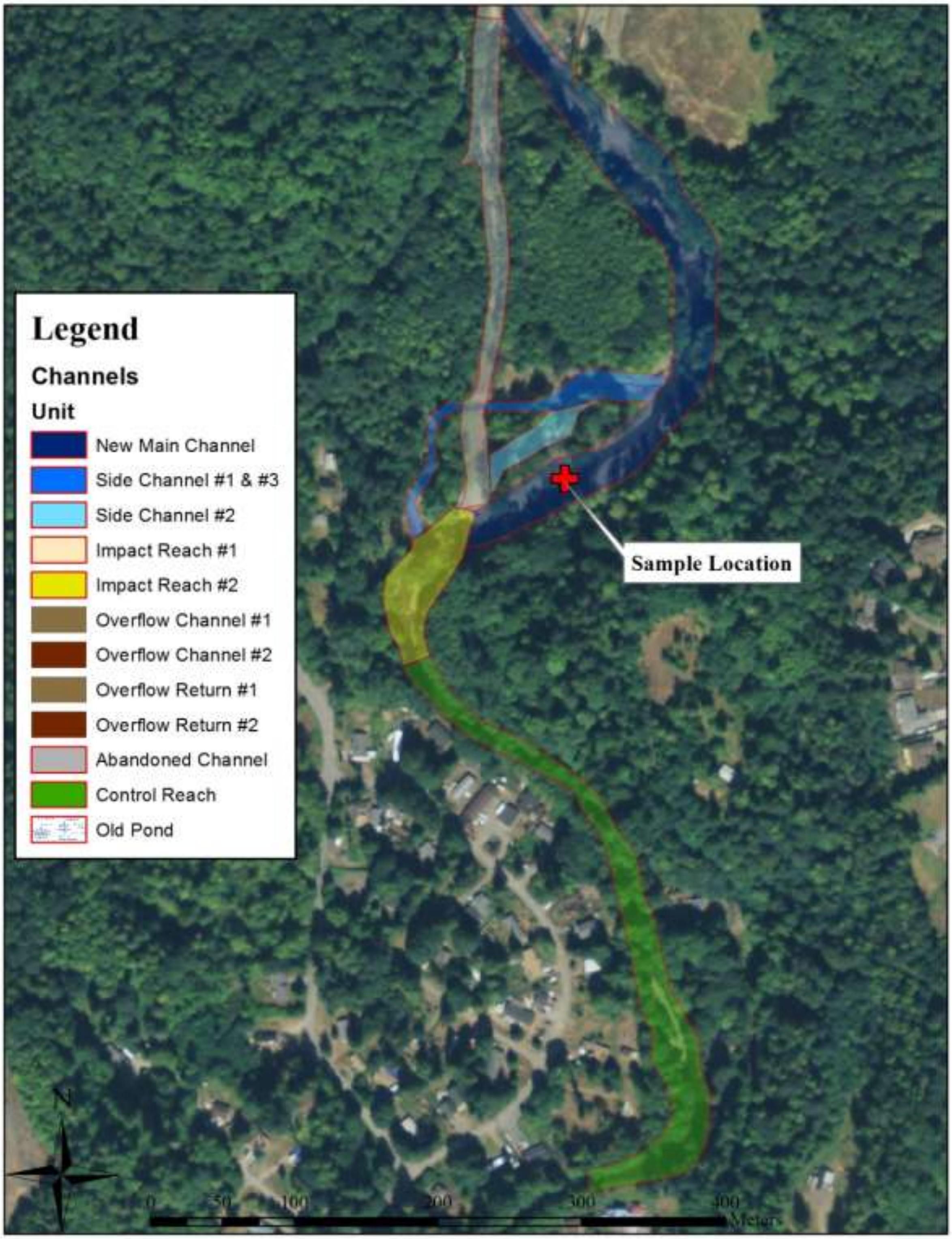

Figure 3.6. Morse Creek macroinvertebrate monitoring location map.

4 RESULTS

This chapter includes the results from field surveys conducted during the summer of 2010, 2011, and 2012. The chapter is divided into four main subsections:

- New Channel Reach (Section 4.1)
- Control Reach (Section 4.2)
- Abandoned Channel Reach (Section 4.3)
- Impact Reach #1 and #2 (Section 4.4)

Within each of the four main subsections detailed results are reported within one to five subsections: channel thalweg and habitat survey results, LWD survey results, channel profile and cross-section results, snorkel survey results, and/or macroinvertebrate sampling results.

4.1 New Channel Reach

4.1.1 Channel Thalweg and Habitat Survey Results

Channel Characteristics

In 2010, thalweg and habitat surveys were conducted September 17, 2010 (DOE gage below aqueduct 30.1 cfs). In 2011, thalweg and habitat surveys were conducted between September 14 and September 21, 2011. Wetted width measurements were made on September 21, 2011 (DOE gage below aqueduct 39.4 cfs). In 2012, thalweg and habitat surveys were conducted on September 11, 2012 (DOE gage below aqueduct 38.7 cfs). Figure 4.1 depicts seasonal low flow data for 2010 through 2012 and the corresponding time periods when the thalweg and habitat surveys were conducted.

In 2010, the constructed stream length was 470 meters. Between 2010 and 2011, the channel thalweg shifted and the thalweg length shortened by 10 meters. This resulted in a 460 meter survey length in 2011 and 2012. Primary transects were established at 50 meter intervals and secondary transects were established at 25 meter intervals. In 2010, bankfull width (BFW) measurements were made only at primary transects. The channel bankfull was only defined at seven of the primary transects in 2010 (due to channel shape from construction). In 2011, BFW measurements were made at primary and secondary transects. The channel bankfull was defined at 17 of 19 transects. Bankfull width averaged 36 meters in

2010 and 27.5 meters in 2011. No bankfull width measurements were made in 2012. Wetted width and thalweg depth measurements were made at 95 stations in 2010 and 93 stations in both 2011 and 2012. A summary of the results is included below in Table 4.1.

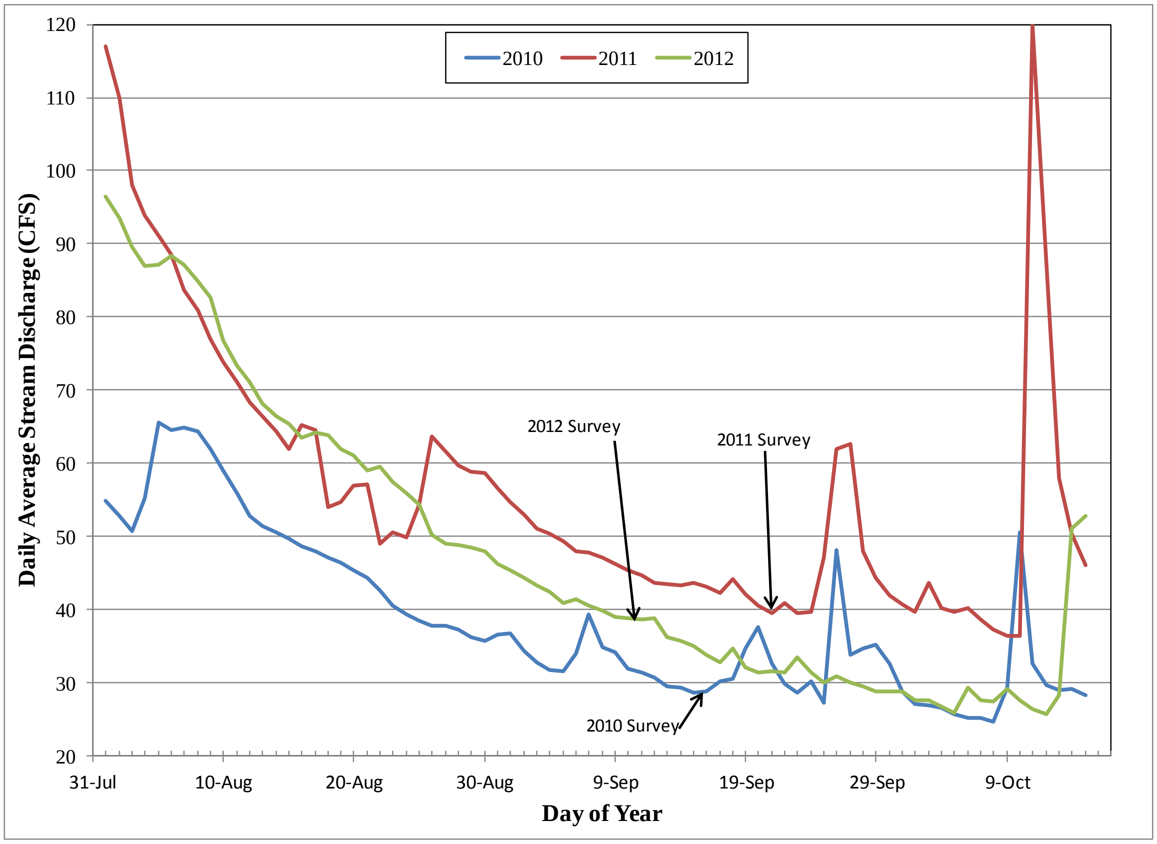

Figure 4.1. Morse Creek streamflow data for low flow seasons 2010 through 2012 (source: DOE stream gage below aqueduct).

Table 4.1. New channel reach summary of measured gradient, wetted width, and thalweg depth for 2010, 2011 and 2012.

Measurement Range	Gradient			Wetted Width meters			Thalweg Depth meters		
	2010 n=22	2011 n=56	2012 n=48	2010 n=95	2011 n=93	2012 n=93	2010 n=95	2011 n=93	2012 n=93
Maximum	na	na	na	33.0	24.0	14.1	0.80	2.1	2.7
Minimum	na	na	na	8.8	4.7	9.4	0.17	0.17	0.17
Average	0.87%	1.00%	0.98%	17.1	12.2	12.3	0.29	0.50	0.52

Riparian Characteristics

In 2010, a total of 44 thalweg canopy closure measurements were made at 11 observation points. Average canopy closure ranged from 5 to 77 percent at the 11 observation points. Reach level canopy closure averaged 37 percent. In 2011, a total of 40 thalweg canopy closure measurements were made at 10 observation points. Average canopy closure ranged from 12 to 75 percent. Reach level canopy closure averaged 35 percent. In 2012, a total of 40 thalweg canopy closure measurements were made at 10 observation points. Average canopy closure ranged from 5 to 69 percent; reach level canopy closure averaged 32 percent. Riparian condition varied along the reach from none (area disturbed by construction), to deciduous, large, dense. Riparian stand conditions are best described as deciduous, medium, dense (see Section 3.1 for definitions).

Habitat Units

In 2010, only three primary habitat units were delineated in the new channel. The units included a low gradient riffle, a shallow glide, and a low gradient riffle w/ pockets. Four small pool sub-units were also identified. In 2011, six different habitat types were classified, these included: low gradient riffle, glide, low gradient riffle w/ pockets, high gradient riffle, pool, and run. One small pool sub-unit and two low gradient riffles were also identified. A total of 16 primary and 3 secondary habitat units were inventoried.

In 2012, the same six different habitat types as classified in 2011 were classified within the reach. A total of 16 primary and 7 secondary habitat units were inventoried. Secondary units consisted of two low gradient riffles, two small side channels within the channel's bankfull width, two small pools, and one run. A summary of habitat units inventoried in 2010, 2011, and 2012 is included below in Table 4.2.

In 2012, total habitat area inventoried equaled 6,038 square meters (not including the three large side channel segments). The habitat area consisted of 5,195 square meters of primary habitat and 843 square meters of secondary habitat (separated from the channels thalweg). Pools and runs/glides made up 28 and 18 percent of the primary habitat unit area respectively. Low gradient riffles, low gradient riffles with pockets, and high gradient riffles made up the remaining 54 percent of the primary habitat area. A total of 343 meters of side channel habitat were inventoried in side channels 1, 2, and 3. Total wetted habitat area at the time of the survey was 837 square meters.

Table 4.2. Summary of 2010 through 2012 habitat data for the new channel reach. Habitat unit percentage by length only includes primary habitat unit lengths. Habitat unit percentage by area includes all primary and secondary habitat units, but does not include the three large side channel units.

Habitat Type	No. of Habitat Units			Habitat Unit Length (percent)			Area Sq.M (percent)		
	2010	2011	2012	2010	2011	2012	2010	2011	2012
High Gradient Riffle	0	2	2	0	32 (7%)	28 (6%)	0	318 (6%)	345 (6%)
Low Gradient Riffle	1	5	4	35 (7%)	162 (35%)	104 (23%)	459 (5%)	2,050 (36%)	1,097 (18%)
Low Gradient Riffle w/pockets	1	3	3	371 (79%)	67 (15%)	119 (26%)	6,313 (73%)	654 (12%)	1,363 (23%)
Sub Unit- Riffle	0	2	2	0	53	67	0	309 (5%)	382 (6%)
Side Channels w/in Bankfull	0	0	2	0	0	85	0	0	178 (3%)
Run	0	1	1	0	36 (8%)	39 (8%)	0	351 (6%)	393 (7%)
Sub Unit- Run	0	0	1	0	0	29	0	0	162 (3%)
Glide	1	1	1	65 (14%)	47 (10%)	44 (10%)	1,664 (20%)	589 (10%)	521 (9%)
Pool	0	4	5	0	118 (25%)	127 (28%)	0	1,365 (24%)	1,476 (24%)
Sub Unit- Pool	4	1	2	36	10	33	158 (2%)	44 (1%)	121 (2%)
Total All Units	7	19	23	508	524	675	8,594	5,679	6,038

Pebble Counts

In 2010, pebble counts were conducted at 20 transects, a total of 99 stream particles were measured (one point fell on LWD). In 2011 and 2012, pebble counts were conducted at 19 transects, a total of 95 stream particles were measured in both years. For reporting purposes fines were tabulated as one mm and bedrock was tabulated as 4,000 mm, one mm was added to all measurements and particles sizes are reported as cumulative percent smaller than. Figure 4.2 depicts the new channel reach particle size distribution in 2010, 2011, and 2012. In 2010, 38 percent of particles were classified as fines. There was a 50 percent decrease in the frequency of pebbles classified as fines in 2011

(19%). In 2012, only 11 percent of the particles were classified as fines; decrease of 71 percent from 2010. Median particle size increased from 13mm in 2010 to 24mm in 2011, to 47 mm in 2012 (261% increase).

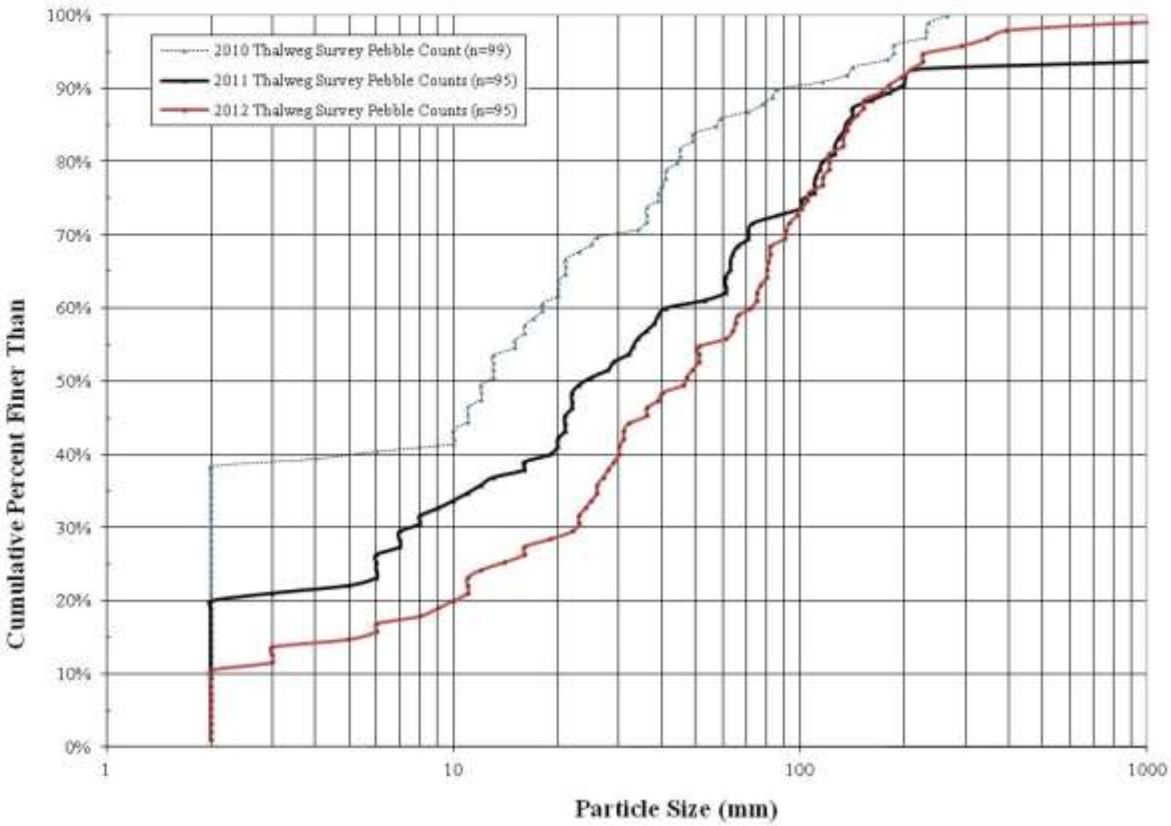

Figure 4.2. New channel reach particle size distribution in 2010, 2011, and 2012.

4.1.2 LWD Survey Results

2010 Survey Results

A detailed LWD and logjam inventory was conducted on September 22, 2010 (for complete details and photos see Haggerty 2010). A total of 675 pieces of LWD were inventoried. Additional pieces of LWD were identified but not inventoried. The LWD pieces not inventoried were outside the channel's bankfull width (and not part of an ELJ structure). Of the 675 pieces inventoried 91 percent (614) were part of the 20 ELJs inventoried. The remaining 9 percent (61 pieces) were located in over-flow and side channels.

The vast majority (73%) of pieces inventoried were classified as medium size (20-50 cm diameter). Only 11 percent of the pieces were greater than 50 cm diameter, no key pieces were identified within the project area. The remaining 16 percent of pieces were classified as small (10-20cm).

Species type (conifer versus deciduous) was determined for 600 pieces (75 pieces were classified as unknown). Conifer type LWD made up approximately 70 percent the LWD contained within the project area.

Five basic ELJ types were used for the Morse Creek restoration project. Several of the ELJs were designed using a combination of these 5 ELJ types. Figure 4.3 depicts ELJ types and their location within the Morse Creek restoration project. There is only one jam type 3+, it is a combination of one type 3 ELJ, one type 5 ELJ, and one type 4 ELJ. A summary of ELJ attributes is included in Table 4.3 (note that the number of LWD pieces is based on the total number of pieces inventoried, additional pieces may be entirely buried and not included in the inventory). For more details on ELJs and ELJ types see Haggerty 2010.

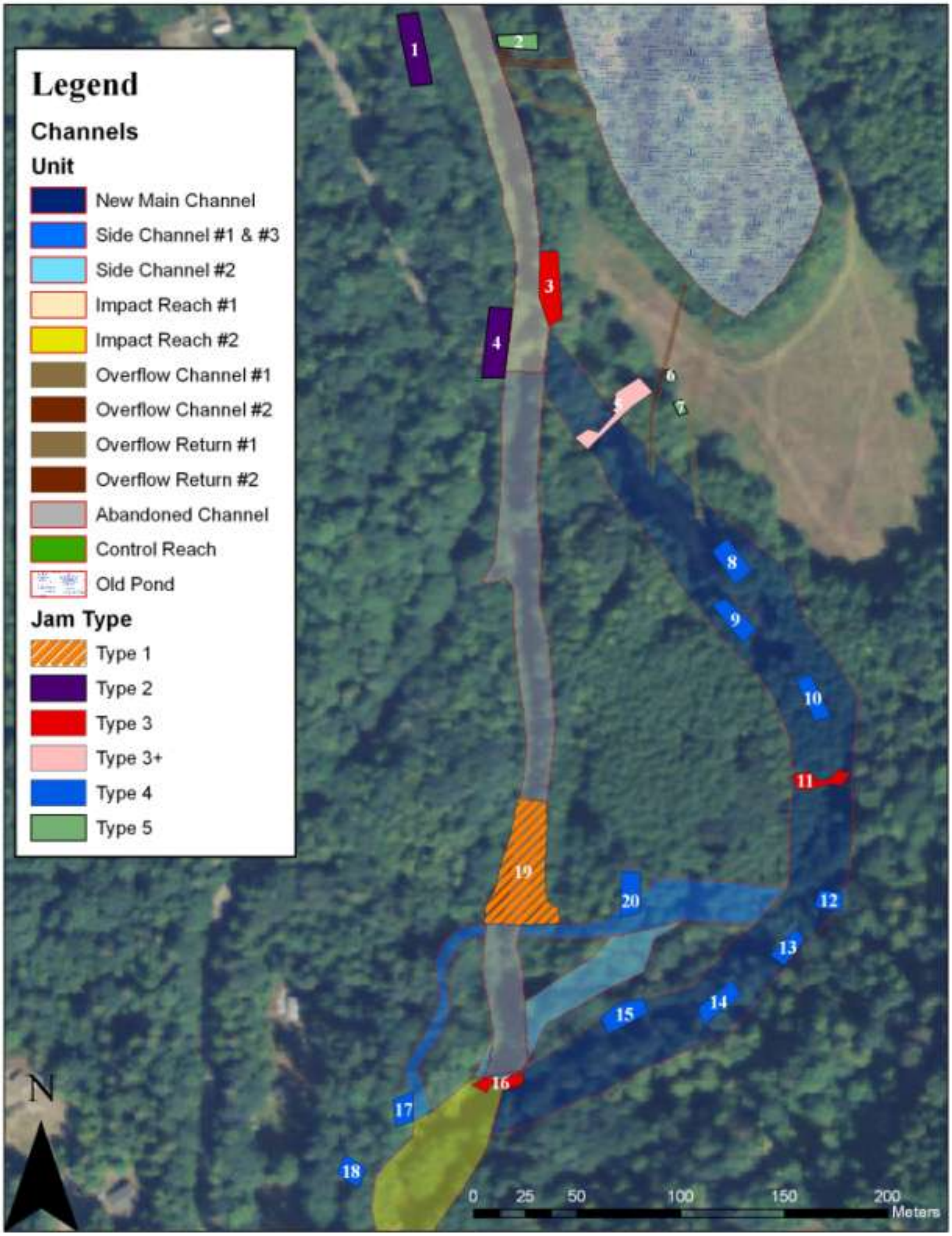

Figure 4.3. As-built map of Morse Creek ELJs with Jam IDs.

Table 4.3. Summary of engineered logjam attributes (all measurements in meters).

Jam ID	Herrera ID 1	Herrera ID 2	Herrera ID 3	Reach	Down stream End Position	No. of LWD Pieces	Length	Avg Width	Max Height	Min Height	Channel Location
1	ELJ 2-2	ELJ 4-12	na	IR1	86	68	34	10	3.6	1	Floodplain
2	ELJ 5-1	ELJ 5-2	ELJ 5-3	IR1	70	9	17	7.5	1.2	0	Floodplain
3	ELJ 3-4	na	na	IR1	220	25	44	-	-	-	Bank/FP
4	ELJ 2-1	ELJ 4-11	na	IR1/AC	230	63	31.5	10	4.75	3.5	Bank/Terrace
5	ELJ 3-3	ELJ 5-4	ELJ 4-14	NC	28	57	40	9	-	0	In-channel, bank, and overflow channel
6	ELJ 5-5	na	na	NC	44	3	5	-	-	-	Overflow channel
7	ELJ 5-6	na	na	NC	58	3	5	-	-	-	Overflow channel
8	ELJ 4-9	na	na	NC	118	19	20	9	3.7	1.2	Right Bank to mid-channel
9	ELJ 4-8	na	na	NC	128	25	29	8	3.7	0.8	LB to Mid-Channel
10	ELJ 4-7	na	na	NC	186	19	23	8.5	3.8	1.2	Right Bank to mid-channel
11	ELJ 3-2	na	na	NC	231	26	10	30	-	-	Across channel
12	ELJ 4-6	na	na	NC	290	22	19	9.2	3.2	0	Right Bank
13	ELJ 4-5	na	na	NC	316	21	15	8	3.5	0	Right Bank
14	ELJ 4-4	na	na	NC	347	35	23.5	8	3.2	1	Mid-Channel
15	ELJ 4-3	na	na	NC	390	25	23	9.4	2.8	0	LB to Mid-Channel
16	ELJ 3-1	na	na	NC/IR2	471	24	23	7	-	-	Overflow channel
17	ELJ 4-2	na	na	NC	-	29	14	10	4.5	0	Overflow/Floodplain
18	ELJ 4-1	na	na	IR2	-	35	12	10	4	0	Bank/Floodplain
19	ELJ 1-1	na	na	NC	-	72	62	24.3	5.2	0	Overflow channel
20	ELJ 4-10	na	na	NC	-	34	20	8.5	3.4	0	Overflow channel

2011 Survey Results

There was no inventory of the wood within constructed ELJs (inventoried in 2010). In 2011, there was no evidence that LWD within ELJs had moved, so LWD was not inventoried again. It was noted that many of the pieces of LWD tagged in 2010 had their tags vandalized and/or removed. A total of 59 pieces of LWD were inventoried, many of these pieces were newly recruited from the adjacent riparian stands. The majority (58%) of pieces surveyed were medium sized (20-50 cm diameter). Nine percent of the pieces were greater than 50 cm diameter and 33 percent of the pieces were classified at small (10-20 cm). Deciduous trees were the most dominant species recruited to the stream with 71 percent of the surveyed LWD being deciduous. Conifer type LWD made up 20% of the recruited LWD within the project area. Five percent of the LWD were of an unknown species type.

2012 Survey Results

There was no inventory of the wood within constructed ELJs (inventoried in 2010). In 2012, there was no evidence that LWD within ELJs had moved, so ELJ LWD was not inventoried in 2012. A total of 61 pieces of LWD were inventoried, many of these pieces were newly recruited from the adjacent riparian stands. The majority (66%) of pieces surveyed were medium sized (20-50 cm diameter). Three percent of the pieces were greater than 50 cm diameter and 31 percent of the pieces were classified at small (10-20 cm). Deciduous trees were the most dominant species recruited to the stream with 75 percent of the surveyed LWD being deciduous. Conifer type LWD made up 15% of the recruited LWD within the project area. Ten percent of the LWD were of an unknown species type.

4.1.3 Channel Profile and Cross-Section Results

A thalweg substrate and water surface elevation profile was run upstream from the downstream end of the new channel to the upstream end of the new channel. In 2010, water surface and substrate elevations were measured and recorded at 15 to 30 meter intervals; elevations were measured at a total of 22 stations. In 2011, water surface and substrate elevations were measured and recorded at 5 to 10 meter intervals; elevations were measured at a total of 56 stations. In 2012, water surface and substrate elevations were measured and recorded at 5 to 10 meter intervals; elevations were measured at a total of 48 stations.

Reach level stream gradient was 0.87, 1.00, and 0.98 percent in 2010, 2011, and 2012 respectively. The measured change in gradient between 2010 and 2011/12 is most directly attributable to the observed head-cutting at the downstream end of the new channel (see Figure 4.4).

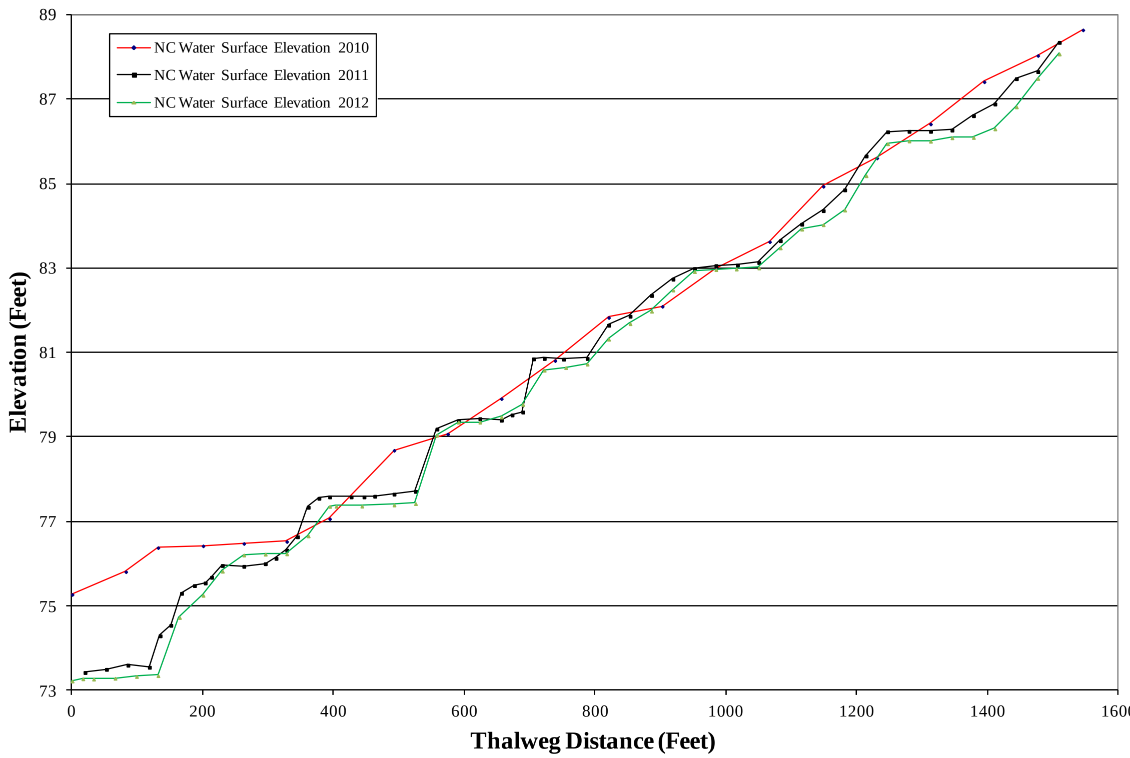

Figure 4.4. New channel reach water surface profile for 2010, 2011, and 2012.

Five long-term monitoring cross-sections were established in the new channel reach (see Figure 3.4). Annotated cross-section plots for NC-XSEC 1 through 5 are included below, as well as photos looking upstream and downstream from the cross-sections in 2010, 2011, and 2012 (see Table 4.4 for reference). Cross-section NC-XSEC 1 is located 61 meters (200 ft) upstream from the start of survey. Cross-section NC-XSEC 2 is located 123 meters (404 ft) upstream from the start of survey. Cross-section NC-XSEC 3 is located 229 meters (751 ft) upstream from the start of survey. Cross-section NC-XSEC 4 is located 316 meters (1,037 ft) upstream from the start of survey. Cross-section NC-XSEC 5 is located 390 meters (1,280 ft) upstream from the start of survey. In 2011, two cross-section pins were vandalized and/or stolen between surveys (NC-XSEC-1 middle pin and NC-XSEC-2 middle pin). These pins were reestablished using the remaining pins. In 2012, three cross-section pins were vandalized and/or stolen between surveys (NC-XSEC-1 left and middle pin and NC-XSEC-4 middle pin). These pins were reestablished using the remaining pins.

The 2010 results from the complete pebble count at NC-XSEC 2 through 5 are included in Figure 4.15**.** The 2011 and 2012 results from the complete pebble count at NC-XSEC-1 through 5 are included in Figure 4.16 and Figure 4.17.

Median average particle size for the five cross-sections averaged 17 mm, 40mm and 26mm in 2010, 2011, and 2012 respectively. This indicates that the average median particle size increased by approximately 140% between 2010 and 2011. Median particle size then fell by 35% to 26mm in 2012 (see Table 4.5).

Table 4.4. Summary of new channel reach cross-section locations and associated figures.

Cross-Section ID	Distance from Downstream End	Cross-Section Plots	Cross-Section Photos	Cross-Section Pebble Counts
NC-XSEC-1	61m/200ft	Figure 4.5	Figure 4.6	Figure 4.15, Figure 4.16, & Figure 4.17
NC-XSEC-2	123m/404ft	Figure 4.7	Figure 4.8	Figure 4.15, Figure 4.16, & Figure 4.17
NC-XSEC-3	229m/751ft	Figure 4.9	Figure 4.10	Figure 4.15, Figure 4.16, & Figure 4.17
NC-XSEC-4	316m/1,037ft	Figure 4.11	Figure 4.12	Figure 4.15, Figure 4.16, & Figure 4.17
NC-XSEC-5	390m/1,280ft	Figure 4.13	Figure 4.14	Figure 4.15, Figure 4.16, & Figure 4.17

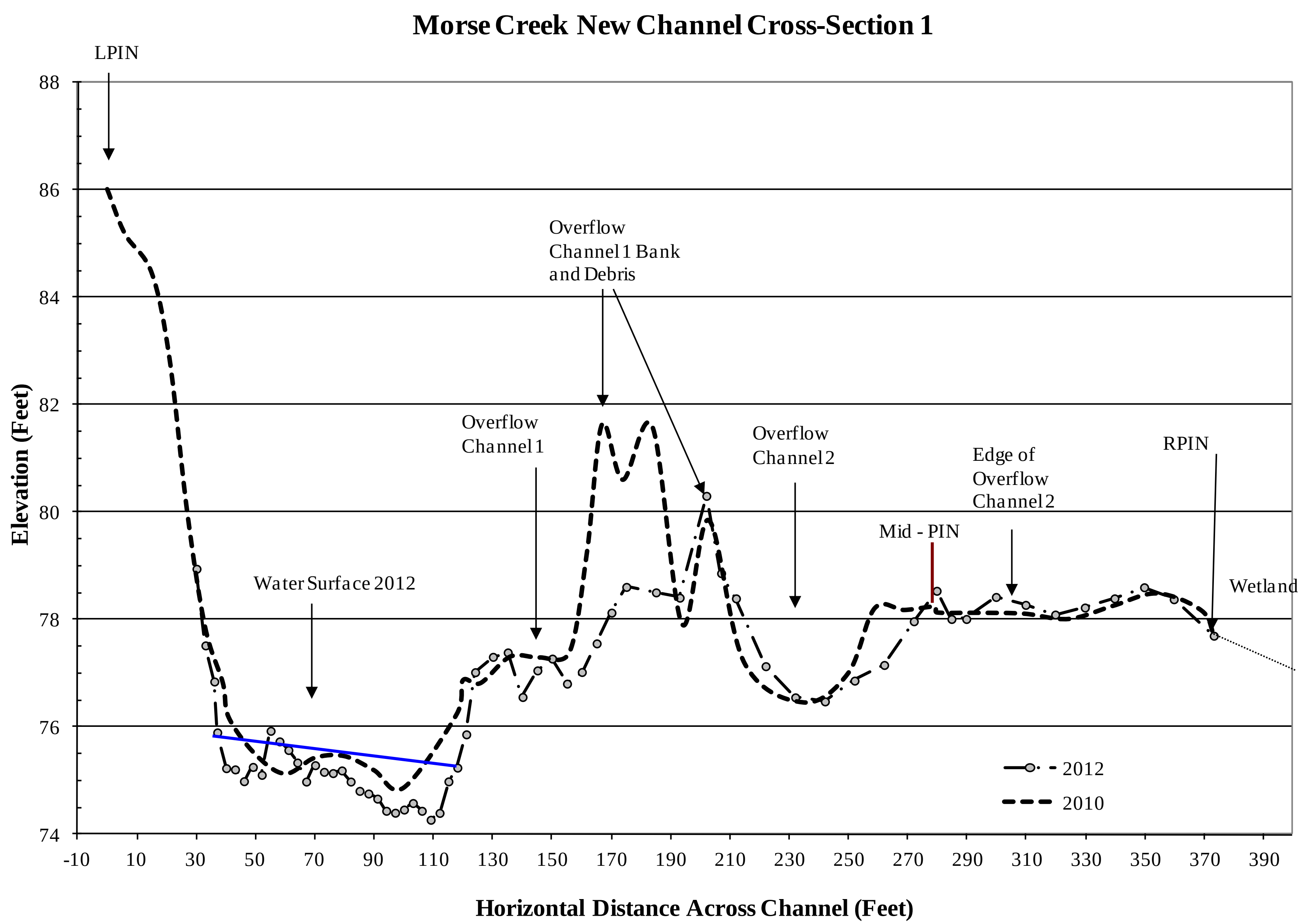

Figure 4.5. Morse Creek New Channel Cross-Section 1 in 2010 and 2012.

Figure 4.6. Photos from Cross-Section NC-1 looking downstream (above) and upstream (below) in 2010 (left) and 2011 (right). No photos available for 2012.

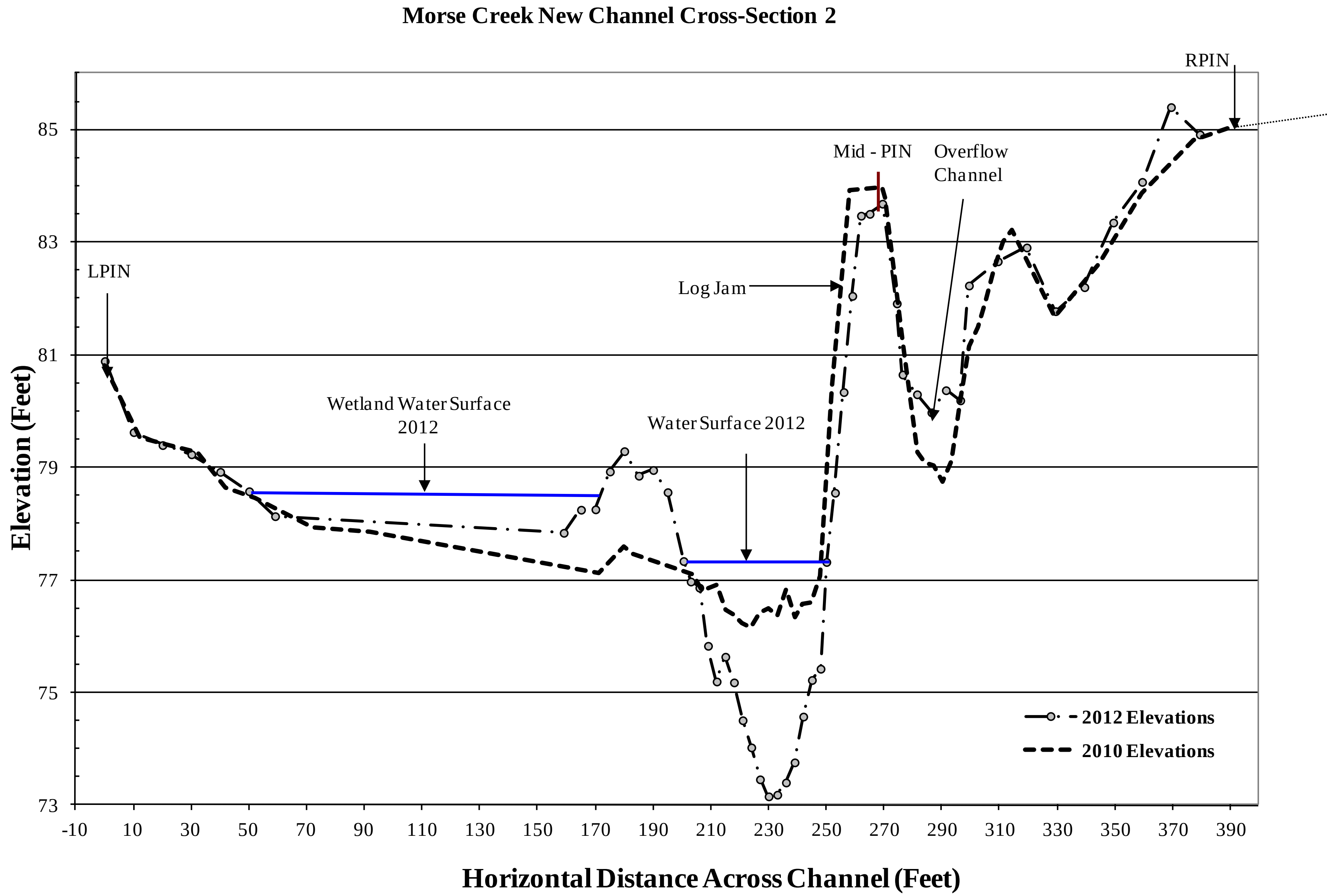

Figure 4.7. Morse Creek New Channel Cross-Section 2 in 2010 and 2012.

Figure 4.8. Photos from Cross-Section NC-2 looking downstream (above) and upstream (below) in 2010 (left) and 2011 (right). No photos available for 2012.

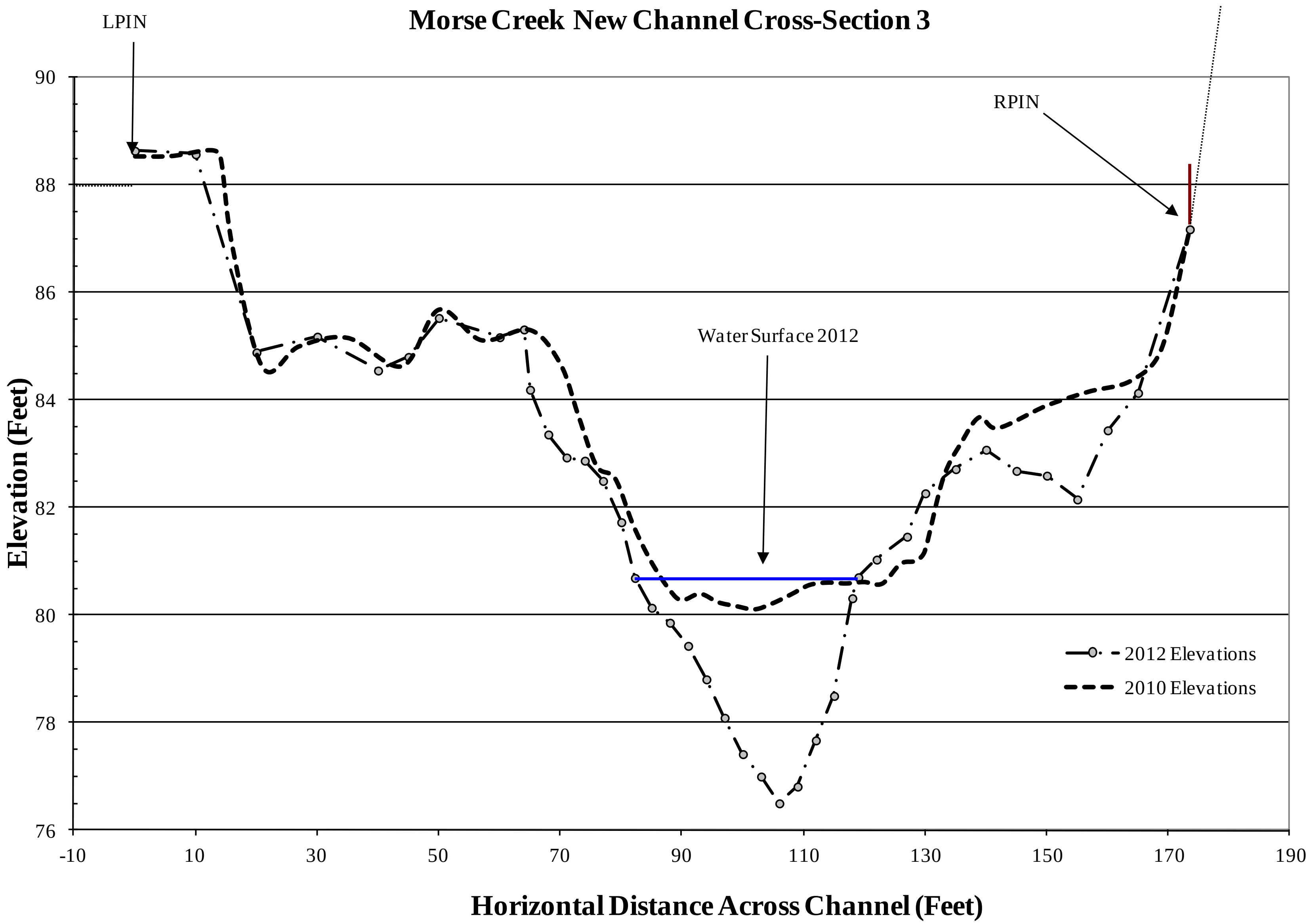

Figure 4.9. Morse Creek New Channel Cross-Section 3 in 2010 and 2012.

Figure 4.10. Photos from Cross-Section NC-3 looking downstream (above) and upstream (below) in 2010 (left) and 2012 (right).

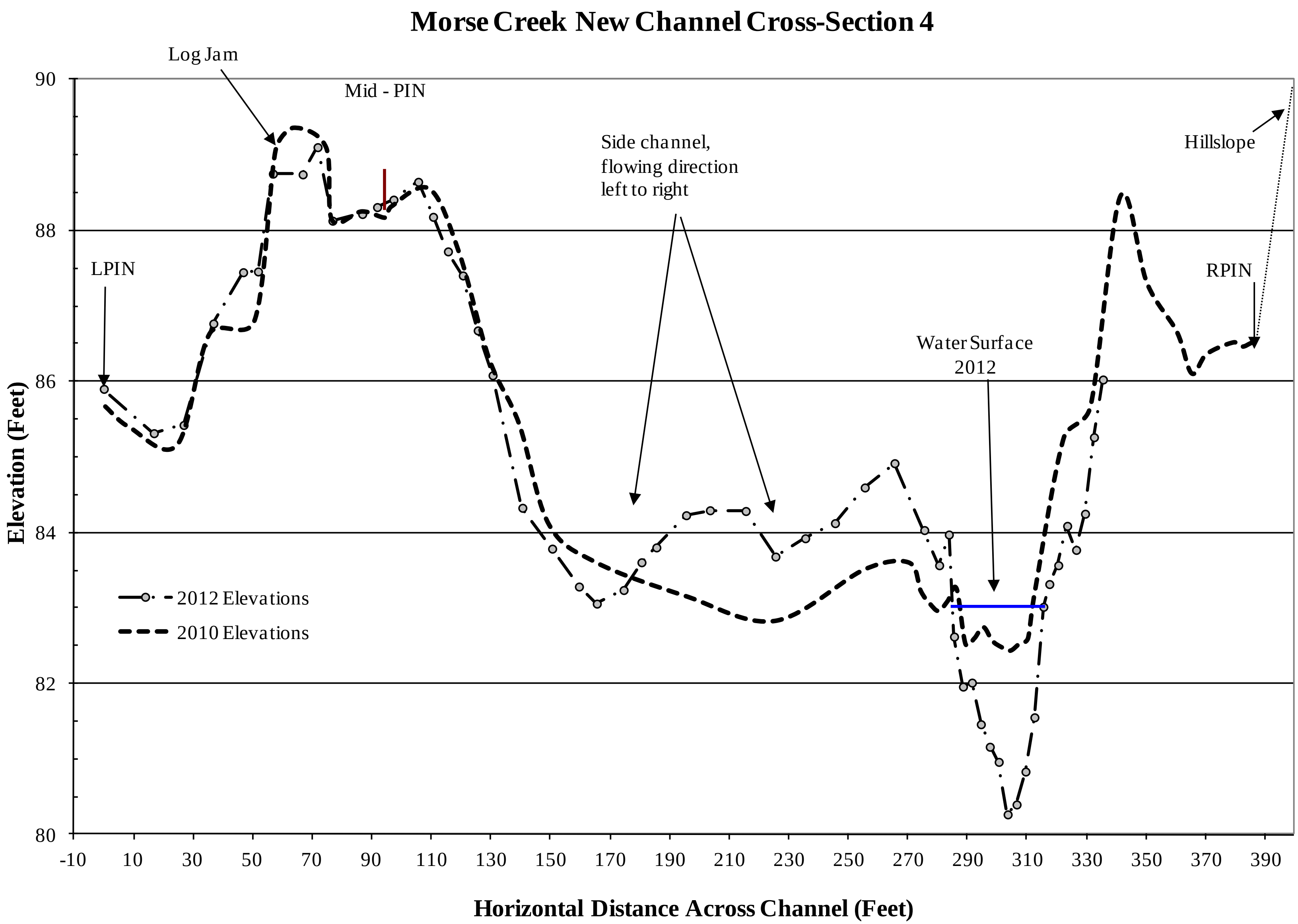

Figure 4.11. Morse Creek New Channel Cross-Section 4 in 2010 and 2012.

Figure 4.12. Photos from Cross-Section NC-4 looking downstream (above) and upstream (below) in 2010 (left) and 2012 (right).

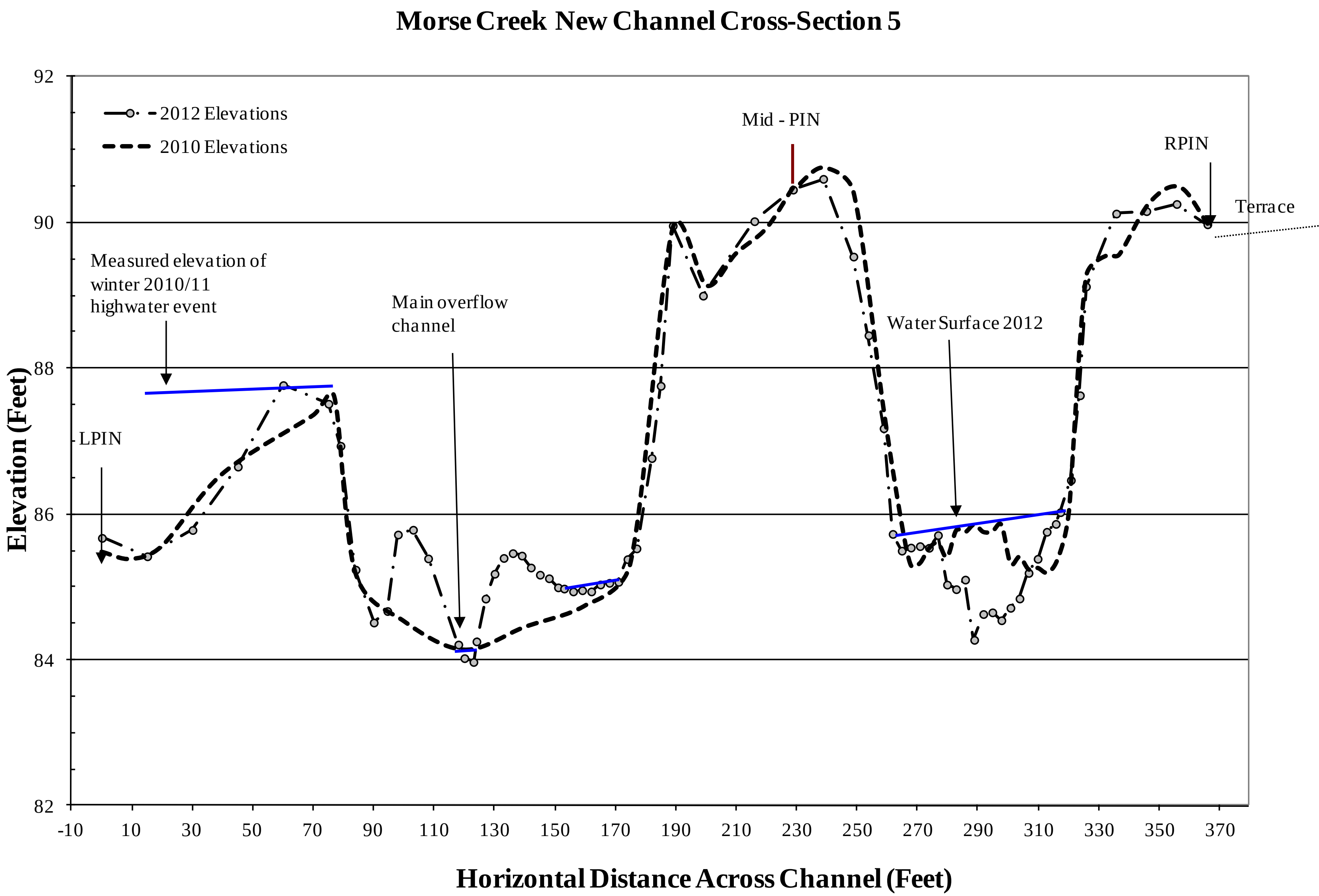

Figure 4.13. Morse Creek New Channel Cross-Section 5 in 2010 and 2012.

Figure 4.14. Photos from Cross-Section NC-5 looking downstream (above) and upstream (below) in 2010 (left) and 2012 (right).

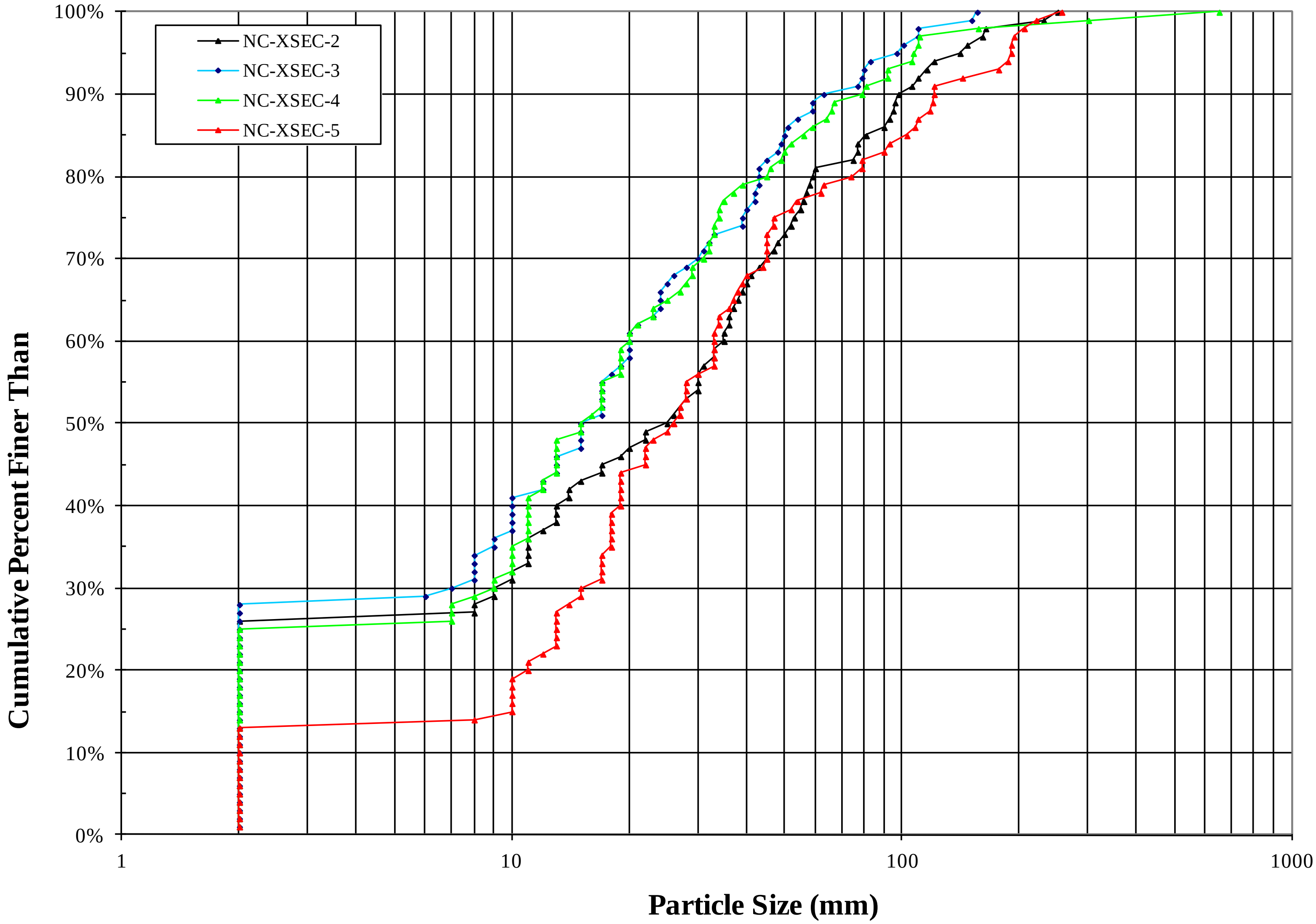

Figure 4.15. 2010 pebble counts from Cross-Sections NC-2 through NC-5 (note in 2010 XSEC-NC-1 was entirely blanketed in fines and therefore was not plotted).

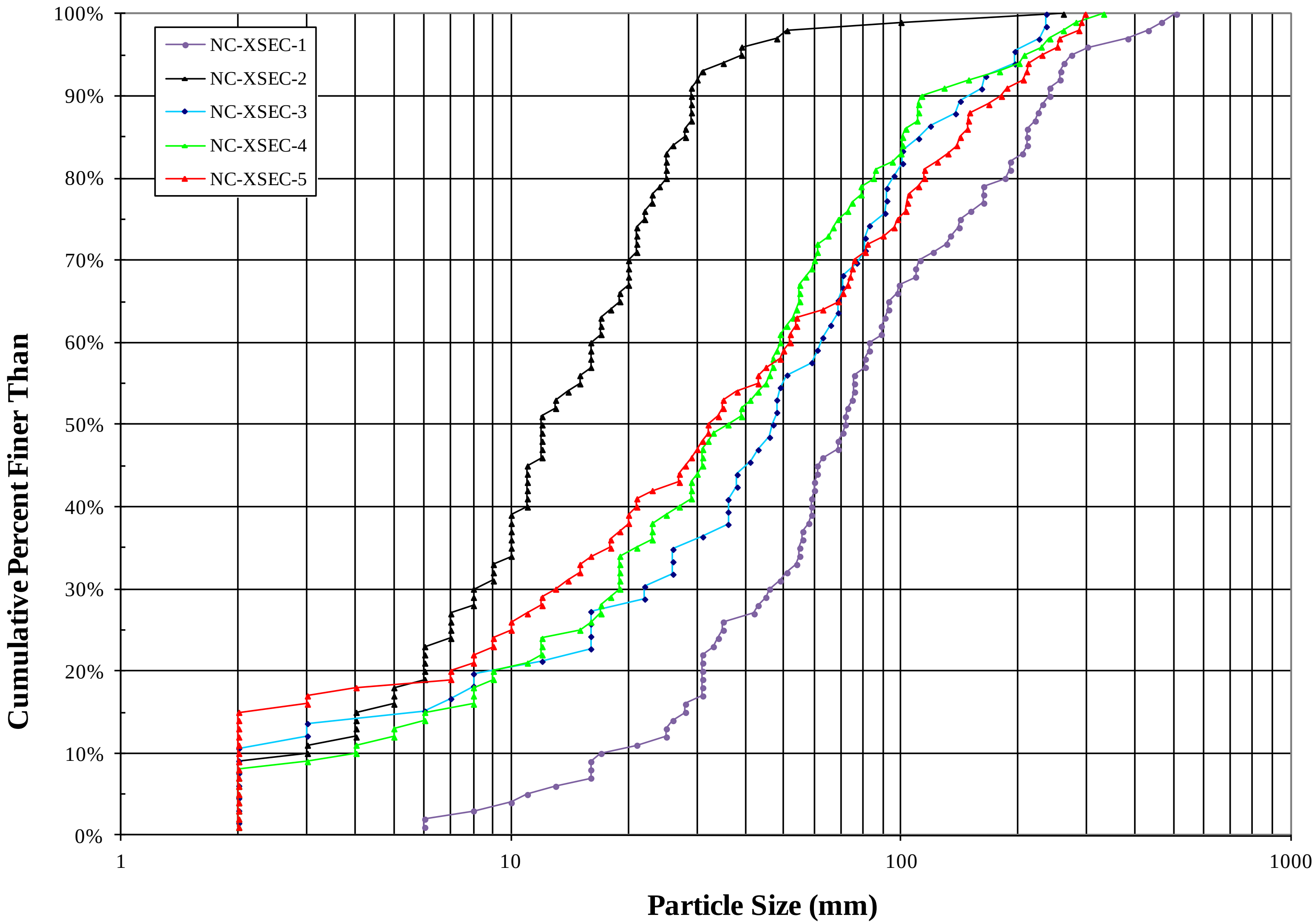

Figure 4.16. 2011 pebble counts from Cross-Sections NC-1 through NC-5.

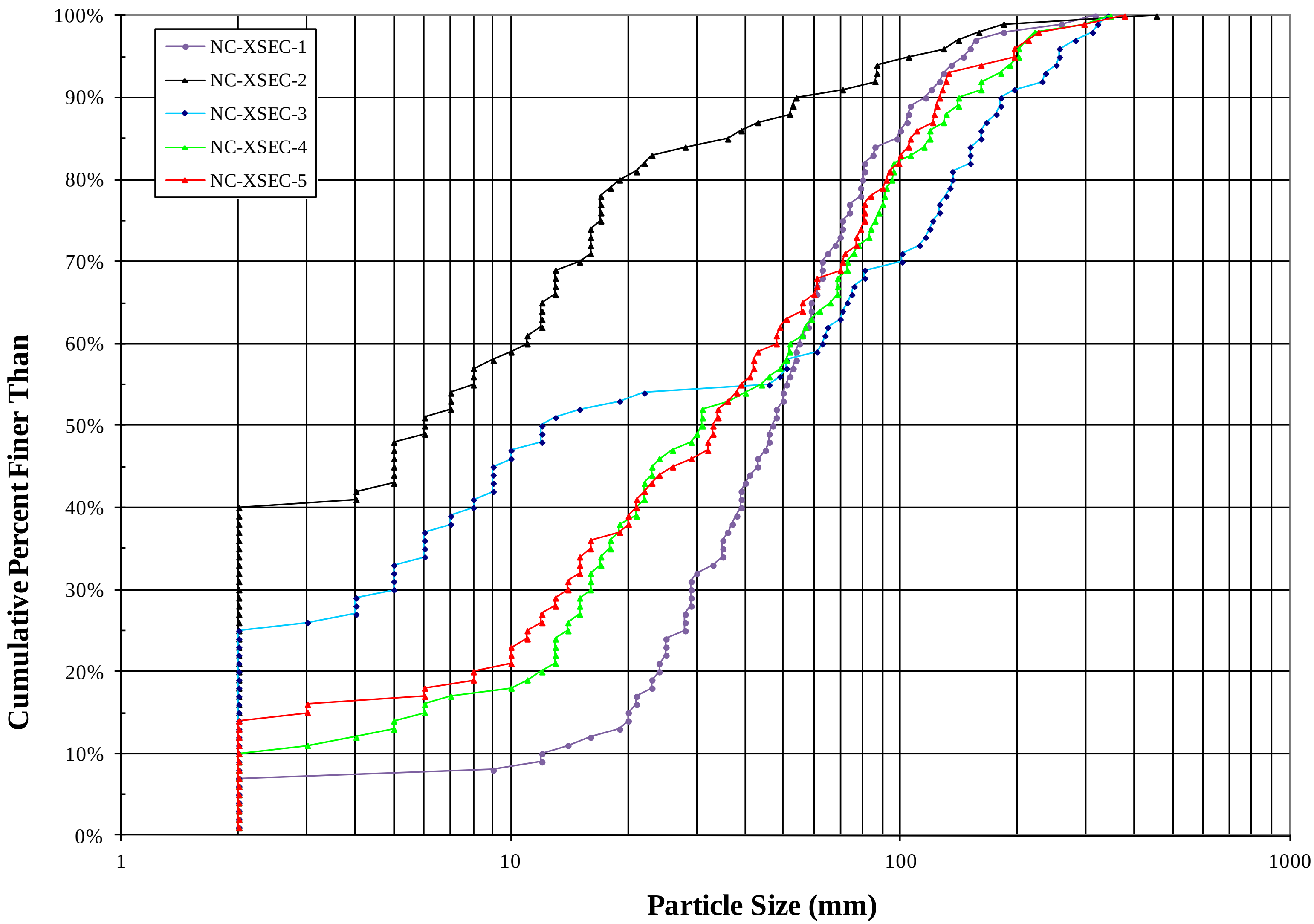

Figure 4.17. 2012 pebble counts from Cross-Sections NC-1 through NC-5.

Table 4.5. D_{16}, D_{50}, and D_{84} particle size distribution for Morse Creek new channel reach cross-sections 1 through 5.

Cross-Section ID	Particle Size (mm) D_{16}			Particle Size (mm) D_{50}			Particle Size (mm) D_{84}		
	2010	2011	2012	2010	2011	2012	2010	2011	2012
NC-XSEC-1	2	28	21	2	72	47	2	211	86
NC-XSEC-2	2	5	2	25	12	6	77	26	28
NC-XSEC-3	2	6	2	15	47	12	49	105	151
NC-XSEC-4	2	8	6	15	36	31	52	101	115
NC-XSEC-5	10	3	3	26	32	33	93	139	105

4.1.4 Snorkel Survey Results

2011 Results

A 460 meter stream segment encompassing the new channel reach was snorkel surveyed on September 19, 2011. The stream segment includes six different habitat types, including: low gradient riffle, glide, low gradient riffle w/ pockets, high gradient riffle, scour pool, and run. A total of 16 primary and 3 secondary habitat units were inventoried (one small pool sub-unit and two low gradient riffles). A summary of habitat units surveyed is included below in Table 4.6 (see also Table 4.2)

A total of seventeen habitat units were surveyed. Surveys were conducted in 15 of the 16 primary habitat units and in one of the three subunits. A total of 5,117 square meters of habitat were surveyed and 2,715 salmonids were observed. The average salmonid density for the new channel reach was 0.53 salmonids per square meter (2,715/5,117). Table 4.7 includes a habitat unit level summary of salmonid densities in the new channel reach. Five salmonid species were documented in the survey reach, two of which were ESA-listed (Puget Sound Chinook and steelhead). The vast majority of salmonids inventoried were juveniles. A total of 9 adult salmonids were observed: four pink salmon, one Chinook, and four cutthroat trout.

Salmonid densities varied by habitat unit, habitat type, species, and age class of juveniles. Snorkel survey data were further summarized by summing fish counts by habitat type. The data were summarized within five habitat types: high gradient riffles, low gradient riffles, low gradient riffles with pockets, runs/glides, and scour pools. Total salmonid, coho, and total trout densities were the lowest in high gradient riffles (see Table 4.8). Salmonid densities progressively increased across habitat types with pools having the highest densities. Coho densities were 10 times higher in pools than in low gradient riffles, but only twice the density of runs/glides. Interestingly, Age 1+ and 2+ trout densities were highest in low gradient riffles with pockets. Within scour pools age 0+ trout were observed in highest overall densities ($0.67/m^2$); roughly three times higher density than coho salmon.

Table 4.6. Summary of 2011 habitat unit IDs and habitat types for new channel reach.

Habitat Unit ID	Habitat Type	Surveyed (Y/N)	Length (M)	Wetted Width (M)	Surface Area (M^2)
1	Run	Y	36	9.7	350.8
2	High Gradient Riffle	Y	15	12.8	192.4
3	Low Gradient Riffle	Y	18	11.9	214.2
4a	Low Gradient Riffle w/ Pockets	Y	17.5	7.7	133.9
4b	Low Gradient Riffle w/ Pockets	Y	13.5	6.2	83.3
5	High Gradient Riffle	Y	17	7.4	125.4
6	Scour Pool	Y	43	12.3	528.4
7	Low Gradient Riffle	Y	12	7.4	88.5
8	Scour Pool	Y	35	11.1	389.1
9	Low Gradient Riffle	N	12	21.1	252.6
10	Scour Pool	Y	20	11.2	223.5
11	Low Gradient Riffle	Y	59	14.8	876.1
12	Scour Pool	Y	19.5	11.5	224.3
13	Low Gradient Riffle	Y	60.5	10.2	618.6
14	Glide	Y	47	12.5	588.9
15	Low Gradient Riffle w/ Pockets	Y	36	12.1	436.5
14a	Scour Pool	Y	10	4.4	43.5
7a	Low Gradient Riffle	N	47	6.0	283.0
7b	Low Gradient Riffle	N	6	4.3	25.8
TOTAL		**19 Units**	**524**	**Avg = 10.8**	**5,679**
TOTAL SURVEYED		**16 Units Surveyed**	**459**	**Avg = 11.1**	**5,117**

Table 4.7. Habitat unit level summary of 2011 salmonid densities in the new channel reach.

Habitat Unit ID	Habitat Type	Total Salmonids per m^2	Coho (Age 0+ and 1+) per m^2	Total Trout per m^2	Age 1+ and 2+ Trout per m^2
1	Run	0.58	0.09	0.49	0.16
2	High Gradient Riffle	0.02	0.00	0.02	0.01
3	Low Gradient Riffle	0.10	0.01	0.09	0.01
4a	Low Gradient Riffle w/ Pockets	1.01	0.06	0.95	0.55
4b	Low Gradient Riffle w/ Pockets	0.67	0.07	0.60	0.32
5	High Gradient Riffle	0.15	0.00	0.15	0.04
6	Scour Pool	0.57	0.10	0.45	0.09
7	Low Gradient Riffle	0.20	0.00	0.20	0.05
8	Scour Pool	1.09	0.22	0.87	0.11
10	Scour Pool	0.00	0.00	0.00	0.00
11	Low Gradient Riffle	1.53	0.21	1.31	0.24
12	Scour Pool	0.33	0.04	0.30	0.03
13	Low Gradient Riffle	1.07	0.22	0.84	0.21
14	Glide	0.27	0.00	0.27	0.02
14a	Scour Pool (subunit)	2.92	1.20	1.72	0.00
15	Low Gradient Riffle w/ Pockets	0.20	0.07	0.14	0.04
AVERAGE		**0.53**	**0.09**	**0.44**	**0.09**

Table 4.8. Habitat type summary of 2011 salmonid densities in the new channel reach.

Habitat Type	No. of Units	Area (m^2)	Total Salmonids per m^2	Coho (Age 0+ and 1+) per m^2	Total Trout per m^2	Age 1+ and 2+ Trout per m^2
High Gradient Riffle	2	318	0.07	0.00	0.07	0.02
Low Gradient Riffle	4	1,797	0.28	0.02	0.26	0.02
Low Gradient Riffle w/ Pockets	3	654	0.43	0.07	0.36	0.18
Run/Glide	2	940	0.51	0.10	0.42	0.09
Pool	5	1,409	1.02	0.21	0.80	0.13

2012 Results

A 460 meter stream segment encompassing the new channel reach was snorkel surveyed on September 13, 2012. The stream segment includes six different habitat types, including: low gradient riffle, glide, low gradient riffle w/ pockets, high gradient riffle, scour pool, and run. A total of 16 primary and 7 secondary habitat units were inventoried. Secondary units consisted of two low gradient riffles, two small side channels within the channel's bankfull width, two small pools, and one run.). A summary of habitat units surveyed is included below in Table 4.6 (see also Table 4.2)

A total of 21 habitat units were surveyed using snorkel techniques, the remaining units were surveyed using visual foot surveys (results are reported separately). A total of 5,859 square meters of habitat were surveyed and 3,085 salmonids were observed. The average salmonid density for the new channel reach was 0.53 salmonids per square meter (3,085/5,859); note this is the exact same density measured in 2011). Table 4.7 includes a habitat unit level summary of salmonid densities in the new channel reach. Five salmonid species were documented in the survey reach, three of which were ESA-listed (Puget Sound Chinook and steelhead, and summer chum salmon). The vast majority of salmonids inventoried were juveniles. A total of 12 adult salmonids were observed: three pink salmon, three Chinook, one summer chum, and five cutthroat trout.

Salmonid densities varied by habitat unit, habitat type, species, and age class of juveniles. Snorkel survey data were further summarized by summing fish counts by habitat type. The data were summarized within five habitat types: high gradient riffles, low gradient riffles, low gradient riffles with pockets, runs/glides, and scour pools. Total salmonid, coho, and total trout densities were the lowest in high gradient riffles (see Table 4.8). Salmonid densities progressively increased across habitat types with pools having the highest densities. Coho densities were 100 times higher in pools than in low gradient riffles, and over four times the density of runs/glides. Interestingly, Age 1+ and 2+ trout densities were highest in pools and low gradient riffles with pockets. In 2011, within scour pools age 0+ trout were observed in highest overall densities (0.67/m^2); roughly three times higher density than coho salmon. However, in 2012 this was not observed, age 0+ trout densities were 0.34/m^2 (roughly half that observed in 2011), were as coho densities were 0.71/m^2 (3.5 fold increase over 2011).

Table 4.9. Summary of 2012 habitat unit IDs and habitat types for new channel reach.

Habitat Unit ID	Habitat Type	Surveyed (Y/N)	Length (M)	Wetted Width (M)	Surface Area (M^2)
1	Run	Y	39	10.1	393
2	High Gradient Riffle	Y	16	16.9	271
3	Low Gradient Riffle	Y	20	12.3	247
3A	Low Gradient Riffle _Secondary Unit	Y	20	6.0	120
3B	Side Channel	Foot Survey	40	2.2	90
4	Scour Pool	Y	12	8.7	105
5	Low Gradient Riffle w/ Pockets	Y	18	7.4	134
6	High Gradient Riffle	Y	12	6.2	74
7	Scour Pool	Y	44	11.8	518
7A	Run Secondary Unit	N	29	5.6	162
7B	Low Gradient Riffle _Secondary Unit	Y	47	5.6	263
8	Low Gradient Riffle	Y	15	7.2	108
9	Scour Pool	Y	29	10.6	308
10	Low Gradient Riffle	Y	12	14.6	175
11	Scour Pool	Y	22.5	13.5	303
12	Low Gradient Riffle w/ Pockets	Y	60.5	15.2	841
12a	Scour Pool Secondary Unit	Y	21.5	3.6	77
13	Scour Pool	Y	19	12.7	241
14	Low Gradient Riffle	Y	57	10.0	568
14A	Side Channel	Foot Survey	45.3	2.0	89
15	Glide	Y	44	11.8	521
15A	Scour Pool Secondary Unit	Y	11	4.0	44
16	Low Gradient Riffle w/ Pockets	Y	40	11.0	388
TOTAL	**23 Units**	**-**	**674**	**Avg = 9.0**	**6,038**
TOTAL SNORKEL SURVEYED		**21 Units Surveyed**	**589**	**Avg = 9.9**	**5,859**

Table 4.10. Habitat unit level summary of 2012 salmonid densities in the new channel reach.

Habitat Unit ID	Habitat Type	Total Salmonids per m^2	Coho (Age 0+ and 1+) per m^2	Total Trout per m^2	Age 1+ and 2+ Trout per m^2
1	Run	0.47	0.17	0.29	0.13
2	High Gradient Riffle	0.01	0.00	0.01	0.00
3	Low Gradient Riffle	0.11	0.03	0.09	0.02
3A	Low Gradient Riffle _Secondary Unit	0.09	0.03	0.07	0.00
4	Scour Pool	0.85	0.46	0.38	0.03
5	Low Gradient Riffle w/ Pockets	0.25	0.16	0.09	0.02
6	High Gradient Riffle	0.16	0.01	0.15	0.03
7	Scour Pool	1.10	0.67	0.43	0.01
7A	Run Secondary Unit	0.99	0.50	0.48	0.02
7B	Low Gradient Riffle _Secondary Unit	0.28	0.00	0.26	0.07
8	Low Gradient Riffle	0.06	0.00	0.06	0.02
9	Scour Pool	0.33	0.23	0.10	0.00
10	Low Gradient Riffle	0.04	0.00	0.04	0.02
11	Scour Pool	2.06	1.12	0.93	0.63
12	Low Gradient Riffle w/ Pockets	0.48	0.20	0.28	0.13
12a	Scour Pool Secondary Unit	1.63	0.72	0.91	0.00
13	Scour Pool	0.91	0.41	0.50	0.07
14	Low Gradient Riffle	0.05	0.00	0.05	0.00
15	Glide	0.11	0.05	0.06	0.00
15A	Scour Pool Secondary Unit	3.86	3.86	0.00	0.00
16	Low Gradient Riffle w/ Pockets	0.46	0.23	0.22	0.09
AVERAGE		**0.53**	**0.27**	**0.25**	**0.08**

Table 4.11. Habitat type summary of 2012 salmonid densities in the new channel reach.

Habitat Type	No. of Units	Area (m^2)	Total Salmonids per m^2	Coho (Age 0+ and 1+) per m^2	Total Trout per m^2	Age 1+ and 2+ Trout per m^2
High Gradient Riffle	2	345	0.04	0.003	0.04	0.006
Low Gradient Riffle	6	1,480	0.10	0.007	0.09	0.02
Low Gradient Riffle w/ Pockets	5	1,363	0.45	0.20	0.24	0.11
Run/Glide	3	1,076	0.37	0.16	0.21	0.05
Pool	6	1,596	1.19	0.71	0.48	0.13

Visual foot surveys were conducted for habitat units too shallow for snorkel surveys. This was the first year this method had been used at Morse Creek. A total of five habitats were surveyed. These habitats included two side channels within the Morse Creek bankfull, as well as the 3 major side channel units. A summary of the results is included below in Table 4.12. The vast majority of juvenile salmonids observed were in deeper "pool" like habitats. Few salmonids were observed in the shallow portions of the side channels. For example, in Side Channel 2, 142 of the 148 (96%) juveniles observed were in deeper "pool" like habitat sub-units.

Table 4.12. Summary of 2012 visual foot surveys in side channels associated with the new channel reach

Habitat Unit ID	Habitat Type	Length (m)	Average Wetted Width (m)	Surface Area (Sq. meters)	Total Salmonids	Total Salmonids / Sq. Meter
3B	Side Channel	40	2.2	89.7	100	1.11
14A	Side Channel	45.3	2.0	88.6	26	0.29
NC Side Channel 1	Side Channel	101.5	3.0	303.5	277	0.91
NC Side Channel 2	Side Channel	78.5	3.5	275.5	148	0.54
NC Side Channel 3	Side Channel	70	3.7	257.9	246	0.95
TOTALS		**335.3**	**Avg=2.9**	**1,015**	**797**	**0.79**

4.1.5 Macroinvertebrate Sampling Results

2010 Results

Macroinvertebrate sampling was conducted on September 22, 2010 by Streamkeepers of Clallam County. The average BIBI score for the three replicate samples was 18, which rated poor on the BIBI score card. The overall taxa diversity was depressed, the proportion of predators and long-lived tax was reduced, there were few mayflies or intolerant taxa present, and dominance by the three most abundant taxa was very high.

2011 Results

Macroinvertebrate sampling was conducted on October 10, 2011 by Streamkeepers of Clallam County. The average BIBI score for the three replicate samples was 23, which rated poor on the BIBI score card. The overall taxa diversity was depressed, the proportion of predators and long-lived tax was reduced, there were few stoneflies or intolerant taxa present and dominance by the three most abundant taxa was very high.

In the first replicate 523 individuals were sampled, in the second replicate 524 individuals were sampled, and in the third replicate there were 596 individuals sampled. The average taxa richness, the total number of taxa from all of the different invertebrates collected from the stream site, was 23. The metric that consistently had poor scores at Morse Creek was the number of long-lived taxa, number of intolerant taxa, and the percentage of predator individuals with both metrics scoring a 1. The metric that scored well on all three replicates was the percentage of tolerant individuals with each replicate having a score of 5. Other metric scores ranged from between 1 and 3. A complete summary of BIBI results are included in Figure 4.18 through Figure 4.20.

2012 Results

Macroinvertebrate sampling was conducted on September 11, 2012 by Streamkeepers of Clallam County. The results of the sampling were not available at the time this report was written.

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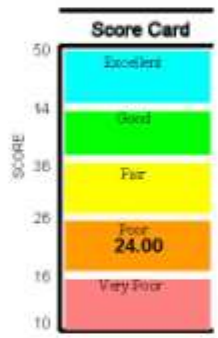
Puget Sound Lowlands BIBI Report - Genus Level

				ES&C ID	12732-A
Client Name	NOSC	Station Number	Morse 1.6a	Project	11-NOSC01-001
Description	3 samples, 500_SID_TI-2	Location	1.6a	Sample Date	10/10/2011
Station Name	Morse 1.6a	Collection Method	Unknown	Sort Date	11/21/2011
Stream Name	Morse	Replicate	1	ID Date	11/23/2011
DS Geo Loc (decimal degrees)	Latitude 0	Longitude	0	Report Date	11/23/2011

Metric	*Value*	*Standardized Score*
Abundance	523	(not used in Index)
Taxa Richness	22	3
Ephemeroptera Richness	5	3
Plecoptera Richness	4	3
Trichoptera Richness	5	3
# of Long-Lived Taxa	1	1
# of Intolerant Taxa	1	1
Tolerant Individuals (%)	0.00	5
# of Clinger Taxa	10	3
Predator Individuals (%)	4.21	1
Dominance -3 taxa (%)	82.03	1
Dominance -1 taxa	Chironomidae	(not used in Index)
Dominance -2 taxa	Antocha	(not used in Index)
Dominance -3 taxa	Glossosoma	(not used in Index)
Standardized Score:		24



Scores calculated in accordance with:
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Figure 4.18. 2011 BIBI results for macroinvertebrate sampling on the new channel reach- replicate 1.

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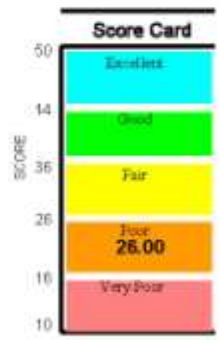
Puget Sound Lowlands BIBI Report - Genus Level

				ES&C ID	12733-A
Client Name	NOSC	Station Number	Morse 1.6a	Project	11-NOSC01-001
Description	3 samples, 500_SID_TI-2	Location	1.6a	Sample Date	10/10/2011
Station Name	Morse 1.6a	Collection Method	Unknown	Sort Date	11/22/2011
Stream Name	Morse	Replicate	2	ID Date	11/22/2011
DS Geo. Loc. (decimal degrees)	Latitude 0	Longitude	0	Report Date	11/23/2011

Metric	*Value*	*Standardized Score*
Abundance	524	(not used in Index)
Taxa Richness	26	3
Ephemeroptera Richness	5	3
Plecoptera Richness	5	3
Trichoptera Richness	6	3
# of Long-Lived Taxa	1	1
# of Intolerant Taxa	2	1
Tolerant Individuals (%)	0.00	5
# of Clinger Taxa	14	3
Predator Individuals (%)	8.97	1
Dominance -3 taxa (%)	61.64	3
Dominance -1 taxa	Glossosoma	(not used in Index)
Dominance -2 taxa	Chironomidae	(not used in Index)
Dominance -3 taxa	Lepidostoma	(not used in Index)
Standardized Score:		26



Scores calculated in accordance with:
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Figure 4.19. 2011 BIBI results for macroinvertebrate sampling on the new channel reach- replicate 2.

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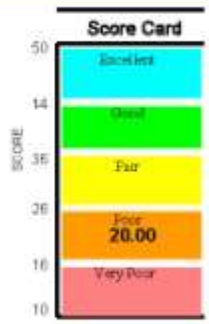
Puget Sound Lowlands BIBI Report - Genus Level

				ES&C ID:	12734-A
Client Name:	NOSC	Station Number:	Morse 1.6a	Project:	11-NOSC01-001
Description:	3 samples, 500_SID_TI-2	Location:	1.6a	Sample Date:	10/10/2011
Station Name:	Morse 1.6a	Collection Method:	Unknown	Sort Date:	11/22/2011
Stream Name:	Morse	Replicate:	3	ID Date:	11/23/2011
DS Geo. Loc. (decimal degrees)	Latitude: 0	Longitude: 0		Report Date:	11/23/2011

Metric	*Value*	*Standardized Score*
Abundance	596	(not used in Index)
Taxa Richness	20	3
Ephemeroptera Richness	3	1
Plecoptera Richness	2	1
Trichoptera Richness	5	3
# of Long-Lived Taxa	1	1
# of Intolerant Taxa	0	1
Tolerant Individuals (%)	0.17	5
# of Clinger Taxa	9	3
Predator Individuals (%)	1.17	1
Dominance -3 taxa (%)	89.26	1
Dominance -1 taxa	Antocha	(not used in Index)
Dominance -2 taxa	Chironomidae	(not used in Index)
Dominance -3 taxa	Oligochaeta	(not used in Index)
	Standardized Score:	20



Scores calculated in accordance with:
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Figure 4.20. 2011 BIBI results for macroinvertebrate sampling on the new channel reach- replicate 3.

4.2 Control Reach

4.2.1 Channel Thalweg and Habitat Survey Results

Channel Characteristics

In 2010, thalweg and habitat surveys were conducted August 13, 2010 (DOE gage below aqueduct 51.4 cfs). In 2011, thalweg and habitat surveys were conducted October 6, 2011 (DOE gage below aqueduct 40.1 cfs). In 2012, thalweg and habitat surveys were conducted September 12, 2012 (DOE gage below aqueduct 38.8 cfs). Figure 4.21 depicts seasonal low flow data for 2010 through 2012 and the corresponding time periods when the thalweg and habitat surveys were conducted.

The total length surveyed in 2010 was 500 meters. In 2011, the total length surveyed was 415 meters. In 2012, the total length surveyed was 400 meters. Primary transects were established at 50 meter intervals and secondary transects were established at 25 meter intervals. In 2010, bankfull width (BFW) measurements were made only at primary transects. In 2011, BFW measurements were made at primary and secondary transects. Differences in BFW between years are attributed to sites sampled, reach length surveyed, inclusion of over-flow channels (2010), and differences in where surveyors determined bankfull. No bankfull width measurements were made in 2012.

In 2010, stream gradient was measured at 25 meter intervals and a total of 20 measurements were made. In 2011 and 2012, stream gradient was measured at 5 to 15 meter intervals, a total of 39 measurements were made in both years. Wetted width and thalweg depth measurements were made at 101, 84, and 81 observation points in 2010, 2011, and 2012 respectively. A summary of the results is included below in Table 4.13

Table 4.13. Control reach summary of measured gradient, wetted width, and thalweg depth for 2010, 2011, and 2012.

Measurement Range	Gradient			Wetted Width (meters)			Thalweg Depth (meters)		
	2010 n=20	2011 n=39	2012 n=39	2010 n=101	2011 n=84	2012 n=81	2010 n=101	2011 n=84	2012 n=81
Maximum	na	na	na	39.4	18.3	16.7	1.4	1.36	1.38
Minimum	na	na	na	8.8	6.1	6.5	0.24	0.28	0.29
Average	0.87%	0.87%	0.88%	14.7	11.4	11.6	0.65	0.65	0.57

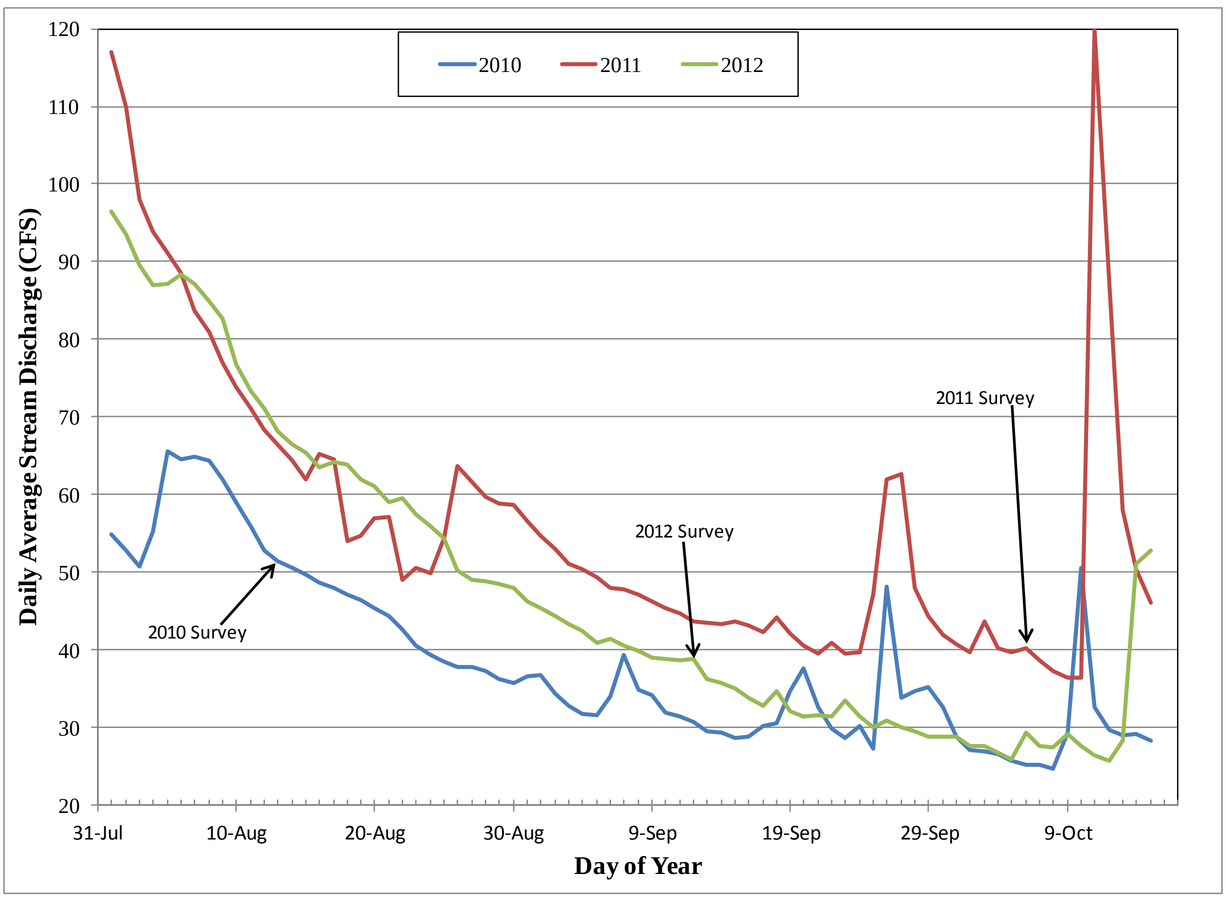

Figure 4.21. Morse Creek streamflow data for low flow seasons 2010 through 2012 -Control Reach surveys. (Source: DOE stream gage below aqueduct).

Riparian Characteristics

In 2010, a total of 44 thalweg canopy closure measurements were made at 11 observation points. In 2011 and 2012, a total of 36 thalweg canopy closure measurements were made at 9 observation points. In 2010, average canopy closure ranged from 35 to 99 percent. In 2011, average canopy closure ranged from 53 to 90 percent. In 2012, average canopy closure ranged from 33 to 99 percent. Reach level canopy closure averaged 70 percent in 2010 and 72 percent in 2011 and 2012. Riparian conditions varied along the reach. Riparian conditions were generally poor along the left bank where yards and structures occupied a portion of the riparian zone. The majority of the left bank riparian area was classified as deciduous, medium, sparse. The right bank riparian forest contained more variability. Riparian classifications of the right bank varied from deciduous, small, sparse to mixed, medium, dense (see Section 3.1 for definitions).

Habitat Units

In 2010, a total of 13 primary habitat units were delineated in the 500 meter reach. Six different habitat types were classified, these included: low gradient riffles (2), high gradient riffles (2), rapids (2), scour pool (4), and a transverse bar (1). These units were later grouped into four categories riffles (all riffle types), rapids (including the transverse bar), pools (all types), and runs. Table 4.14 depicts the habitat unit breakdown including percent of habitat by length and area.

Table 4.14. Summary of 2010 habitat unit data for the control reach.

Unit Type	Number of Units	Total Primary Unit Length (Meters)	Percent (length)	Total Unit Surface Area	Percent (area)
Pool	6	186.2	37%	2,508	34%
Rapid	3	45	9%	1,007	14%
Riffle	5	233.8	47%	3,511	47%
Run	1	35	7%	369	5%
Primary Totals	**15**	**500**	**-**	**7,395**	**-**

In 2011, a total of 11 primary habitat units were delineated in the 415 meter reach of stream surveyed. In 2012, a total of 11 primary habitat units were delineated in the 400 meter reach of stream surveyed. A summary of primary habitat units measured in 2010, 2011, and 2012 is included below in Table 4.15. Total habitat surface area in 2011 was 22 percent less than measured in 2010. In 2011, streamflow at the time of the survey was 28 percent less than in 2010 (based on DOE stream gage data). Habitat area in 2011 and 2012 were essentially the same for the 400 meters surveyed in both years with 4,539 and 4,516 square meters in 2011 and 2012 respectively.

Table 4.15. Summary of 2010, 2011, and 2012 habitat unit data for the control reach. Note: this table only summarizes 415 meters of data for 2010 and 2011; and only 400 meters for 2012.

Habitat Type	**No. of Habitat Units**			**Habitat Unit Length (percent)**			**Area Sq.M (percent)**		
	2010	2011	2012	2010	2011	2012	2010	2011	2012
Pool	4	4	4	153 (37%)	145 (35%)	141 (35%)	1,852 (32%)	1,583 (34%)	1,605 (36%)
Rapid	3	3	3	45 (11%)	55 (13%)	31 (8%)	1,007 (18%)	594 (13%)	336 (7%)
Riffles Only	4	4	4	182 (44%)	183 (44%)	181 (44%)	2,497 (44%)	2,247 (48%)	2,269 (50%)
Run	1	1	0	35 (8%)	32 (8%)	0	369 (6%)	285 (6%)	0
Low Gradient Riffle w/ Pockets	0	0	1	0	0	37 (9%)	0	4,709	306 (7%)
Total All Units	12	12		415	415	400	5,725	4,709	4,516

Pebble Counts

In 2010, pebble counts were conducted at 21 transects, a total of 105 substrate particles were measured. In 2011 and 2012, pebble counts were conducted on 17 transects, a total of 85 stream particles were measured. For reporting purposes fines were tabulated as one mm and bedrock was tabulated as 4,000 mm, one mm was added to all measurements and particles sizes are reported as cumulative percent smaller than. In order to compare differences between years the 2010 data is summarized for the lower 400 meters only. Figure 4.2 depicts the control reach particle size distribution in 2010, 2011, and 2012 (lower 400 meters only). Median particle size decreased from 115 mm in 2010 to 100 mm in 2011 (13% decrease). However, median particle size increased to 161 mm in 2012.

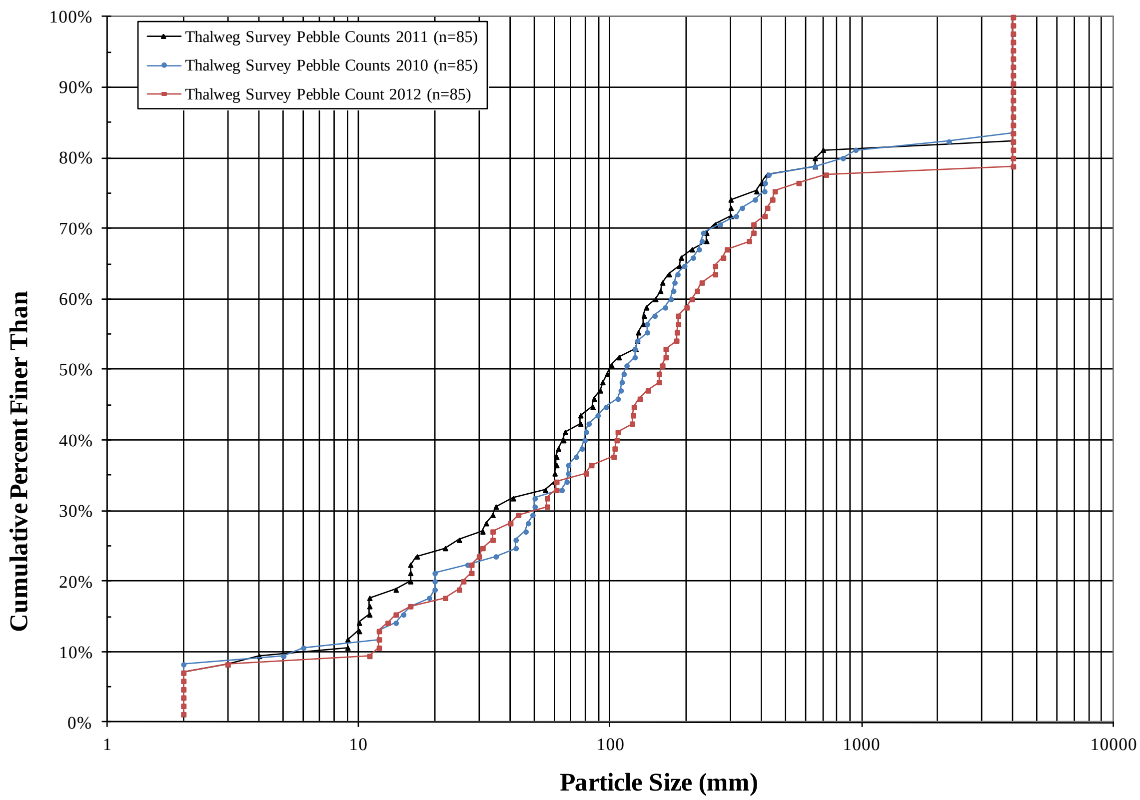

Figure 4.22. Control reach particle size distribution from the 415 meters surveyed in 2010, 2011, and 2012.

4.2.2 LWD Survey Results

2010 Results

A total of only 39 pieces of LWD were identified within the 500 meter reach. Nearly 67 percent of pieces were classified as deciduous and 26 percent were classified as conifer, the remaining pieces were classified as unknown. The 39 pieces inventoried resulted in 2.1 pieces per channel width. Total volume of LWD within the BFW of the control reach equaled only 22.1 m^3. This equates to a volume of 4.42 m^3 per 100 meters of channel length or 0.0017 m^3 per square meter of channel.

In order to compare 2010, 2011, and 2012 data the 2010 data are also summarized based on the lower 400 meters. A total of 33 pieces of LWD were identified within the 400 meter reach. Nearly 73 percent of pieces were classified as deciduous and 22 percent were classified as conifer, and 3 percent were classified as unknown. The 33 pieces inventoried resulted in 2.1 pieces per channel width. Total volume of LWD within the BFW of the lower 400 meters of control reach equaled only 8.7 m^3. This equates to a volume of 2.09 m^3 per 100 meters of channel length or 0.00078 m^3 per square meter of channel.

2011 Results

As described above, only 415 meters of channel were monitored in 2011. A total of only 25 pieces of LWD were identified within the surveyed reach. Sixty-eight percent of the LWD pieces were classified as deciduous and 32 percent were classified as conifer. The 25 LWD pieces result in 1.6 pieces per channel width (based on 2010 BFW measurements). The total volume of LWD within the BFW of the control reach equaled 7.4 m^3. This equates to a volume of 1.8 m^3 per 100 meters of channel length or 0.00067 m^3 per m^2 of channel. Measured LWD volumes were 15% less in 2011 than in 2010 (comparing only the lower 415 meters).

2012 Results

Only 400 meters of channel were monitored in 2012. A total 25 pieces of LWD were indentified within the surveyed reach. Seventy-two percent of the LWD pieces were classified as deciduous and 24 percent were classified as conifer. The 25 LWD pieces result in 1.7 pieces per channel width (based on 2010 BFW measurements). The total volume of LWD within the BFW of the control reach equaled 9.3 m^3. This equates to a volume of 2.3 m^3 per 100 meters of channel length or 0.00087 m^3 per m^2 of channel. Measured LWD volumes were 10% higher in 2012 than in 2010 (comparing only the lower 400 meters).

4.2.3 Channel Profile and Cross-Section Results

A thalweg substrate and water surface elevation profile was run upstream from the downstream end of the control reach (corresponds to the upstream end of impact reach 2). In 2010, water surface and substrate elevations were measured and recorded at 25 meter intervals; elevations were measured at a total of 21 stations. In 2011 and 2012, surface and substrate elevations were measured and recorded at 5 to 15 meter intervals; elevations were measured at a total of 39 stations. Reach level stream gradient was approximately 0.9% in 2010, 2011, and 2012.

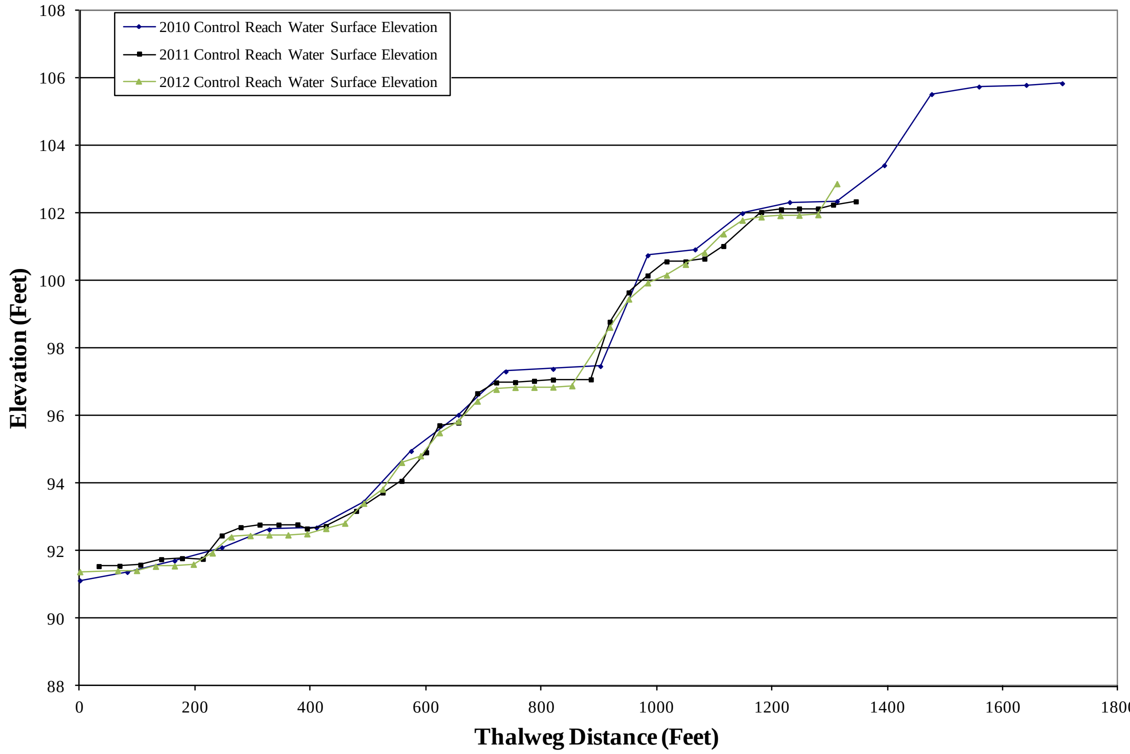

Figure 4.23. Control reach water surface profile for data collected in 2010, 2011, and 2012.

Four long-term monitoring cross-sections were established in the control reach (see Figure 3.4). Annotated cross-section plots for CR-XSEC 1 through 4 are included below, as well as photos looking upstream and downstream from the cross-sections in 2010 and 2012 (see Table 4.16 for reference). Cross-section CR-XSEC 1 is located 0 meters upstream from the start of survey. Cross-section CR-XSEC 2 is located 69 meters (222 ft) upstream from the start of survey. Cross-section CR-XSEC 3 is located 175 meters (572 ft) upstream from the start of survey. Cross-section CR-XSEC 4 is located 349 meters (1,145 ft) upstream from the start of survey. In 2011, one cross-section pin was stolen between surveys (CR-XSEC-1 right pin). This pin was reestablished using the two remaining pins.

The 2010, 2011, and 2012 results from the complete pebble count at CR-XSEC 1 through 4 are included in Figure 4.32 through Figure 4.35. Median average particle size for the four cross-sections averaged 206 mm, 112 mm, and 68 mm in 2010, 2011, and 2012 respectively. The average median particle size at the four cross-sections decreased by approximately 67 percent between 2010 and 2012 (see Table 4.17).

Table 4.16. Summary of control reach cross-section locations and associated figures.

Cross-Section ID	Distance from Downstream End (m)	Cross-Section Plots	Cross-Section Photos	Cross-Section Pebble Counts
CR-XSEC-1	0	Figure 4.24	Figure 4.25	Figure 4.32
CR-XSEC-2	69	Figure 4.26	Figure 4.27	Figure 4.33
CR-XSEC-3	175	Figure 4.28	Figure 4.29	Figure 4.34
CR-XSEC-4	349	Figure 4.30	Figure 4.31	Figure 4.35

Table 4.17. D_{16}, D_{50}, and D_{84} particle size distribution for Morse Creek control reach cross-sections 1 through 4.

Cross-Section ID	Particle Size (mm) D_{16}			Particle Size (mm) D_{50}			Particle Size (mm) D_{84}		
	2010	2011	2012	2010	2011	2012	2010	2011	2012
NC-XSEC-1	36	26	16	173	211	60	4,001	4,001	4,001
NC-XSEC-2	46	31	14	282	77	51	4,001	456	141
NC-XSEC-3	44	20	18	250	97	49	4,001	453	311
NC-XSEC-4	49	31	46	119	64	112	213	196	201
Average	44	27	24	206	112	68	3,054	1,277	1,163

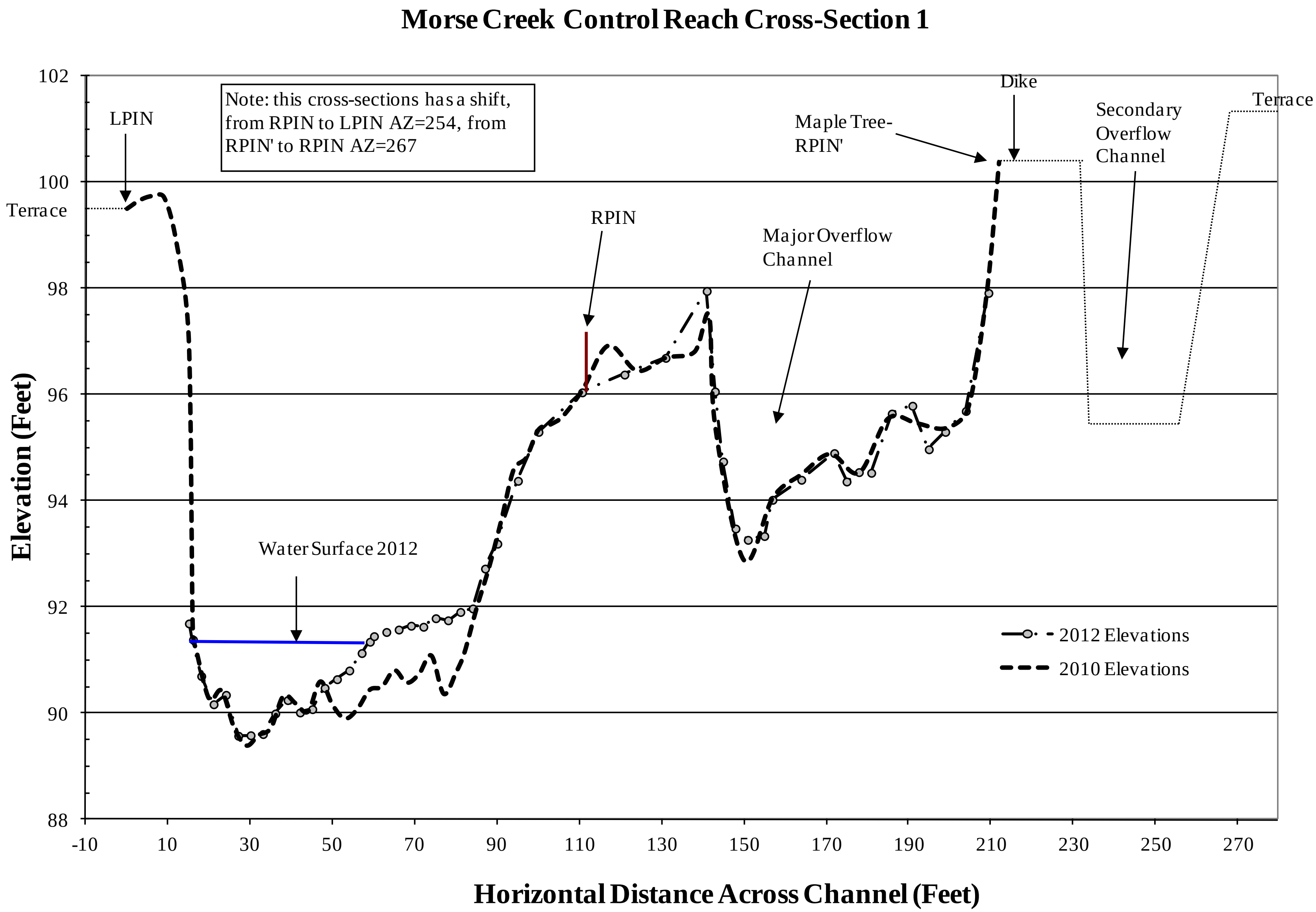

Figure 4.24. Morse Creek Control Reach Cross-Section 1 in 2010 and 2012.

Figure 4.25. Photos from Cross-Section CR-1 looking downstream (above) and upstream (below) in 2010 (left) and 2012 (right).

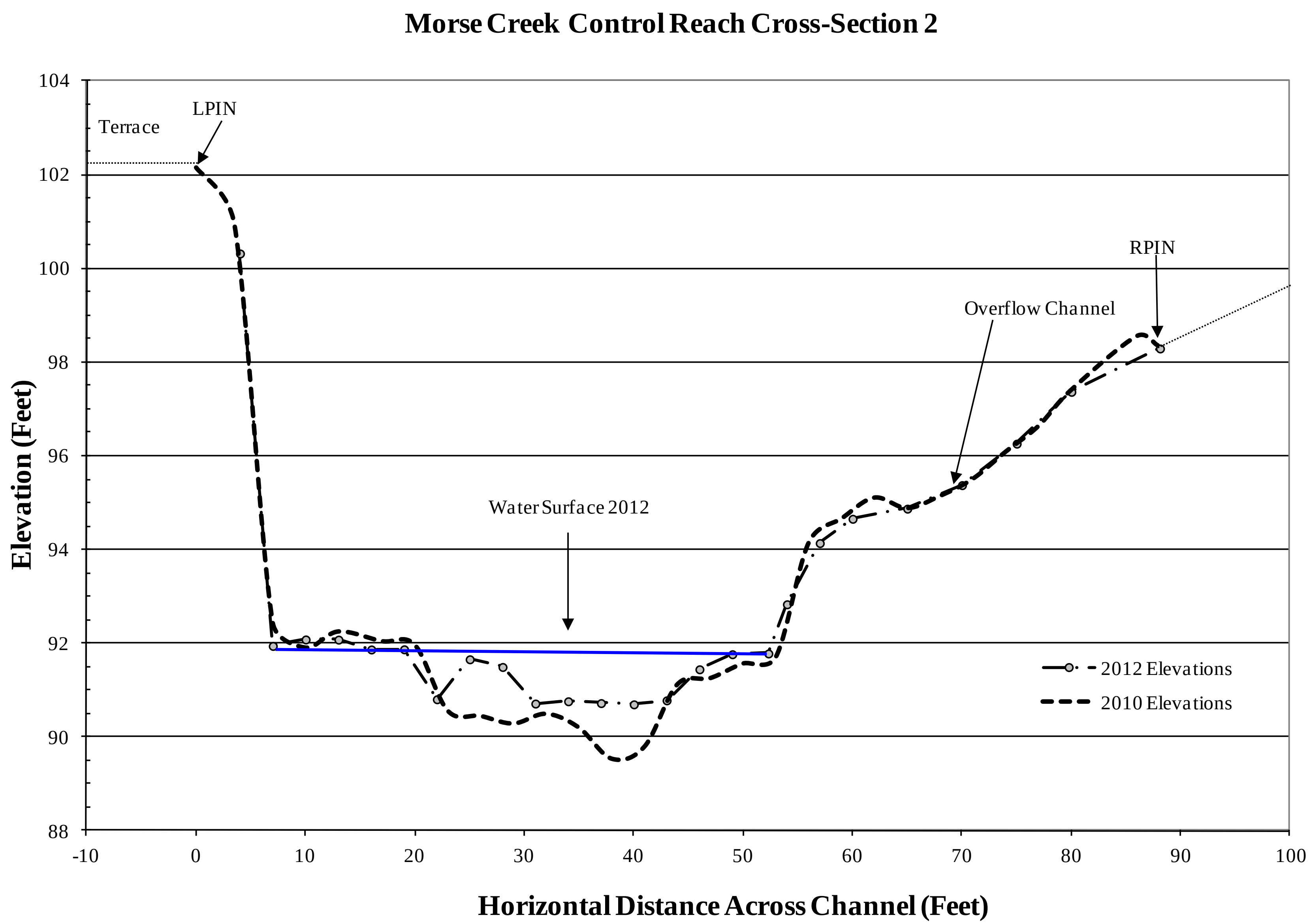

Figure 4.26. Morse Creek Control Reach Cross-Section 2 in 2010 and 2012.

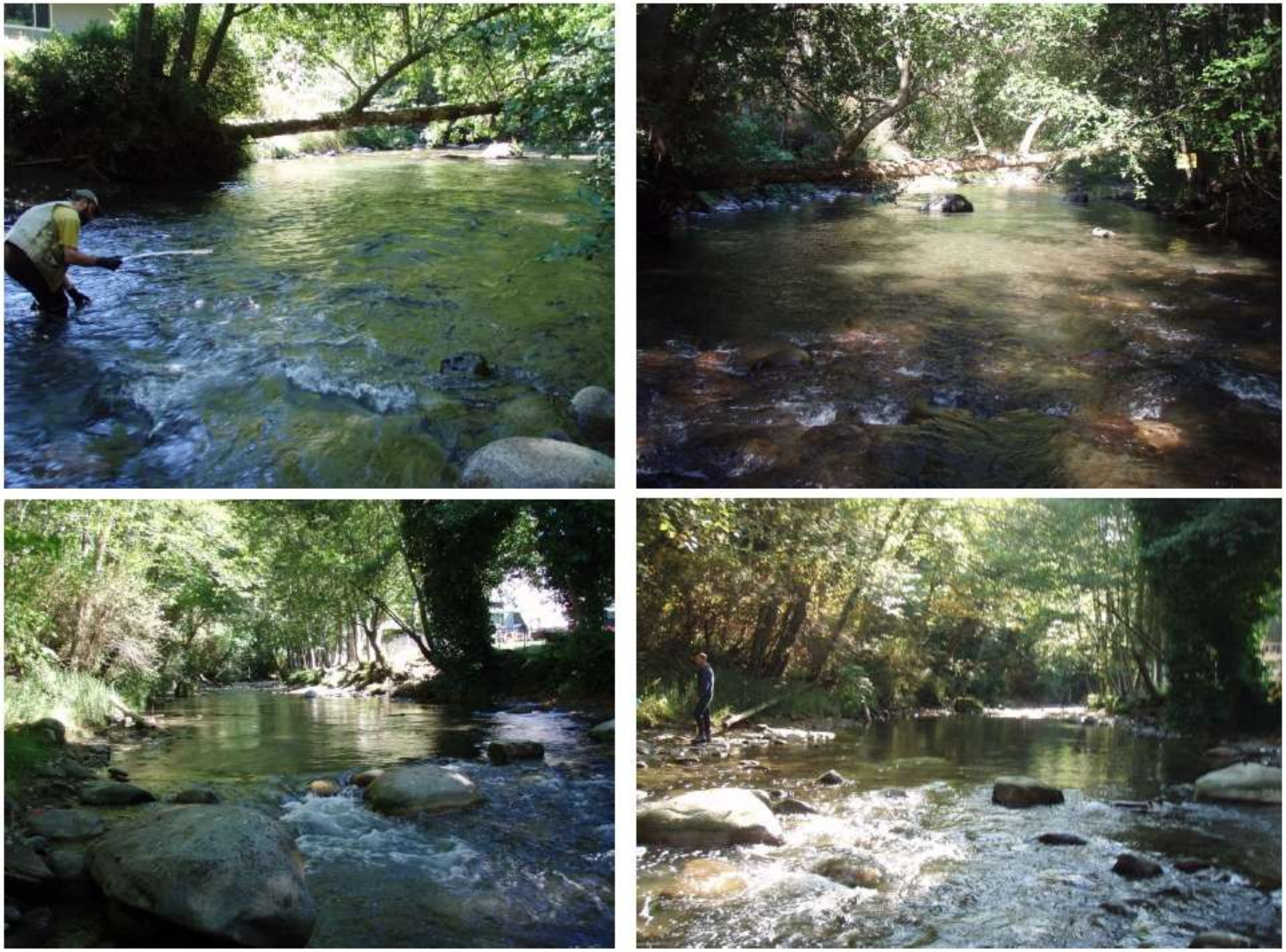

Figure 4.27. Photos from Cross-Section CR-2 looking downstream (above) and upstream (below) in 2010 (left) and 2012 (right).

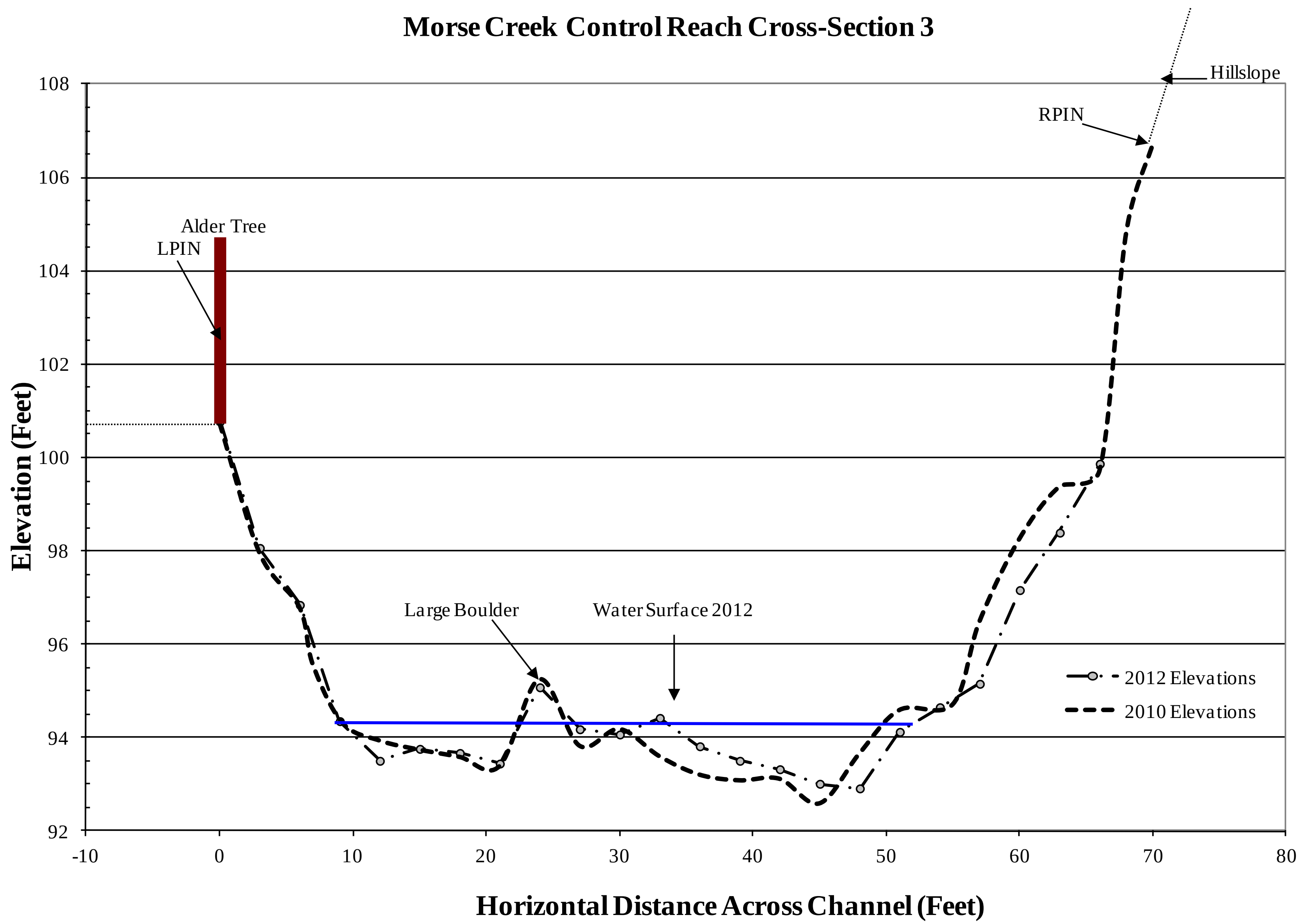

Figure 4.28. Morse Creek Control Reach Cross-Section 3 in 2010 and 2012.

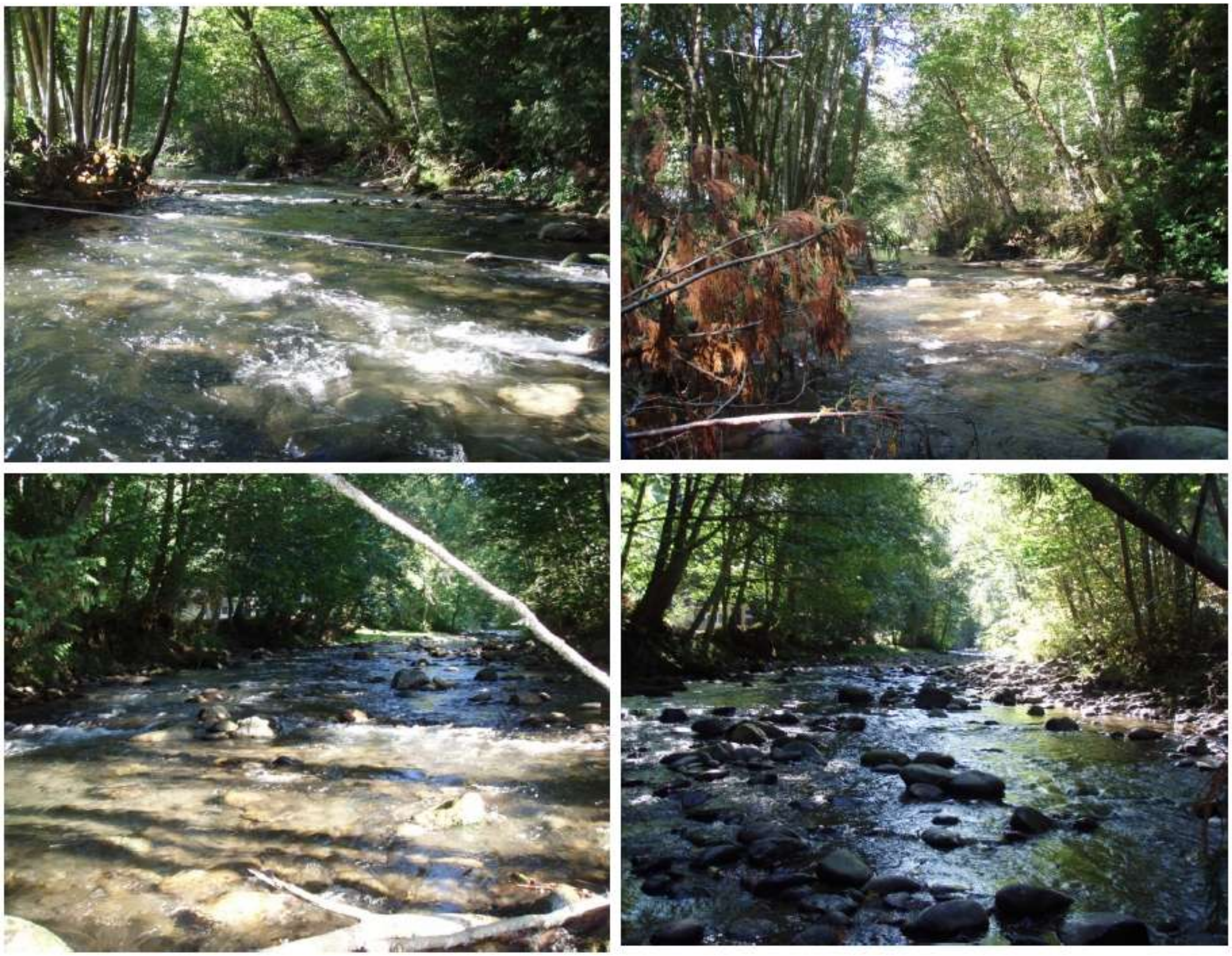

Figure 4.29. Photos from Cross-Section CR-3 looking downstream (above) and upstream (below) in 2010 (left) and 2012 (right).

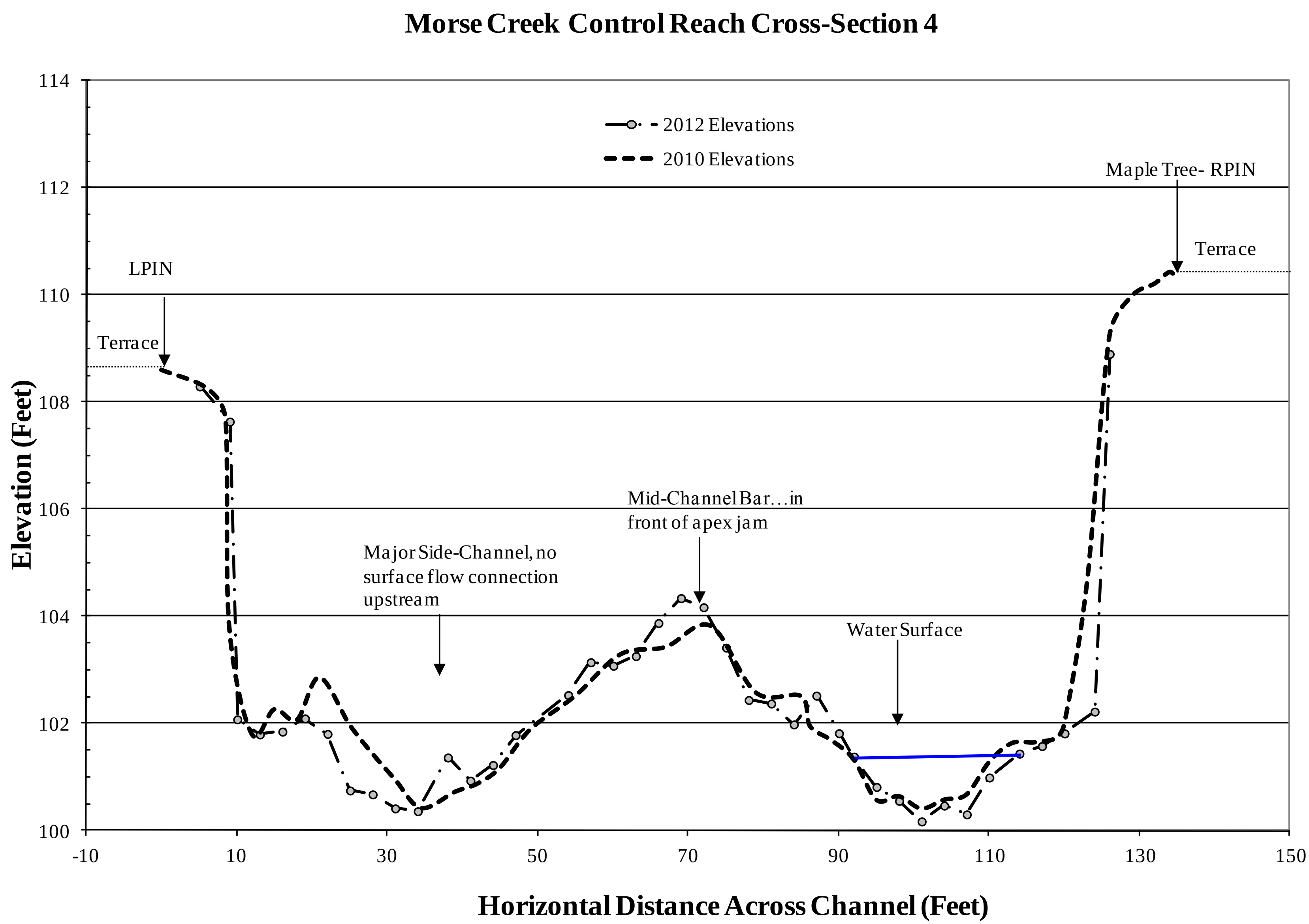

Figure 4.30. Morse Creek Control Reach Cross-Section 4 in 2010 and 2012.

Figure 4.31. Photos from Cross-Section CR-4 looking downstream (above) and upstream (below) in 2010 (left) and 2011 (right).

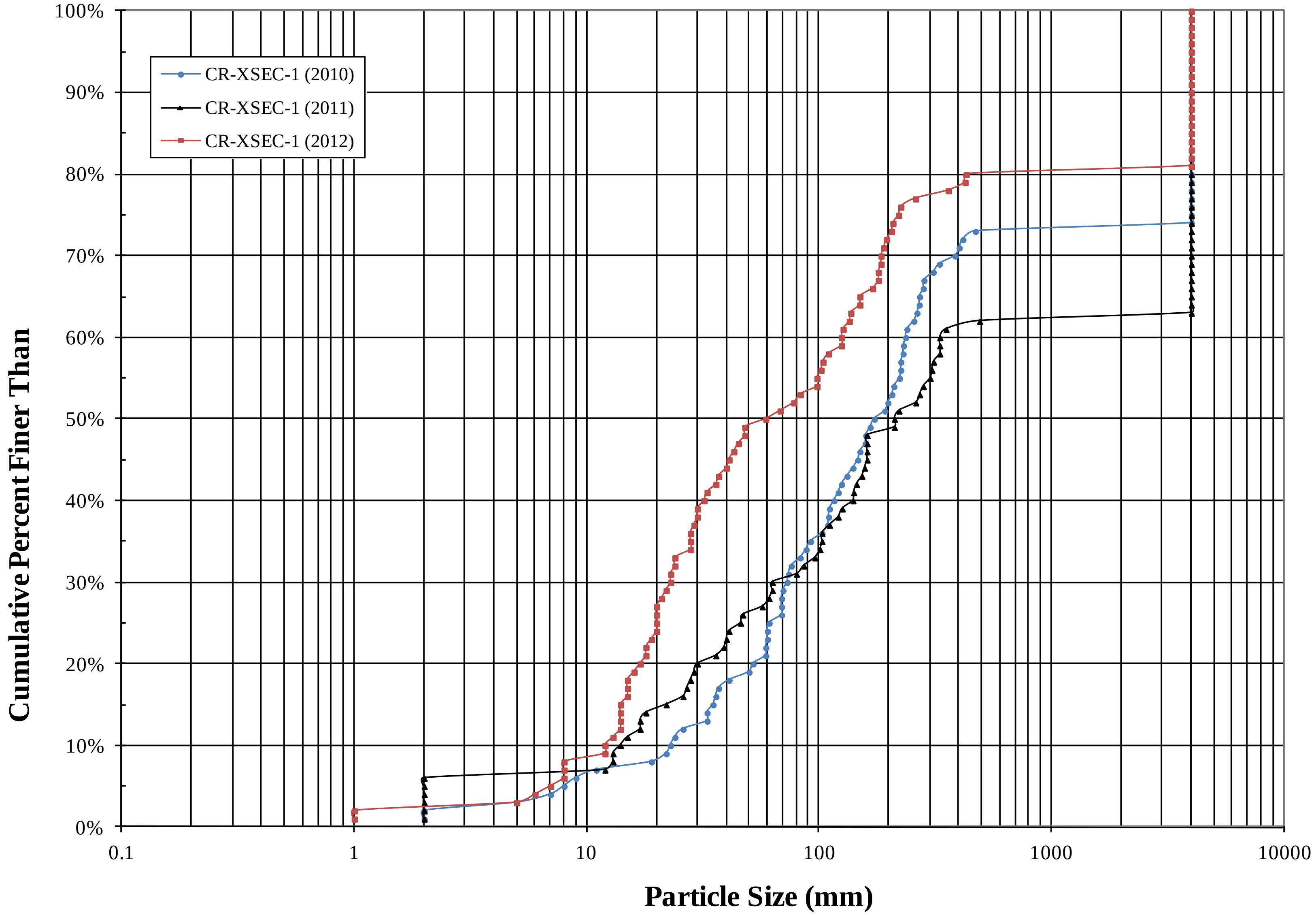

Figure 4.32. 2010, 2011, and 2012 pebble counts from Cross-Section Control Reach X-Section 1.

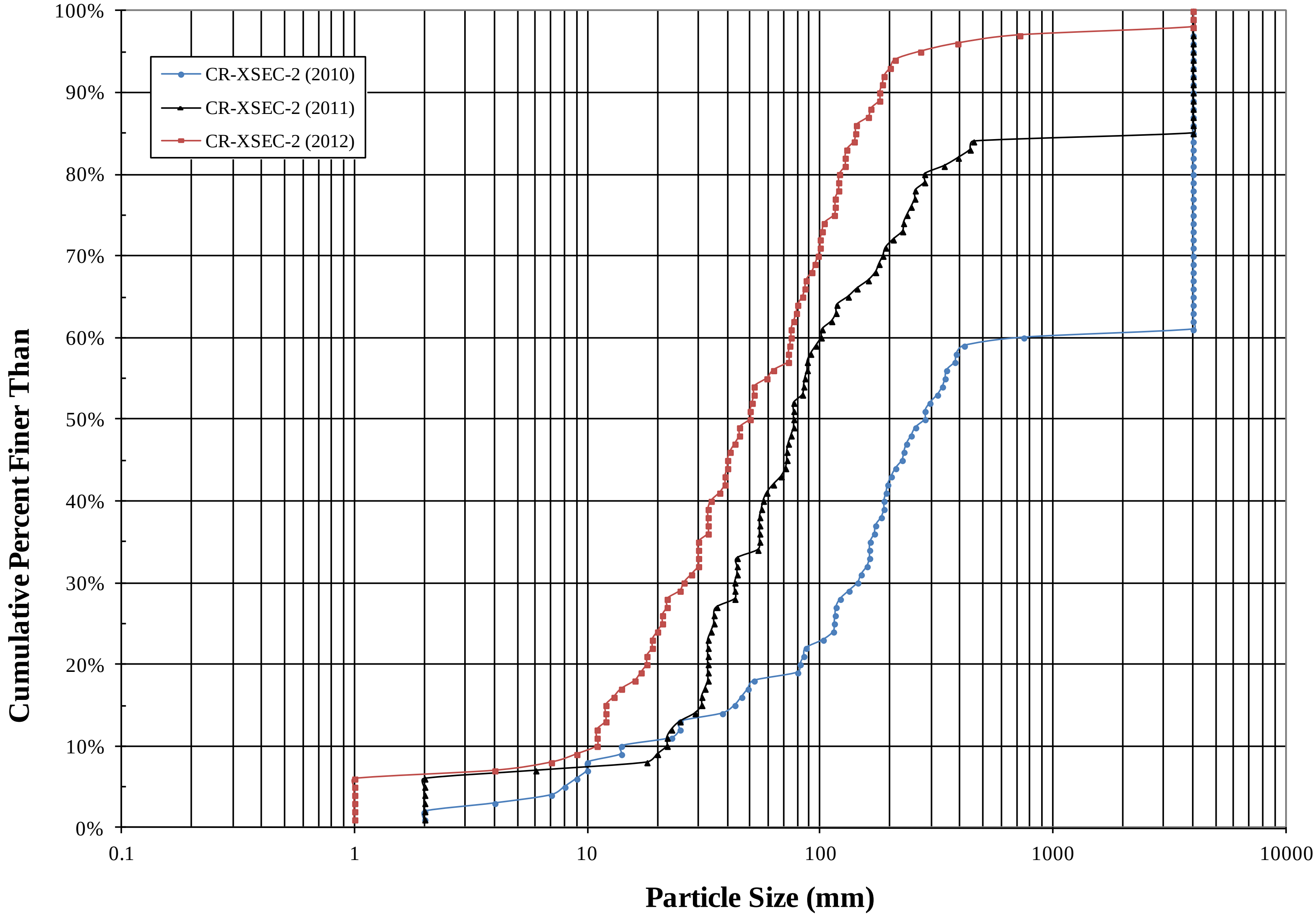

Figure 4.33. 2010, 2011, and 2012 pebble counts from Cross-Section Control Reach X-Section 2.

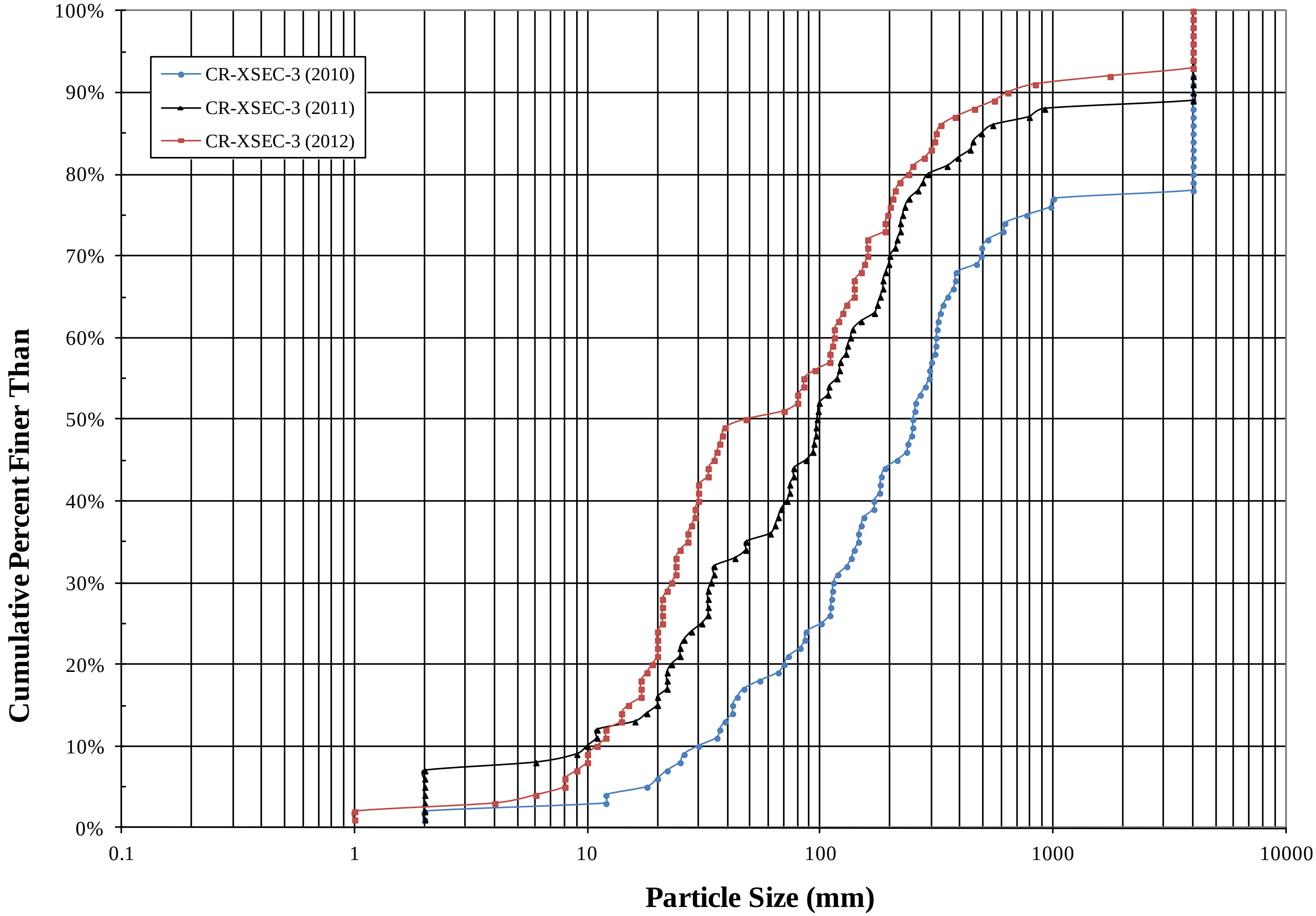

Figure 4.34. 2010, 2011, and 2012 pebble counts from Cross-Section Control Reach X-Section 3.

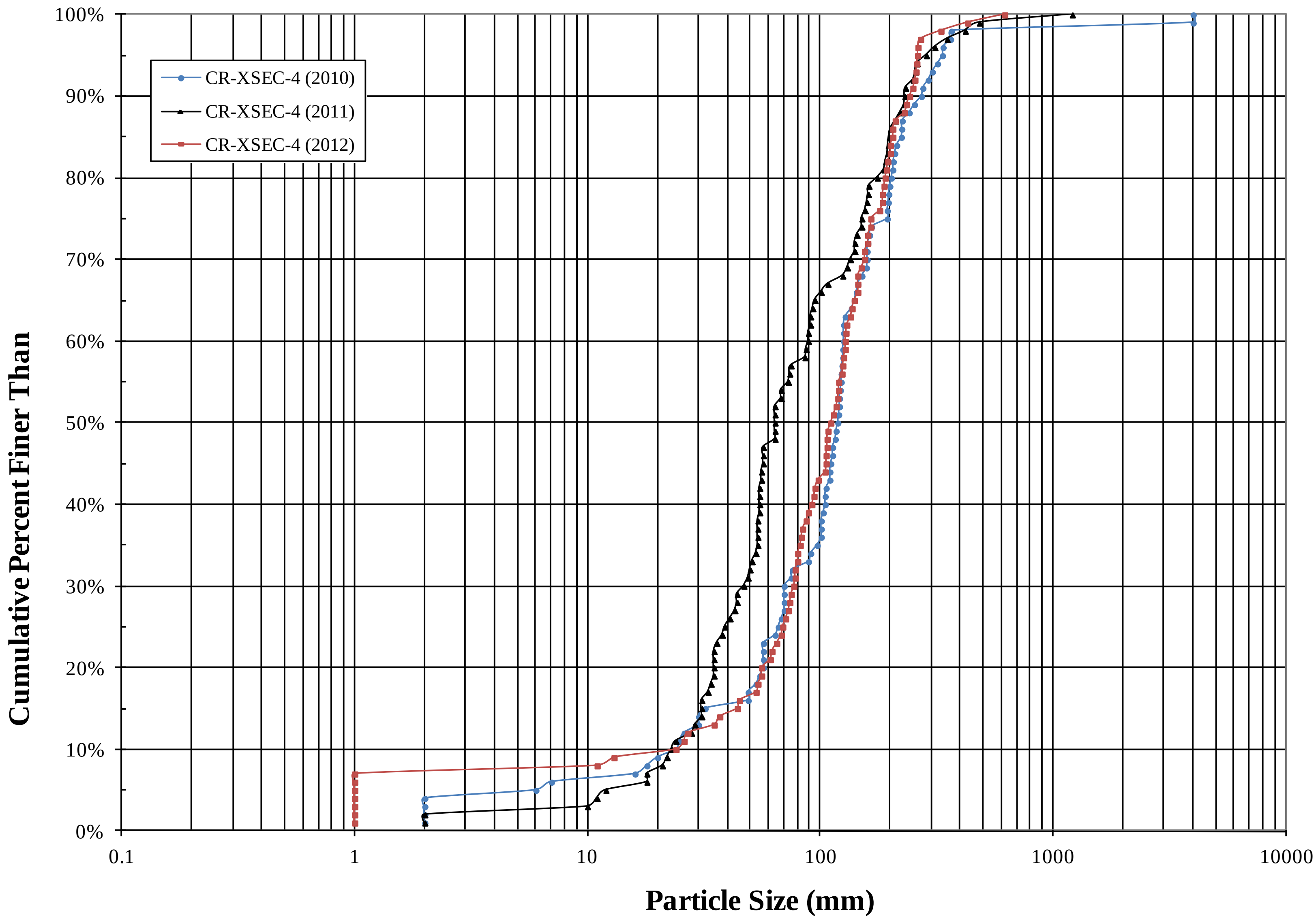

Figure 4.35. 2010, 2011, and 2012 pebble counts from Cross-Section Control Reach X-Section 4.

4.2.4 Snorkel Survey Results

A 127 meter stream segment was snorkel surveyed on August 16, 2010 (DOE gage below aqueduct 48.7 cfs), September 19, 2011 (DOE gage below aqueduct 42.1 cfs), and September 13, 2012 (DOE gage below aqueduct 36.2 cfs). This stream segment contained three primary habitat units and one secondary habitat unit. There were three habitat types sampled in this segment: two pools, a riffle, and a short rapid (classified as a high gradient riffle [HGR] in 2012). A summary of habitat units surveyed is included below in Table 4.18.

Table 4.18. Summary of 2010, 2011, and 2012 habitat unit IDs and habitat types for control reach snorkel surveys.

Habitat Type	**Length (m)**			**Wetted Width (m)**			**Surface Area (m^2)**		
	2010	2011	2012	2010	2011	2012	2010	2011	2012
Riffle	65	65	62	14	13.2	12.7	913	856	678
Pool (subunit)	18.4	18.4	15.5	5.5	5	6.9	100	92	106
Rapid (HGR in 2012)	13	14	14.5	12.6	11.9	11.7	164	167	169
Pool	49	48	49.5	11.5	11.3	11.1	565	540	551
TOTALS	127	127	126	-	-	-	1,743	1,656	1,505

In 2010, a total of 609 salmonids were observed in 1,743 square meters surveyed; yielding a total salmonid density of 0.35 salmonids/m^2. In 2011, a total of 556 salmonids were observed in 1,656 square meters surveyed; yielding a total salmonid density of 0.34 salmonids/m^2. In 2012, a total of 276 salmonids were observed in 1,505 square meters surveyed; yielding a total salmonid density of 0.18 salmonids/m^2. Total salmonids observed decreased by 54 percent in 2012 as compared to 2010; total salmonid densities decreased by 49 percent over the same period. However, coho densities remained similar in all three years averaging 0.08 coho/m^2. In 2012, total trout density decreased by 62 percent compared to the average in 2010 and 2011.

4.19. Habitat unit level summary of 2010, 2011, and 2012 salmonid densities in the control reach.

Habitat Type	Total Salmonids per m^2			Coho (Age 0+ and 1+) per m^2			Total Trout per m^2			Age 1+ and 2+ Trout per m^2		
	2010	2011	2012	2010	2011	2012	2010	2011	2012	2010	2011	2012
Riffle	0.25	0.20	0.12	0.03	0.05	0.05	0.22	0.15	0.06	0.04	0.01	0.00
Pool (subunit)	0.92	1.20	0.63	0.44	0.28	0.50	0.47	0.91	0.13	0.11	0.18	0.04
Rapid (HGR 2012)	0.12	0.12	0.08	0.00	0.00	0.00	0.12	0.12	0.08	0.04	0.03	0.05
Pool	0.48	0.47	0.21	0.14	0.07	0.05	0.34	0.40	0.15	0.05	0.03	0.04
AVERAGE	0.35	0.34	0.18	0.09	0.07	0.08	0.26	0.27	0.10	0.05	0.03	0.02

4.3 Abandoned Channel Reach

4.3.1 Channel Thalweg and Habitat Survey Results

Channel Characteristics

The baseline thalweg and habitat surveys were conducted August 6 and 7, 2010 (prior to abandoning the channel; DOE stream flow below aqueduct-65 cfs) and first-year post-project surveys were conducted on October 13, 2011 (DOE stream flow below aqueduct- 56.2 cfs). In 2010, the total length surveyed was 364 meters. Stream gradient was measured at 17.5 meter (intervals, a total of 20 measurements were made. Bankfull width measurements were made at 11 observation points. Wetted width and thalweg depth measurements were made at 105 observation points.

In 2011, the total length surveyed was 225 meters; the remainder of the channel was either dry or backfilled and plugged to divert the stream into the new channel reach. Stream gradient was measured at 10 to 15 meter intervals, 23 measurements were made. Wetted width and thalweg depth measurements were made at 45 observation points. The abandoned channel's streamflow now comes from hyporheic flow through the channel plug and groundwater inputs.

In 2012, the total length surveyed was 240 meters and ended at the base of the backfilled channel. Stream gradient was measured at 10 to 15 meter intervals, 24 measurements were made. Wetted width and thalweg depth measurements were made at 65 observation points. A summary of the 2010, 2011, and 2012 results is included below in Table 4.20.

Table 4.20. Abandoned channel reach summary of measured gradient, wetted width, and thalweg depth for 2010, 2011, and 2012.

Measurement Range	BFW (M)	Gradient			Wetted Width (M)			Thalweg Depth meters		
	2010 n=11	2010 n=20	2011 n=23	2010 n=24	2010 n=105	2011 n=44	2012 n=65	2010 n=105	2011 n=44	2012 n=65
Maximum	29.7	NA	NA	NA	21.4	10.5	10.8	1.2	0.71	1.03
Minimum	18.7	NA	NA	NA	6.4	1.0	1.1	0.25	0.04	0.03
Average	23.7	1.00%	0.79%	0.71%	13.9	4.5	4.3	0.65	0.22	0.19

Riparian Characteristics

In 2010, a total of 44 thalweg canopy closure measurements were made at 11 observation points. Average canopy closure ranged from 14 to 95 percent. Reach level canopy closure averaged 63 percent. Observation point 1 had been disturbed (construction of new stream reach), excluding this point, reach level canopy closure averaged 68 percent. In 2011, a total of 16 thalweg canopy closure measurements were made at four observation points. Average canopy closure ranged from 79 to 98 percent. Reach level canopy closure averaged 91%.

In 2012, a total of 28 thalweg canopy closure measurements were made at seven observation points. Average canopy closure ranged from 20 to 97 percent. Reach level canopy closure averaged 67%. Differences between reach level average canopy closure between years is likely attributable to sites sampled in 2012. Riparian stand conditions along the right bank are deciduous, small, dense (see Section 3.1 for definitions). The road and road prism occupy much of the potential riparian area along the left bank. The construction of the plug resulted in lower canopy closure values at the top end of the reach.

Habitat Units

Habitat unit data were only collected in 2010. A total of 15 habitat units were delineated in this stream reach. Eight different habitat types were classified, these included: a low gradient riffle (1), low gradient riffles w/pockets (3), high gradient riffles (3), rapids (3), a cascade (1), a lateral scour pool (1), a bedrock pool (1), and runs (2). These units were later grouped together into four categories: riffles (all riffle types), rapids (including cascades), pools (all types), and runs. Table 4.21 depicts the habitat unit breakdown including percentage of habitat by length and area.

Table 4.21. Summary of 2010 habitat unit data for the abandoned channel reach.

Unit Type	Number of Units	Total Primary Unit Length (Meters)	Percent (length)	Total Unit Surface Area	Percent (area)
Pool	2	70	19%	758	15%
Rapid	4	84	23%	1,161	23%
Riffle	7	175	48%	2,711	54%
Run	2	35	10%	425	8%
Primary Totals	**15**	**364**	**-**	**5,055**	**-**

Pebble Counts

In 2010, pebble counts were conducted at 21 transects, and a total of 105 stream particles were measured. In 2011, pebble counts were conducted at 9 transects, and a total of 45 stream particles were measured. In 2012, pebble counts were conducted at 12 transects, and a total of 60 stream particles were measured. For reporting purposes, fines were tabulated as one mm and bedrock was tabulated as 4,000 mm, one mm was added to all measurements and particle sizes are reported as cumulative percent smaller than. Figure 4.36 depicts the abandoned channel reach particle size distribution in 2010, 2011, and 2012.

4.3.2 LWD Survey Results

Large woody debris surveys were only conducted in 2010. A total of 10 pieces of LWD were identified within the reach. This resulted in 0.65 pieces per channel width. Total volume of LWD within the BFW of this channel reach was 6.3 m^3. This equates to a volume of 1.7 m^3 per 100 meters of channel or 0.0007 m^3 per square meter of channel. No LWD surveys were conducted in 2011 and 2012.

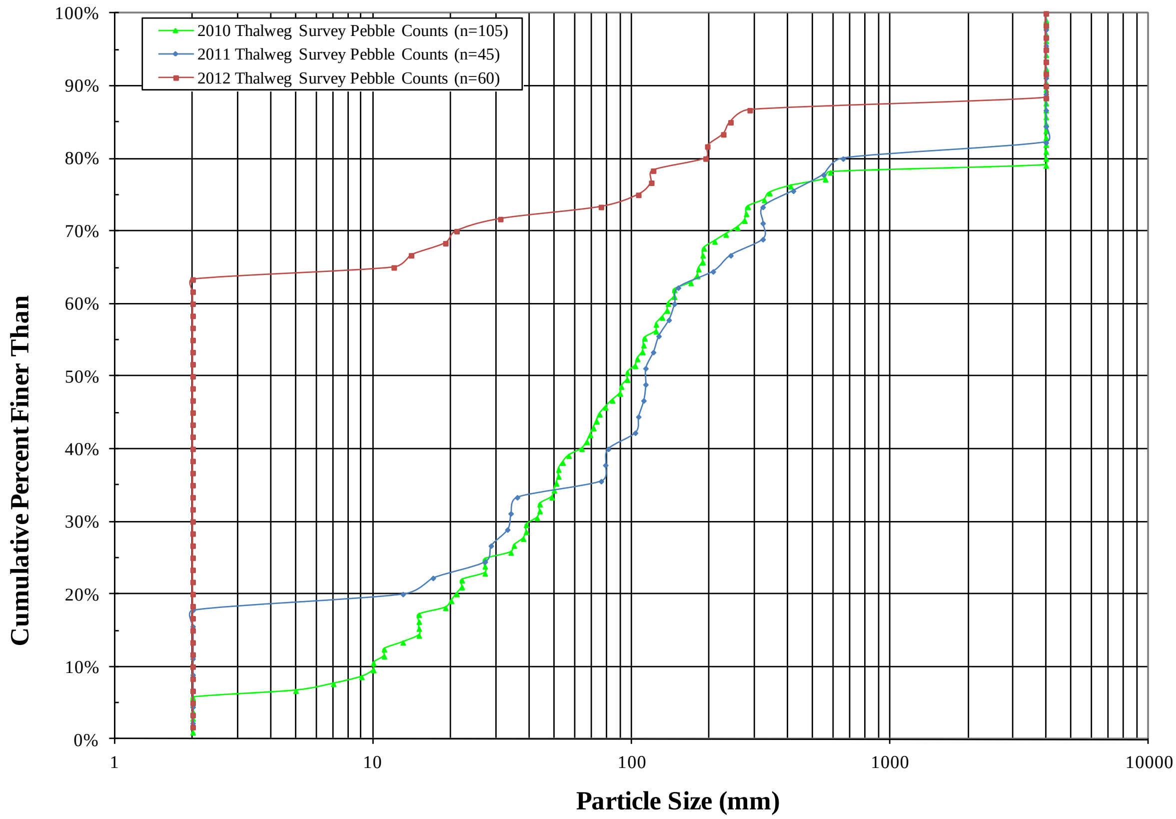

Figure 4.36. Abandoned channel reach particle size distribution in 2010, 2011, and 2012.

4.3.3 Channel Profile and Cross-Section Results

A thalweg substrate and water surface elevation profile was run upstream from the downstream end of the abandoned channel reach (corresponds to the top of impact reach one and bottom end of the new channel reach). In 2010, water surface and substrate elevations were measured and recorded at 17.5 meter increments. Elevations were measured at a total of 21 stations. In 2010, the water surface gradients between stations ranged from 0.1 percent to 3.9 percent, averaging 1.0 percent.

In 2011, the total length surveyed was 225 meters; the remainder of the channel was backfilled and plugged to divert the stream into the new channel reach. Stream gradient was measured at 10 to 15 meter intervals, 23 measurements were made. In 2011, the water surface gradients between stations ranged from less than 0.1 percent to 7.03 percent, averaging 0.76 percent.

In 2012, a total length of 240 meters was surveyed. Stream gradient was measured at 10 to 15 meter intervals, 24 measurements were made. The water surface and substrate profile for this reach is depicted in Figure 4.37.

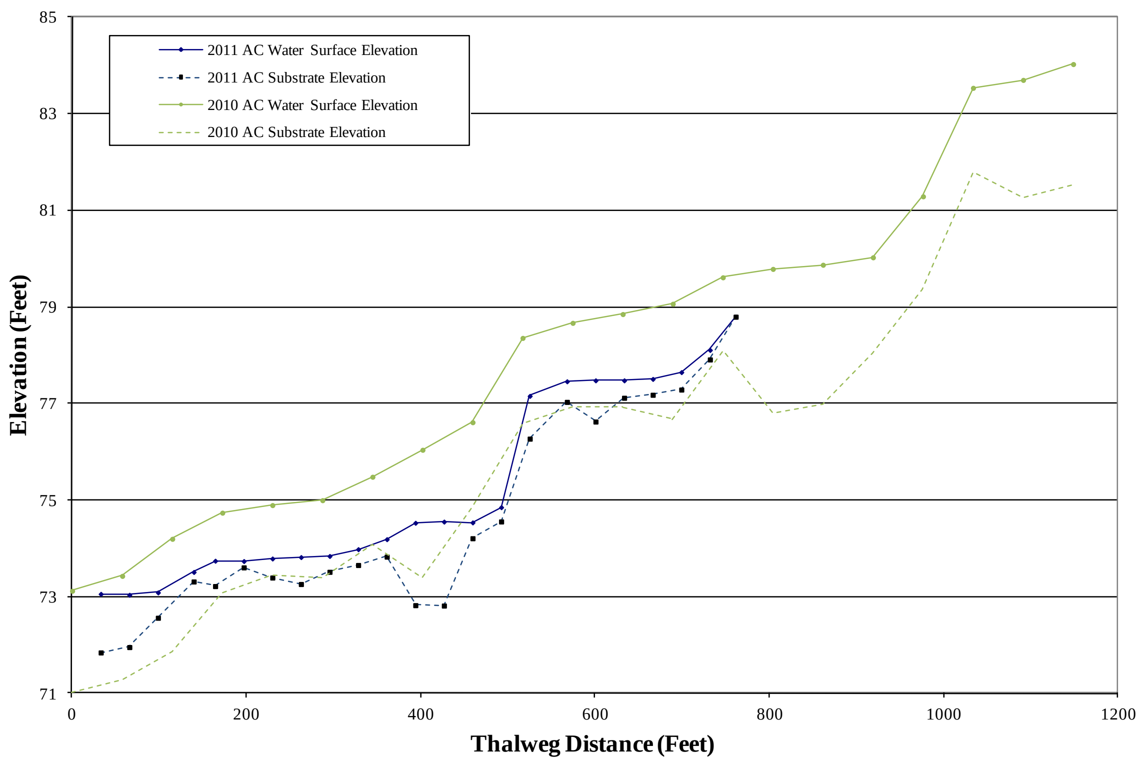

Figure 4.37. Abandoned channel reach thalweg water surface and substrate profile for data collected in 2010 and 2011.

Three long-term monitoring cross-sections were established in the abandoned channel reach (see Figure 3.4). Annotated cross-section plots for AC-XSEC 1 through 3 are included below, as well as photos looking upstream and downstream from the cross-sections in 2010 and 2012 (see Table 4.22 for reference). Cross-section AC-XSEC 1 is located 62 meters (203 ft) upstream from the start of survey. Cross-section AC-XSEC 2 is located 114 meters (374 ft) upstream from the start of survey. Cross-section AC-XSEC 3 is located 167 meters (546 ft) upstream from the start of survey. In 2011, two cross-section pins were vandalized and/or stolen between surveys (AC-XSEC-2 left pin and AC-XSEC-3 left pin); these pins were reestablished using the remaining pins. Also, note reference elevation tags at AC-XSEC-3 were also vandalized. In 2012, one pin was stolen; this pin was reestablished using right bank pin and a hole in the tree from which the pin was stolen.

The 2010, 2011, and 2012 results from the complete pebble count at AC-XSEC 1 through 3 are included in Figure 4.44 through Figure 4.46. The D16, D50, and D84 particle size measurements for each cross-section are included in Table 4.23. .

Table 4.22. Summary of abandoned channel reach cross-section locations and associated figures.

Cross-Section ID	Distance from Downstream End (m)	Cross-Section Plots	Cross-Section Photos	Cross-Section Pebble Counts
AC-XSEC-1	62	Figure 4.38	Figure 4.39	Figure 4.44
AC-XSEC-2	114	Figure 4.40	Figure 4.41	Figure 4.45
AC-XSEC-3	167	Figure 4.42	Figure 4.43	Figure 4.46

Table 4.23. D_{16}, D_{50}, and D_{84} particle size distribution for Morse Creek abandoned channel reach cross-sections 1 through 3.

Cross-Section ID	Particle Size (mm) D_{16}			Particle Size (mm) D_{50}			Particle Size (mm) D_{84}		
	2010	2011	2012	2010	2011	2012	2010	2011	2012
AC-XSEC-1	19	9	2	52	41	11	145	4,001	131
AC-XSEC-2	31	18	19	143	136	111	4,001	4,001	261
AC-XSEC-3	21	NA	21	90	NA	79	176	NA	200
Average	24	14	14	95	89	67	1,441	4,001	197

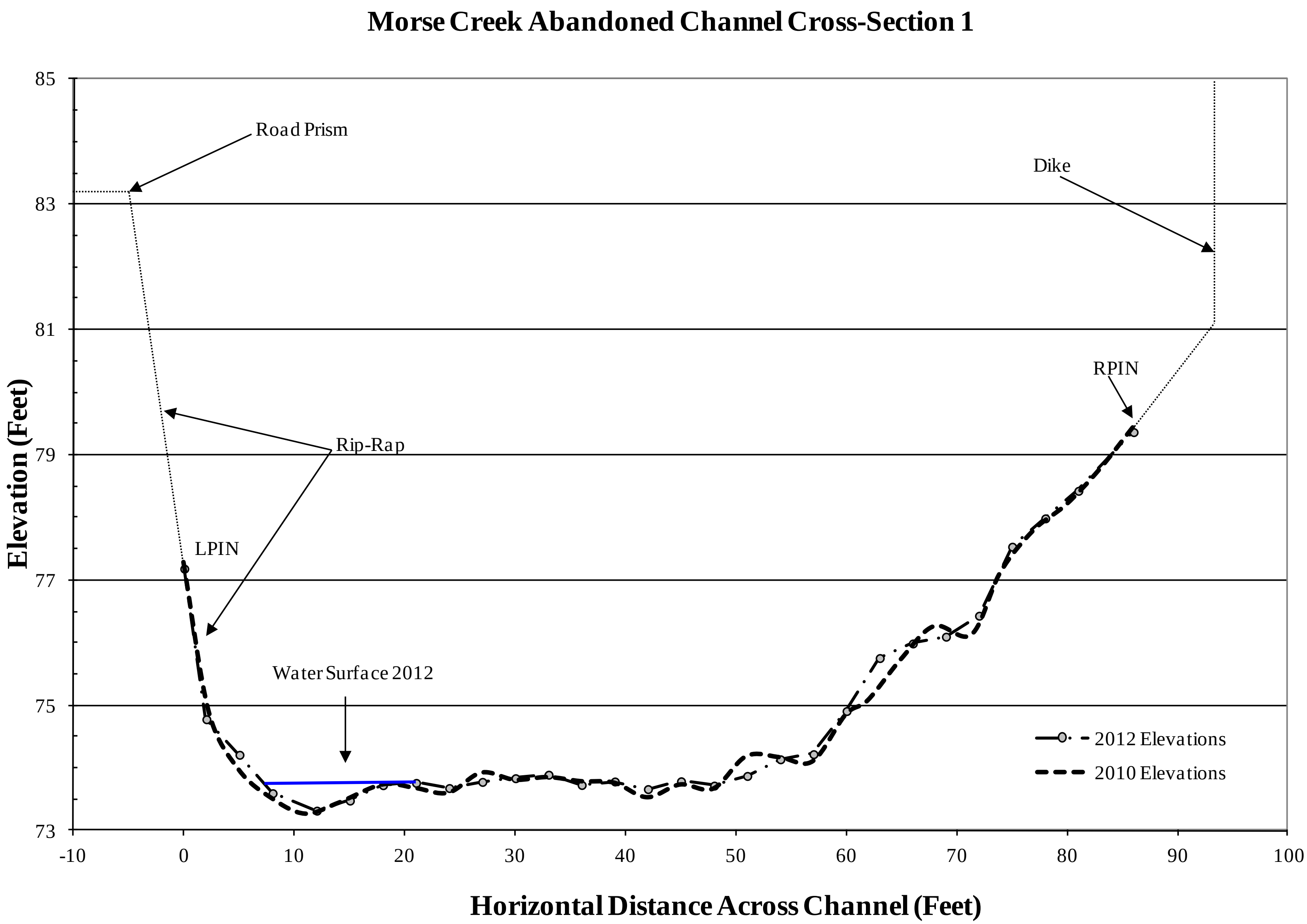

Figure 4.38. Morse Creek Abandoned Channel Reach Cross-Section 1 in 2010 and 2012.

Figure 4.39. Photos from Cross-Section AC-1 looking downstream (above) and upstream (below) in 2010 (left) and 2012 (right).

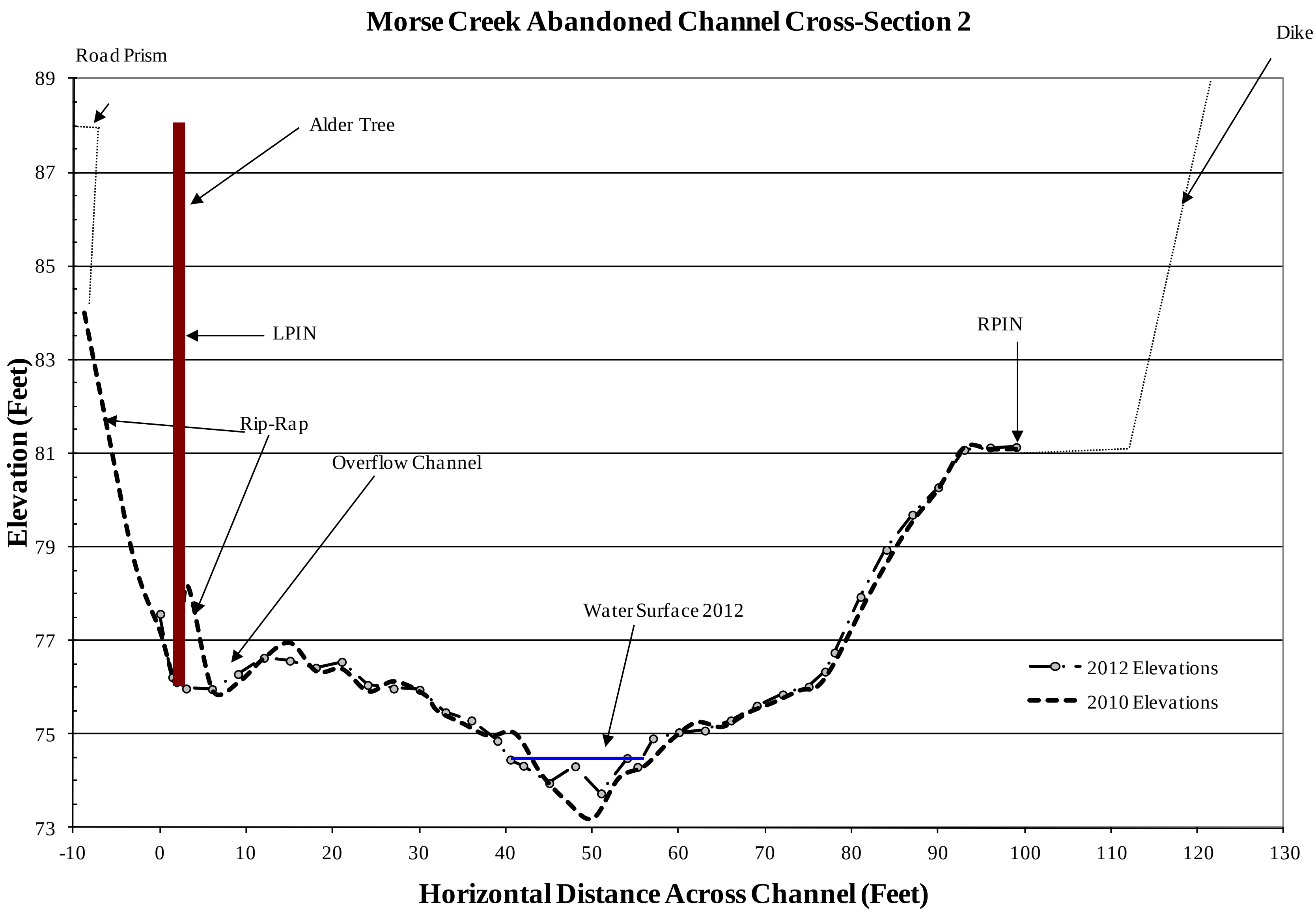

Figure 4.40. Morse Creek Abandoned Channel Reach Cross-Section 2 in 2010 and 2012.

Figure 4.41. Photos from Cross-Section AC-2 looking downstream (above) and upstream (below) in 2010 (left) and 2012 (right).

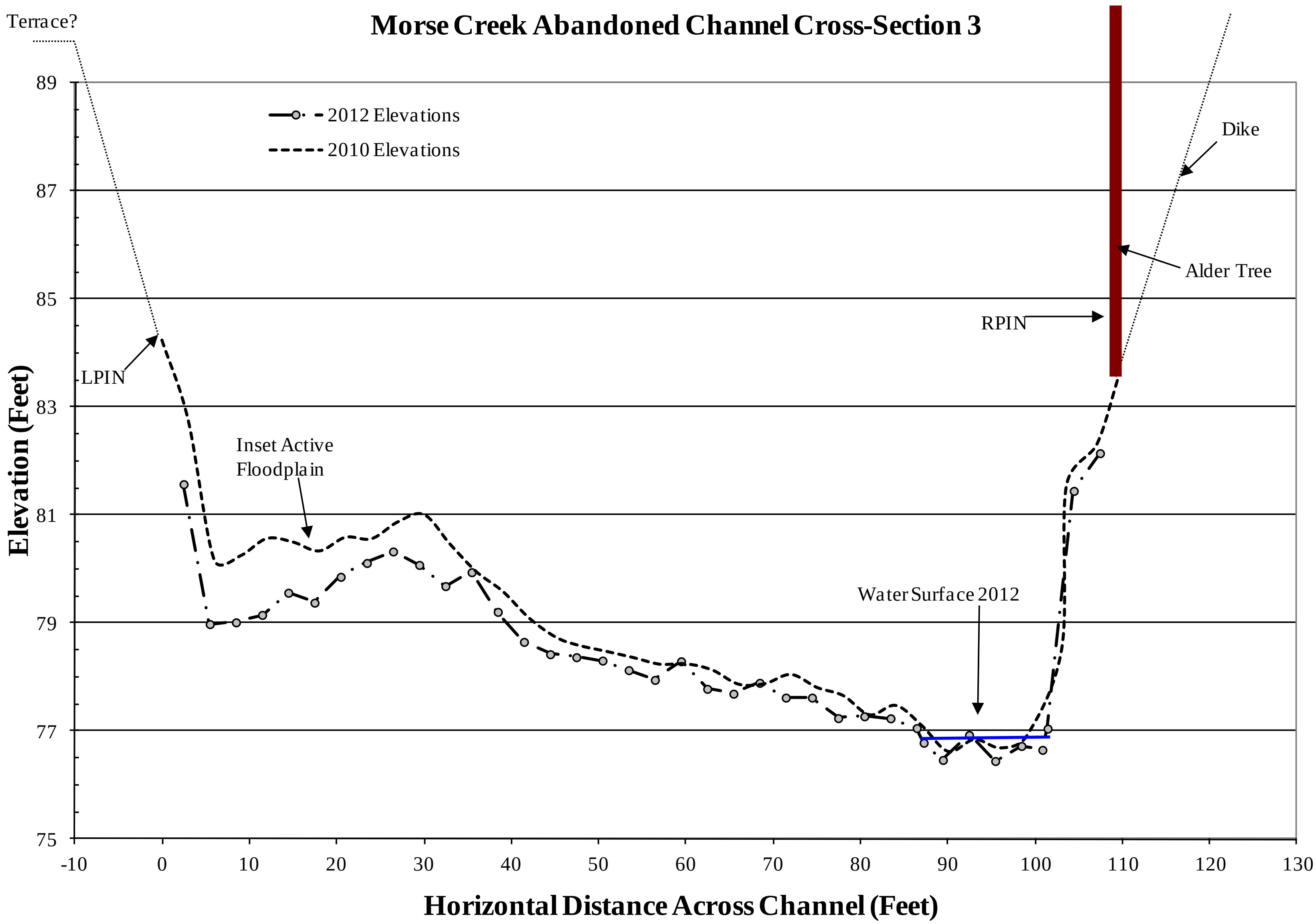

Figure 4.42. Morse Creek Abandoned Channel Reach Cross-Section 3 in 2010 and 2012.

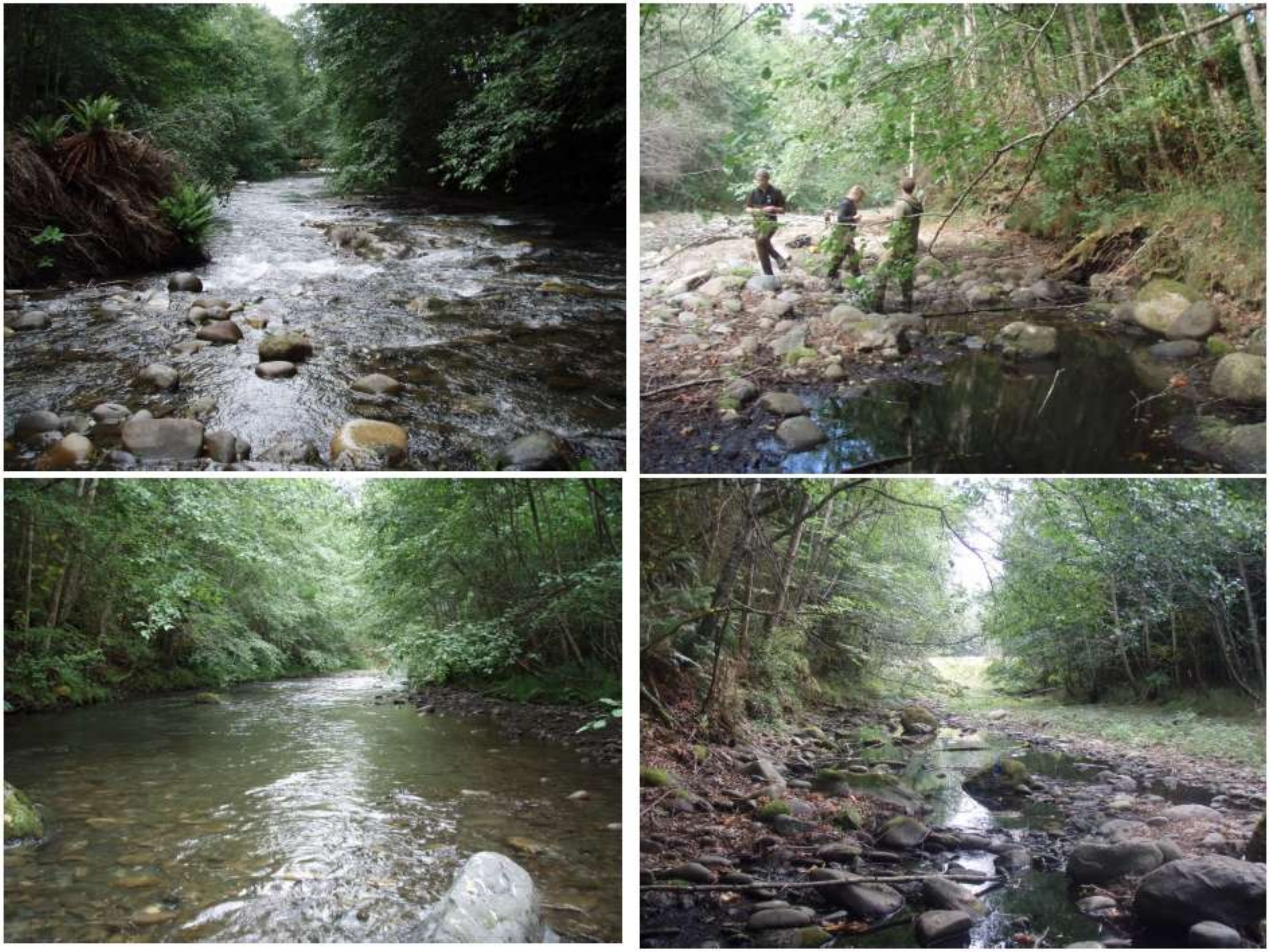

Figure 4.43. Photos from Cross-Section AC-3 looking downstream (above) and upstream (below) in 2010 (left) and 2012 (right).

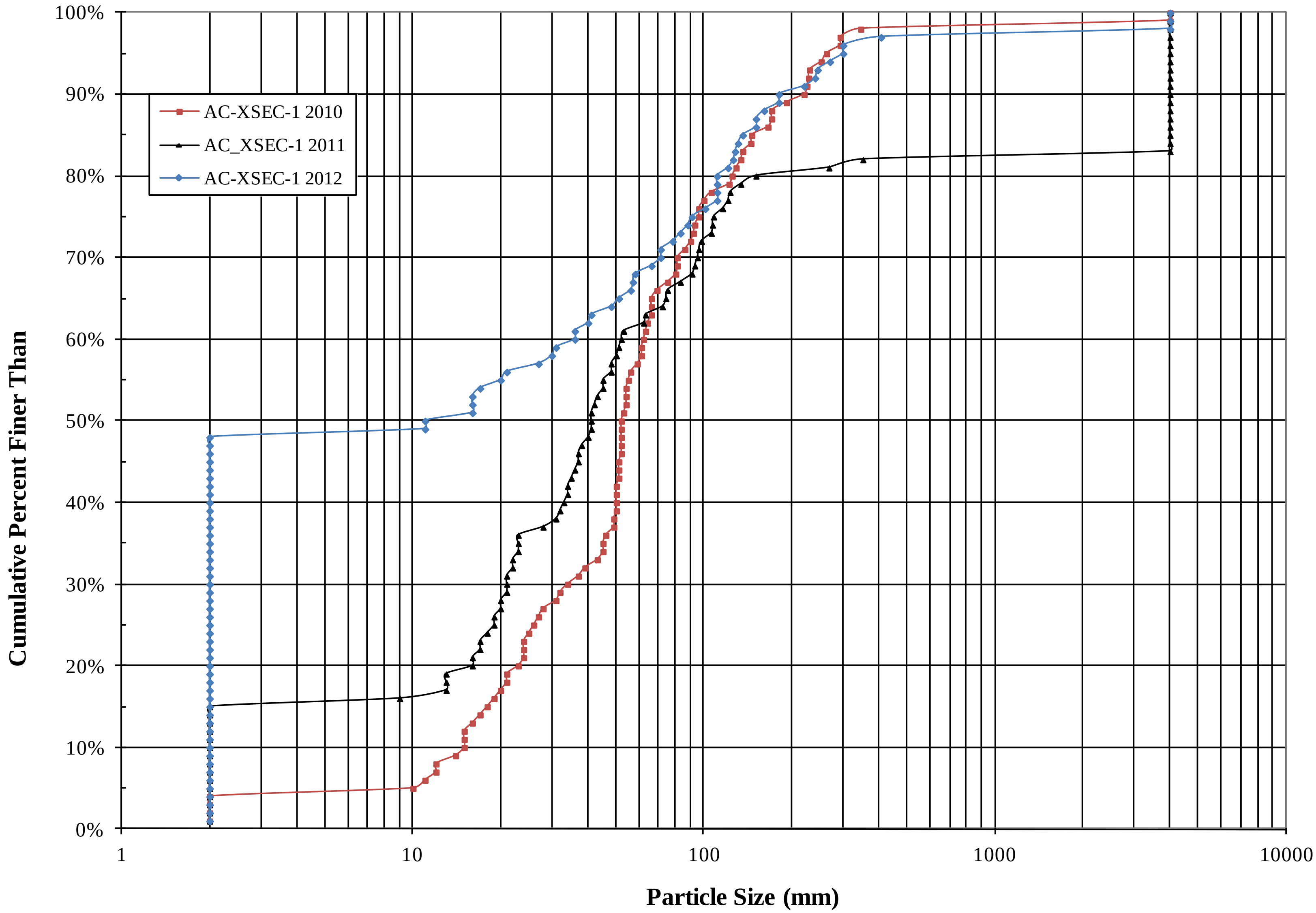

Figure 4.44. 2010, 2011, and 2012 pebble counts from Cross-Sections AC-1.

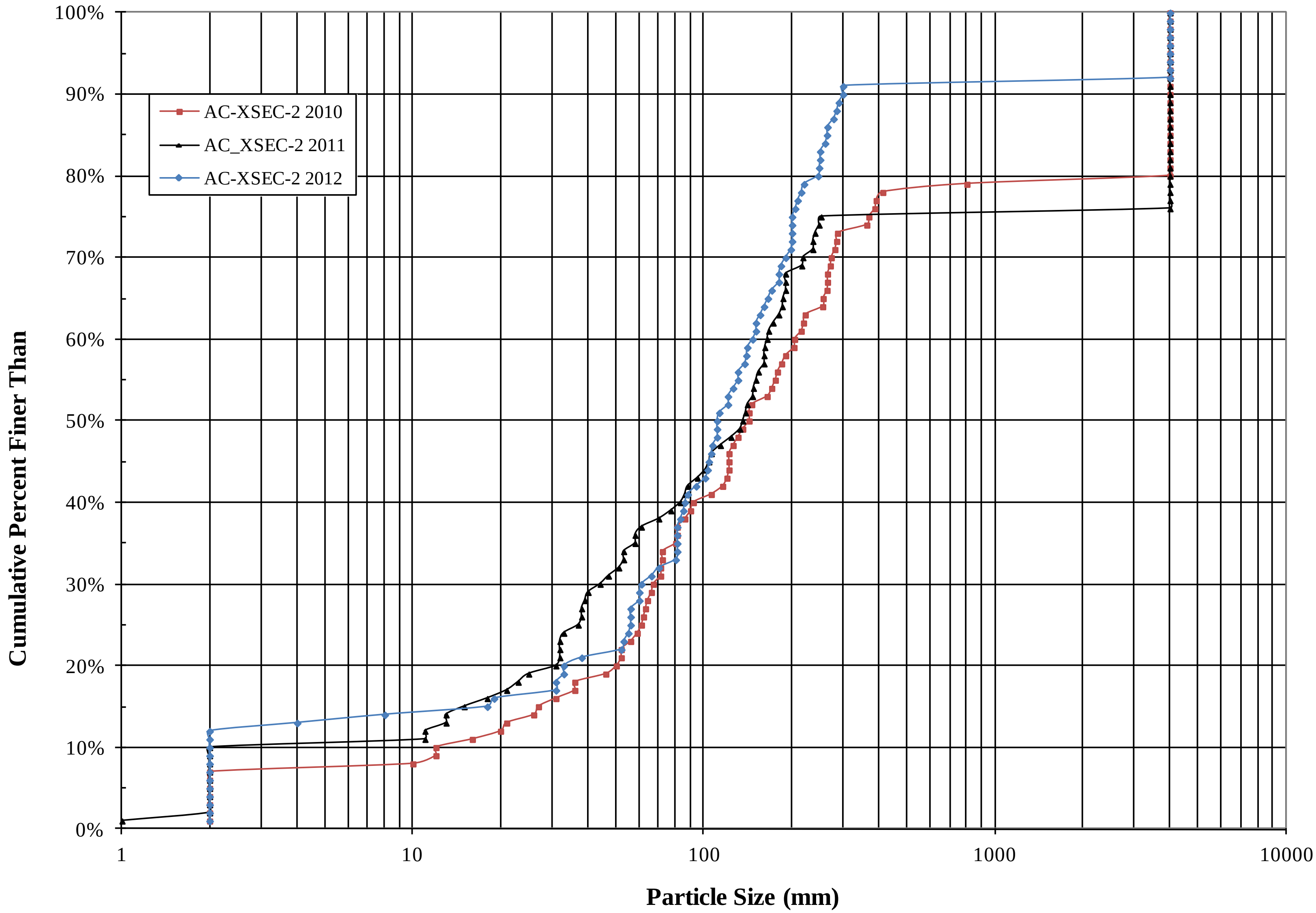

Figure 4.45. 2010, 2011, and 2012 pebble counts from Cross-Sections AC-2.

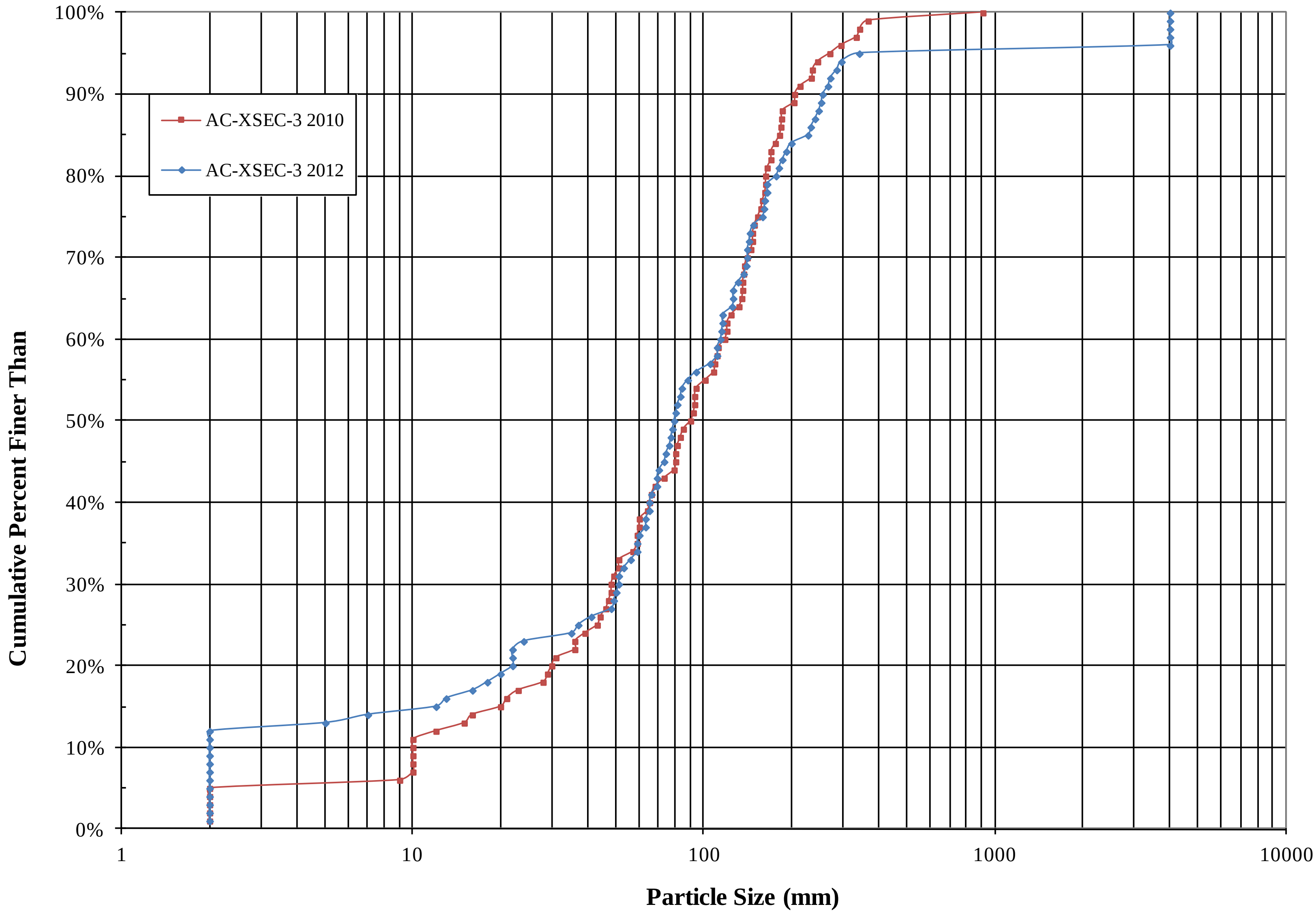

Figure 4.46. 2010 and 2012 pebble counts from Cross-Sections AC-3.

4.3.4 Snorkel Survey Results

2010 Results

Two short stream segments were snorkel surveyed on August 16, 2010. The lower survey segment consisted of 108.5 meters of channel. There were three habitat types sampled in this segment. This segment is now backwatered during high flows and is groundwater fed during periods of lower flow. The upper survey reach was 84 meters in length and included three habitat types. Part of this reach was subsequently filled in as part of the restoration project. A summary of the habitat units contained within the snorkel survey segments is included in Table 4.24. In 2010, a total of 788 salmonids were observed in 2,604 square meters surveyed; yielding a total salmonid density of 0.30 salmonids/m^2. A summary of trout and salmon densities observed in snorkel surveys is included in Table 4.25. Note that no other juvenile salmonids other than coho salmon and trout were observed during the snorkel surveys. Also note that 2 of 118 juvenile coho were classified as age 1+.

Table 4.24. Summary of 2010 habitat unit IDs and habitat types for abandoned channel reach.

Habitat Unit ID	Habitat Type	Surveyed (Y/N)	Length (M)	Wetted Width (M)	Surface Area (M^2)
1	Riffle	N	10.5	12.9	136
2	Rapid	N	21	12.8	268
3	Riffle	N	14	19.6	274
4/5	Riffle	Y	49	17.2	843
6	Rapid	Y	17.5	16.6	290
7	Run	Y	21	11.6	244
8	Rapid	Y	21	12.9	271
9	Riffle	N	77	14.3	1,100
10	Pool	Y	49	10.4	509
11	Rapid	Y	24.5	12.3	300
12	Riffle	Y	10.5	13.9	146
13	Pool	N	21	10.9	229
14	Run	N	14	12.1	170
15	Riffle	N	14	9.9	139
TOTAL		15 Units	364	-	4,919
TOTAL SURVEYED		8 Units Surveyed	192.5	-	2,603

Table 4.25. Habitat unit level summary of 2010 salmonid densities in the abandoned channel reach.

Habitat Unit ID	Habitat Type	Total Salmonids per m^2	Coho (Age 0+ and 1+) per m^2	Total Trout per m^2	Age 1+ and 2+ Trout per m^2
4/5	Riffle	0.21	0.04	0.16	0.04
6	Rapid	0.13	0.01	0.12	0.02
7	Run	0.44	0.03	0.41	0.13
8	Rapid	0.38	0.05	0.32	0.06
10	Pool	0.46	0.08	0.37	0.07
11	Rapid	0.34	0.03	0.31	0.09
12	Riffle	0.23	0.03	0.20	0.05
AVERAGE		0.30	0.05	0.26	0.06

Salmonid densities varied by habitat unit, habitat type, species, and age class of juveniles. Snorkel survey data were further summarized by summing fish counts by habitat type. The data were summarized within four habitat types: rapids, riffles, runs/glides, and pools. Total salmonid and total trout densities were the lowest in riffles and the highest in the pool and run (see Table 4.8). Age 1+ and 2+ trout densities were highest in the run.

Table 4.26. Habitat type summary of 2010 salmonid densities in the abandoned channel reach.

Habitat Type	No. of Units	Area (m^2)	Total Salmonids per m^2	Coho (Age 0+ and 1+) per m^2	Total Trout per m^2	Age 1+ and 2+ Trout per m^2
Rapid	3	862	0.28	0.03	0.25	0.06
Riffle	3	989	0.21	0.04	0.17	0.04
Run/Glide	1	244	0.44	0.03	0.41	0.13
Pool	1	509	0.46	0.08	0.37	0.07

2012 Results

The abandoned channel is too shallow for snorkel surveys, so instead visual foot surveys were conducted; 2012 was the first year this method had been used at Morse Creek. he survey included all 237 meters of wetted habitat. A total of 178 juvenile salmonids were documented in 1,024 m^2; yielding a density of 0.17 salmonids/m^2. The abandoned channel habitat is separated by a steep narrow chute where the water surface drops 0.8 meters over 20 meters. No fish were observed above the chute. Due the lack of fish and no obvious barrier to their migration we examined dissolved oxygen levels along the stream's longitudinal profile. Dissolved oxygen levels were the lowest at the base of the plug (1.45 mg/L) and increased in the downstream direction to 4.98 mg/L at the top of the chute (Figure 4.47). D.O. levels were above 6.0 mg/l at all locations below the chute. Approximately 39 percent of the habitat area measured did not include any fish. Total salmonid density in the occupied habitat was 0.28 salmonids/m^2.

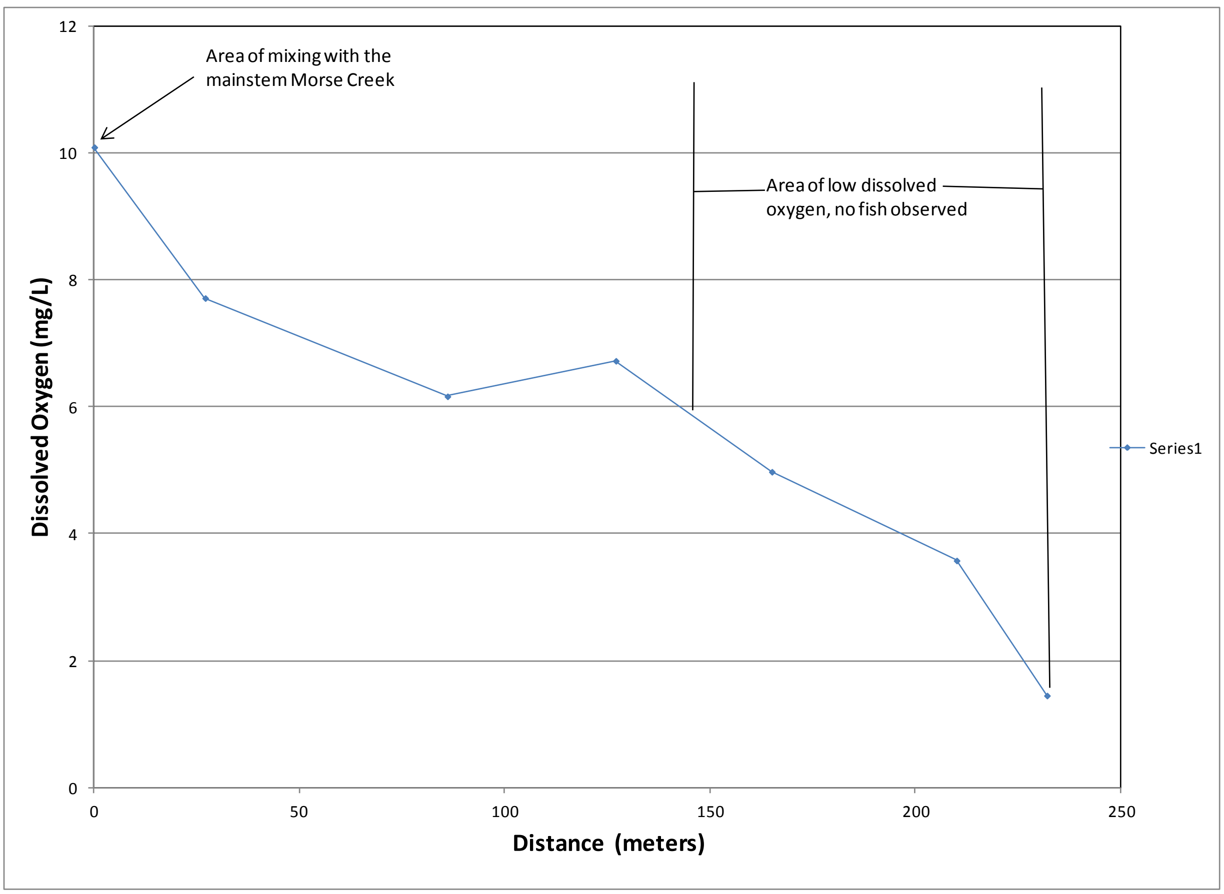

Figure 4.47. Dissolved oxygen levels and fish use in abandoned channel summer 2012.

4.4 Impact Reach #1 and #2

4.4.1 Channel Profile and Cross-Section Results

Impact Reach 1 Profile

In 2010, a thalweg substrate and water surface elevation profile survey was conducted on September 19, 2010 (DOE gage below aqueduct 34.7 cfs). In 2011, the survey was conducted August 30, 2011 (DOE gage below aqueduct 58.6 cfs). In 2012, the survey was conducted August 28, 2012 (DOE gage below aqueduct 48.8 cfs). The profile was run upstream from the downstream end of impact reach 1 to the downstream end of the new channel reach (all three surveys are post construction and diversion).

In 2010, water surface and substrate elevations were measured and recorded at 15-25 meter intervals; elevations were measured at a total of 13 stations. In 2011, water surface and substrate elevations were measured and recorded at 15 meter intervals; elevations were measured at a total of 19 stations. In 2012, water surface and substrate elevations were measured and recorded at 10 meter intervals; elevations were measured at a total of 26 stations (Figure 4.48). Reach level stream gradient was 1.26, 0.99, and 1.01 percent in 2010, 2011, and 2012 respectively. Pre-project gradient was approximately 1.0%. The increase in gradient measured in 2010 is directly attributable to the vertical step between the new channel, impact reach 1, and the pre-project streambed.

Impact Reach 1 Cross-Sections

Two long-term monitoring cross-sections were established in impact reach 1 (see Figure 3.4). Cross-section IR1-XSEC 1 and IR1-XSEC 2 are located 14 meters and 146 meters upstream from the start of survey respectively. Annotated cross-section plots for IR1-XSEC 1 and 2 are included below in Figure 4.49 and Figure 4.51. Photos looking upstream and downstream at the cross-sections are included in Figure 4.50 and Figure 4.52.

Pebble counts were conducted at both cross-sections in all three years. Results from pebble count surveys are depicted in Figure 4.53 and Figure 4.54. The D16, D50, and D84 particle size measurements for each cross-section are included in Table 4.27. Median average particle size for the two cross-sections averaged 135 mm, 87 mm, and 101 mm in 2010, 2011, and 2012 respectively.

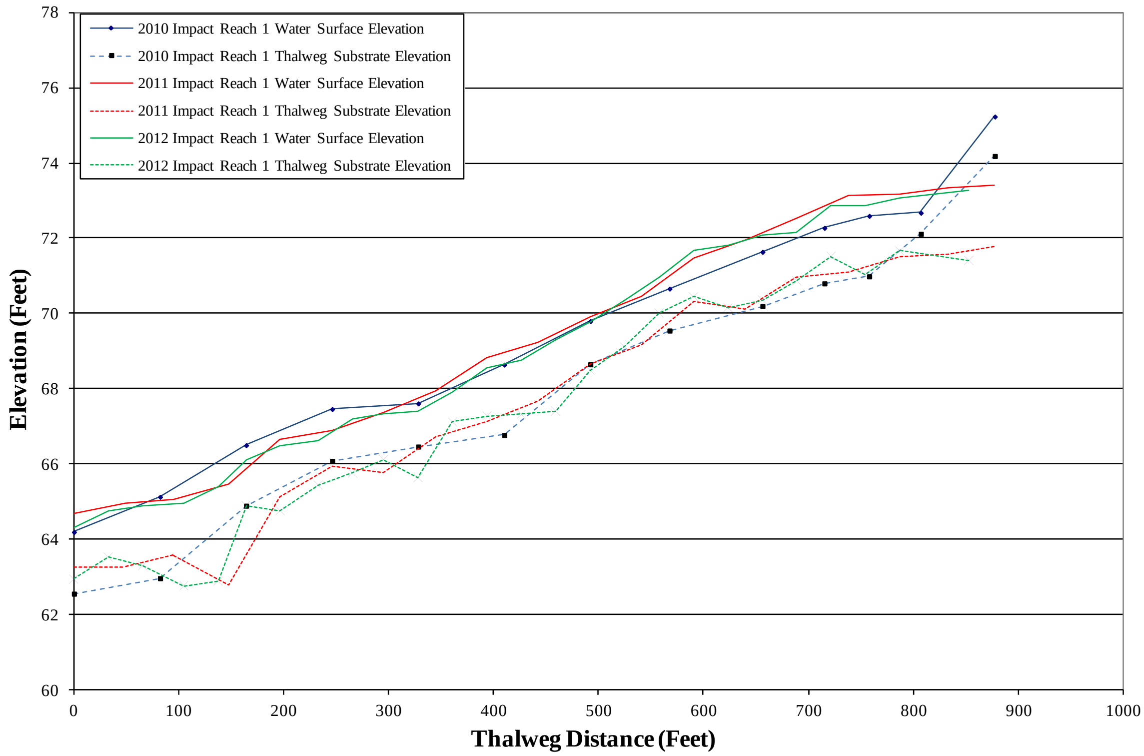

Figure 4.48. Impact Reach 1 thalweg water surface and substrate profile for data collected in 2010, 2011, and 2012.

Table 4.27. D_{16}, D_{50}, and D_{84} particle size distribution for Morse Creek impact reach 1 cross-sections 1 and 2.

Cross-Section ID	Particle Size (mm) D_{16}			Particle Size (mm) D_{50}			Particle Size (mm) D_{84}		
	2010	2011	2012	2010	2011	2012	2010	2011	2012
IR1-XSEC-1	36	11	18	133	78	71	254	197	166
IR1-XSEC-2	19	19	15	136	95	131	280	212	266
Average	28	15	16	135	87	101	267	205	216

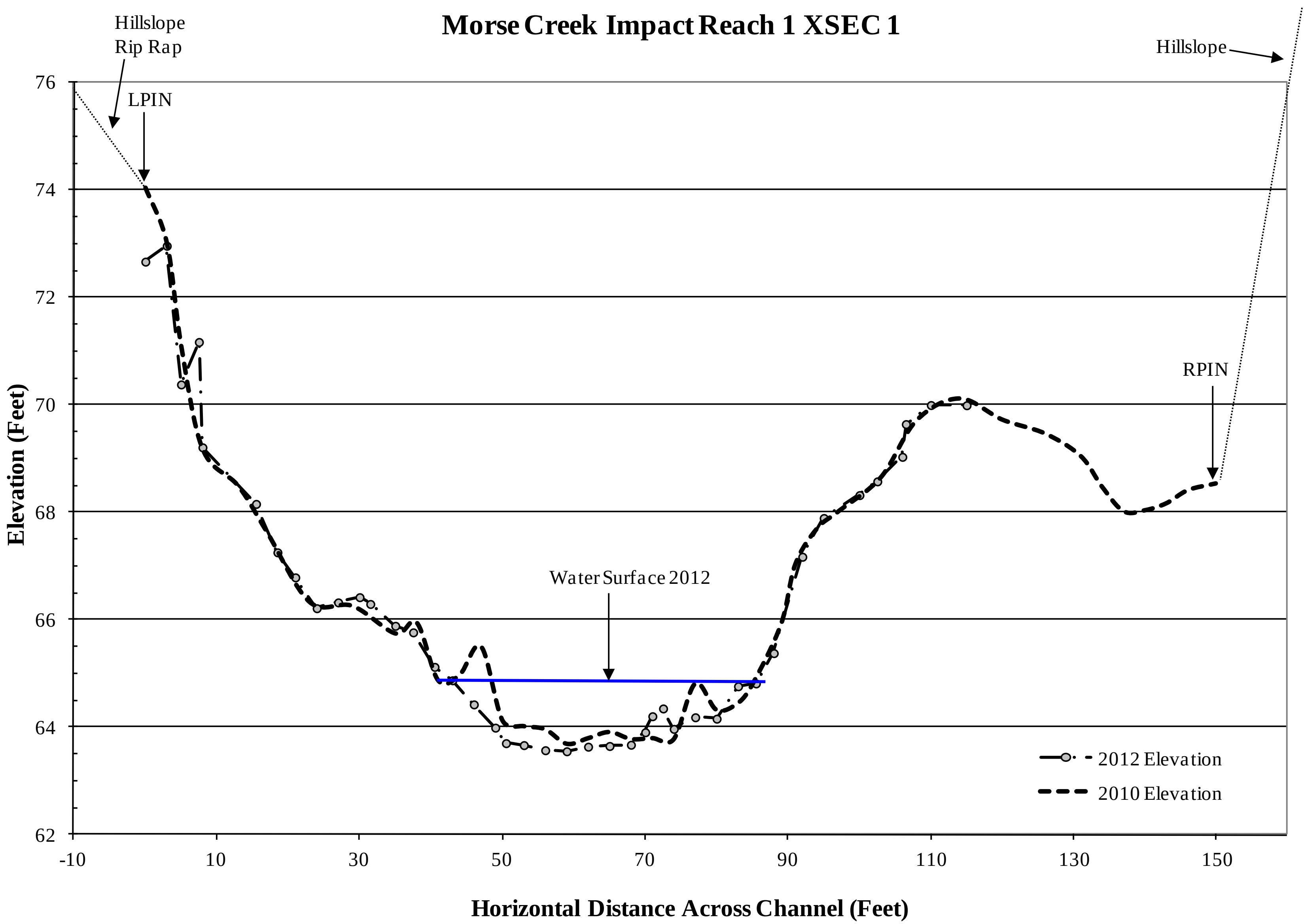

Figure 4.49. Morse Creek Impact Reach 1 Cross-Section 1 in 2010 and 2012.

Figure 4.50. Photos from Cross-Section IR1-1 looking downstream (above) and upstream (below) in 2010 (left) and 2012 (right).

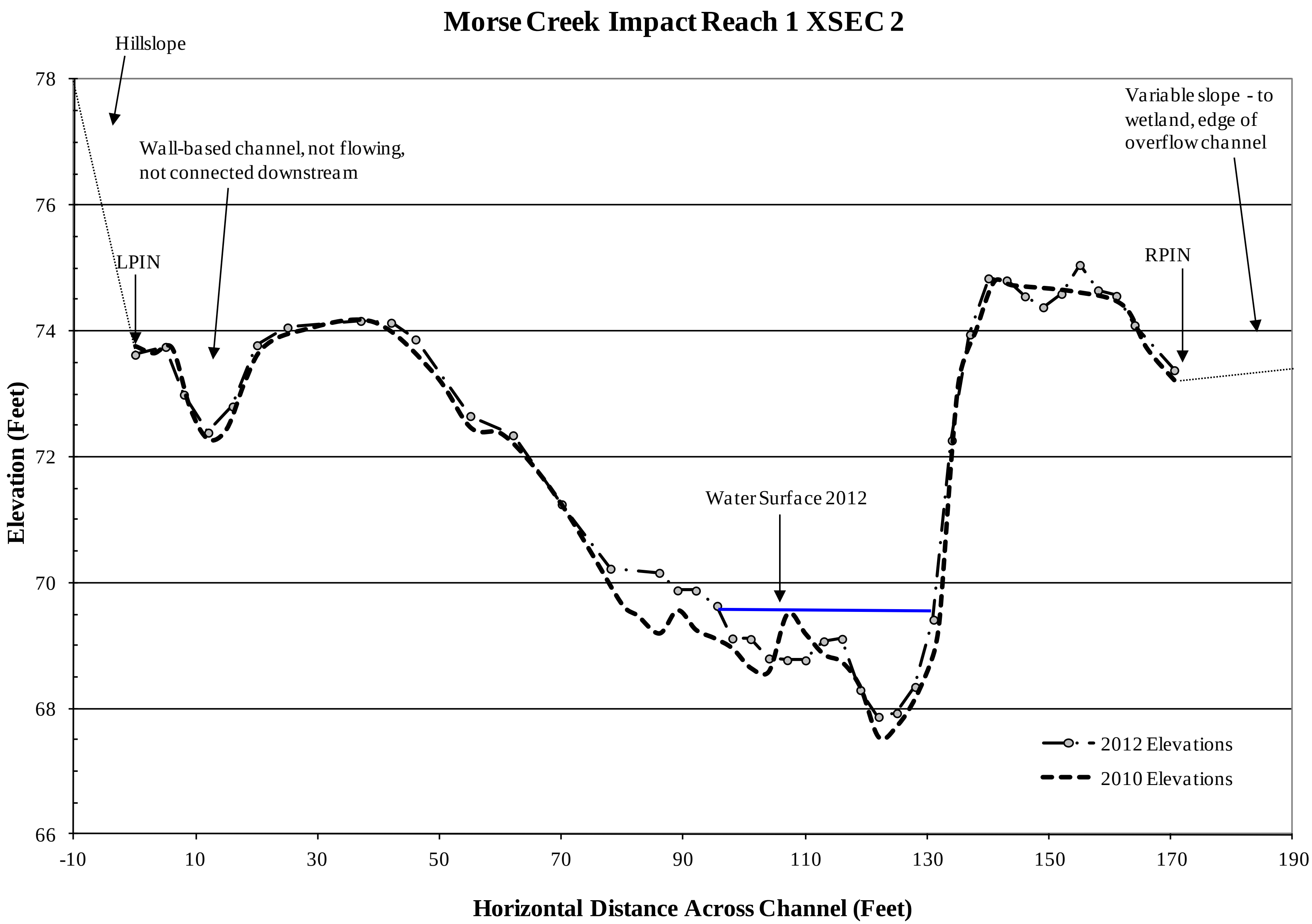

Figure 4.51. Morse Creek Impact Reach 1 Cross-Section 2 in 2010 and 2012.

Figure 4.52. Photos from Cross-Section IR1-2 looking downstream (above) and upstream (below) in 2010 (left) and 2012 (right).

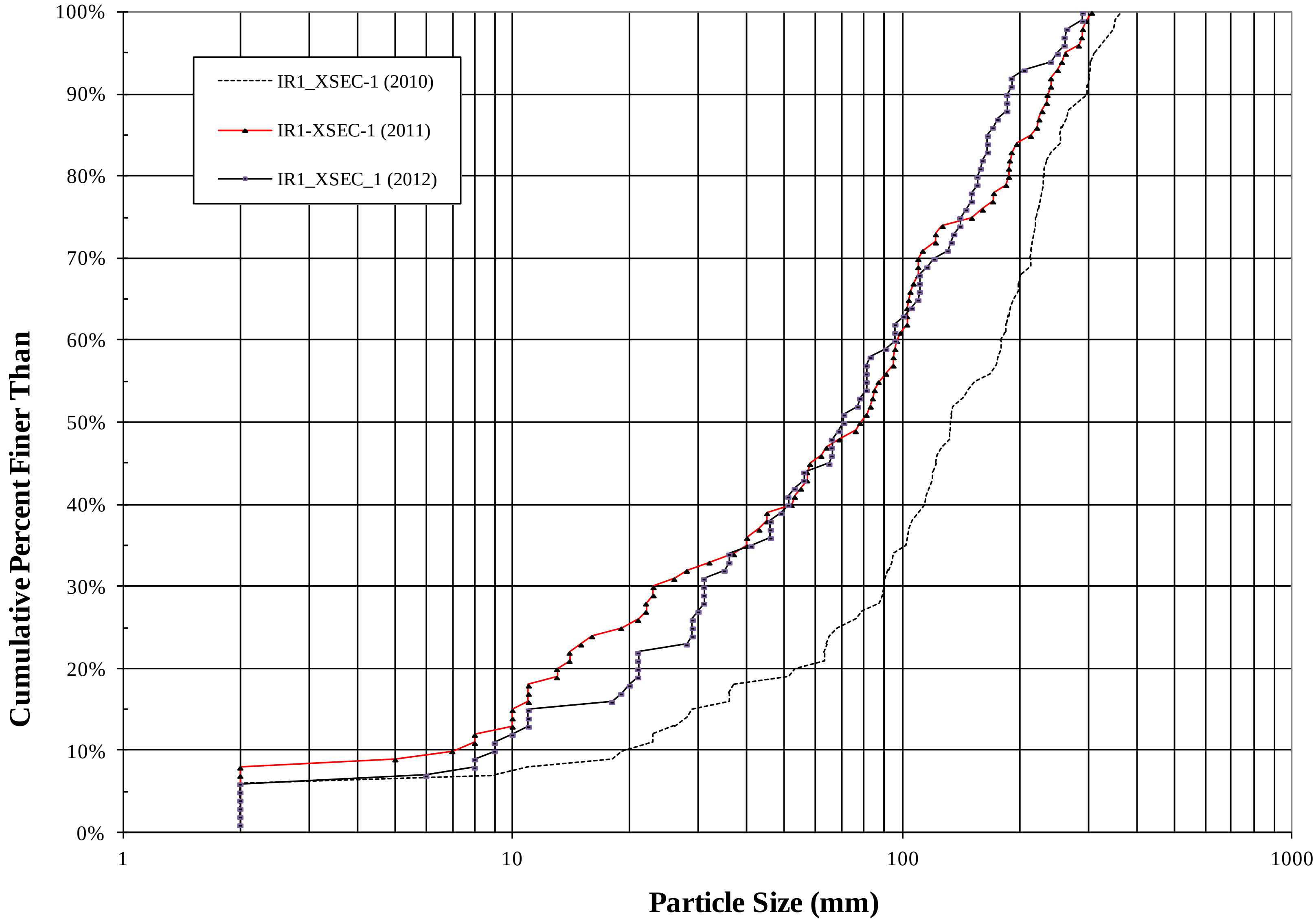

Figure 4.53. 2010, 2011, and 2012 pebble counts from Impact Reach #1 Cross-Section 1.

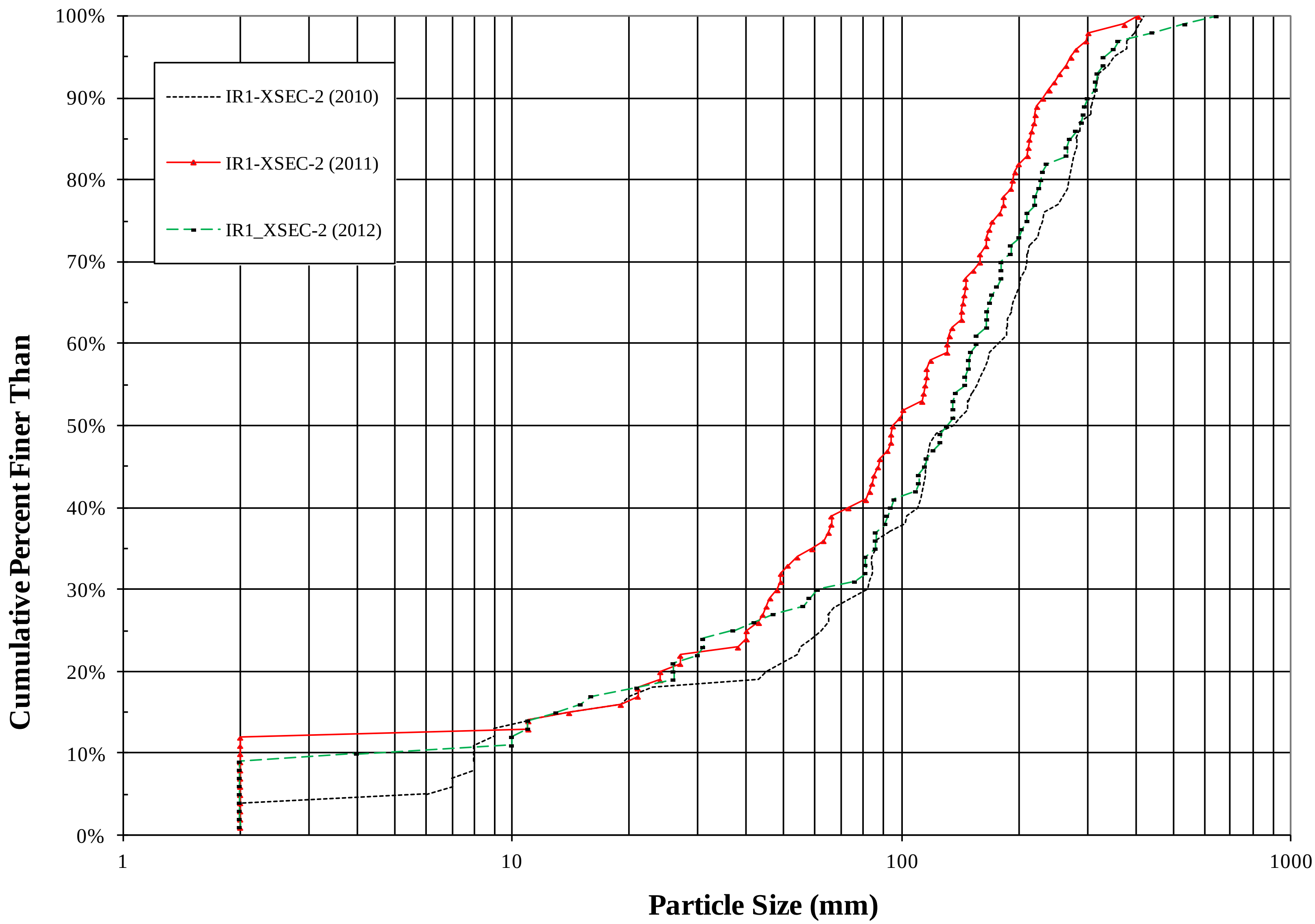

Figure 4.54. 2010, 2011, and 2012 pebble counts from Impact Reach #1 Cross-Section 2.

Impact Reach 2 Profile

In 2010, a thalweg substrate and water surface elevation profile survey was conducted on August 14, 2010 (DOE gage below aqueduct 50.6 cfs). In 2011, the thalweg substrate and water surface elevation profile survey was conducted on August 31, 2011 (DOE gage below aqueduct 56.6 cfs). The 2012 survey was conducted on September 6, 2012 (DOE gage below aqueduct 41.3 cfs). The profile was run upstream from the downstream end of impact reach 2 (upstream end of new channel reach) to the downstream end of the control reach (the 2010 survey was conducted prior to channel diversion). In 2010, water surface and substrate elevations were measured and recorded at 10-20 meter intervals; elevations were measured at a total of 7 stations (Figure 4.55). In 2011, water surface and substrate elevations were measured and recorded at 10-20 meter intervals; elevations were measured at a total of 9 stations. In 2012, water surface and substrate elevations were measured and recorded at 10 meter intervals; measurements were taken at 11 stations. Reach level stream gradient was 1.7% in 2010 and 0.65% in both 2011 and 2012. The decreased gradient measured in 2011 and 2012 is directly attributable to project implementation which raised the bed and water surface approximately four feet at the upstream end of the new channel.

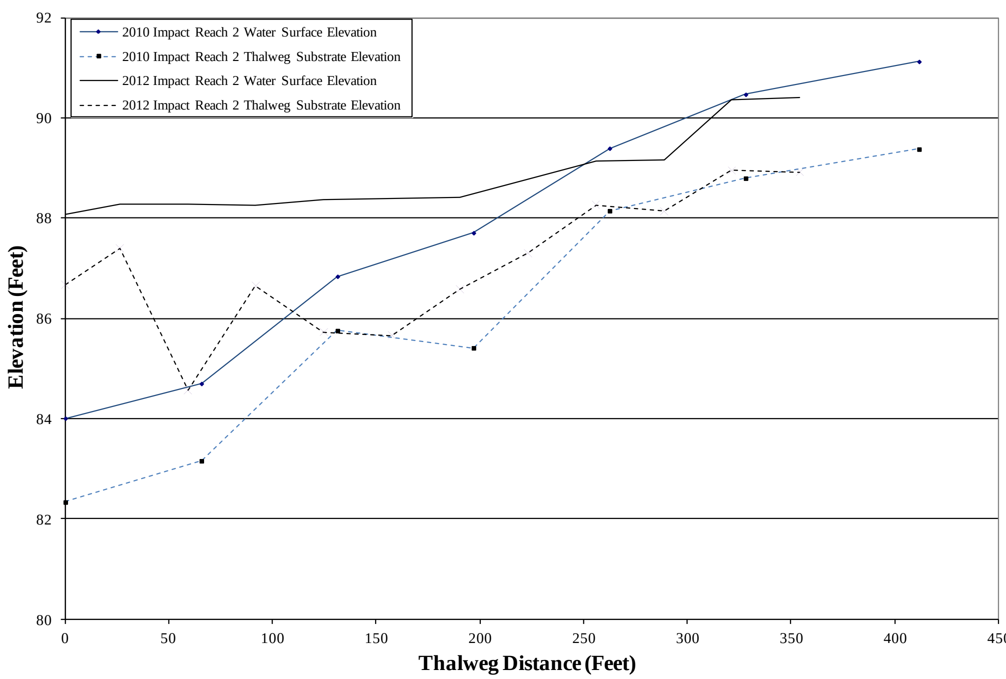

Figure 4.55. Impact reach 2 thalweg water surface and substrate profile for data collected in 2010 and 2012.

The decrease in gradient within impact reach 2 has resulted in aggradation throughout the short reach. As can be seen in Figure 4.55, the water surface and substrate elevation at the downstream end of impact reach 2 both increased by approximately 4 feet. Figure 4.56 illustrates localized sediment aggradation in impact reach 2 just upstream of the new channel reach.

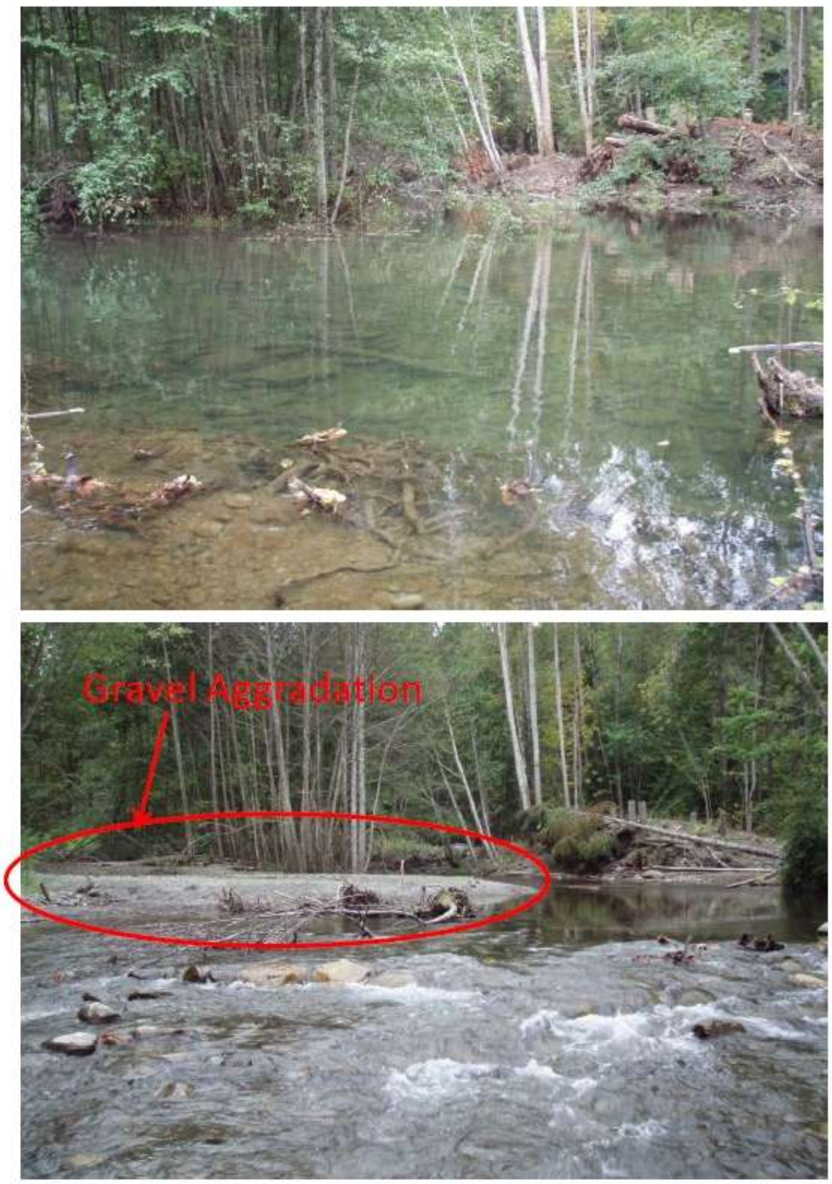

Figure 4.56. Photos taken in 2010 (top; taken from new channel at 471 meters looking upstream) and 2011 (bottom; taken from 450 meters looking upstream) depicting sediment aggradation in the lower section of impact reach 2.

5 DISCUSSION

5.1 Channel Thalweg and Habitat Survey Results

5.1.1 Channel Characteristics

The Morse Creek new channel reach has continued to evolve since the completion of the project in the summer of 2010. The new channel reach was constructed with a relatively uniform gradient of 0.87 percent. However, the gradient was not evenly distributed throughout the reach. Gradient across the lower 100 meters averaged 0.38%, whereas the gradient was 1.00% in the upstream 370 meters. The channel was designed anticipating that the channel would evolve as hydrologic and hydraulic processes take force.

In 2011 and 2012, this channel evolution was evident in the stream profile and changes in channel and habitat characteristics. The gradient increased to 0.98% in 2012, with the steeper gradient mainly being attributed to head cutting at the bottom of the new channel. Channel head cutting has reduced the low flow water surface elevation by 1.5 to 2.0 feet at the downstream end of the reach (see Figure 4.4. Thalweg substrate elevations have been reduced by 2.5 feet at the same location (Figure 5.1 and Figure 5.2).

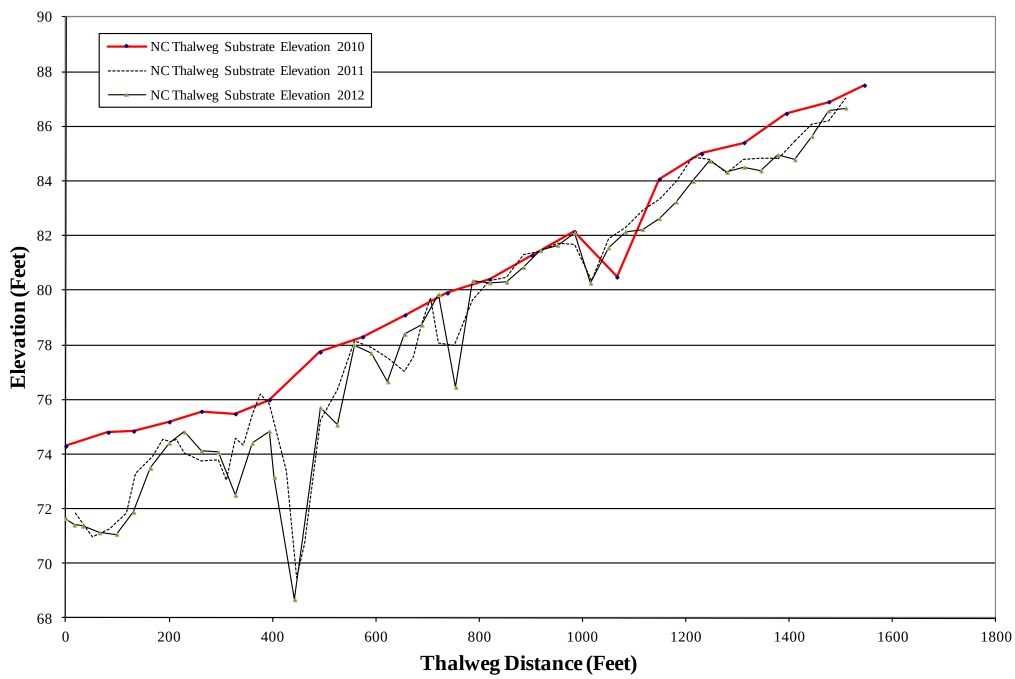

Figure 5.1. New channel reach thalweg substrate profile for 2010, 2011, and 2012.

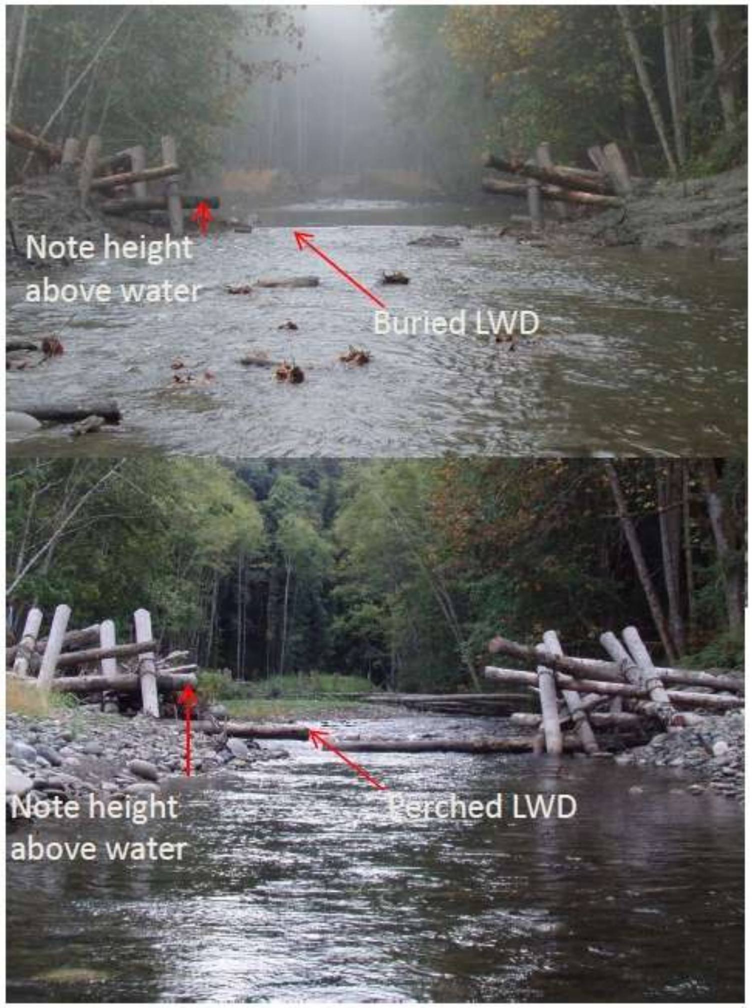

Figure 5.2. Photo depicting channel incision in the lower 50 meters of the new channel reach; top (2010) and bottom (2011).

The channel has evolved from a uniformly plane bed channel into a pool-riffle channel type. Figure 4.4 and Figure 5.1 clearly illustrate a sequence of lower and higher gradient habitat units. Figure 5.1 also shows that significant thalweg deepening occurred between survey years. Most of the lowered thalweg elevations (deeper spots) measured in 2011 and 2012 correspond to scour pools (thalweg elevation lowering in the lower 100 meters was caused by head cutting). At one location there was at least eight vertical feet of thalweg scour. These pools were formed when water scoured around the constructed logjams.

The thalweg and pool scouring displaced hundreds of tons of streambed material. Much of the scoured sediment was deposited in close proximity, forming gravel and cobble bars, as well as secondary channels; thus increasing channel complexity. The change in channel shape and form between years has affected the low flow wetted width and thalweg depth (please also note differences in streamflow between years- see Figure 4.1). Thalweg depth increased from 0.29 meters in 2010 to 0.50 meters in 2011, and 0.52 meters in 2012. Wetted width decreased from 17.1 meters in 2010 to 12.2 and 12.3 meters in 2011 and 2012 respectively.

5.1.2 Habitat Units

The sequence of pools and riffles observed in the new channel reach in 2011 and 2012 provides a heterogeneous physical environment that is utilized by many different types of organisms. Pools and riffles provide refuge from high velocity waters and extreme temperatures, spawning sites for salmonids, and attachment sites for benthic invertebrates and plants (Gore and Shields 1995). The complexity of pool-and-riffle sequences offers the wide variety of habitat types needed to support a diverse lotic community.

In 2010, only three primary habitat units were delineated in the new channel. These included; a low gradient riffle, a shallow glide, and a low gradient riffle w/ pockets. Four small pool sub-units were also identified. In 2011, six different habitat types were classified, these included: low gradient riffle, glide, low gradient riffle w/ pockets, high gradient riffle, scour pool, and run. One small pool sub-unit and two low gradient riffles were also identified. In 2012, the same six different habitat types as classified in 2011 were classified within the reach. A total of 16 primary and 7 secondary habitat units were inventoried. Secondary units consisted of two low gradient riffles, two small side channels within the channel's bankfull width, two small pools, and one run. Figure 5.3 and Figure 5.4 illustrate habitat change between years. These figures show the effects of streambed scour and deposition, and the resulting habitat development associated with constructed LWD structures.

The pool-riffle sequence observed in the profile of the new channel is an improvement from the steep cascades and lack of pools observed in the abandoned channel. The abandoned channel provided little to no opportunity for deposition of spawning gravel sized sediments or resting places for juvenile salmonids due to the high velocity of the straightened and incised channel. The survey of the habitat units along the constructed channel also indicates a vast improvement in salmonid spawning and rearing habitat. The abandoned channel consisted of 2 pools, 2 runs, 4 rapids and 7 riffles (Table 5.1). The abandoned channel was in a state of disequilibrium with a degraded pool-riffle structure and continuous high velocity units scouring the channel substrate to bedrock. By developing a longer, meandering channel with log jams the project created habitat complexity and established a pool-riffle sequence. The increase in habitat complexity is evident in the 2011 and 2012 habitat unit surveys conducted on the restored reach one and two years after the restoration project.

Figure 5.3. Photos depicting the development of large scour pool associated with LWD Jam #8 (Habitat Unit #6); left (2010) and right (2011).

Figure 5.4. Photos depicting the development of large scour pool associated with LWD Jam #11; left (2010) and right (2011).

Direct habitat area comparisons between the new channel in 2011/2012 and the abandoned channel in 2010 must be done with caution. In 2011 and 2012, stream flows were 39% lower than when surveyed in the abandoned channel in 2010. Nonetheless, habitat area in the new channel increased by nearly 20% in 2012 (despite flows which were 39% lower). In addition, another 1,861 m^2 of side and off-channel habitat were measured in 2012. If the 2010 abandoned channel reach habitat areas are adjusted based on lower flows and reduced wetted widths (assuming that wetted widths at ~39 cfs [flow during 2011 and 2012 new channel reach surveys} are 85% of wetted widths at 64.6 cfs [flow during 2010 abandoned channel reach survey]) then the new habitat area increased by 35-percent. This estimate may underestimate the increase in habitat area. Within the control reach habitat areas were measured at two different stream flow levels (51.4 cfs and 40.1 cfs [at DOE stream gage below aqueduct). Streamflows in the control reach were 22-percent lower in 2010 than in 2011 and habitat area was 18-percent less.

Table 5.1. Summary of 2010, 2011, and 2012 habitat data for new channel reach (NC) and 2010 habitat data for the abandoned channel reach (AC).

Habitat Type	**No. of Habitat Units**				**Area Square Meters**			
	AC-2010	NC-2010	NC-2011	NC-2012	AC-2010	NC-2010	NC-2011	NC-2012
Rapid/Cascade	4	0	0	0	1,161 (23%)	0	0	0
High Gradient Riffle	3	0	2	2	564 (11%)	0	318 (6%)	345 (6%)
Low Gradient Riffle	1	1	5	4	569 (11%)	459 (5%)	2,050 (36%)	1,097 (18%)
Low Gradient Riffle w/pockets	3	1	3	3	1,578 (31%)	6,313 (73%)	654 (12%)	1,363 (23%)
Sub Unit- Riffle	0	0	2	2	0	0	309 (5%)	382 (6%)
Run	2	0	1	1	425 (8%)	0	351 (6%)	393 (7%)
Sub Unit- Run	0	0	0	1	0	0	0	162 (3%)
Glide	0	1	1	1	0	1,664 (20%)	589 (10%)	521 (9%)
Pool	2	0	4	5	758 (15%)	0	1,365 (24%)	1,476 (24%)
Sub Unit- Pool	0	4	1	2	0	158 (2%)	44 (1%)	121 (2%)
Side Channels W/in bankfull	0	0	0	2	0	0	0	178 (3%)
Total All Units	15	7	19	23	5,056	8,594	5,679	6,038

The quality of mainstem habitat was also vastly improved in the new channel as compared to the abandoned channel. For example, the abandoned channel was only composed of 23-percent low gradient/lower energy habitats (pools, runs, and glides). The new channel was composed of 45-percent low gradient habitat (2,730 m^2); an increase of nearly 100-percent. Please note this does not include the other side and off channel habitat which includes an additional 1,861 m^2 of low energy summer rearing habitat. Collectively, the reach went from having just less than 1,300 m^2 of low gradient/low energy habitat to approximately 4,600 m^2; despite flows that were 39% lower at the time of the survey.

5.1.3 Large Woody Debris Surveys

Large woody debris (LWD) performs key functions in streams that drain lowland forested watersheds. These functions include dissipation of stream energy, stabilization of the streambed and banks, the trapping, sorting and storage of sediment, and formation of pools (Booth et al 1997). Lack of LWD may alter channel form and processes, yielding greater sediment fluxes, more rapid bank erosion and incisions, and loss of heterogeneity in channel morphology. In the case of the abandoned channel of Morse Creek, high water velocity resulting from a straightened and diked channel prevented the recruitment of stable LWD; reducing and/or eliminating critical ecological and biological functions.

The restored channel included engineered logjams that play a variety of roles in the stream, including creating habitat units, altering of channel form and type, trapping, sorting and storage of sediment, and trapping LWD moving through the reach. The value of these engineered logjams to the system was made evident during LWD surveys and snorkel surveys for fish utilization. Large woody debris has been recruited at the restoration site, either through the trapping/catching of debris floating downstream or due to trees falling directly into the creek as a result of bank erosion and channel development.

Figure 5.5 demonstrates the size, type, and volume of debris that has been captured by the engineered logjams during high water events. This logjam has scoured a deep pool that is utilized by juvenile salmonids for rearing and adults for holding. The two dominant species utilizing these habitats were coho

Figure 5.5. Photo looking at Logjam #11 and racked LWD trapped by jam.

salmon and steelhead trout. The pools and associated logjams are important rearing habitat for both of these species. The LWD creates areas of low water velocity, where fish seek refuge to improve in-stream survival. The number of pieces of LWD in the new channel reach is 60 to 70 times greater than what was documented in the abandoned channel reach.

5.1.4 Streambed Characteristics

The overall goal of this project was to improve spawning and rearing habitat conditions along this degraded stretch of Morse Creek. The size and location of streambed sediment can limit the success of spawning by salmonids (Groot and Margolis 1991). The abandoned channel provided little spawning habitat as a result of high energy and large substrate size. The abandoned channel reach thalweg survey data indicate that greater than 20 percent of the streambed was composed of bedrock and that the median particle size was approximately 95 mm. The median particle size in the new channel reach was 75 percent smaller (24 mm) than in the abandoned channel reach in 2011. In 2012, the median particle size increased to 47 mm (still roughly 50% smaller than in the abandoned channel reach).

In 2011, the new channel still had a high proportion of fine sediment. Conditions appeared improved in 2012. Fines made up 38, 20, and 11 percent of the thalweg pebbles counted in 2010, 2011, and 2012. Several Chinook salmon redds were observed within the new channel reach during surveys in 2012.

No fine sediment in-spawning-gravel sampling has been conducted but it is assumed that current levels are higher than what is ideal for salmon and steelhead spawning habitat. Ideally less than 12-14% of gravels should be finer than 1 mm for successful incubation. Studies have demonstrated that interstitial fine sediment can reduce gravel permeability and lead to less intragravel flow, which can result in lower levels of dissolved oxygen resulting in suffocation of embryos (McNeil and Ahnell 1964; Cooper 1965; Koski 1966; Chevalier et al. 1984).

Changes to streambed elevations and streambed particle size were observed within the lowest portions of impact reach 2 (Figure 4.56). Several feet of aggradation occurred within the right bank side channel. Aggradation was also evident at the upstream portion of impact reach 2. Figure 5.6 shows minor amounts (~0.5 to 1 ft) of aggradation adjacent to a large boulder.

Figure 5.6. Photos looking downstream from CR-XSEC-1 at large boulder showing sediment aggradation between 2010 and 2011 surveys (Top photos taken in 2010; bottom photos taken in 2011).

5.1.5 Riparian Characteristics

Riparian areas provide a number of important functions that benefit salmonids and salmonid habitat. For example, trees fall into streams from adjacent riparian stands and provide critical fish habitat structure and complexity. In addition to wood recruitment riparian forests also provide canopy cover (shade), leaf litter, bank protection, microclimates, and other important ecological functions.

Figure 5.7. Example of red alder seedlings taking root in area disturbed by restoration project.

Canopy cover within the new channel reach averaged 37, 35, and 32 percent in 2010, 2011, and 2012 respectively (see Section 4.1.1). Canopy cover within the abandoned channel is estimated to have averaged 68 percent (see Section 4.3.1). The restoration project reduced canopy cover by over 50 percent. The short term reduction in canopy cover has the potential to increase stream temperatures throughout the new channel reach. The project sacrificed short term canopy cover for vastly improved overall habitat conditions.

Although the canopy cover percentage is low, great care was taken during the restoration project to minimize tree removal and disturbance. Alder, maple and salmonberry seedlings have begun to recruit on surfaces that were disturbed by the restoration. It is anticipated that in the next 10-15 years, canopy cover will increase as deciduous trees fill in canopy gaps caused by the project. In addition, new riparian vegetation will grow over the years and eventually provide additional shade. In order to speed succession, conifers (Douglas fir, western red cedar, western hemlock and sitka spruce) were planted amongst the alder and big-leaf maple. Since restoration, the number of trees planted within the riparian area of Morse Creek totals more than 3,000.

Conifer trees, which are lacking along the riparian area, were planted in the understory to improve the quality and diversity of riparian habitat. Large riparian conifers have many important ecological functions. They provide leaf matter for stream life and large woody debris (LWD) for the creation of pools and other fish habitat, stabilize stream banks, and provide shade to stablize water temperatures (Nakamura and Swanson 1992). Past clear-cutting at the Morse Creek site resulted in early successional stands dominated by hardwood species such as red alder and big leaf maple (Harrington 1990). The establishment of these stands can preclude conifer establishment, especially of shad-intolerant species such as douglas-fir (Newton and Cole 1994). The hardwood forest has substantial riparian value as it provides leaf litter for associated invertebrates, and root systems that stabilize stream banks. However, when the riparian system is hardwood dominant, it lacks important ecological functions provided by large conifers. For example, logs of deciduous trees such as red alder have shorter residency times in the stream than conifer logs and cannot create and maintain the same type and quality of fish habitat (Hayes et al 1996).

5.2 Channel Profile and Cross-Section Results

5.2.1 Channel Profile

The new channel reach was constructed with a relatively uniform gradient of 0.87 percent. However, the gradient was not evenly distributed throughout the reach. Gradient across the lower 100 meters averaged 0.38 percent, whereas gradient was 1.0 percent in the upstream 370 meters. In 2012, reach level gradient increased to 0.98 percent, with the steeper gradient mainly being attributed to head cutting at the bottom of the restored channel. Channel head cutting has reduced the low flow water surface elevation by 1.5 to 2.0 feet at the downstream end of the reach (see Figure 4.4). Thalweg substrate elevations have been reduced by 2.5 feet at the same location (Figure 5.2 and Figure 5.1). The gradient within the new channel reach (0.98%) is the same as the gradient in the abandoned channel reach (1.0%). The upper portion of the new channel reach was constructed ~4 feet higher than the existing channel. The length of the new channel is approximately 318 feet longer than the abandoned channel.

The most significant changes in stream gradient occurred within impact reach 2. Reach level stream gradient was reduced from 1.7% in 2010 to 0.65% in both 2011 and 2012. The decreased gradient measured in 2011 and 2012 is directly attributable to project implementation which raised the bed and water surface approximately four feet at the upstream end of the new channel.

5.2.2 Channel Cross-Sections

Results from the cross-section surveys are presented above in Sections 4.1.3, 4.2.3, 4.3.3, and 4.4.1. Within the new channel reach significant change was observed at all five cross-sections. At NC-XSEC-1 (see Figure 4.5 and Figure 4.6) the thalweg elevation incised ~0.6 ft. Within the primary channel average bed elevation decreased 0.4 ft. Bankfull area (not including the overflow channel) increased from 405 sq ft^2 to 464 ft^2 in 2012. The downward shift in bed elevation at this cross-section is a result of head cutting. Particle size distribution at NC-XSEC-1 increased from a median particle size of less than 2 mm to 72mm in 2011, and then decreased to 47 mm in 2012.

At NC-XSEC 2 (see Figure 4.7 and Figure 4.8) the thalweg elevation incised 1.3 ft. Within the primary channel average bed elevation decreased 0.4 ft. Bankfull area (not including the right bank side channel) increased from 154 ft^2 to 180 ft^2 in

2011, and to 229 ft^2 in 2012. The downward shift in bed elevation at this cross-section is a result of scour and pool development associated with Logjam #8. Particle size distribution at NC-XSEC-2 decreased from a median particle size of 25 mm to 12 mm in 2011, and to 6 mm in 2012.

At NC-XSEC 3 (see Figure 4.9 and Figure 4.10) the thalweg elevation incised 3.5 ft. Within the primary channel average bed elevation decreased 0.7 ft in 2011. Bankfull area increased from 167 ft^2 to 234 ft^2 in 2011, and 265 ft^2 in 2012. The downward shift in bed elevation at this cross-section is a result of scour and pool development associated with Logjam #11. Particle size distribution at NC-XSEC-3 increased from a median particle size of 15 mm to 47 mm in 2011, but the size median particle size fell to 12 mm in 2012.

At NC-XSEC 4 (see Figure 4.11 and Figure 4.12) the thalweg elevation incised 2.1 ft. Bankfull area was poorly defined due to the confluence with a major side channel. The downward shift in bed elevation at this cross-section is a result of scour and pool development associated with Logjam #13.

At NC-XSEC 5 (see Figure 4.13 and Figure 4.14) the thalweg elevation incised 0.8 ft in 2011 and 1.0 ft in 2012. Within the primary channel average bed elevation decreased 0.55 ft in 2012. Bankfull area (not including the left bank side channel) increased from 251 $ft^2$to 276 ft^2 in 2011. Bankfull area was 269 ft^2 in 2012. The downward shift in bed elevation at this cross-section is a result of scour associated with Logjam #15. Particle size distribution at NC-XSEC-5 increased from a median particle size of 26 mm to 32 mm in 2011, and 33 mm in 2012. Significant aggradation (1-2 feet in places) within the left bank side channel was also measured in this cross-section.

Impact reach 1 cross-sections showed very little change between years. Minor aggradation along the left bank bar at IR-1-XSEC 2 was documented. More significant change was documented in control reach cross-section 1 where approximately 1 to 1.5 feet of gravel was deposited along a 40 ft wide zone along the right bank. The deposition of gravel within the cross-section is likely a result of decreased stream gradient in impact reach 2. In 2011, pink salmon spawning was also documented during field surveys within the newly deposited gravels. Little change was observed at the other cross-sections.

5.3 Snorkel Surveys

All of the elements of this project were created in order to restore degraded fish habitat in Morse Creek. Thus, the analysis of fish utilization in the newly created channel is critical to knowing how successful this project was for restoring and increasing available fish habitat and consequently increasing fish numbers. As described above snorkel surveys were conducted during all three years of monitoring. In this section of the report we will discuss the results and implications of the snorkel survey data and attempt to describe any measurable changes in salmonid densities and total abundance. Snorkel survey data collected in the control reach in 2010 and 2011 indicate very similar total salmonid densities between years; 0.35 and 0.34 salmonids/m^2 respectively. However, total salmonid densities were only 0.18 salmonids/m^2 in 2012. Figure 5.8 depicts Morse Creek streamflow for the days snorkel surveys were conducted. As can be seen streamflows were similar between surveys.

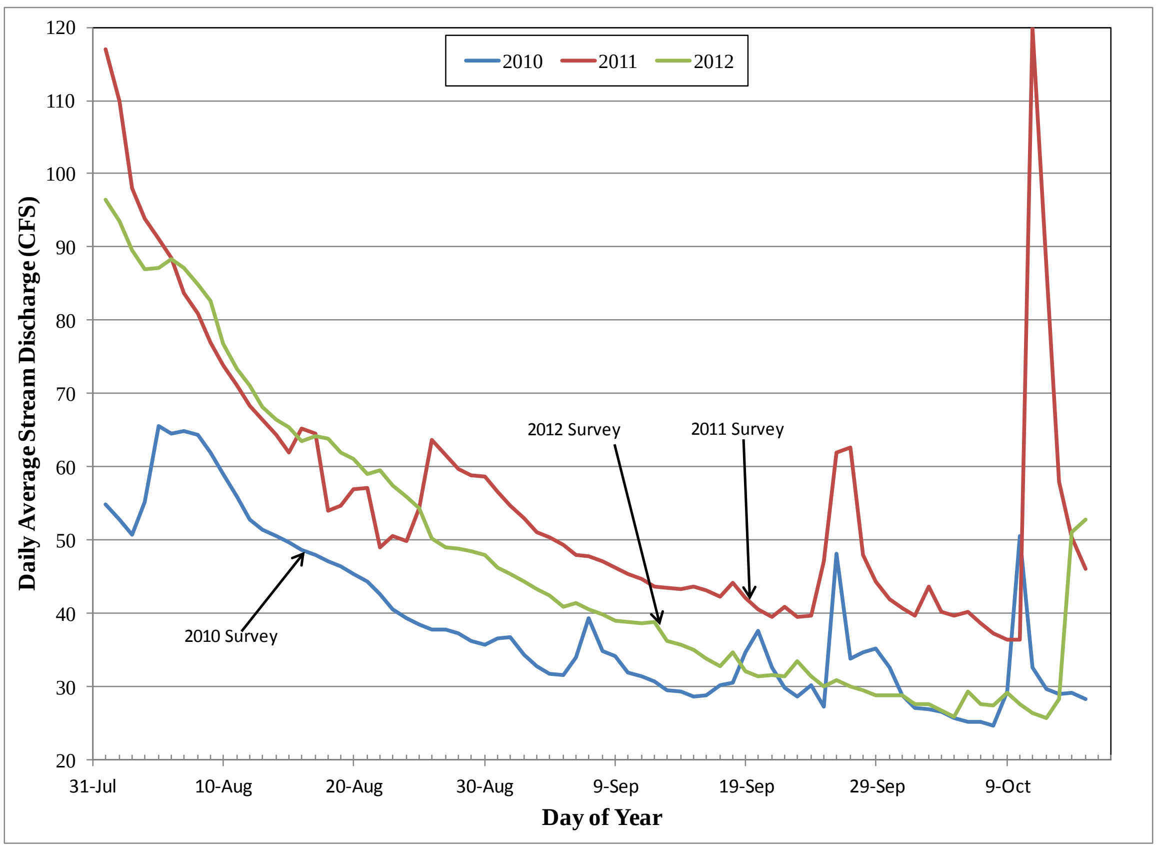

Figure 5.8. Morse Creek streamflow data for low flow seasons 2010, 2011, and 2012 -Snorkel surveys (source: DOE stream gage below aqueduct).

By comparing salmonid densities within habitat unit types we were able to generate estimates for unsurveyed habitat units. This was done in order to develop an estimate of the number of salmonids which would have been counted if 100 percent of reaches were surveyed. Figure 5.9 depicts total salmonid densities by habitat unit for each stream reach and year surveyed.

Measured habitat unit type total salmonid densities were applied to the unsurveyed units. In 2011, within the new channel reach there were eight habitat units not surveyed and they include the following: mainstem riffle (1), mainstem secondary riffle unit (2), side channel segments 1 through 3 (3), and the abandoned channel off-channel habitat unit (1). High densities of age 0+ coho and trout were observed in all side channel segments, as well as the abandoned channel reach. For 2011, the average total salmonid density from the surveyed portion of the new channel reach was used to estimate densities in side and off-channel habitat units. The same methods were used to expand for seven unsurveyed habitat units in the abandoned channel reach (2010). All units were surveyed in 2012 and no expansion was needed.

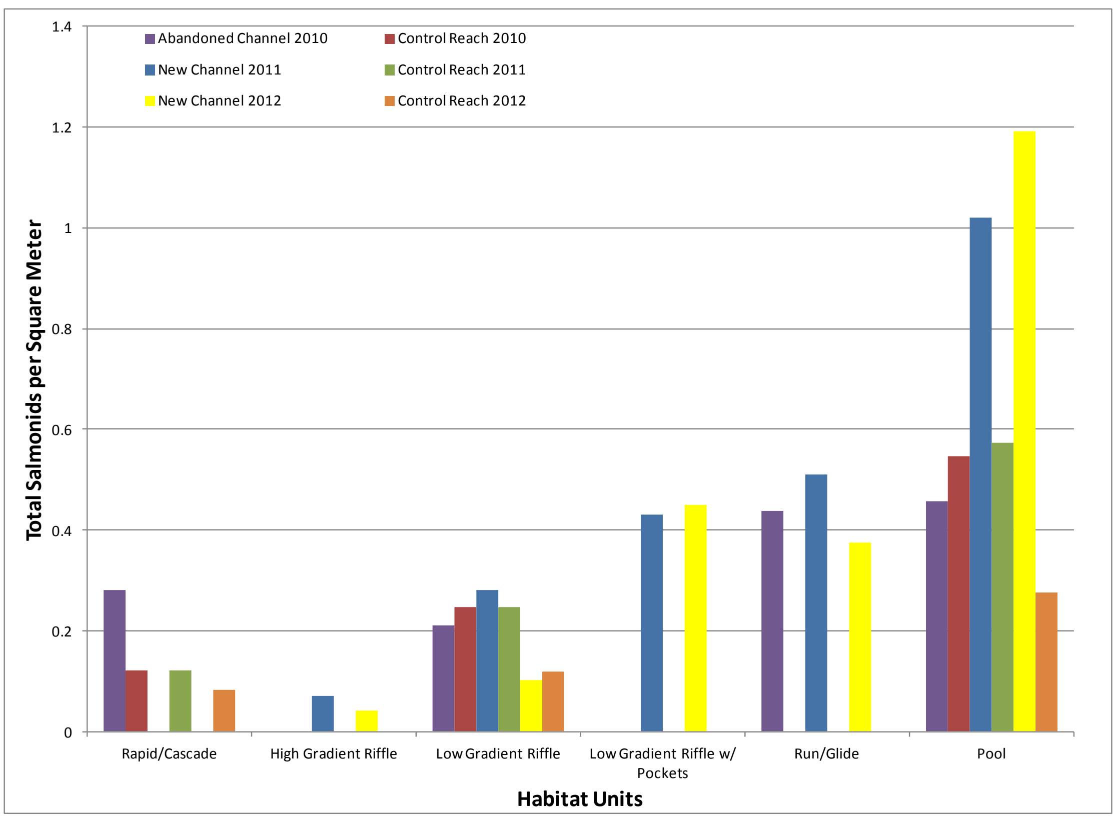

Figure 5.9. Total salmonid densities by habitat unit for each stream reach and year surveyed.

The estimated number of total salmonids that would have been detected in 2010 and 2011 by a snorkel or visual survey of the entire new channel and abandoned channel reaches is included below in Table 5.2. Measured total salmonid density in the new channel reach was 0.53 salmonids per m^2. In 2011, the measured density in the new channel reach was 79 percent higher than measured in the abandoned channel reach in 2010 (0.30 salmonids per m^2). Expansion based on unsurveyed units estimates 3,983 detectable salmonids in the new channel reach (including side and off-channel habitats). The expansion for the abandoned channel reach yielded an estimate of 1,389 detectable salmonids. The expansion and estimate suggest that total salmonid abundance within the main project area increased by nearly 200 percent in 2011.

Table 5.2. The estimated number of total salmonids that would have been detected by a snorkel or visual surveys of the entire new channel and abandoned channel reaches for 2010 and 2011.

Channel Reach	Habitat Type	No. of Units	Surveyed (Y/N)	Surface Area (M^2)	Total Salmonids	Total Salmonids per M^2
New Channel Reach	High Gradient Riffle	2	YES	318	23	0.07
	Low Gradient Riffle	4	YES	1,797	449	0.28
	Low Gradient Riffle w/ Pockets	3	YES	654	280	0.43
	Run/Glide	2	YES	940	482	0.51
	Pool	5	YES	1,409	1,431	1.02
	Low Gradient Riffle	3	NO	561	157	0.28
	Side and off-channel	4	NO	2,190	1,161	0.53
	TOTALS	**23**	**YES**	**7,869**	**3,983**	**-**
Abandoned Channel Reach	Rapid	3	YES	862	241	0.28
	Riffle	3	YES	989	208	0.21
	Run/Glide	1	YES	244	107	0.44
	Pool	1	YES	509	232	0.46
	Riffle	4	NO	1,649	347	0.21
	Rapid	1	NO	268	75	0.28
	Run	1	NO	170	74	0.44
	Pool	1	NO	229	104	0.46
	TOTALS	**15**	**YES**	**4,920**	**1,389**	**-**

As described above no expansion was needed to estimate total detectable salmonids in the new channel reach (including side and off-channel habitats) in 2012. A total of 4,060 total salmonids were documented in 2012 which represents a 2 percent increase over the 2011 estimate and a nearly 200 percent increase over the 2010 abandoned channel estimate. When comparing 2012 new channel estimates to the abandoned channel one must consider annual fluctuations in abundance. For example, within the control reach the number of total salmonid counted in 2012 was only 45 percent of that counted in 2010. Adjusting the abandoned channel total salmonid estimate based on the control reach ratio of 2012 to 2010 yields an estimate for 2012 of only 629 total salmonids. The new channel 2012 total salmonid abundance is 488 percent higher than this estimate.

5.4 Macroinvertebrate Sampling

Post-project macroinvertebrate sampling at Morse Creek indicates poor biological integrity. The low BIBI scores are likely due to the restoration project having rerouted the stream into a new streambed. The new channel would be expected to have few long-lived taxa, intolerant taxa, and predator taxa. The sampling indicated that the percentage of predator individuals and long-lived taxa were low.

The BIBI score was much improved in 2011 (23) as compared to 2010 (18). The improved score was directly attributable to increases in clinger taxa, mayfly richness, and overall taxa richness. The score for long-lived taxa in both years was likely low due their requirement of more than one year to complete their life cycle. Additional monitoring is needed to see if these taxa will establish at the site. Samples were collected in 2012 but results were not available at the time this report was written.

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