# WHEEL CREEK

# GEOMORPHIC ASSESSMENT

# YEAR 2

# FINAL REPORT

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**May 20, 2013**

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# WHEEL CREEK
# GEOMORPHIC ASSESSMENT
# YEAR 2 FINAL REPORT

Prepared for:

Harford County
Department of Public Works
Division of Highways and Water Resources
220 South Main Street, 2nd Floor
Bel Air, Maryland 21014

Prepared by

Versar, Inc.
9200 Rumsey Road, Suite 100
Columbia, Maryland 21045

May 20, 2013

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# TABLE OF CONTENTS

Page

**1.0 INTRODUCTION ..... 1-1**

**2.0 METHODOLOGIES ..... 2-1**
2.1 GEOMORPHIC ASSESSMENT ..... 2-1
2.1.1 Longitudinal Profile and Cross-sectional Surveys ..... 2-1
2.1.2 Bank Stability (Bank Pins) ..... 2-2
2.1.3 Bed Scour (Scour Chains) ..... 2-2
2.1.4 Particle Size Analysis ..... 2-3

**3.0 RESULTS AND DISCUSSION ..... 3-1**
3.1 FLUVIAL GEOMORPHIC ASSESSMENT ..... 3-1
3.1.1 Longitudinal Profiles and Cross-sectional Surveys ..... 3-1
3.1.2 Bed/Bank Stability ..... 3-2
3.1.3 Particle Size Analysis ..... 3-7

**4.0 COMPARISONS BETWEEN YEARS ..... 4-1**
4.1 WC01 ..... 4-1
4.2 WC02 ..... 4-2
4.3 WC03 ..... 4-2
4.4 WC04 ..... 4-3

**5.0 CONCLUSIONS ..... 5-1**

**6.0 REFERENCES ..... 6-1**

APPENDICES

A PHOTOS ..... A-1
B GEOMORPHIC ASSESSMENT DATA ..... B-1
C ANNUAL COMPARISONS ..... C-1

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# LIST OF TABLES

**Table No.** **Page**

2-1. Cross-sectional survey locations ..... 2-1
2-2. Scour chain locations ..... 2-3
3-1. Results of longitudinal profile survey ..... 3-1
3-2. Results of cross-sectional survey analysis ..... 3-2
3-3. WC01 Bank Pin Erosion – Year 2 ..... 3-2
3-4. WC02 Bank Pin Erosion – Year 2 ..... 3-3
3-5. WC03 Bank Pin Erosion – Year 2 ..... 3-3
3-6. WC04 Bank Pin Erosion – Year 2 ..... 3-5
3-7. Bed scour rates Year 2 ..... 3-7
3-8. Particle size distribution ..... 3-8

# LIST OF FIGURES

**Figure No.** **Page**

1-1. Site vicinity map ..... 1-3
2-1. Wheel Creek monitoring locations ..... 2-2
3-1. Cumulative change in Bankpin Exposure by Reach ..... 3-4
3-2. Bed scour measurements ..... 3-6

# 1.0 INTRODUCTION

Harford County Department of Public Works (DPW) is undertaking the restoration of the Wheel Creek watershed, which is located in the Bush River Basin in the central portion of Harford County near Bel Air (Figure 1-1). The restoration project is the result of previous planning efforts including the Bush River Watershed Restoration Strategy (WRAS), the Bush River Watershed Management Plan in 2003, and more recently, the Wheel Creek Watershed Assessment completed in 2008.

As part of implementing the restoration efforts, the County has been awarded funds from a Local Government Implementation Grant through the Chesapeake and Atlantic Bays 2010 Trust Fund. Under the grant proposal, the County will be implementing five stormwater retrofits and four stream restoration projects to improve water quality, decrease stormwater discharges, and improve stream habitat.

Beginning in 2009, the County initiated monitoring to demonstrate measureable reductions of sediment and nutrients, improvement in physical stability and instream habitat, and improvement in fish and benthic macroinvertebrates communities. As a collaborative monitoring effort, Harford County DPW, Maryland Department of Natural Resources (DNR), the United States Geologic Survey (USGS), and two consulting firms (KCI Technologies and Versar, Inc.) have performed select data collection activities. The study design was developed to compare pre-construction conditions (i.e., baseline conditions) to future post-construction restoration conditions. This report focuses on baseline geomorphic monitoring, conducted by KCI and Versar. Data generated by other project partners includes:

- USGS –flow gaging at the downstream end of Wheel Creek (5-minute interval discharge record);
- Maryland DNR – flow gaging at three stations, one at Wheel Road and two upstream on the eastern tributary at Cinnabar Lane and Wheel Court (5-minute interval discharge record);
- Maryland DNR MBSS – Biological and physical habitat data; and
- Harford County DPW – Nutrient and sediment data at three stations, one at Wheel Road and two upstream on the eastern tributary at Cinnabar Lane and Wheel Court (pollutant loads and loading rates for the measured parameters for each sampled event).

Assessment and monitoring of the physical geomorphologic conditions was initially performed by KCI in 2010 (Year 1) to evaluate baseline conditions and was continued by Versar in 2012 (Year 2). The geomorphic monitoring program was designed to assess the geomorphic stability of the stream channels in the Wheel Creek watershed as they respond to restoration activities. The geomorphic monitoring includes surveying and analyzing monumented cross-sections and longitudinal profiles at four (4) reaches, monitoring bankpins and scour chains, mapping substrate facies (Year 1 only), and evaluating substrate particle size distribution. The

methods evaluate bed and bank stability, channel profile, and bed features. For a complete description of the Year 1 Study see Wheel Creek Watershed Restoration Project, Pre-Construction Monitoring, Baseline Conditions, 2009-2011 (KCI, 2012). This report focuses on continued baseline geomorphic monitoring, including a comparison of Year 1 and Year 2 data.

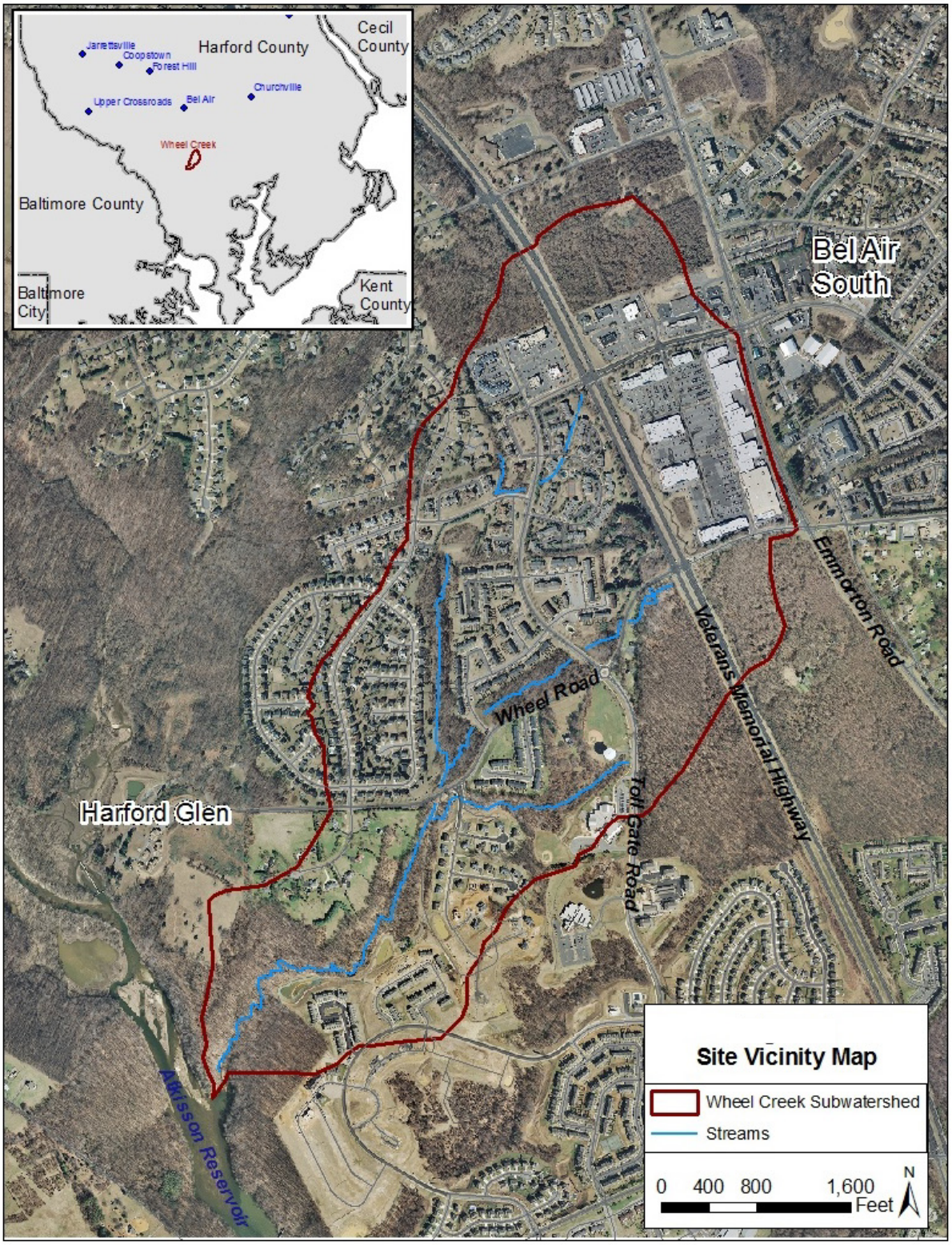


Figure 1-1. Site vicinity map

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# 2.0 METHODOLOGIES

## 2.1 GEOMORPHIC ASSESSMENT

The primary goal of the geomorphic monitoring is to assess the geomorphic stability of the stream channels in the Wheel Creek watershed as they respond to restoration activities. Assessment techniques include a survey of permanently-monumented channel cross-sections, a longitudinal profile survey, particle size analysis, substrate facies mapping (Year 1 only), and assessment of bank pins and scour chains. In 2010, four (4) assessment reaches (Figure 2-1) were established by KCI for geomorphic monitoring based on the following treatments:

1) within a proposed stream stabilization reach (WC01);
2) downstream of a stream stabilization reach and BMP retrofit location (WC02);
3) downstream of a BMP retrofit location only (WC03); and
4) a control site with no proposed restoration activities (WC04).

These reaches were re-surveyed by Versar in 2012 to provide an additional year of pre-restoration monitoring data. Cross-sectional and longitudinal profile surveys were conducted to establish baseline conditions of channel geometry and slope, to which subsequent data can be compared in determining whether lateral or vertical migration of the channel is occurring. Bank and bed pins are monitored to determine rates of potential bank and channel bed erosion or aggradation, while scour chains are used to quantify the extent of bed material scouring. Pebble counts are conducted to assess substrate particle size distribution and track changes in channel roughness. Detailed methods are described below.

### 2.1.1 Longitudinal Profile and Cross-sectional Surveys

KCI installed and surveyed three (3) benchmark monuments at each reach during the initial baseline monitoring effort to establish consistent survey elevations from year to year, as well as start and end points for each survey reach. Two benchmarks (one concrete monument and one capped iron rebar pin) were placed on either side of the channel, whereby a measuring tape run from the left bank pin to the right bank monument marks the starting point (i.e., station 0+00) in the channel for the longitudinal profile. The concrete monument was set in 2-inch PVC piping to a depth of 30 inches, with a rounded stove bolt set in the concrete to establish the monumented benchmark elevation, which will be used to compare longitudinal profiles over time. A third monument (capped iron rebar) was placed at the upstream end of the reach to mark the end of the survey reach. Versar re-surveyed these benchmarks during the Year 2 effort to enable overlays between surveys.

A longitudinal profile of each reach was surveyed using a laser level, calibrated stadia rod, and 300-foot measuring tape following the procedure outlined in Harrelson et al. (1994). The profiles were established along the centerline of each bankfull channel and included a survey of breakpoints in and between bed features and delineation of riffle, run, pool, and glide features.

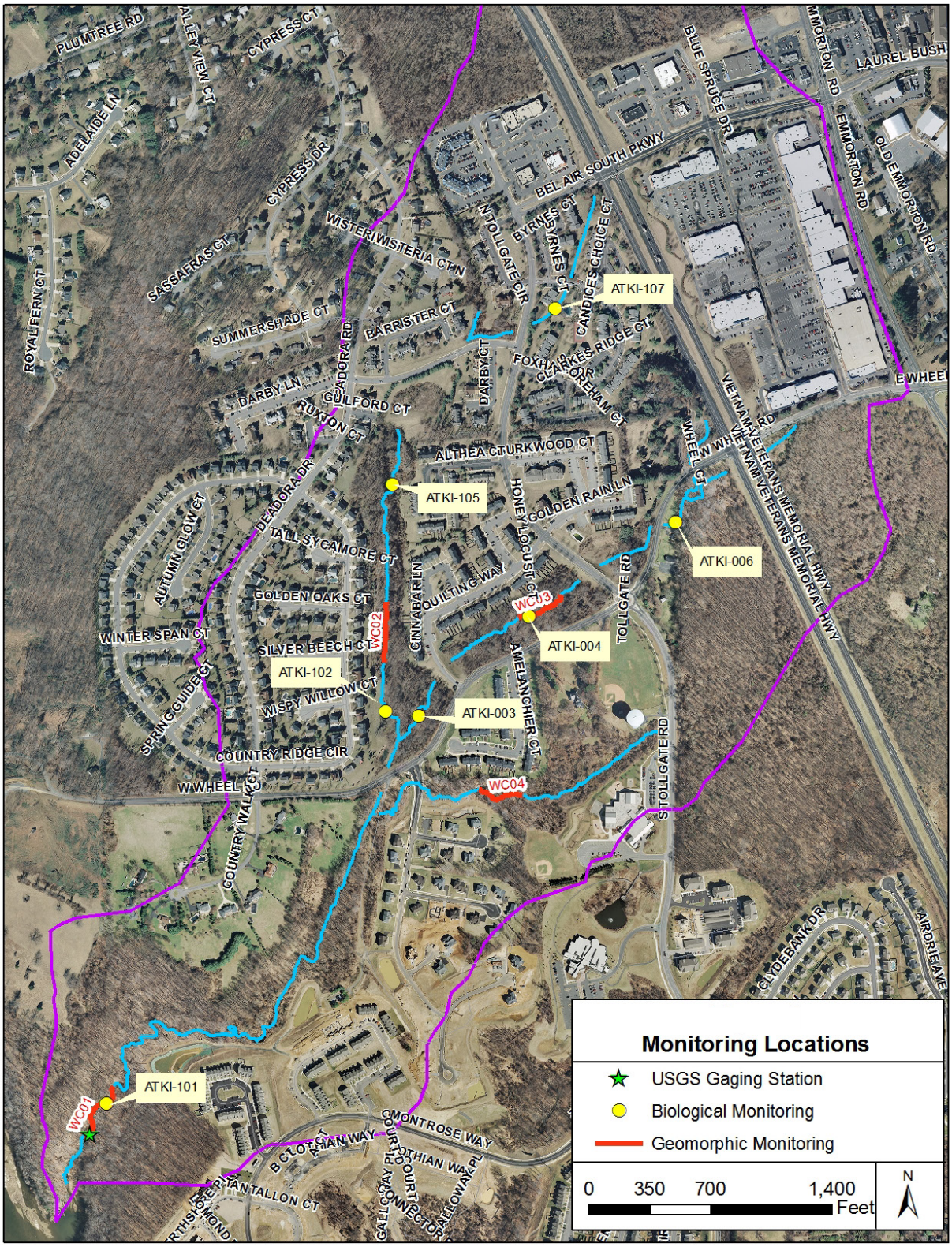


Figure 2-1. Wheel Creek monitoring locations

A survey of the bankfull elevation (where discernible), top of bank, and water surface was also performed. The plotted longitudinal profile was overlaid with the plot from Year 1. These pre-restoration plots serve as baselines for comparison during subsequent years and will be used to track changes that occur in the bed sequences and channel slopes.

In order to establish locations where fluvial geomorphic characteristics of the channel could be measured and compared from one year to the next for assessing bed and bank stability, KCI established permanent cross-sections at two (2) locations within each monitoring reach; one located on a meander bend and one within a riffle feature. KCI established monuments (one concrete and one capped iron rebar) on either side of the channel to mark the cross-section locations and benchmark elevations. Concrete monuments were set in 2-inch PVC piping to a depth of 30 inches, with a rounded metal stove bolt set in the concrete to mark the monumented elevation. Wherever possible, the monuments were set flush to the ground surface for safety concerns, and the location of each monument was recorded using a GPS unit capable of sub-meter accuracy.

Permanent cross-sections were established and surveyed within each reach at profile stations as shown in Table 2-1. Stationing differed slightly at two stations during Year 2 due to channel migration.

Table 2-1. Cross-sectional survey locations

| Reach | Profile Station (Year 1) | Profile Station (Year 2) | Feature |
|---|---|---|---|
| WC01 | 2+30 | 2+30 | Riffle |
| | 2+95 | 2+95 | Meander |
| WC02 | 1+37 | 1+38 | Riffle |
| | 3+24 | 3+24 | Meander |
| WC03 | 1+55 | 1+57 | Riffle → Pool |
| | 2+07 | 2+08 | Meander |
| WC04 | 1+08 | 1+08 | Meander |
| | 1+68 | 1+68 | Riffle |

During Year 2, Versar resurveyed the cross-sections using a laser level, calibrated stadia rod, and measuring tape following the procedure outlined in Harrelson et al. (1994). The cross-sectional surveys captured features of the floodplain, monuments, and all pertinent channel features including:

- Top of bank
- Bankfull elevation
- Edge of water
- Limits of point and instream depositional features
- Thalweg
- Floodprone elevation

Longitudinal profile and cross-sectional data were entered into *The Reference Reach Spreadsheet* version 4.3L (ODNR 2012) for data analysis and graphical interpretation. Profile and cross-sectional data collected in 2010 and 2012 will provide the pre-restoration baseline conditions to which subsequent monitoring events will be overlaid and compared to assess whether any measureable change is occurring to the channel dimensions.

For the purpose of this report, bankfull elevations were selected based upon bankfull indicators observed in the field. Channel geometry and cross-sectional areas were calculated using *The Reference Reach Spreadsheet* (ODNR 2012). Because bankfull indicators are not always easily discernible from year to year and best professional judgment is often required to determine bankfull elevations, top of bank features were also measured. Top of low bank cross-sectional areas were also calculated and will be utilized for future monitoring events to generate hydraulic geometry values that are more directly comparable between each monitoring effort.

### 2.1.2 Bank Stability (Bank Pins)

To monitor channel adjustments and measure rates of bank erosion and/or deposition, KCI installed bank and toe pins at four (4) locations exhibiting notable erosion within each monitoring reach during the initial year of investigation. Three (3) bank pins were installed at each location, two along the visibly eroding bank and one on the opposite bank or point bar, for a total of 12 pins per reach. During the 2012 geomorphic survey, Versar located and measured the exposed length of each pin along the upper surface of the pin. In five (5) cases, pins initially installed during Year 1 were not recovered, and were replaced during the Year 2 survey (two pins at WC01, one pin at WC02, and two pins at WC03).

When replacement was necessary, two-foot iron rebar pins (1/2-inch diameter) were hammered horizontally into the vertical bank face of each bank, or vertically if on a depositional feature (i.e., toe pin), until only a few inches were exposed above the surface. To assist with finding pins during subsequent monitoring events, the exposed portion was spray painted orange and bright pink ribbon flagging was attached, the approximate stations within the reach were recorded and photo-documented. In general, bank pins were installed at approximately bankfull and bank toe elevations along outer meanders and at the bank toe or lower point bar on inner meanders.

### 2.1.3 Bed Scour (Scour Chains)

During the initial year of monitoring, KCI installed scour chains in each reach within the thalweg thread of the channel, typically at both cross section locations. When the channel was wide enough, KCI installed two chains within the riffle cross section location. In some instances, KCI was unable to install scour chains at both cross section locations due to the bed substrate, thus only one scour chain was installed per reach for site WC03 and WC04. The stations within each cross section where each chain is located was recorded (Table 2-2), and a GPS device was also used to record the spatial location within the reach. During the Year 2

monitoring effort, Versar located and (when possible) measured the exposed length of each chain (excluding the washer) to assess bed scour and deposition rates.

Table 2-2. Scour chain locations

| Reach | Profile Station | Cross-Section Station |
|---|---|---|
| WC01 | 2+30 | 47 |
| | 2+30 | 50.7 |
| | 2+95 | 21.5 |
| WC02 | 1+37 | 12 |
| | 1+37 | 15 |
| | 3+24 | 25.5 |
| WC03 | 1+55 | 12 |
| WC04 | 1+68 | 21 |

### 2.1.4 Particle Size Analysis

Channel substrate composition (e.g., gravel, sand, silt) is an important aspect of a stream's biological and geomorphic character. The substrate size and complexity affects the stream's available habitat for benthic fauna and determines a channel's roughness, which influences the channel flow characteristics. To quantify the distribution of channel substrate particle sizes within the study area, modified Wolman pebble counts (Wolman, 1954; Harrelson et al., 1994) were performed. A total of three (3) pebble counts were conducted within each monitoring reach; feature-specific pebble counts were conducted at each cross section location within the cross-sectional bed feature (typically riffles), and a weighted pebble count was conducted throughout the entire reach based on the proportion of bed features (e.g., riffle, run, pool, glide) present within the survey reach. Feature-specific pebble counts were performed via 10 evenly-spaced transects positioned throughout the survey feature, and 10 particles (spaced as evenly as possible) were measured across the bankfull channel of each transect for a total of 100 particles. The weighted (proportional) pebble count was conducted at 10 transects positioned throughout the entire reach based on the proportion of bed features, and 10 particles (spaced as evenly as possible) were measured across the bankfull channel of each transect for a total of 100 particles. For both types of counts, particles were chosen without visual bias by reaching forth with an extended finger into the stream bed while looking away and choosing the first particle that comes in contact with the sampler's finger. All particles were then measured across the intermediate axis using a gravelometer and resultant data were entered into *The Reference Reach Spreadsheet* (ODNR 2012). The results of each weighted pebble count were used to determine the median particle size (i.e., $D_{50}$) of the specific reach. Additionally, the $D_{84}$ was calculated from the feature pebble counts to determine the particle size that 84 percent of the sample is of the same size or smaller. The $D_{84}$ particles were used in calculating channel velocity and

discharge. Results from Versar's Year 2 evaluations were compared to those found during the initial year of monitoring to evaluate changes in channel substrate composition.

# 3.0 RESULTS AND DISCUSSION

## 3.1 FLUVIAL GEOMORPHIC ASSESSMENT

### 3.1.1 Longitudinal Profiles and Cross-sectional Surveys

The second year of baseline longitudinal profile and cross-sectional surveys were completed between November 6 and November 20, 2012. While performing the longitudinal profile, bed features including riffles, runs, pools, glides, bankfull indicators (where readily discernible), and water surface were noted to sufficiently assess conditions. The longitudinal profile data were analyzed to calculate the water surface slope and proportion of bed features for each monitoring reach (Table 3-1). These data will be compared to previous and subsequent annual monitoring data to track potential changes in the overall channel slope. Refer to Appendix A for photographs depicting the overall site conditions during the Year 2 baseline survey. Graphical depictions of each profile are presented in Appendix B. In addition, each surveyed profile was plotted, overlain and compared to the Year 1 baseline condition profile (Appendix C) and will be compared to subsequent annual surveyed profiles in order to assess changes occurring in the bed structure.

Table 3-1. Results of longitudinal profile survey – Year 2

| Reach | Length (ft) | Slope | Proportion of Features | | | |
|---|---|---|---|---|---|---|
| | | | Riffle | Run | Pool | Glide |
| WC01 | 420 | 2.2% | 54.6% | 7.3% | 29.2% | 8.9% |
| WC02 | 350 | 2.4% | 33.7% | 11.0% | 38.6% | 16.7% |
| WC03 | 300 | 1.8% | 24.0% | 8.5% | 54.9% | 12.6% |
| WC04 | 300 | 3.4% | 41.3% | 16.2% | 30.3% | 12.2% |

Cross-sectional surveys were analyzed at each of the eight permanent monitoring locations to determine bankfull width, mean depth, width/depth ratio, and overall cross-sectional area during baseline conditions. Since bankfull elevation is based on field indicators and can be somewhat subject to determine in the field, top-of-bank elevation was also calculated and will be utilized to track changes in the cross-sectional dimensions listed below. Results of the cross-sectional measurements are included in Table 3-2 and graphical depictions of each section are presented in Appendix B. In addition, each surveyed section was plotted, overlain and compared to the Year 1 baseline condition graph (Appendix C) and will be compared to subsequent annual cross-section graphs in order to assess changes to channel dimensions.

Table 3-2. Results of cross-sectional survey analysis – Year 2

| Reach | Station | Feature | Bankfull Width (ft) | Mean Depth (ft) | Width/ Depth Ratio | Entrench-ment Ratio | Bankfull Area ($ft^2$) | Top of Bank Area ($ft^2$) |
|---|---|---|---|---|---|---|---|---|
| WC01 | 2+30 | Crossover Riffle | 21.3 | 1.1 | 18.6 | 1.5 | 24.5 | 78.1 |
| | 2+95 | Meander/Riffle | 28.9 | 0.8 | 37.5 | 1.5 | 22.3 | 246.9 |
| WC02 | 1+38 | Crossover Riffle | 14.3 | 0.6 | 24.1 | 1.2 | 8.5 | 37.1 |
| | 3+24 | Meander/Riffle | 14.6 | 0.6 | 23.8 | 1.4 | 9 | 71.7 |
| WC03 | 1+57 | Pool | 10.6 | 1.1 | 9.8 | 1.3 | 11.4 | 41.3 |
| | 2+08 | Meander/Pool | 10.2 | 1.2 | 8.4 | 2.5 | 12.5 | 56.2 |
| WC04 | 1+08 | Meander/Pool | 6.7 | 0.6 | 11.4 | 3.9 | 4.0 | 95.9 |
| | 1+68 | Crossover Riffle | 9.2 | 0.5 | 18.9 | 1.5 | 4.4 | 57.8 |

### 3.1.2 Bed/Bank Stability

Tables 3-3 through 3-6 display the location of bank pins within each reach as well as the corresponding annual erosion rates as measured from end of March 2011 to mid-November 2012. Erosion rates were calculated from cumulative changes in pin exposure over time for each bank pin (Figure 3-1), whereby positive values depict erosion and negative values depict deposition or other geotechnical bank failure processes acting on the banks (e.g., mass wasting, bank slumping, frost heaving). It should be noted that annual erosion rates, presented in feet per year, were derived by calculating the total erosion or deposition over the 85-week period between measurements and scaling it to a one-year period based on the standard of 52 weeks in a year. Complete data on pin measurements for each visit are included in Appendix B.

Table 3-3. WC01 bank pin erosion – Year 2

| Profile Station | Bank | Pin Location | Measured Erosion Rate (ft/yr) |
|---|---|---|---|
| 0+21 | Left - outer | Upper | 0.03 |
| | Left - outer | Lower | 0.02 |
| | Right - inner | Lower | -0.05 |
| 1+30 | Left - inner | Toe | -0.13 |
| | Right - outer | Upper | 0.00 |
| | Right - outer | Lower | 0.00 |
| 1+92 | Left - inner | Toe | NA* |
| | Right - outer | Upper | -0.03 |
| | Right - outer | Lower | 0.14 |
| 3+80 | Left - inner | Toe | -0.25 |
| | Right - outer | Upper | 0.77 |
| | Right - outer | Lower | NA* |

* Not Available – due to pin loss between the Year 1 and Year 2 assessments, erosion rate could not be caluclated at these locations.

Table 3-4. WC02 bank pin erosion – Year 2

| Profile Station | Bank | Pin Location | Measured Erosion Rate (ft/yr) |
|---|---|---|---|
| 0+24 | Left - outer | Upper | 0.04 |
| | Left - outer | Lower | NA* |
| | Right - inner | Toe | -0.24 |
| 2+00 | Left - outer | Upper | -0.02 |
| | Left - outer | Lower | -0.01 |
| | Right - inner | Toe | NA* |
| 2+88 | Left - outer | Upper | 0.00 |
| | Left - outer | Lower | 0.07 |
| | Right - inner | Toe | -0.17 |
| 3+50 | Left - outer | Upper | 0.17 |
| | Left - outer | Lower | -0.01 |
| | Right - inner | Toe | 0.15 |

* Not Available – due to pin loss between the Year 1 and Year 2 assessments, erosion rate could not be caluclated at these locations.

Table 3-5. WC03 bank pin erosion – Year 2

| Profile Station | Bank | Pin Location | Measured Erosion Rate (ft/yr) |
|---|---|---|---|
| 0+75 | Left - outer | Upper | 0.00 |
| | Left - outer | Lower | 0.00 |
| | Right - inner | Lower | 0.01 |
| 1+41 | Left - outer | Upper | 0.05 |
| | Left - outer | Lower | 0.08 |
| | Right - inner | Lower | 0.03 |
| 1+83 | Left - inner | Lower | -0.05 |
| | Right - outer | Upper | 0.04 |
| | Right - outer | Lower | 0.02 |
| 2+73 | Left - outer | Upper | NA* |
| | Left - outer | Lower | NA* |
| | Right - inner | Lower | 0.31 |

* Not Available – due to pin loss between the Year 1 and Year 2 assessments, erosion rate could not be caluclated at these locations.

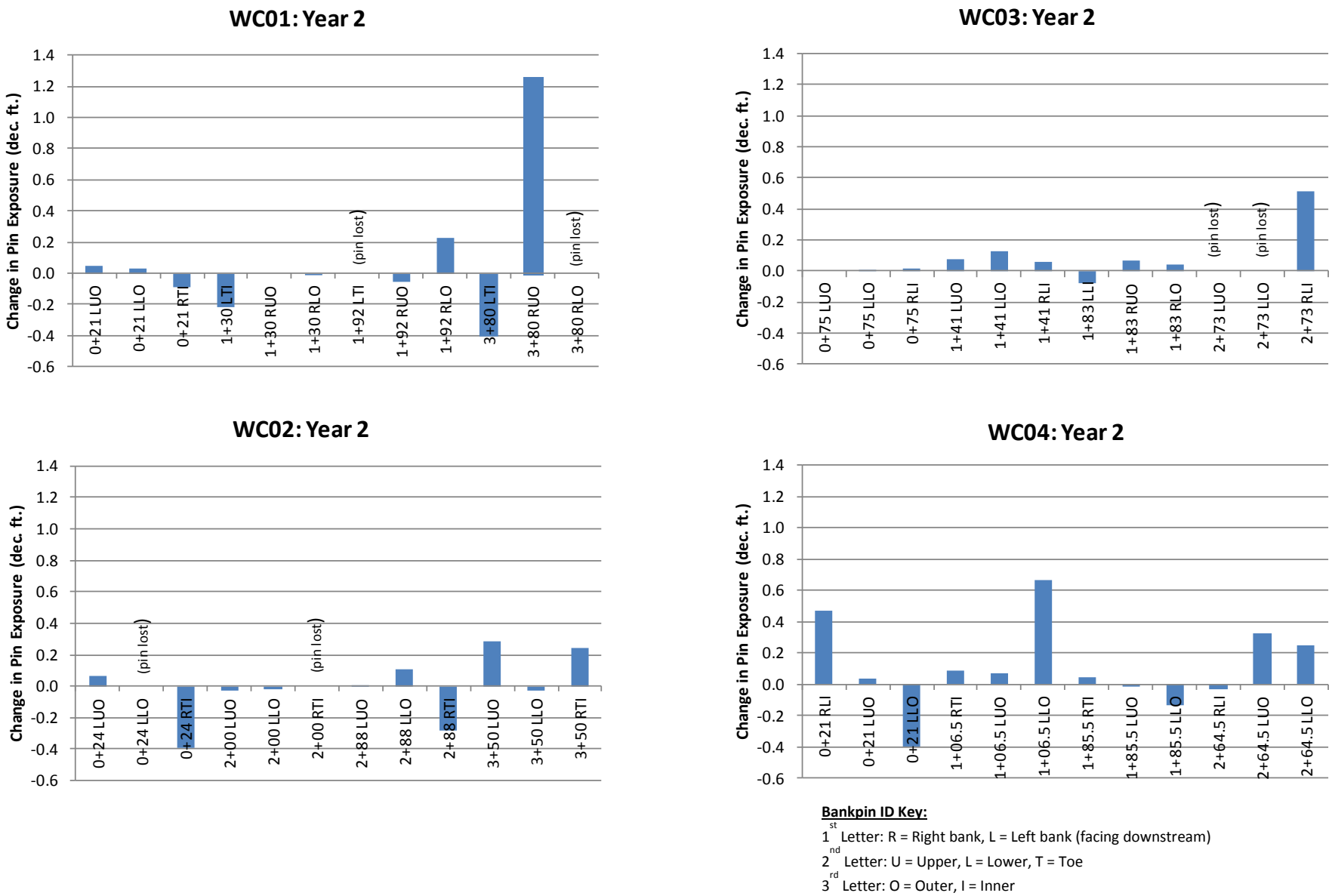


Figure 3-1. Cumulative change in Wheel Creek bankpin exposure by reach between March 31, 2011 and mid-November 2012. Between Year 1 and Year 2, pins were lost at WC01 Station 1+92 LTI and 3+80 RLO, at WC02 Stations 0+24 LLO and 2+00 RTI, and at WC03 Stations 2+73 LUO and 2+73 LLO.

Table 3-6. WC04 bank pin erosion – Year 2

| Profile Station | Bank | Bank Location | Measured Erosion Rate (ft/yr) |
|---|---|---|---|
| 0+21 | Right - inner | Lower | 0.29 |
| | Left - outer | Upper | 0.02 |
| | Left - outer | Lower | -0.24 |
| 1+06.5 | Right - inner | Toe | 0.06 |
| | Left - outer | Upper | 0.04 |
| | Left - outer | Lower | 0.41 |
| 1+85.5 | Right - inner | Toe | 0.03 |
| | Left - outer | Upper | -0.01 |
| | Left - outer | Lower | -0.08 |
| 2+64.5 | Right - inner | Toe | -0.02 |
| | Left - outer | Upper | 0.20 |
| | Left - outer | Lower | 0.15 |

Measured erosion rates in reach WC01 ranged from 0.00 to 0.77 ft/year with the highest erosion occurring along the outer meander bend at profile station 3+80. It should be noted that the lower pin at this station was washed out of the banks between sampling events and was reset in November 2012 for future monitoring. Deposition rates at WC01 ranged from -0.03 to -0.25 ft/yr. Deposition likely also prevented Versar crews from locating the left toe pin at profile station 1+92, as a large bar has built up along this bank. Erosion rates ranged from 0.00 to 0.17 ft/yr at WC02, while deposition rates ranged from -0.01 to -0.24 ft/yr. At this site, one left bank pin was not found at profile station 0+24, an area experiencing significant bank undercutting. Similarly, the right bank pin at station 2+00 was found fallen out of the bank, as the right bank had collapsed somewhat at this location. Erosion rates at site WC03 ranged from 0.00 to 0.31 ft/yr with the highest erosion occurring at profile station 2+73. Erosion of the outside bend at this location is so severe that both pins were lost between surveys (see Appendix A for photograph). Thus, the maximum erosion rate at this site is likely significantly higher than these data show, but could not be calculated due to pin loss. Erosion also occurred along the point bar on the opposite bank at this station. Deposition at WC03 was only observed at one pin, a left toe pin at station 1+83, where the deposition rate was -0.05 ft/yr. At reach WC04, measured erosion rates ranged from 0.02 to 0.41 ft/yr, with the highest erosion rate occurring on the left bank just downstream of the meander bend cross section. Depositional rates in this reach ranged from -0.01 to -0.24 ft/yr.

Figure 3-2 displays the cumulative depth of scour for each scour chain during the March 31, 2011 to mid-November 2012 period of measurement, whereby positive values indicate cumulative bed scouring and negative values indicate cumulative deposition. When deposition occurred on top of a scoured chain, the cumulative change was calculated. It is important to note that the chain at station 2+95 in reach WC01 was not able to be located after September 3, 2010, and no measures of scour (or deposition) could be made during the Year 2 survey. Also of note, at reach WC02, crews were unable to uncover the entire length of chain after excavating down more than half a foot to reach the buried chains at station 1+38 (left chain) and 3+34. In these

cases, we assumed no additional scour occurred. Complete data reflecting individual scour chain measurements are included in Appendix B.

During the period of March 31, 2011 to mid-November 2012, cumulative bed scour occurred within two reaches (WC01 and WC04). The largest amount of scour, 0.47 feet, was measured at station 2+30 in reach WC01. Cumulative deposition occurred at all other chains, with the most deposition occurring in reach WC02. Station 3+24 (WC02) had 0.58 feet of deposition, the most observed at any chain.

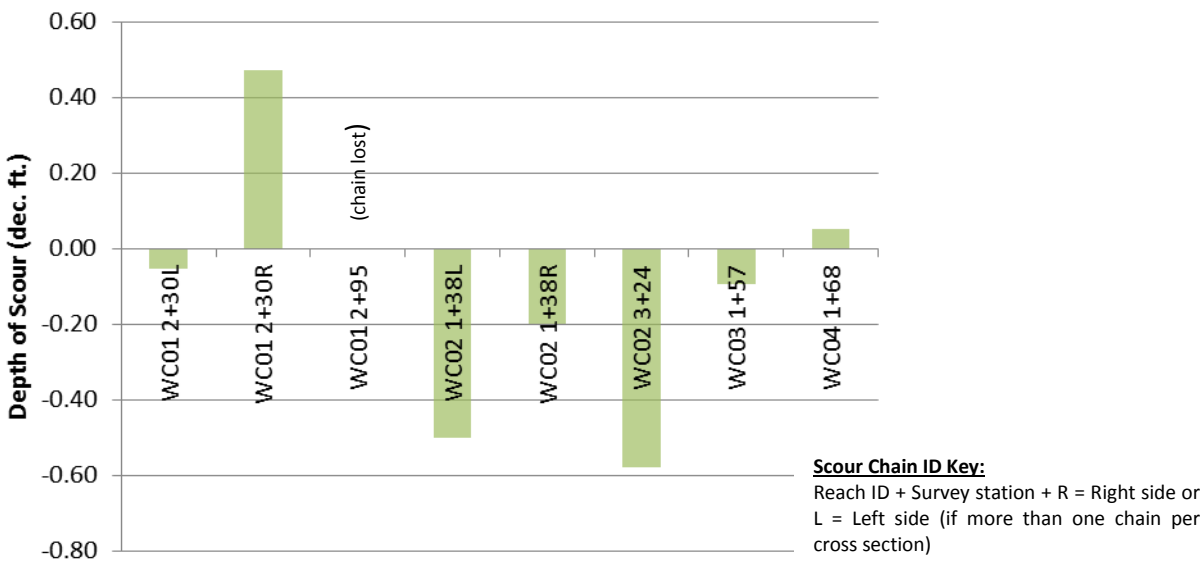


Figure 3-2. Bed scour in Wheel Creek between March 31, 2011 and mid-November 2012 as measured through scour chain analysis at each reach. The scour chain at station 2+95 in WC01 was not able to be located for measurement.

Table 3-7 displays the location of scour chains within each reach as well as the corresponding annual scour rates as measured from end of March 2011 to mid-November 2012. Scour rates were calculated from cumulative changes in chain exposure and deposition on top of chains over time for each scour chain (Figure 3-2), whereby positive values depict scour and negative values depict deposition. It should be noted that annual scour rates, presented in feet per year, were derived by calculating the cumulative change over the 85-week period between measurements and scaling it to a one-year period based on the standard of 52 weeks in a year.

Table 3-7. Bed scour rates Year 2

| Reach | Profile Station, 2012 | Feature, 2012 | Cross Section Station | Cumulative Change from March 2011 | Annual rate of scour (ft/yr) |
|---|---|---|---|---|---|
| WC01 | 2+30 | Riffle | 47 | -0.05 | -0.03 |
| | 2+30 | Riffle | 50.7 | 0.47 | 0.29 |
| | 2+95 | Meander | 21.5 | N/A* | N/A* |
| WC02 | 1+38 | Riffle | 12 | -0.50 | -0.31 |
| | 1+38 | Riffle | 15 | -0.20 | -0.12 |
| | 3+24 | Riffle | 25.5 | -0.58 | -0.35 |
| WC03 | 1+57 | Pool | 12 | -0.09 | -0.06 |
| WC04 | 1+68 | Riffle | 21 | 0.05 | 0.03 |

* N/A = Not available – scour chain at WC01 station 2+95 was not able to be located.

### 3.1.3 Particle Size Analysis

The results of the pebble count data collected during the Year 2 monitoring are shown in Table 3-8. Reachwide and riffle surface pebble counts indicate a D50 median particle size class ranging from coarse to very coarse gravel across all sites. Meander feature surface pebble counts indicate a D50 ranging from medium to very coarse gravel, due to pool features at sites WC03 and WC04 yielding slightly smaller particles. Riffle surface and meander surface D84 size classes range from small to large cobble at sites WC01, WC02, and WC04, with the largest particles found at site WC01. At WC03, riffle surface and meander surface D84 are in the very coarse gravel size class. Reachwide, all sites had D84 in the small cobble size class, with the exception of WC01, which had a D84 of 120 mm representing large cobble material. Compete particle size distribution charts are included in Appendix B.

Table 3-8. Particle size distribution

| ***Riffle Feature Surface*** | | | ***Meander Feature Surface*** | | | ***Reachwide*** | | |
|---|---|---|---|---|---|---|---|---|
| **Measure** | **Size (mm)** | **Size Class** | **Measure** | **Size (mm)** | **Size Class** | **Measure** | **Size (mm)** | **Size Class** |
| *WC01* | | | | | | | | |
| D50 | 56 | very coarse gravel | D50 | 40 | very coarse gravel | D50 | 51 | very coarse gravel |
| D84 | 180 | large cobble | D84 | 77 | small cobble | D84 | 120 | medium cobble |
| *WC02* | | | | | | | | |
| D50 | 40 | very coarse gravel | D50 | 33 | very coarse gravel | D50 | 28 | coarse gravel |
| D84 | 80 | small cobble | D84 | 69 | small cobble | D84 | 80 | small cobble |
| *WC03* | | | | | | | | |
| D50 | 27 | coarse gravel | D50 | 15 | medium gravel | D50 | 23 | coarse gravel |
| D84 | 59 | very coarse gravel | D84 | 43 | very coarse gravel | D84 | 72 | small cobble |
| *WC04* | | | | | | | | |
| D50 | 36 | very coarse gravel | D50 | 15 | medium gravel | D50 | 24 | coarse gravel |
| D84 | 64 | small cobble | D84 | 70 | small cobble | D84 | 76 | small cobble |

# 4.0 COMPARISONS BETWEEN YEARS

## 4.1 WC01

This site exhibited the most drastic changes in longitudinal profile over the two years of baseline monitoring. At the downstream-most part of the reach, the stream's thalweg followed along the left bank outside bend during the first year of survey with a large mid-channel bar separating the thalweg from a cutoff channel along the right bank. During the second year of baseline monitoring, the thalweg followed what had been the cutoff channel along the right bank and the previous thalweg channel had only minimal flows. At the upstream-most part of the reach, the stream's pattern also changed. Stationing differed from above Cross-Section 2 (Station 2+95) to the end of the reach. During the first year of monitoring, the reach was 400 feet from top to bottom, but during the second year, the reach was 420 feet in length. Sinuosity above Cross-section 2 likely increased, adding length to the profile. (*Note: To complete the graphical overlay of the longitudinal profiles of Year 1 and Year 2 (Figure C-1), we adjusted the stationing of the Year 1 survey from above Cross-Section 2 to the longitudinal profile survey end pin. The end pin stationing was adjusted to 420 feet to match the profile stationing of Year 2.*)

Changes in the cross-sections were also observed at WC01 between the two years of survey (Figures C-5, C-6). Bed scour was observed at Cross-section 1 (Crossover Riffle at Station 2+30) especially near the right bank. Significant bank erosion and undercutting along the left bank (almost 6 feet) was observed at Cross-Section 2 (Meander Bend at Station 2+95). This has resulted in increases of bankfull cross-sectional area and top of bank cross-sectional area at this station. A side-bar has formed on the right bank, burying the scour chain at this cross-section. In addition, the thalweg is no longer perpendicular to the permanently monumented cross-section markers at this location.

Annual bank erosion rates as estimated from bank pin measurements followed similar patterns between the two years, with increased deposition occurring at the toe pins during the second year of study (Table C-3). Deposition resulted in the complete burying and inability to recover the toe pin at one station (1+92). During both years, the most significant bank erosion was observed at the upper-most portion of the reach (station 3+80), which is also where the most significant change in channel length and sinuosity was observed.

Annual rates of scour were estimated based on the baseline scour chain exposure from initial chain installation in June 2010 through chain measurement in November of 2012 (Table C-4). Scour rates were calculated from cumulative changes in chain exposure and deposition on top of chains over time for each scour chain, whereby positive values depict scour and negative values depict deposition. It should be noted that annual scour rates, presented in feet per year, were derived by calculating the cumulative change over the 127-week period between measurements and scaling it to a one-year period based on the standard of 52 weeks in a year. The chain at WC01 Station 2+30 (right) exhibited the highest scour rate of all chains surveyed over the two years of monitoring (0.09 feet per year).

At WC01, $D_{50}$ particle size classes remained the same between both years of study at both cross-sections, and reachwide (Table C-5). $D_{84}$ particle size classes changed, coarsening at Cross-section 1 (Crossover Riffle at Station 2+30) from medium to large cobble, and becoming slightly finer at Cross-Section 2 (Meander Bend at Station 2+95) from medium to small cobble and reachwide from large to medium cobble.

## 4.2 WC02

Significant changes in profile were not observed at WC02 between the two years of study (Figure C-2). Reach length remained constant and stream slope measurements were fairly consistent. During the second year of survey, crews observed a slightly greater percentage of pools and glides than riffles and runs (55.3% of the surveyed reach was classified as pools and glides, while 44.7% was classified as riffles and runs) (Table C-1). This mix was flipped from feature percentages observed during Year 1, where 46.6% of the reach was classified as pools and glides and 53.4% as riffles and runs. Some bed aggradation was observed in the surveyed profile at the lower portion of the reach.

Bed aggradation was also observed at Cross-section 1 (Crossover Riffle at Station 1+38), but banks here remained relatively stable (Figure C-7). Conversely, channel scour occurred at Cross-section 2 (Meander Bend at Station 3+24), as well as slight erosion of the upper portion of the right bank (Figure C-8). At this station, a bankfull bar grew along the left bank, altering the cross-section bankfull dimensions.

Annual bank erosion rates as estimated from bank pin measurements followed similar patterns between the two years, with increased deposition occurring at some toe pins during the second year of study (Table C-3). Bank collapse around station 2+00 resulted in the loss of the lower right bank pin during the second year of study. This pin had exhibited the most bank erosion during the first year of study. Combining two years of scour chain data, the chains within reach WC02 exhibited the largest rates of deposition of all chains surveyed (Table C-4), with the left scour chain at Station 1+38 having the highest rate (-0.39 feet per year).

$D_{50}$ particle size classes remained the same between both years of study at both cross-sections, and reachwide (Table C-5). $D_{84}$ particle size classes became slightly finer at both cross sections and reachwide, diminishing from medium-sized cobble to small cobble.

## 4.3 WC03

Pool and glide features dominate reach WC03, as 65.6% and 67.5% of the reach was made up of pools and glides during Years 1 and 2, respectively (Table C-1). Changes in longitudinal profile were noted between the two years' of study, most notably the deepening of most pools reachwide (Figure C-3).

Cross-section 1 (Station 1+57) had been a Crossover Riffle at Station 1+55 when initially established during Year 1 of the study. However, changes in channel profile resulted in the riffle feature migrating downstream, and this cross-section was within a pool feature when surveyed in Year 2 (Figure C-9). As a result, bankfull cross-sectional dimensions changed significantly at this station, with the deepening of the channel bed (Table C-2). Streambanks remained relatively unchanged at Cross-section 1. Significant deepening also occurred at Cross-section 2 (Meander Bend at Station 2+08), and erosion of the outside (left) bank was also observed between the two years of study (Figure C-10). Consequently, bankfull cross-sectional dimensions also differed significantly at this station between Year 1 and Year 2 (Table C-2).

As observed at other sites, annual bank erosion rates estimated from bank pins exhibited similar patterns between the two years (Table C-3). At WC03, the most significant amount of erosion was observed along the outside bend at Station 2+73 during the first year of the study. Significant erosion continued at this station during Year 2, but both pins fell out of the bank during this period, so Year 2 rates could not be estimated. During Year 1, deposition occurred along the opposite bank at this station, but during Year 2, 0.31 feet/year of erosion occurred along this opposite bank as well. Combining two years of scour chain data into an annual scour rate, this site had a rate of 0.03 feet per year of bed scour at Cross-section 1 (Station 1+57) (Table C-4).

Along with the channel deepening at Cross-section 1 (Pool at Station 1+57), channel substrate became more fine, with the D50 decreasing from very coarse gravel to coarse gravel, and the D84 decreasing from small cobble to very coarse gravel (Table C-5). The D84 also decreased at Cross-section 2 (Meander Bend at Station 2+08) from small cobble in Year 1 to very coarse gravel in Year 2. At Cross-section 2, D50 particle size classes remained the same between both years of study (medium gravel). Reachwide, the D50 (coarse gravel) and D84 (small cobble) particle size classes also did not change between years.

## 4.4 WC04

No significant changes were observed in the profile of the downstream portion of the reach at site WC04 between the two years' of study. However, during the Year 2 survey, the stream channel was dry from above the run feature at Station 1+82 to the top of the reach at Station 3+00 and beyond. Around this same station and above, channel aggradation can be seen when comparing the profiles of the Year 1 and Year 2 surveys (Figure C-4), which may explain the decrease in water depth between these surveys. This aggradation can be explained by a slight decrease in stream power caused by the net stream bank erosion that has occurred throughout the study period in the upper portion of this reach (Table C-4; WC04 Station 2+64.5), which is explained in detail below. Reach length, slope, and proportion of features within the reach remained relatively unchanged (Table C-1).

The cross-sections within this reach also remained relatively unchanged between the two years of study, with the exception of some lower bank erosion observed at Cross-section 1 (Meander at Station 1+08) (Figures C-11 and C-12). This station was identified as a riffle

located just above the top of a pool during the initial year of monitoring, but was within part of the pool when surveyed in Year 2. The channel was actively widening and cutting into the bank at this station during the Year 2 survey, resulting in changes in cross-sectional dimensions (Table C-2).

Annual bank erosion rates and patterns at this reach differed somewhat between the two years of study (Table C-3). While aggradation was observed on the right bank and the upper portion of the left bank during Year 1 at Station 0+20, these locations exhibited erosion during Year 2. Conversely, erosion was observed along the lower portion of the left bank at this station during Year 1, while aggradation occurred in Year 2. Similarly, at the upstream portion of the reach, the area around the right bank toe pin at Station 2+64.5 exhibited erosion (0.14 feet/year) during 2010, but aggradation in 2012 (-0.02 feet/year). On the opposite bank, however, the upper bank pin that showed aggradation in Year 1 eroded during Year 2. While cross-section and profile surveys do not show instability at this reach, these slight changes in bank erosion rates are evidence of the dynamic nature of these stream channels. Combining the two years of scour chain data into an annual scour rate, this site had a scour rate of 0.00 feet per year, meaning no net bed scour or deposition occurred (Table C-4).

D84 particle size classes remained the same between both years' of study at both cross-sections, and reachwide (all were small cobble, Table C-5). The D50 particle size class remained constant for the reachwide survey (coarse gravel), but became slightly coarser at Cross-section 1 and finer at Cross-Section 2, further evidence of the dynamic nature of these systems.

# 5.0 CONCLUSIONS

The data presented herein provide a second year of assessment of pre-restoration conditions within the Wheel Creek watershed. Results of the geomorphic monitoring show that bank erosion continues to be prevalent throughout the watershed, a sign of channel instability. Erosion of stream banks not only increases the sediment supply to the watershed but also provides a potential source of nutrients, especially phosphorus. Stream bank erosion is a common symptom of streams like those in Wheel Creek, where urban land cover is dominant (46.1%), contributing large amounts of impervious cover (21.4%) to the watershed (Becker, 2011). Channel instability was also evident during this second year of pre-restoration monitoring, with significant changes seen in some channel cross sections and longitudinal profiles.

Additional geomorphic surveys following restoration activities will enable future comparisons to quantitatively evaluate changes in geomorphological conditions as a result of restoration efforts throughout the watershed. By comparing post-restoration conditions to the baseline data, we can potentially quantify any benefits to the stream ecosystem resulting from restoration activities. With the current monitoring design, we may have the ability to assess the benefits of individual projects and assess the efficacy of individual restoration techniques. This would provide valuable data that may help guide the selection of restoration techniques in the future.

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# 6.0 REFERENCES

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# APPENDIX A

# PHOTOS

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WC01 – Facing upstream at Station 3+91

WC01 - Facing upstream at Station 2+51

WC01 – Facing downstream at Station 1+45

WC01 – Facing downstream at Station 0+70

WC01 – Facing upstream at Station 0+00

WC02 – Facing downstream at Station 3+50

WC02 – Facing downstream at Station 3+00

WC02 – Facing downstream at Station 1+38

WC02 – Facing downstream at Station 0+72

WC02 – Facing upstream at Station 0+00

WC03 – Facing downstream at Station 2+86

WC03 – Facing downstream at Station 1+98

WC03 – Facing downstream at Station 1+59

WC03 – Facing upstream at Station 0+86

WC03 – Facing downstream to 0+00 at Station 0+25

WC04 – Facing downstream at Station 2+77

WC04 – Facing upstream at Station 2+00

WC04 – Facing downstream at Station 1+67

WC04 – Facing downstream at Station 0+33

WC04 – Facing upstream at Station 0+00

WC01 – XS-1 facing upstream

WC01 – XS-1 facing downstream

WC01 – XS-1 facing right bank

WC01 – XS-1 facing left bank

WC01 – XS-2 facing upstream

WC01 – XS-2 facing downstream

WC01 – XS-2 facing right bank

WC01 – XS-2 facing left bank

WC02 – XS-1 facing upstream

WC02 – XS-1 facing downstream

WC02 – XS-1 facing right bank

WC02 – XS-1 facing left bank

WC02 – XS-2 facing upstream

WC02 – XS-2 facing downstream

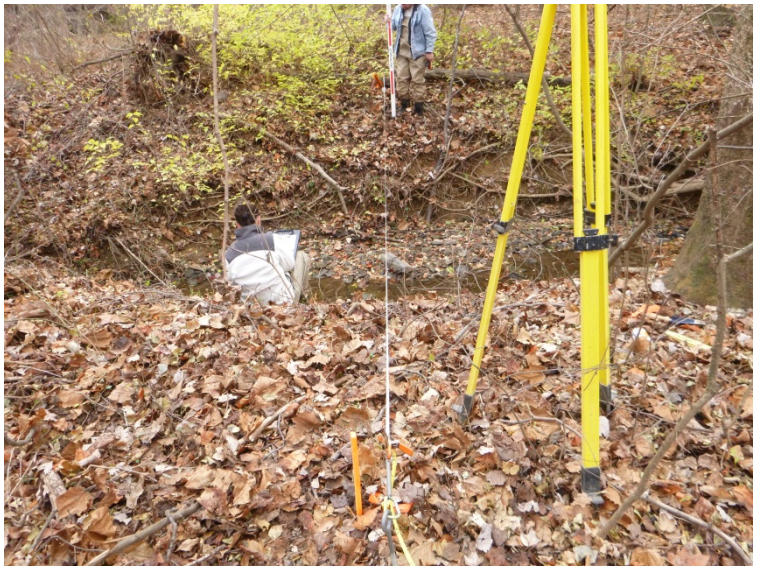
WC02 – XS-2 facing right bank

WC02 – XS-2 from left bank

WC03 – XS-1 facing upstream

WC03 – XS-1 facing downstream

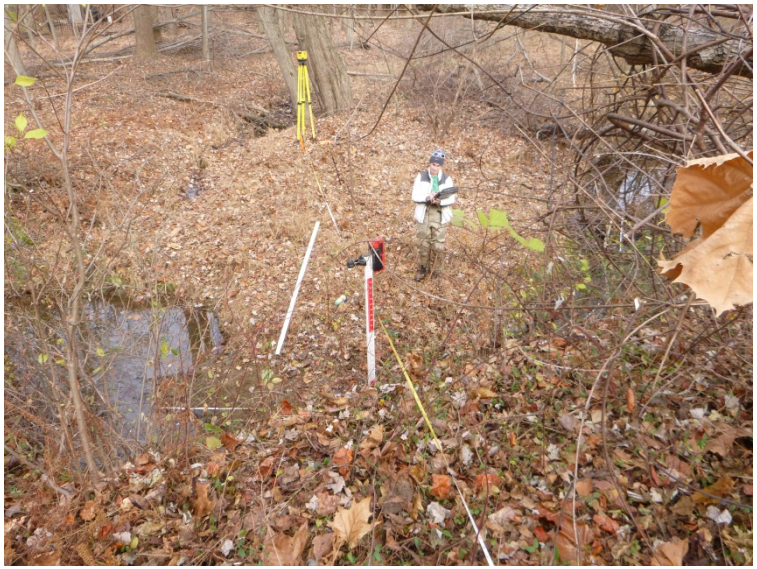
WC03 – XS-1 facing right bank



WC03 – XS-1 facing left bank

WC03 – XS-2 facing upstream

WC03 – XS-2 facing downstream



WC03 – XS-2 facing right bank

WC03 – XS-2 facing left bank

WC04 – XS-1 facing upstream

WC04 – XS-1 facing downstream

WC04 – XS-1 facing right bank

WC04 – XS-1 facing left bank

WC04 – XS-2 facing upstream

WC04 – XS-2 facing downstream

WC04– XS-2 facing right bank

WC04 – XS-2 facing left bank

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# APPENDIX B

# GEOMORPHIC ASSESSMENT DATA

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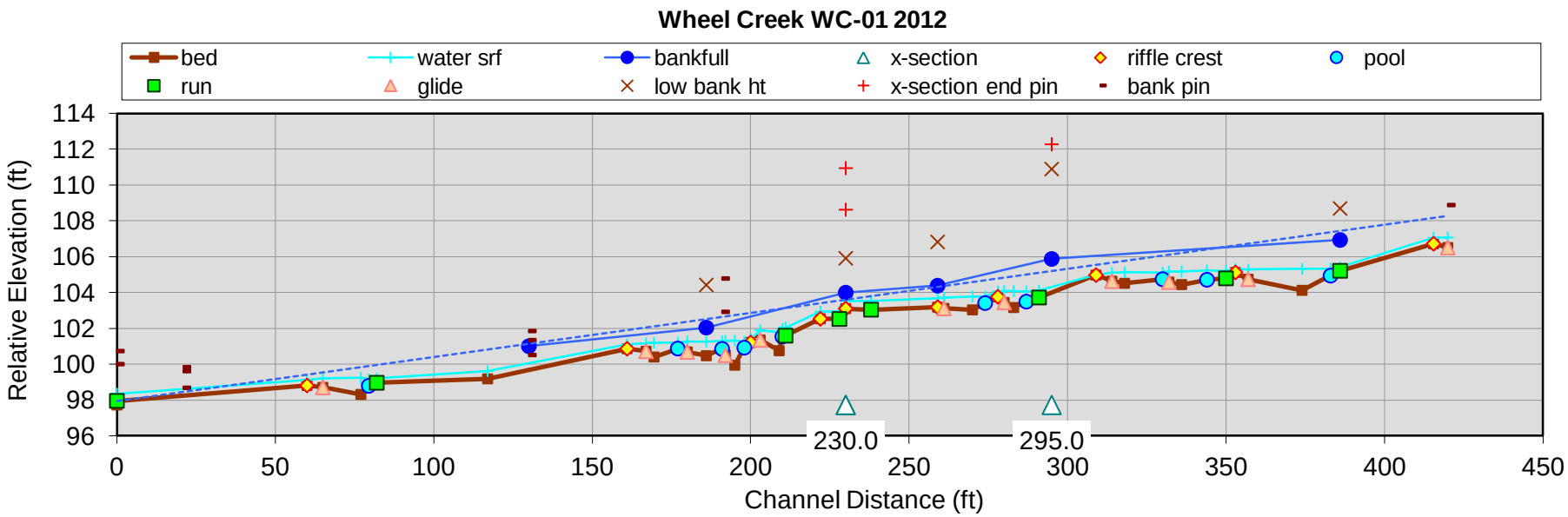
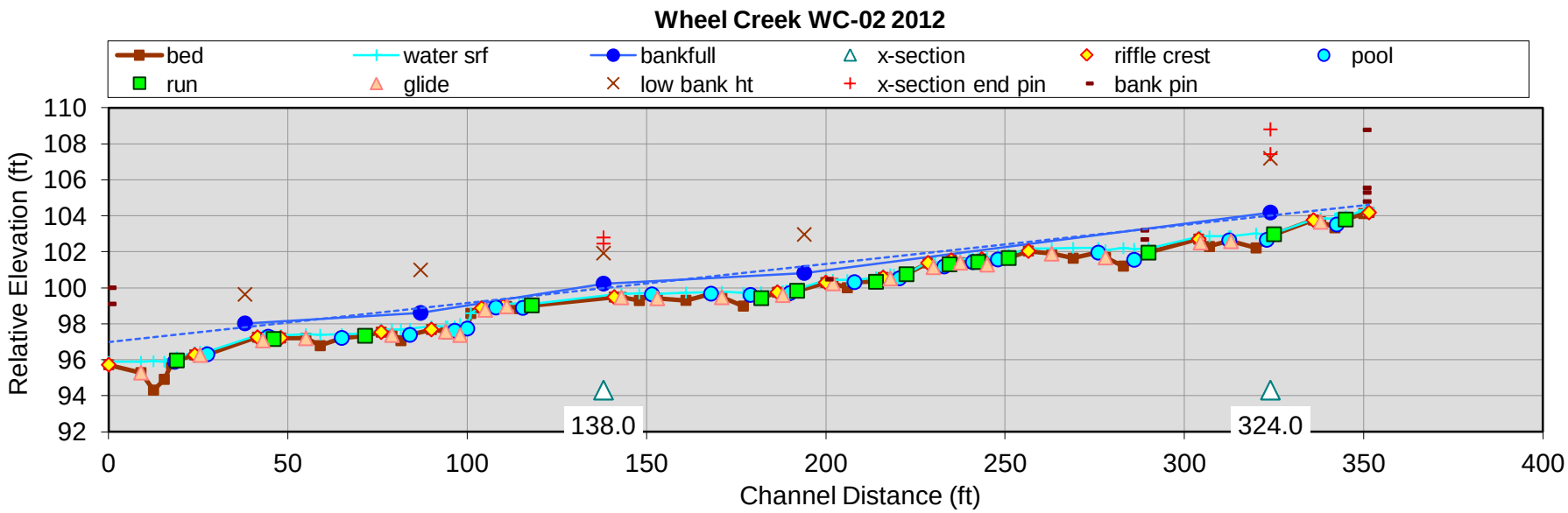
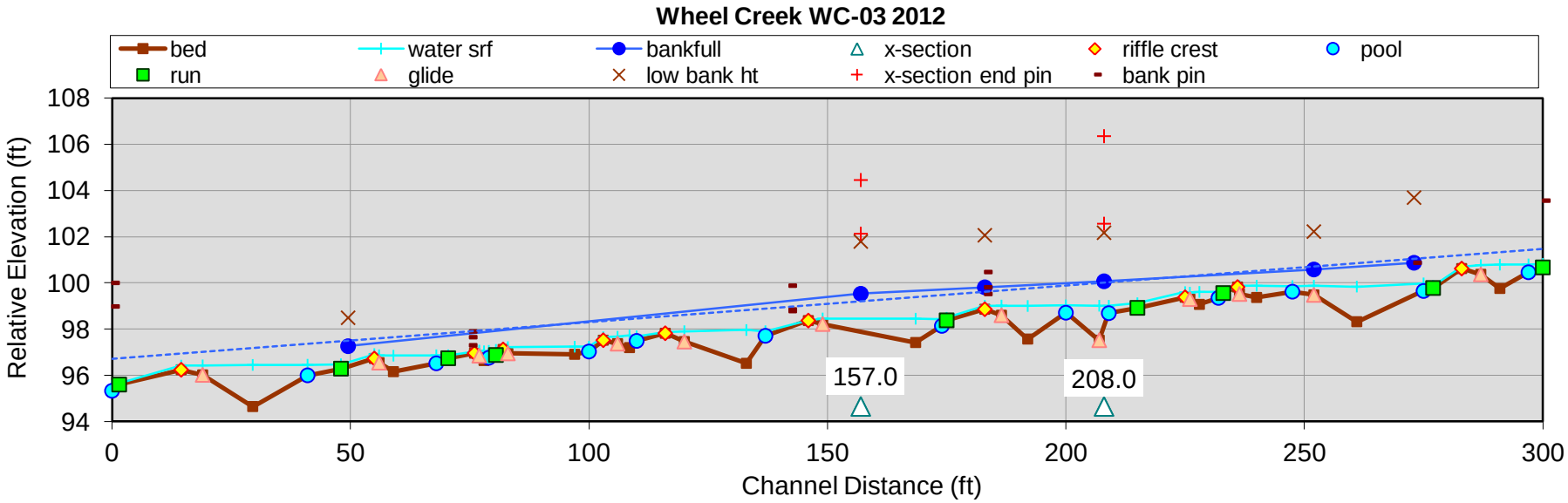
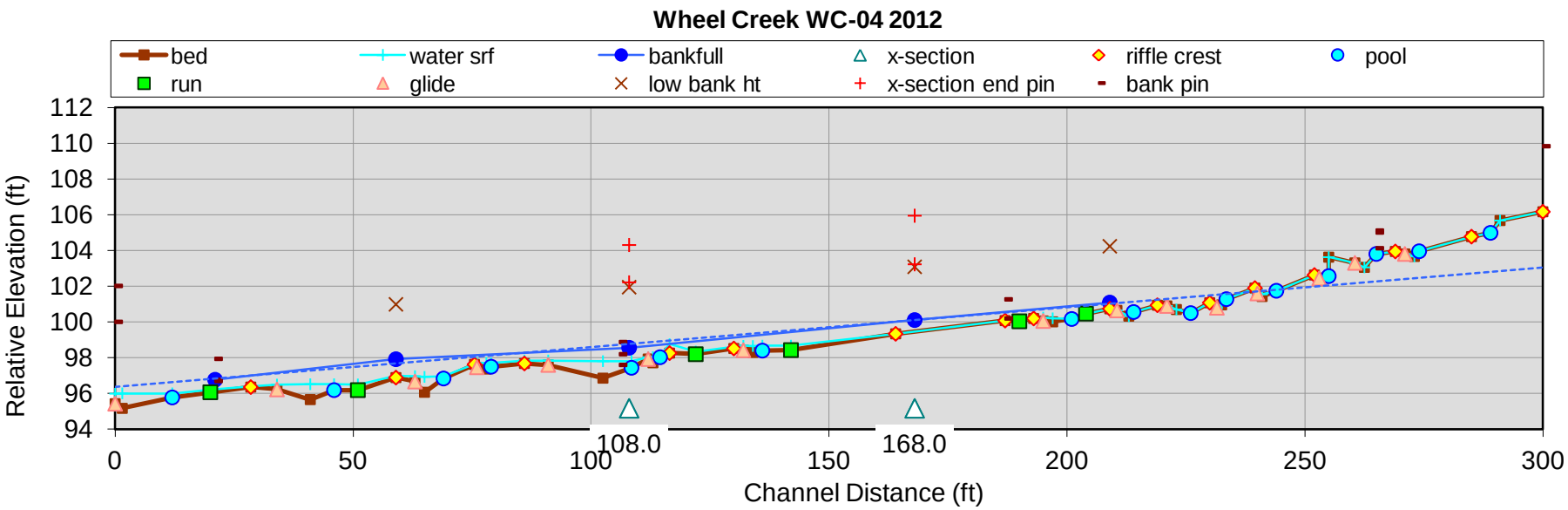
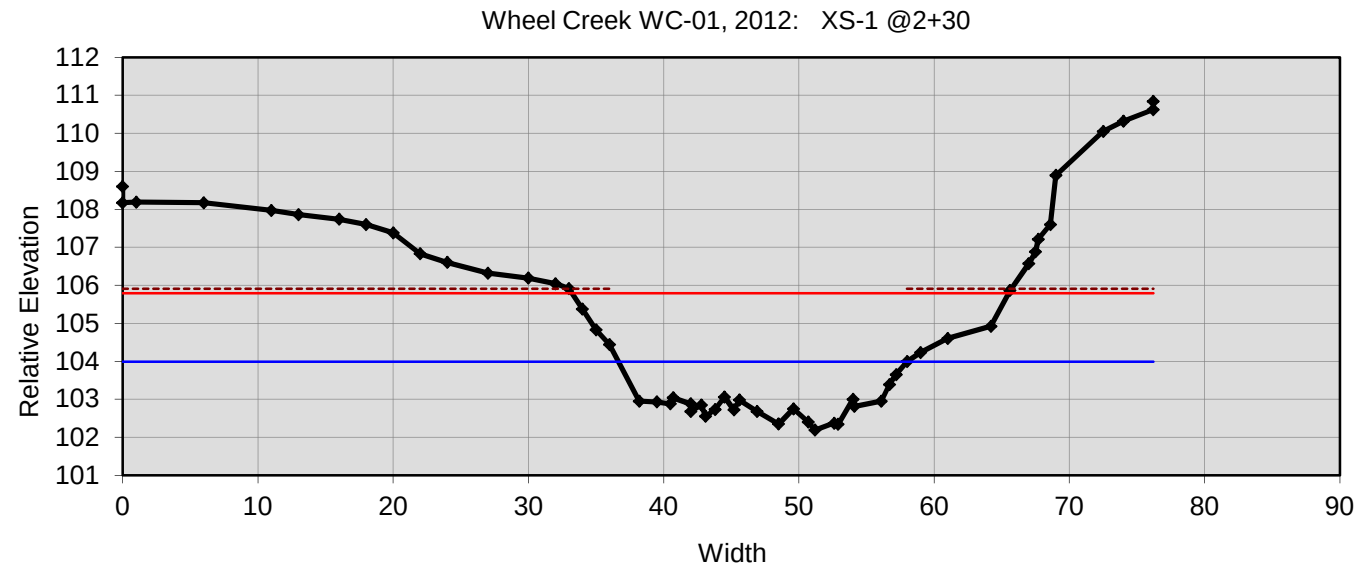

Wheel Creek WC-01 2012
bed
water srf
bankfull
x-section
riffle crest
pool
run
glide
low bank ht
x-section end pin
bank pin
Relative Elevation (ft)
114
112
110
108
106
104
102
100
98
96
0
50
100
150
200
250
300
350
400
450
230.0
295.0
Channel Distance (ft)

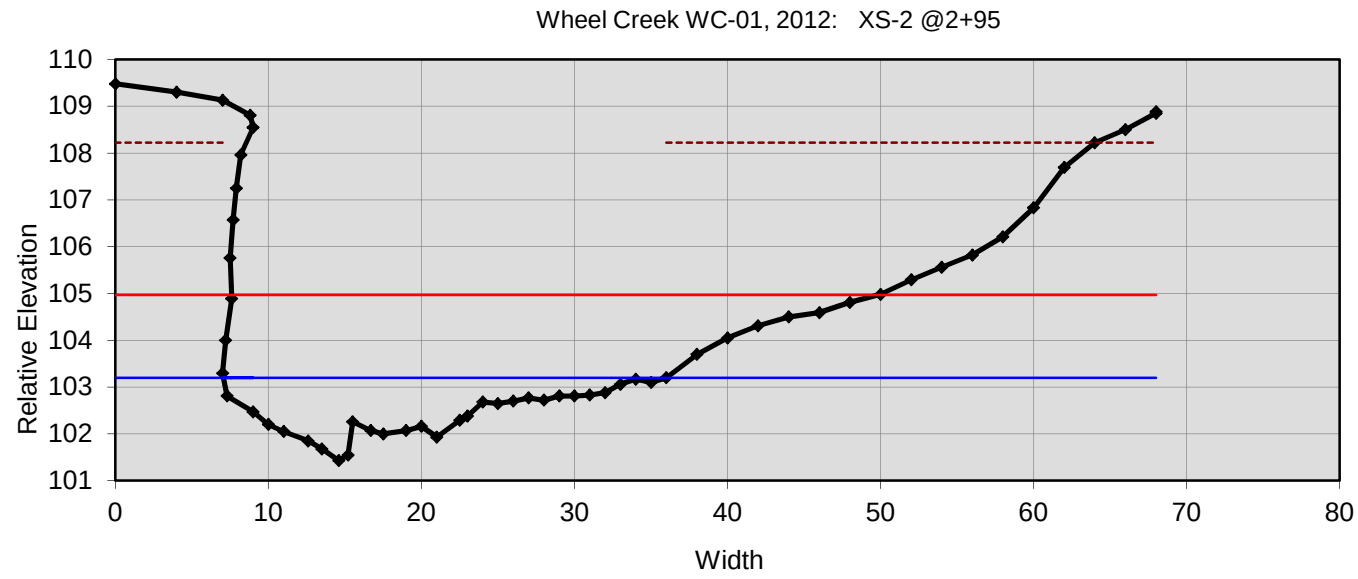

Wheel Creek WC-02 2012
bed
water srf
bankfull
x-section
riffle crest
pool
run
glide
low bank ht
x-section end pin
bank pin
Relative Elevation (ft)
110
108
106
104
102
100
98
96
94
92
0
50
100
150
200
250
300
350
400
138.0
324.0
Channel Distance (ft)


Wheel Creek WC-03 2012
bed
water srf
bankfull
x-section
riffle crest
pool
run
glide
low bank ht
x-section end pin
bank pin
Relative Elevation (ft)
108
106
104
102
100
98
96
94
0
50
100
150
200
250
300
Channel Distance (ft)
157.0
208.0

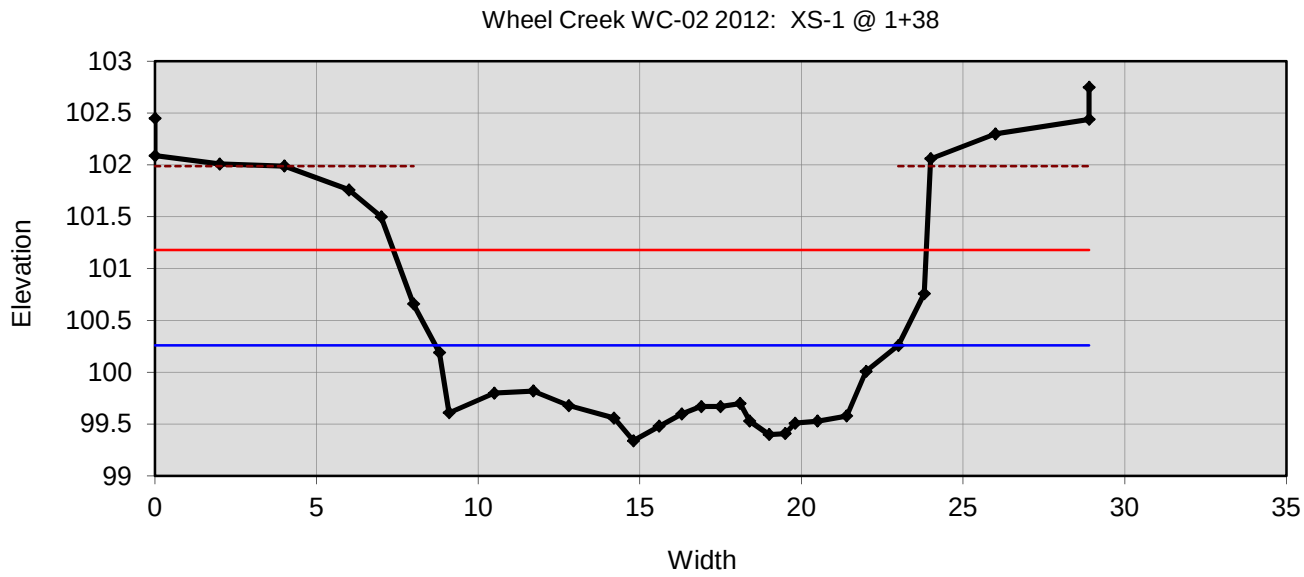

Wheel Creek WC-04 2012
bed
water srf
bankfull
x-section
riffle crest
pool
run
glide
low bank ht
x-section end pin
bank pin
Relative Elevation (ft)
112
110
108
106
104
102
100
98
96
94
0
50
100
150
200
250
300
Channel Distance (ft)
108.0
168.0



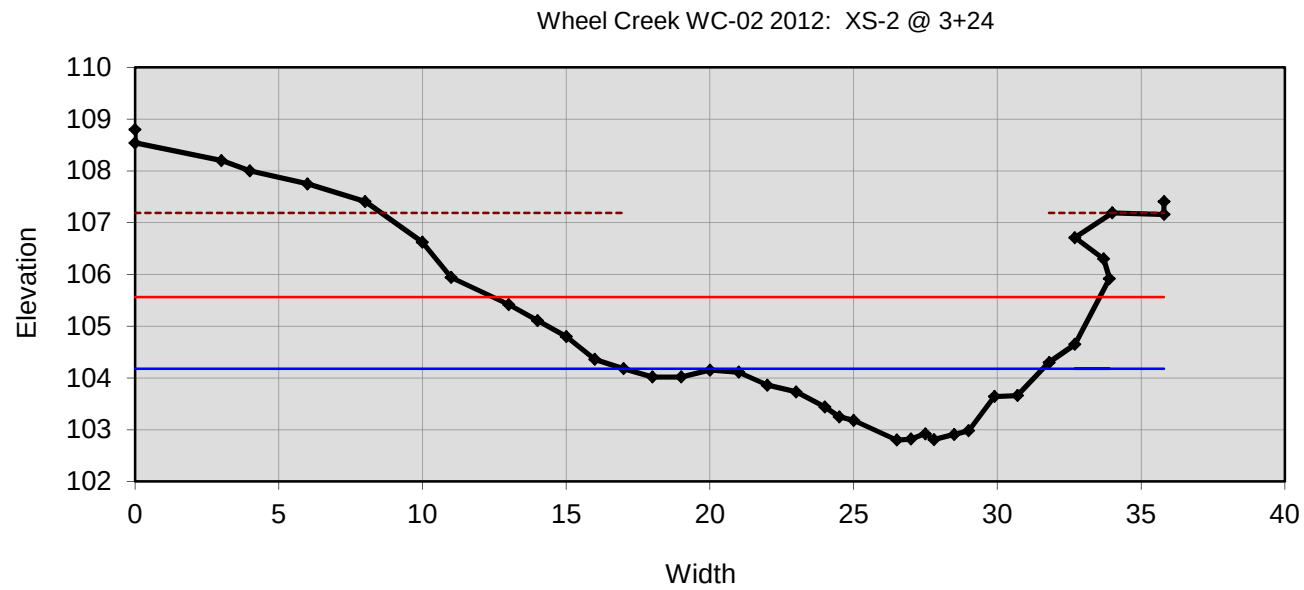

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 24.5 | x-section area (ft.sq.) | 32.3 | W flood prone area (ft) | 56 | D50 Riffle (mm) |
| 21.3 | width (ft) | 1.5 | entrenchment ratio | 180 | D84 Riffle (mm) |
| 1.1 | mean depth (ft) | 3.7 | low bank height (ft) | | |
| 1.8 | max depth (ft) | 2.1 | low bank height ratio | | |
| 23.1 | wetted parimeter (ft) | | | | |
| 1.1 | hyd radi (ft) | | | | |
| 18.6 | width-depth ratio | | | | |



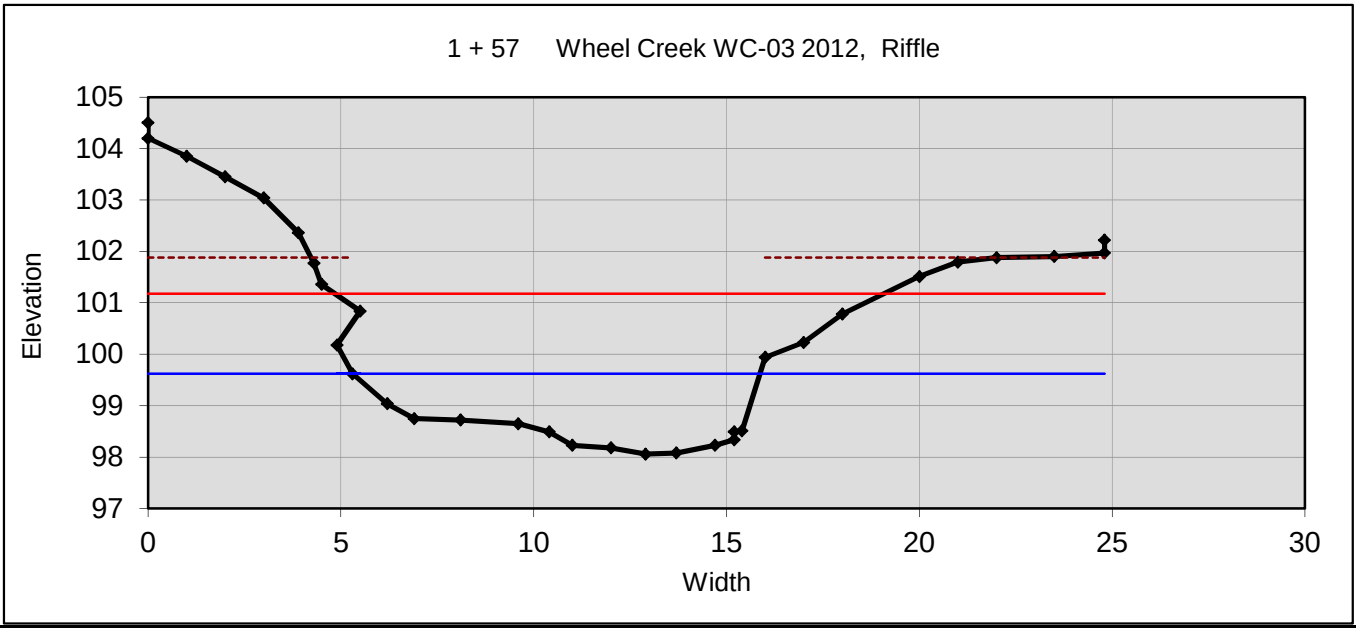

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 22.3 | x-section area (ft.sq.) | 42.3 | W flood prone area (ft) | 40 | D50 Riffle (mm) |
| 28.9 | width (ft) | 1.5 | entrenchment ratio | 77 | D84 Riffle (mm) |
| 0.8 | mean depth (ft) | 6.8 | low bank height (ft) | | |
| 1.8 | max depth (ft) | 3.8 | low bank height ratio | | |
| 30.0 | wetted parimeter (ft) | | | | |
| 0.7 | hyd radi (ft) | | | | |
| 37.5 | width-depth ratio | | | | |



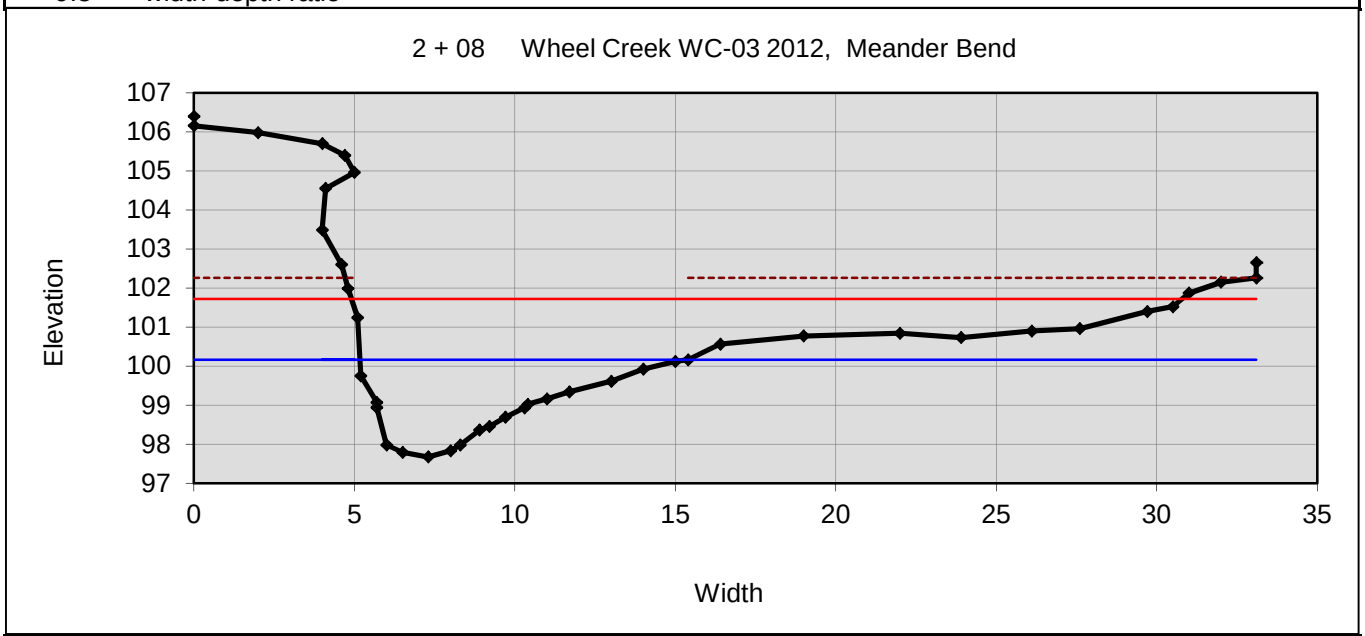

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 8.5 | x-section area (ft.sq.) | 16.5 | W flood prone area (ft) | 40 | D50 Riffle (mm) |
| 14.3 | width (ft) | 1.2 | entrenchment ratio | 80 | D84 Riffle (mm) |
| 0.6 | mean depth (ft) | 2.6 | low bank height (ft) | | |
| 0.9 | max depth (ft) | 2.9 | low bank height ratio | | |
| 15.0 | wetted parimeter (ft) | | | | |
| 0.6 | hyd radi (ft) | | | | |
| 24.1 | width-depth ratio | | | | |



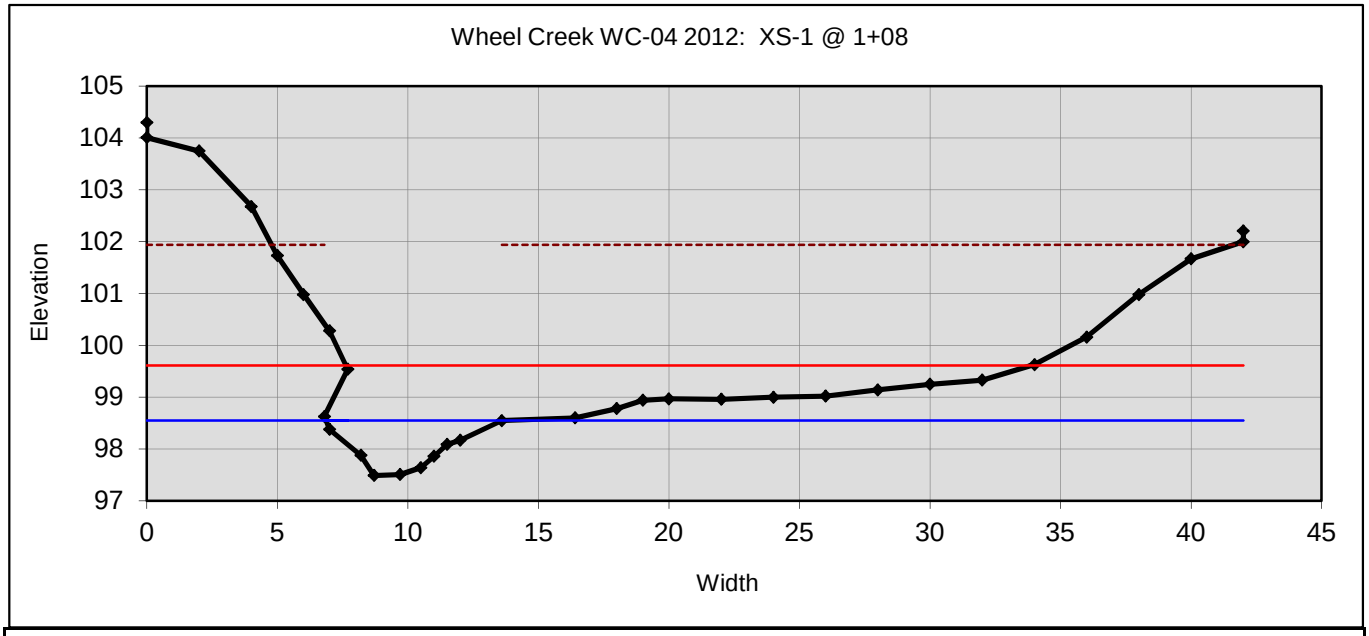

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 9.0 | x-section area (ft.sq.) | 21.1 | W flood prone area (ft) | 33 | D50 Riffle (mm) |
| 14.6 | width (ft) | 1.4 | entrenchment ratio | 69 | D84 Riffle (mm) |
| 0.6 | mean depth (ft) | 4.4 | low bank height (ft) | | |
| 1.4 | max depth (ft) | 3.2 | low bank height ratio | | |
| 15.2 | wetted parimeter (ft) | | | | |
| 0.6 | hyd radi (ft) | | | | |
| 23.8 | width-depth ratio | | | | |



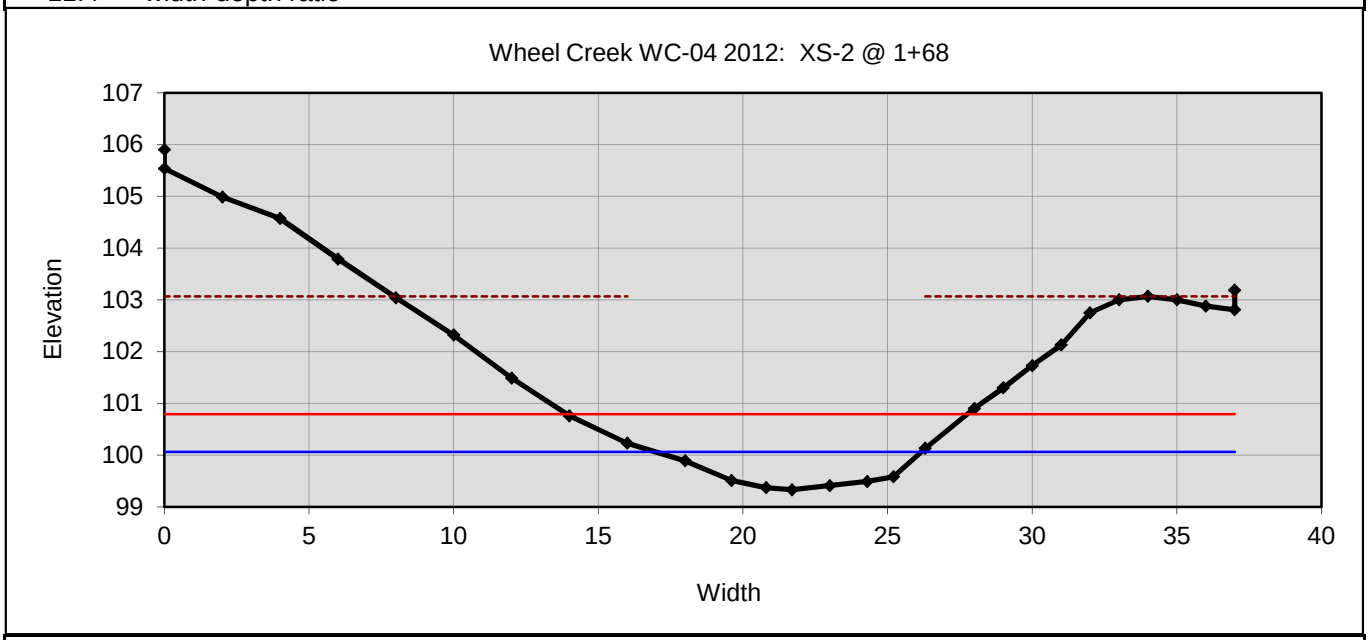

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 11.4 | x-section area (ft.sq.) | 14.2 | W flood prone area (ft) | 27 | D50 Riffle (mm) |
| 10.6 | width (ft) | 1.3 | entrenchment ratio | 59 | D84 Riffle (mm) |
| 1.1 | mean depth (ft) | 3.8 | low bank height (ft) | | |
| 1.6 | max depth (ft) | 2.4 | low bank height ratio | | |
| 11.8 | wetted parimeter (ft) | | | | |
| 1.0 | hyd radi (ft) | | | | |
| 9.8 | width-depth ratio | | | | |



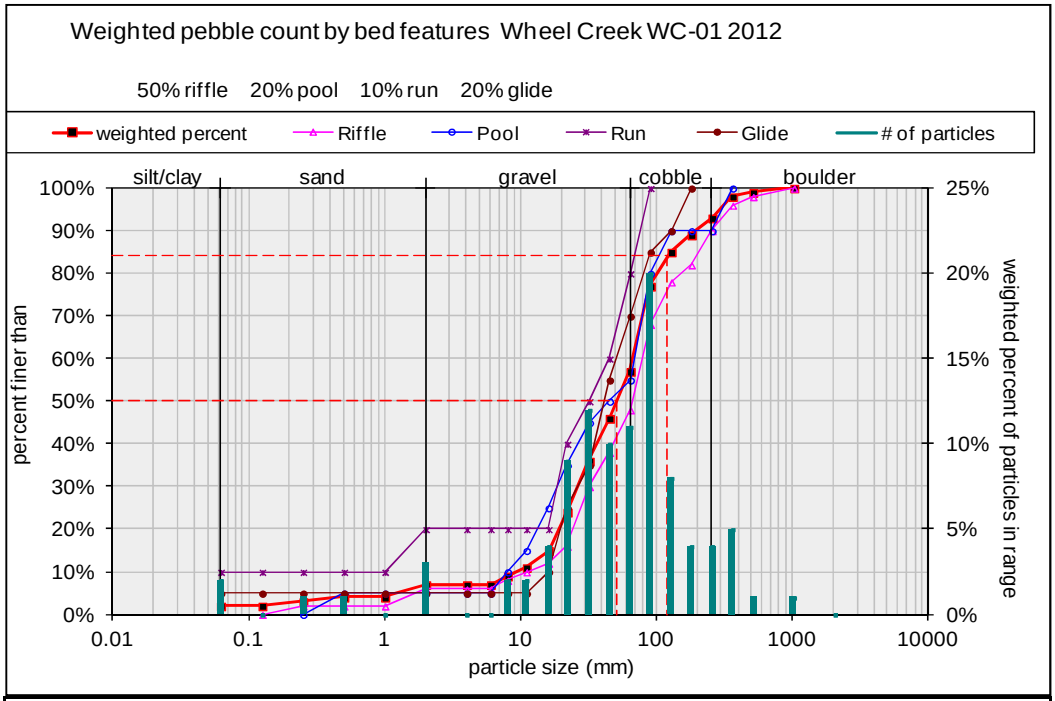

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 12.5 | x-section area (ft.sq.) | 25.9 | W flood prone area (ft) | 15 | D50 Riffle (mm) |
| 10.2 | width (ft) | 2.5 | entrenchment ratio | 43 | D84 Riffle (mm) |
| 1.2 | mean depth (ft) | 4.6 | low bank height (ft) | | |
| 2.5 | max depth (ft) | 1.8 | low bank height ratio | | |
| 12.3 | wetted parimeter (ft) | | | | |
| 1.0 | hyd radi (ft) | | | | |
| 8.4 | width-depth ratio | | | | |



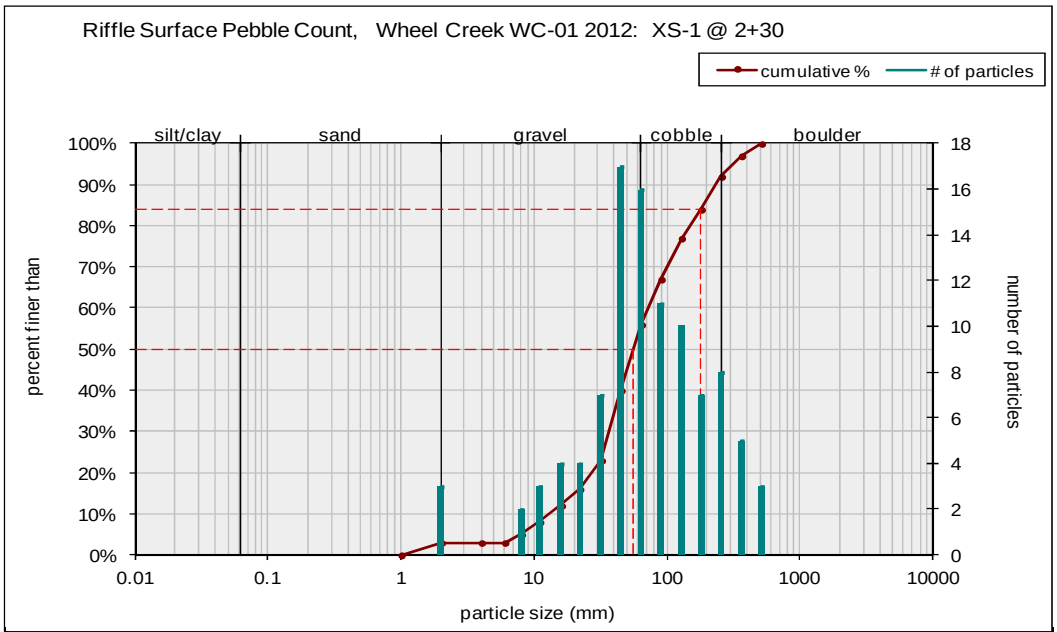

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 4.0 | x-section area (ft.sq.) | 26.2 | W flood prone area (ft) | 15 | D50 Riffle (mm) |
| 6.7 | width (ft) | 3.9 | entrenchment ratio | 70 | D84 Riffle (mm) |
| 0.6 | mean depth (ft) | 4.4 | low bank height (ft) | | |
| 1.1 | max depth (ft) | 4.2 | low bank height ratio | | |
| 7.2 | wetted parimeter (ft) | | | | |
| 0.6 | hyd radi (ft) | | | | |
| 11.4 | width-depth ratio | | | | |



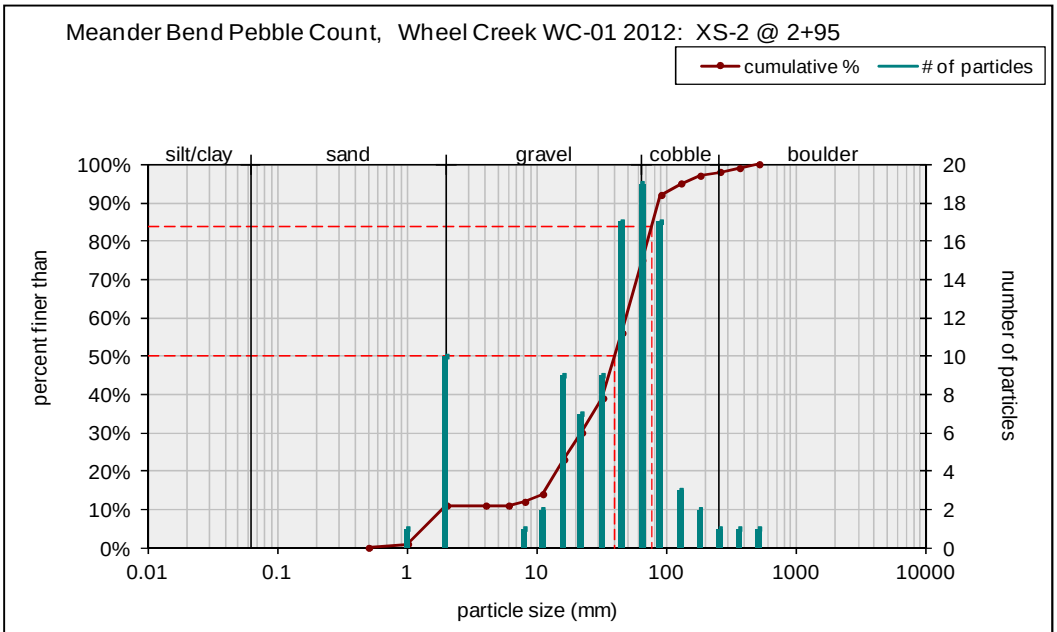

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 4.4 | x-section area (ft.sq.) | 13.8 | W flood prone area (ft) | 36 | D50 Riffle (mm) |
| 9.2 | width (ft) | 1.5 | entrenchment ratio | 64 | D84 Riffle (mm) |
| 0.5 | mean depth (ft) | 3.7 | low bank height (ft) | | |
| 0.7 | max depth (ft) | 5.1 | low bank height ratio | | |
| 9.4 | wetted parimeter (ft) | | | | |
| 0.5 | hyd radi (ft) | | | | |
| 18.9 | width-depth ratio | | | | |



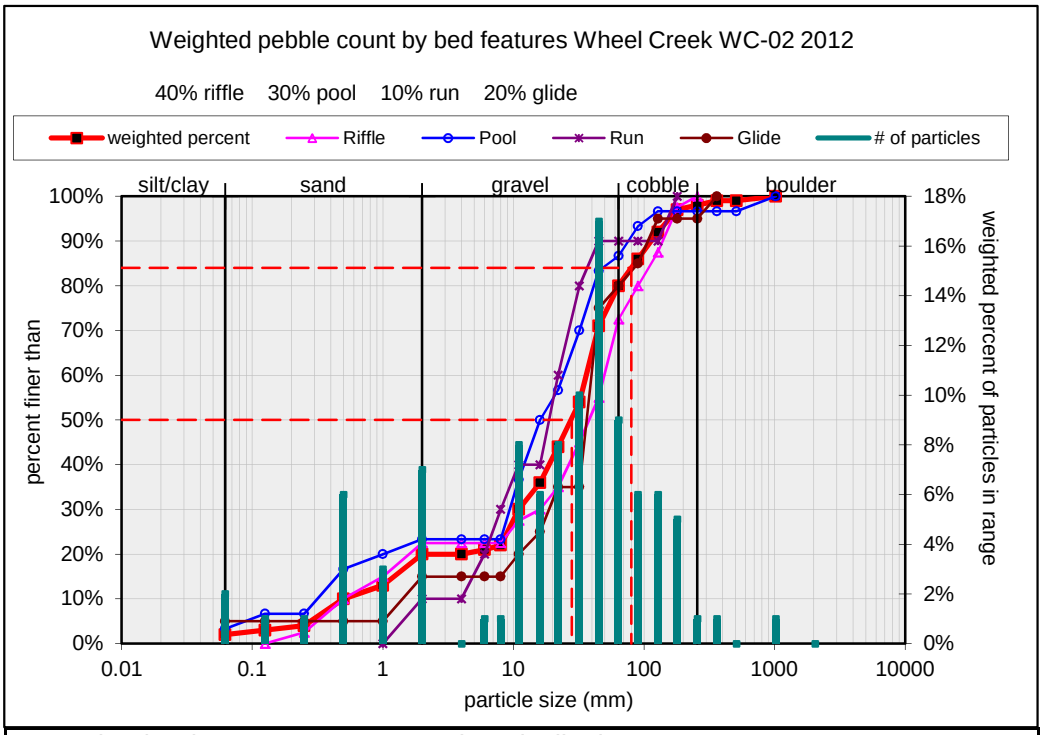

| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 17 | mean | 45.2 | silt/clay | 2% |
| D35 | 31 | dispersion | 2.7 | sand | 5% |
| D50 | 51 | skewness | -0.06 | gravel | 50% |
| D65 | 73 | | | cobble | 36% |
| D84 | 120 | | | boulder | 7% |
| D95 | 290 | | | | |



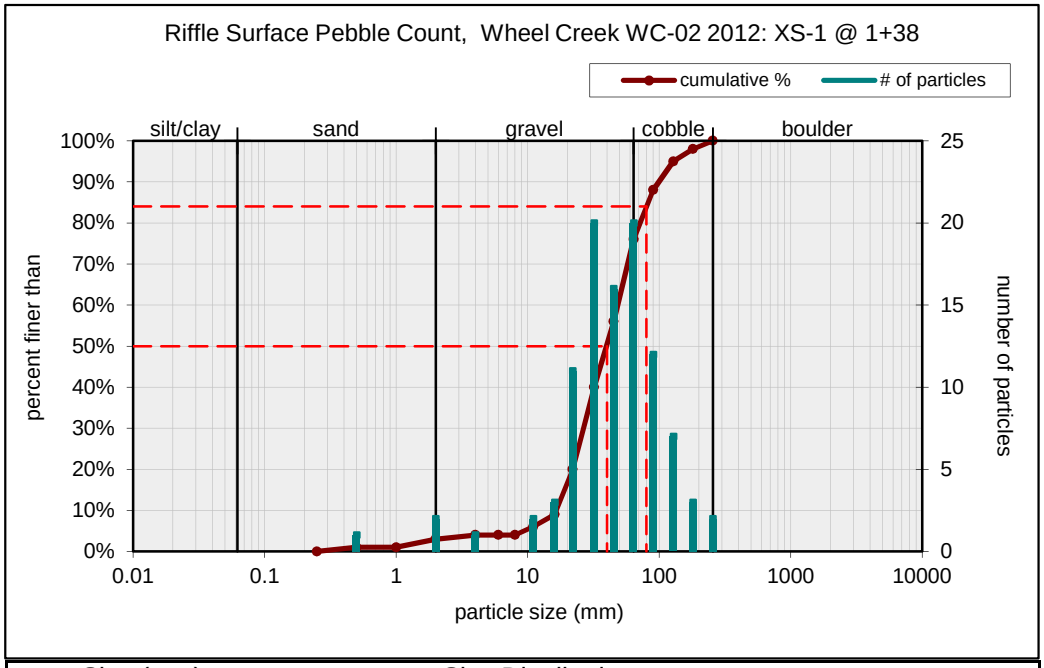

| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 22 | mean | 62.9 | silt/clay | 0% |
| D35 | 41 | dispersion | 2.9 | sand | 3% |
| D50 | 56 | skewness | 0.05 | gravel | 53% |
| D65 | 85 | | | cobble | 36% |
| D84 | 180 | | | boulder | 8% |
| D95 | 320 | | | | |



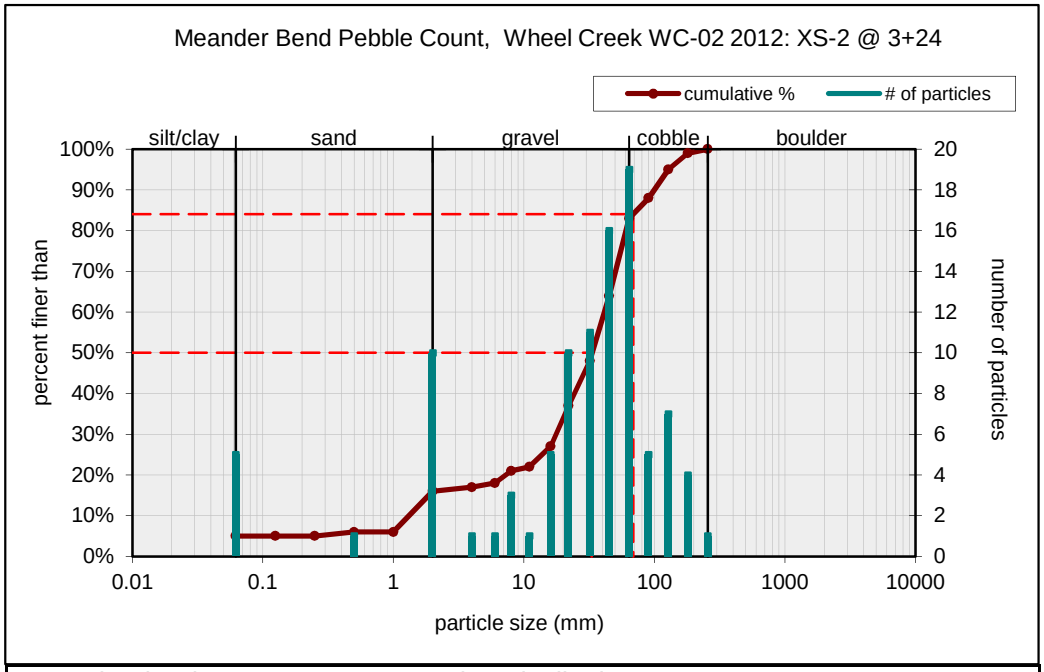

| Size (mm) | | | Size Distribution | | Type | |
|---|---|---|---|---|---|---|
| D16 | 12 | 3.4 | mean | 30.4 | silt/clay | 0% |
| D35 | 27 | 12 | dispersion | 2.6 | sand | 11% |
| D50 | 40 | 17 | skewness | -0.13 | gravel | 64% |
| D65 | 53 | 20 | | | cobble | 23% |
| D84 | 77 | 29 | | | boulder | 2% |
| D95 | 130 | 39 | | | | |



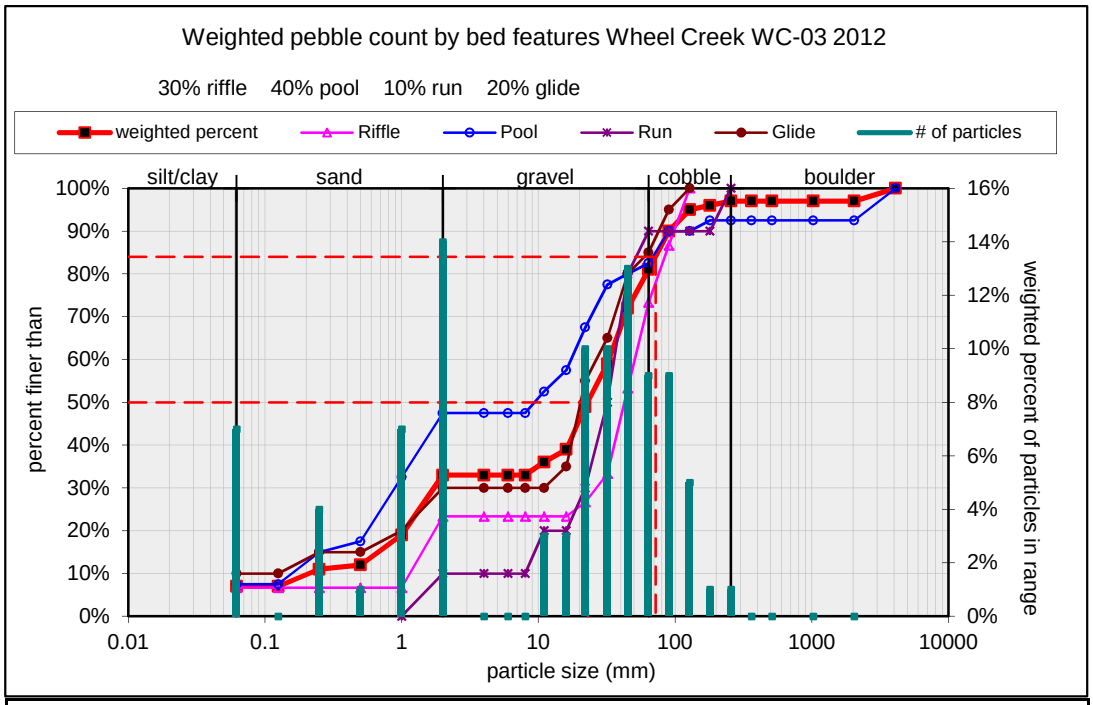

| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 1.3 | mean | 10.2 | silt/clay | 2% |
| D35 | 15 | dispersion | 12.2 | sand | 18% |
| D50 | 28 | skewness | -0.33 | gravel | 60% |
| D65 | 40 | | | cobble | 18% |
| D84 | 80 | | | boulder | 2% |
| D95 | 160 | | | | |



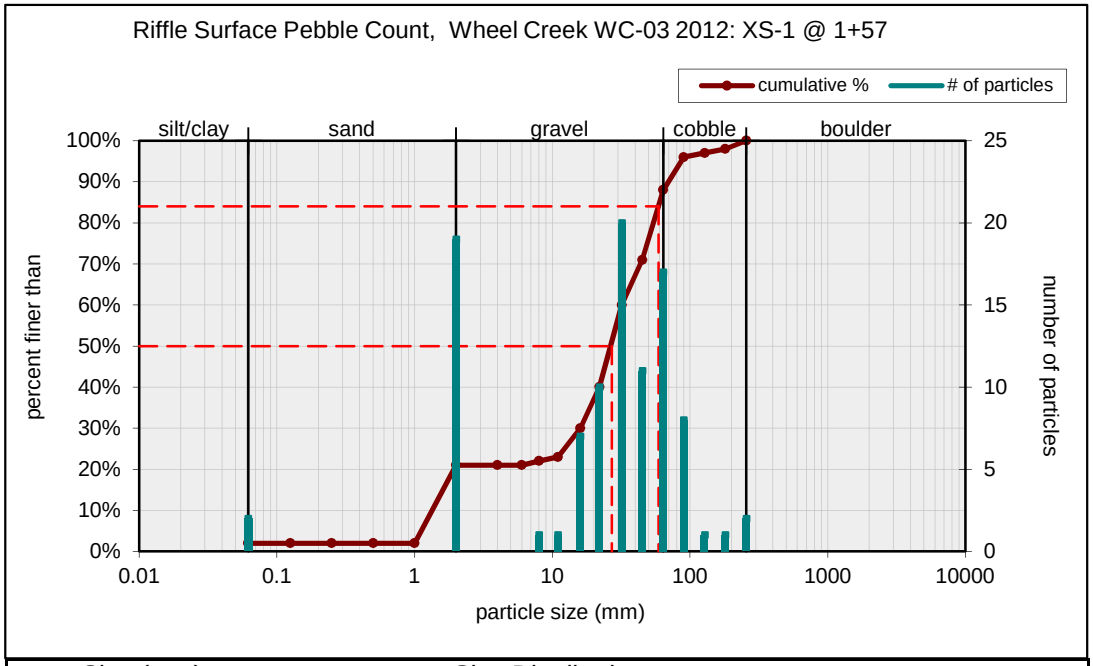

| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 20 | mean | 40.0 | silt/clay | 0% |
| D35 | 29 | dispersion | 2.0 | sand | 3% |
| D50 | 40 | skewness | 0.00 | gravel | 73% |
| D65 | 53 | | | cobble | 24% |
| D84 | 80 | | | boulder | 0% |
| D95 | 130 | | | | |



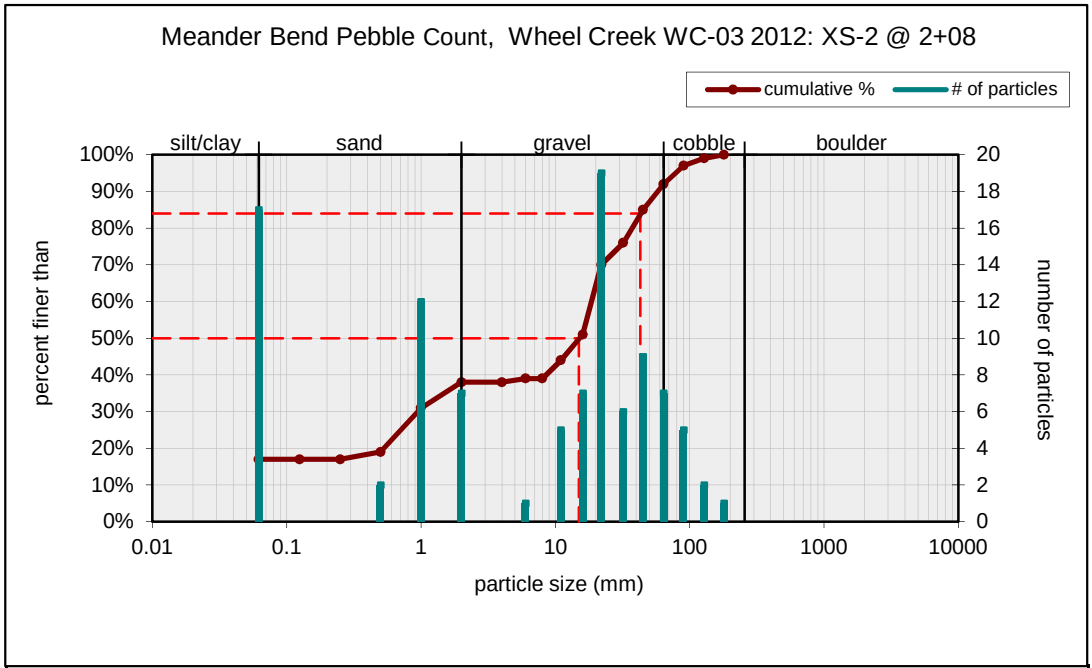

| Size (mm) | | | Size Distribution | | Type | |
|---|---|---|---|---|---|---|
| D16 | 2 | 3.4 | mean | 11.7 | silt/clay | 5% |
| D35 | 21 | 12 | dispersion | 9.3 | sand | 11% |
| D50 | 33 | 17 | skewness | -0.36 | gravel | 67% |
| D65 | 46 | 20 | | | cobble | 17% |
| D84 | 69 | 29 | | | boulder | 0% |
| D95 | 130 | 39 | | | | |



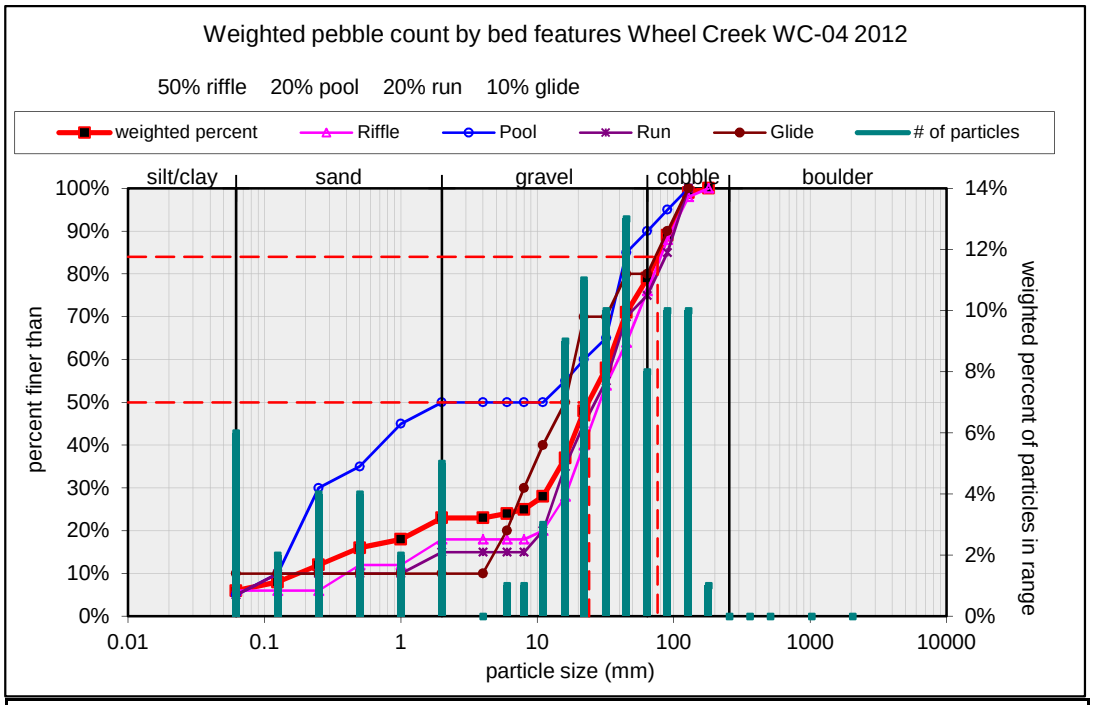

| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 0.74 | mean | 7.3 | silt/clay | 7% |
| D35 | 9.9 | dispersion | 17.1 | sand | 26% |
| D50 | 23 | skewness | -0.35 | gravel | 48% |
| D65 | 37 | | | cobble | 16% |
| D84 | 72 | | | boulder | 3% |
| D95 | 130 | | | | |



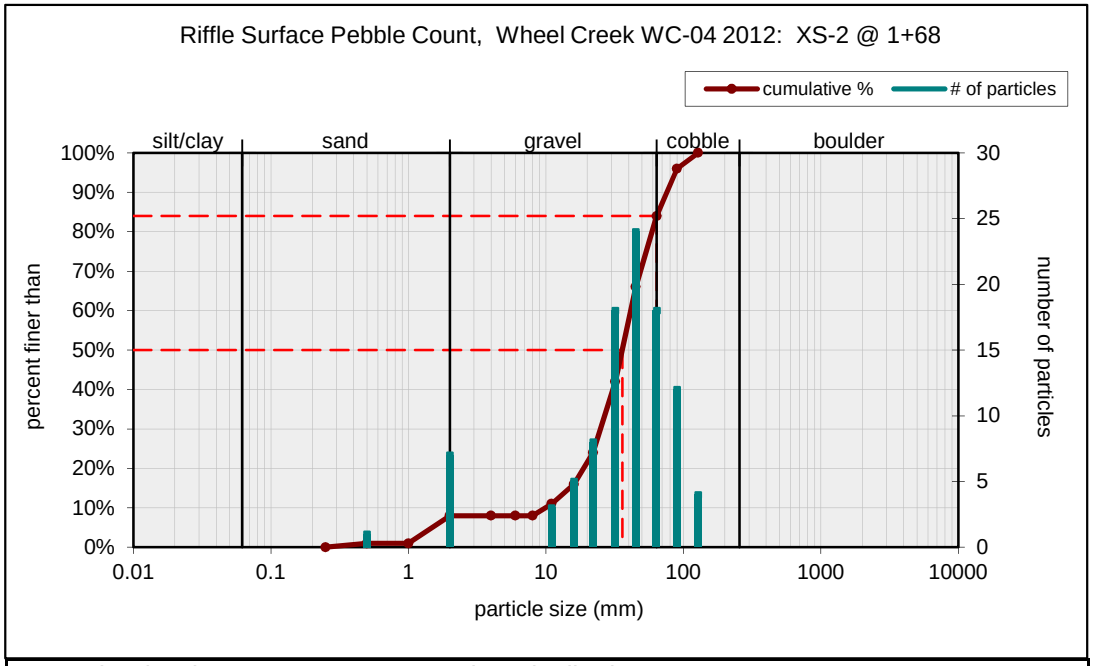

| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 1.7 | mean | 10.0 | silt/clay | 2% |
| D35 | 19 | dispersion | 9.0 | sand | 19% |
| D50 | 27 | skewness | -0.35 | gravel | 67% |
| D65 | 37 | | | cobble | 12% |
| D84 | 59 | | | boulder | 0% |
| D95 | 86 | | | | |



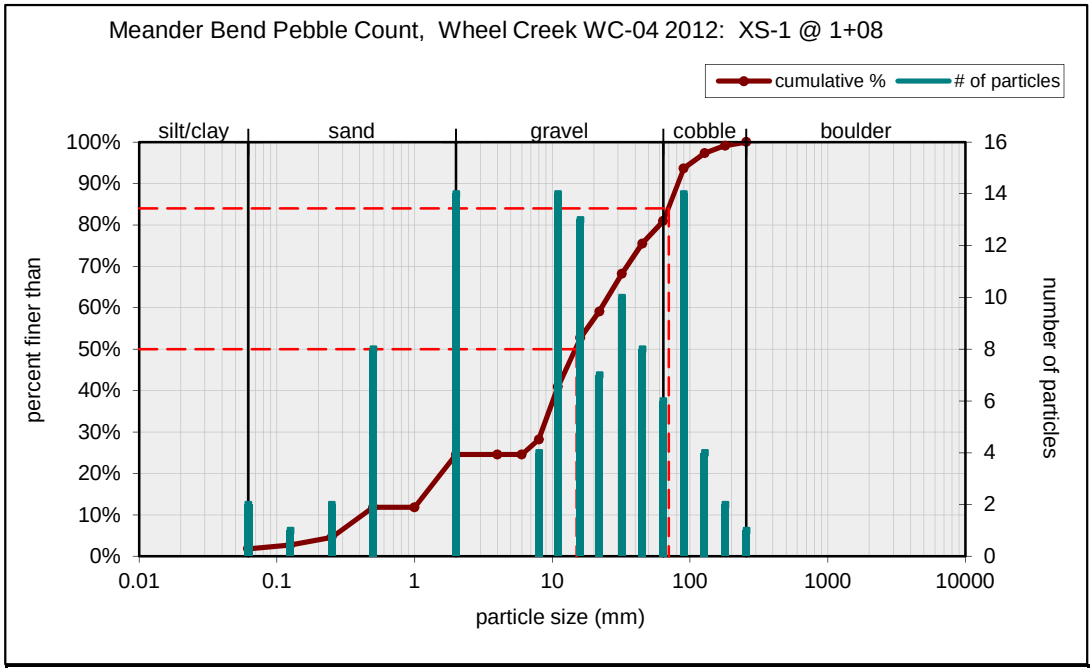

| Size (mm) | | | Size Distribution | | Type | |
|---|---|---|---|---|---|---|
| D16 | 0.062 | 3.4 | mean | 1.6 | silt/clay | 17% |
| D35 | 1.5 | 12 | dispersion | 122.4 | sand | 21% |
| D50 | 15 | 17 | skewness | -0.57 | gravel | 54% |
| D65 | 20 | 20 | | | cobble | 8% |
| D84 | 43 | 29 | | | boulder | 0% |
| D95 | 79 | 39 | | | | |




| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 0.5 | mean | 6.2 | silt/clay | 6% |
| D35 | 15 | dispersion | 25.6 | sand | 17% |
| D50 | 24 | skewness | -0.40 | gravel | 56% |
| D65 | 38 | | | cobble | 21% |
| D84 | 76 | | | boulder | 0% |
| D95 | 110 | | | | |




| Size (mm) | | | Size Distribution | | Type | |
|---|---|---|---|---|---|---|
| D16 | 16 | 3.4 | mean | 32.0 | silt/clay | 0% |
| D35 | 28 | 12 | dispersion | 2.0 | sand | 8% |
| D50 | 36 | 17 | skewness | -0.07 | gravel | 76% |
| D65 | 44 | 20 | | | cobble | 16% |
| D84 | 64 | 29 | | | boulder | 0% |
| D95 | 87 | 39 | | | | |




| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 1.3 | mean | 9.5 | silt/clay | 2% |
| D35 | 9.5 | dispersion | 8.1 | sand | 23% |
| D50 | 15 | skewness | -0.15 | gravel | 56% |
| D65 | 28 | | | cobble | 19% |
| D84 | 70 | | | boulder | 0% |
| D95 | 100 | | | | |

| Reach | Profile Station 2012 | Bank Location | 3/30/2011 Length Exposed (dec. ft.) | November 2012 Length Exposed (dec. ft.) |
|---|---|---|---|---|
| WC01 | 0+21 | LB-UPPER | 0.54 | 0.58 |
| | 0+21 | LB-LOWER | 0.43 | 0.46 |
| | 0+21 | RB-PIN | 0.36 | 0.27 |
| | 1+30 | LB-TOE PIN | 0.59 | 0.38 |
| | 1+30 | RB-UPPER | 0.50 | 0.50 |
| | 1+30 | RB-LOWER | 0.32 | 0.31 |
| | 1+92 | LB-TOE PIN | N/A* | N/A* |
| | 1+92 | RB-UPPER | 0.40 | 0.34 |
| | 1+92 | RB-LOWER | 0.26 | 0.49 |
| | 3+80 | LB-TOE PIN | 0.24 | -0.17 |
| | 3+80 | RB-UPPER | 0.51 | 1.77 |
| | 3+80 | RB-LOWER | 0.66 | N/A* |
| WC02 | 0+24 | LB-UPPER | 0.52 | 0.58 |
| | 0+24 | LB-LOWER | 0.39 | N/A* |
| | 0+24 | RB-TOE PIN | 0.33 | -0.06 |
| | 2+00 | LB-UPPER | 0.32 | 0.29 |
| | 2+00 | LB-LOWER | 0.27 | 0.25 |
| | 2+00 | RB-TOE PIN | 0.69 | N/A* |
| | 2+88 | LB-UPPER | 0.56 | 0.56 |
| | 2+88 | LB-LOWER | 0.64 | 0.75 |
| | 2+88 | RB-TOE PIN | 0.20 | -0.08 |
| | 3+50 | LB-UPPER | 0.36 | 0.65 |
| | 3+50 | LB-LOWER | 0.42 | 0.40 |
| | 3+50 | RB-TOE PIN | 0.38 | 0.63 |
| WC03 | 0+75 | LB-UPPER | 0.25 | 0.25 |
| | 0+75 | LB-LOWER | 0.33 | 0.33 |
| | 0+75 | RB-PIN | 0.23 | 0.25 |
| | 1+41 | LB-UPPER | 0.38 | 0.46 |
| | 1+41 | LB-LOWER | 0.33 | 0.46 |
| | 1+41 | RB-PIN | 0.32 | 0.38 |
| | 1+83 | LB-PIN | 0.20 | 0.13 |
| | 1+83 | RB-UPPER | 0.18 | 0.25 |
| | 1+83 | RB-LOWER | 0.17 | 0.21 |
| | 2+73 | LB-UPPER | 0.51 | N/A* |
| | 2+73 | LB-LOWER | 0.79 | N/A* |
| | 2+73 | RB-PIN | -0.7 | -0.19 |
| WC04 | 0+21 | RB-PIN | -0.3 | 0.17 |
| | 0+21 | LB-UPPER | -0.04 | 0.00 |
| | 0+21 | LB-LOWER | 0.15 | -0.25 |
| | 1+06.5 | RB-TOE PIN | 0.16 | 0.25 |
| | 1+06.5 | LB-UPPER | 0.18 | 0.25 |
| | 1+06.5 | LB-LOWER | 0.25 | 0.92 |
| | 1+85.5 | RB-TOE PIN | 0.04 | 0.08 |
| | 1+85.5 | LB-UPPER | 0.18 | 0.17 |
| | 1+85.5 | LB-LOWER | -0.12 | -0.25 |
| | 2+64.5 | RB-TOE PIN | 0.20 | 0.17 |
| | 2+64.5 | LB-UPPER | 0.30 | 0.63 |
| | 2+64.5 | LB-LOWER | 0.08 | 0.33 |

* N/A - Not available due to buried or lost pins

| Reach | Profile Station, 2012 | Feature, 2012 | Cross Section Station | Baseline, June 2010 (dec. ft.) | 3/30/2011 (dec. ft.) | Nov 2012 (dec. ft.) | |
|---|---|---|---|---|---|---|---|
| | | | | | | Amount buried (dec. ft.) | Length exposed (dec. ft.) |
| WC01 | 2+30 | Riffle | 47 | 0.52 | 0.45 | 0.17 | 0.56 |
| | 2+30 | Riffle | 50.7 | 0.52 | 0.28 | 0.08 | 0.83 |
| | 2+95 | Meander | 21.5 | 0.60 | DNF[1] | DNF[1] | DNF[1] |
| WC02 | 1+38 | Riffle | 12 | 0.50 | 0.04 | 0.50 | N/A[2] |
| | 1+38 | Riffle | 15 | 0.32 | 0.32 | 0.15 | 0.27 |
| | 3+24 | Riffle | 25.5 | 0.52 | 0.69 | 0.58 | N/A[2] |
| WC03 | 1+57 | Pool | 12 | 1.60 | 1.76 | 0.42 | 2.08 |
| WC04 | 1+68 | Riffle | 21 | 0.50 | 0.45 | 0.00 | 0.50 |

[1]DNF = Scour chain at WC01 Station 2+95 was not located during surveys

[2]N/A= Scour chains at WC02 Stations 1+38 (left) and 3+24 were partially uncovered during survey but due to heavy deposition, the entire length of chain exposed could not be measured

Notes:

Scour chains installed-

WC01 6/7/2010
WC02 6/7/2010
WC03 6/8/2010
WC04 6/11/2010

# APPENDIX C

# ANNUAL COMPARISONS

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Table C-1. Comparisons of Longitudinal Profile Survey Year 1 – Year 2

| Reach | Year | Length (ft) | Slope | Proportion of Features | | | |
|---|---|---|---|---|---|---|---|
| | | | | Riffle | Run | Pool | Glide |
| WC01 | 2010 | 400 | 2.3% | 43.6% | 11.3% | 22.1% | 23.0% |
| | *2012* | *420* | *2.2%* | *54.6%* | *7.3%* | *29.2%* | *8.9%* |
| WC02 | 2010 | 350 | 2.3% | 53.4% | 0% | 46.6% | 0% |
| | *2012* | *350* | *2.4%* | *33.7%* | *11.0%* | *38.6%* | *16.7%* |
| WC03 | 2010 | 300 | 1.7% | 34.4% | 0% | 65.6% | 0% |
| | *2012* | *300* | *1.8%* | *24.0%* | *8.5%* | *54.9%* | *12.6%* |
| WC04 | 2010 | 300 | 3.5% | 60.0% | 0% | 40.0% | 0% |
| | *2012* | *300* | *3.4%* | *41.3%* | *16.2%* | *30.3%* | *12.2%* |

Table C-2. Comparisons of Cross-sectional Survey Analyses Year 1 – Year 2

| Reach | Year | Station | Feature | Bankfull Width (ft) | Mean Depth (ft) | Width/ Depth Ratio | Entrench-ment Ratio | Bankfull Area ($ft^2$) | Top of Bank Area ($ft^2$) |
|---|---|---|---|---|---|---|---|---|---|
| WC01 | 2010 | 2+30 | Crossover Riffle | 21.1 | 1.0 | 22.2 | 1.5 | 20.1 | 73.0 |
| | *2012* | *2+30* | *Crossover Riffle* | *21.3* | *1.1* | *18.6* | *1.5* | *24.5* | *78.1* |
| | 2010 | 2+95 | Meander/Riffle | 22.1 | 0.8 | 26.0 | 1.5 | 18.8 | 230.1 |
| | *2012* | *2+95* | *Meander/Riffle* | *28.9* | *0.8* | *37.5* | *1.5* | *22.3* | *246.9* |
| WC02 | 2010 | 1+37 | Crossover Riffle | 13.1 | 0.7 | 18.4 | 1.2 | 9.3 | 31.6 |
| | *2012* | *1+38* | *Crossover Riffle* | *14.3* | *0.6* | *24.1* | *1.2* | *8.5* | *37.1* |
| | 2010 | 3+24 | Meander/Riffle | 16.7 | 0.9 | 19.3 | 1.3 | 14.5 | 70.3 |
| | *2012* | *3+24* | *Meander/Riffle* | *14.6* | *0.6* | *23.8* | *1.4* | *9* | *71.7* |
| WC03 | 2010 | 1+55 | Crossover Riffle | 9.2 | 0.4 | 24.1 | 1.1 | 3.5 | 37.5 |
| | *2012* | *1+57* | *Pool* | *10.6* | *1.1* | *9.8* | *1.3* | *11.4* | *41.3* |
| | 2010 | 2+07 | Meander/Pool | 7.2 | 0.5 | 13.0 | 1.9 | 3.9 | 43.8 |
| | *2012* | *2+08* | *Meander/Pool* | *10.2* | *1.2* | *8.4* | *2.5* | *12.5* | *56.2* |
| WC04 | 2010 | 1+08 | Meander/Riffle | 4.3 | 0.4 | 9.8 | 4.3 | 1.9 | 92.5 |
| | *2012* | *1+08* | *Meander/Pool* | *6.7* | *0.6* | *11.4* | *3.9* | *4.0* | *95.9* |
| | 2010 | 1+68 | Crossover Riffle | 8.9 | 0.4 | 24.0 | 1.4 | 3.3 | 55.9 |
| | *2012* | *1+68* | *Crossover Riffle* | *9.2* | *0.5* | *18.9* | *1.5* | *4.4* | *57.8* |

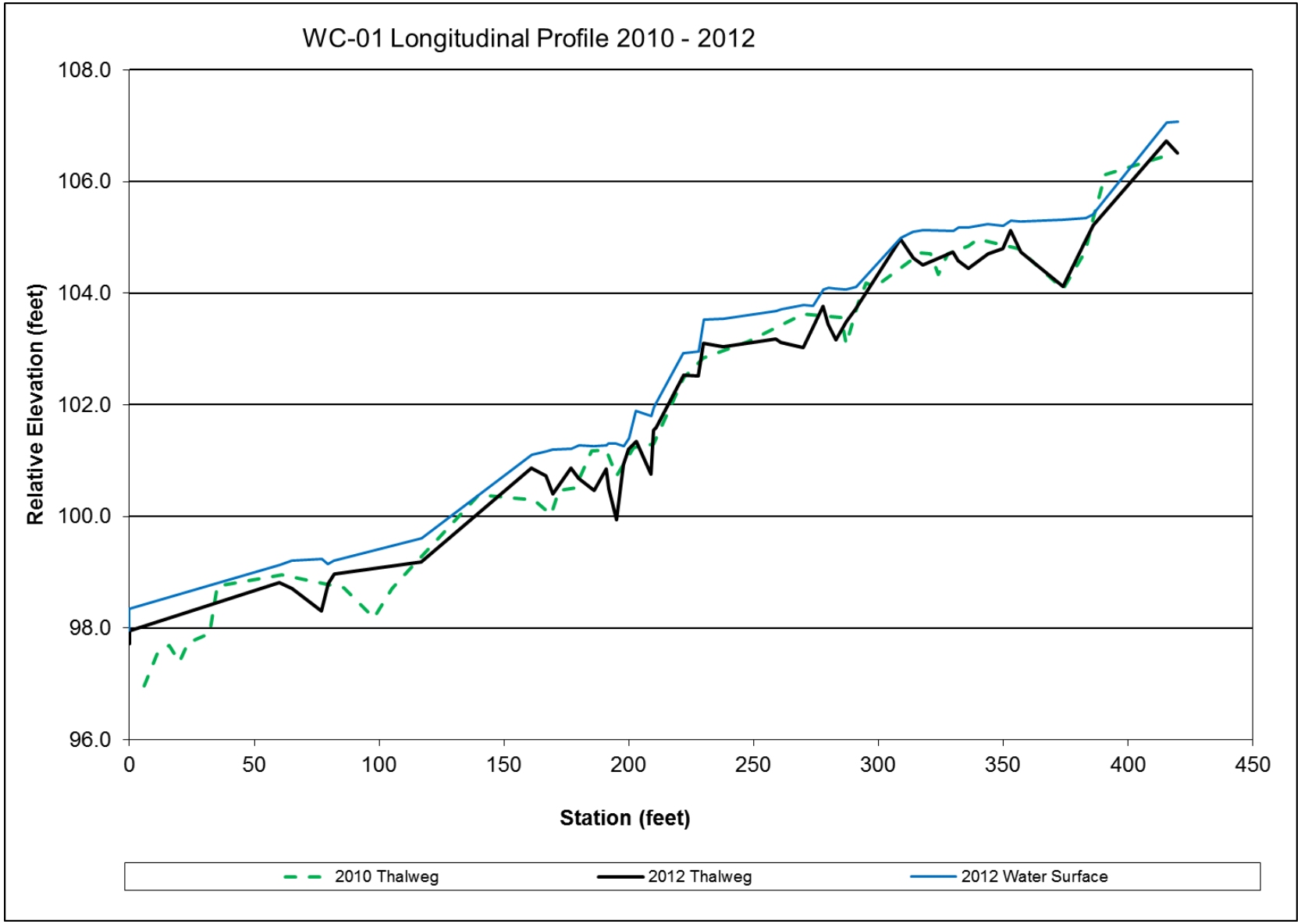


Figure C-1. WC-01 Longitudinal Profiles

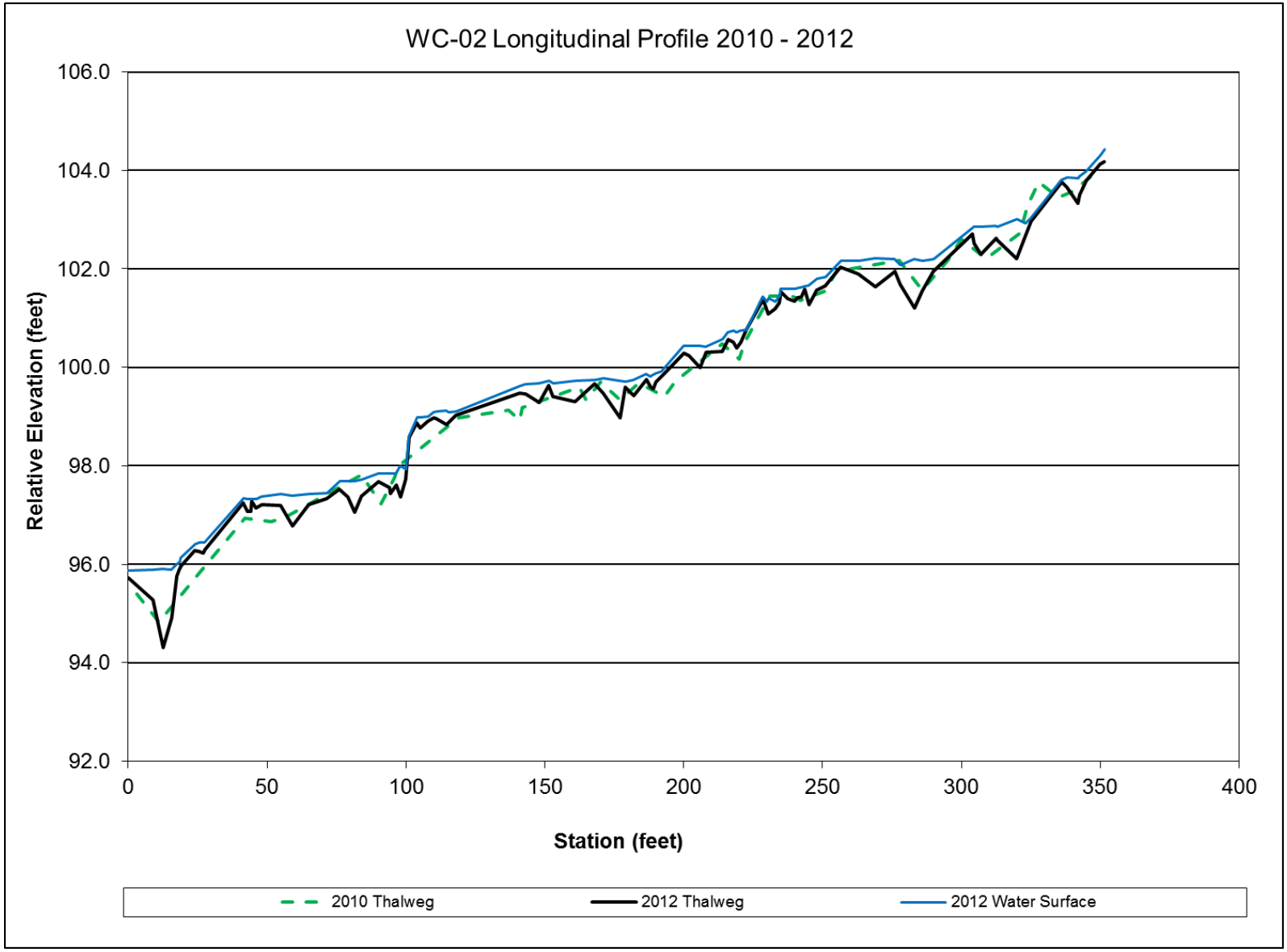


Figure C-2: WC-02 Longitudinal Profiles

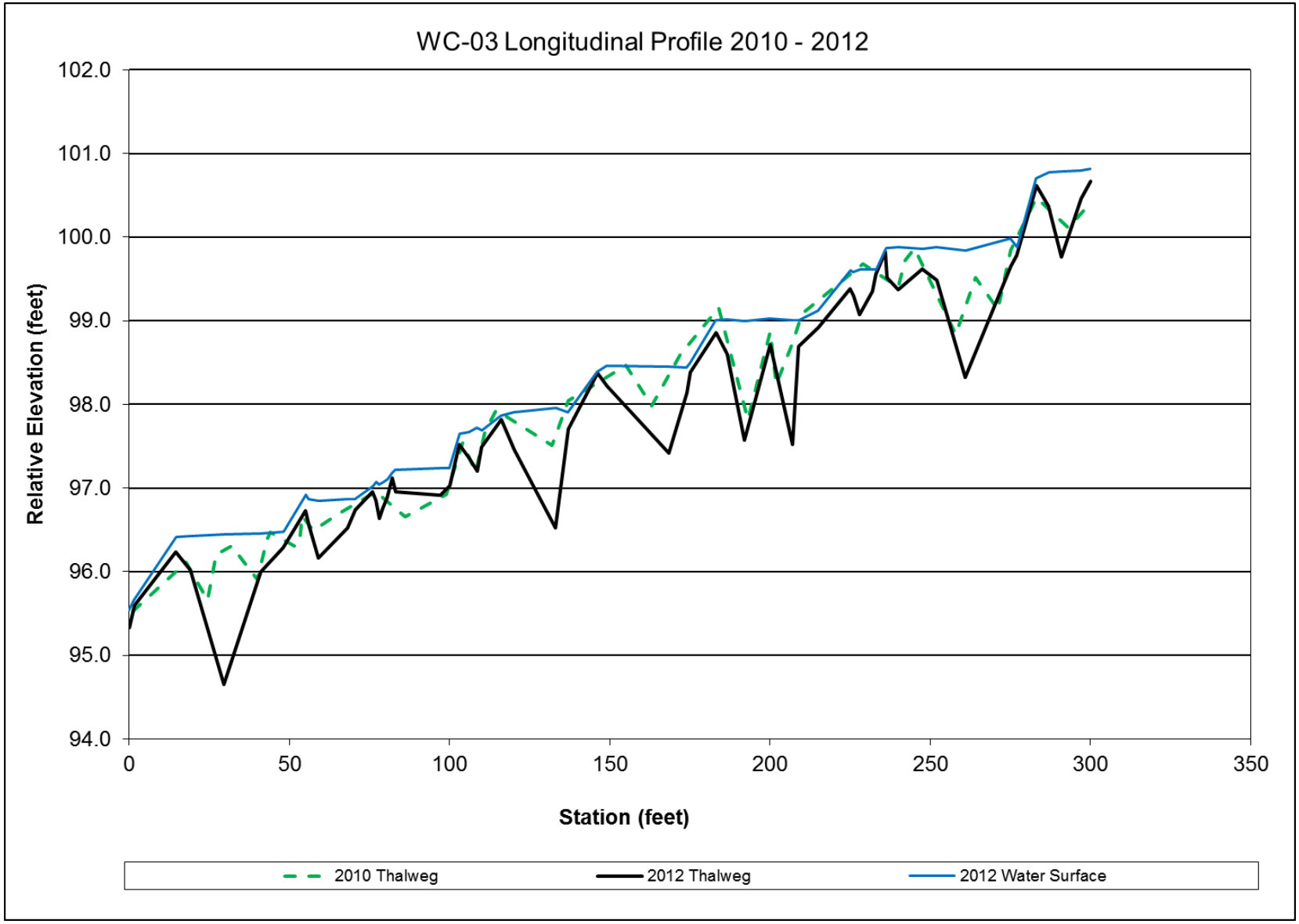


Figure C-3: WC-03 Longitudinal Profiles

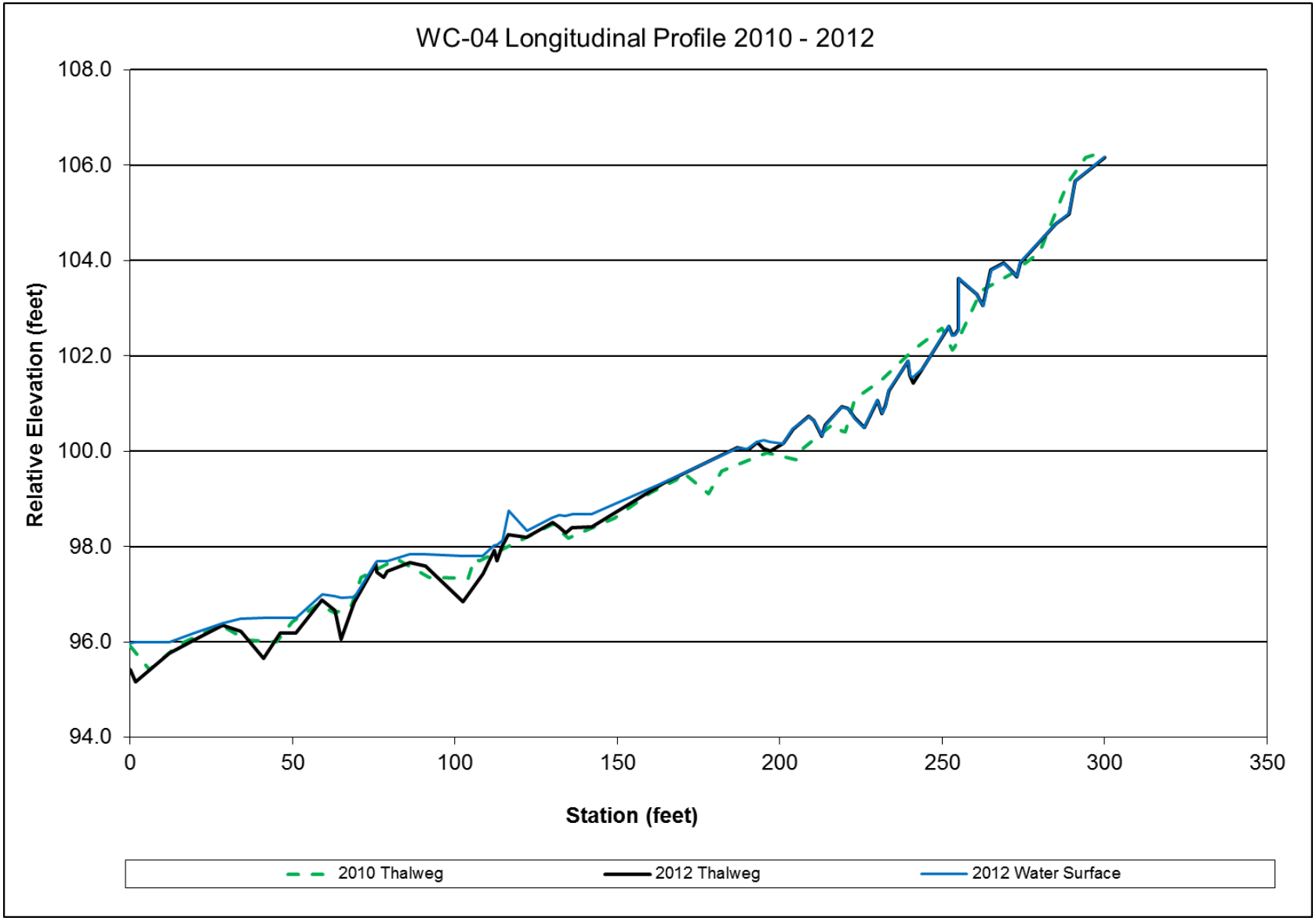


Figure C-4: WC-04 Longitudinal Profiles

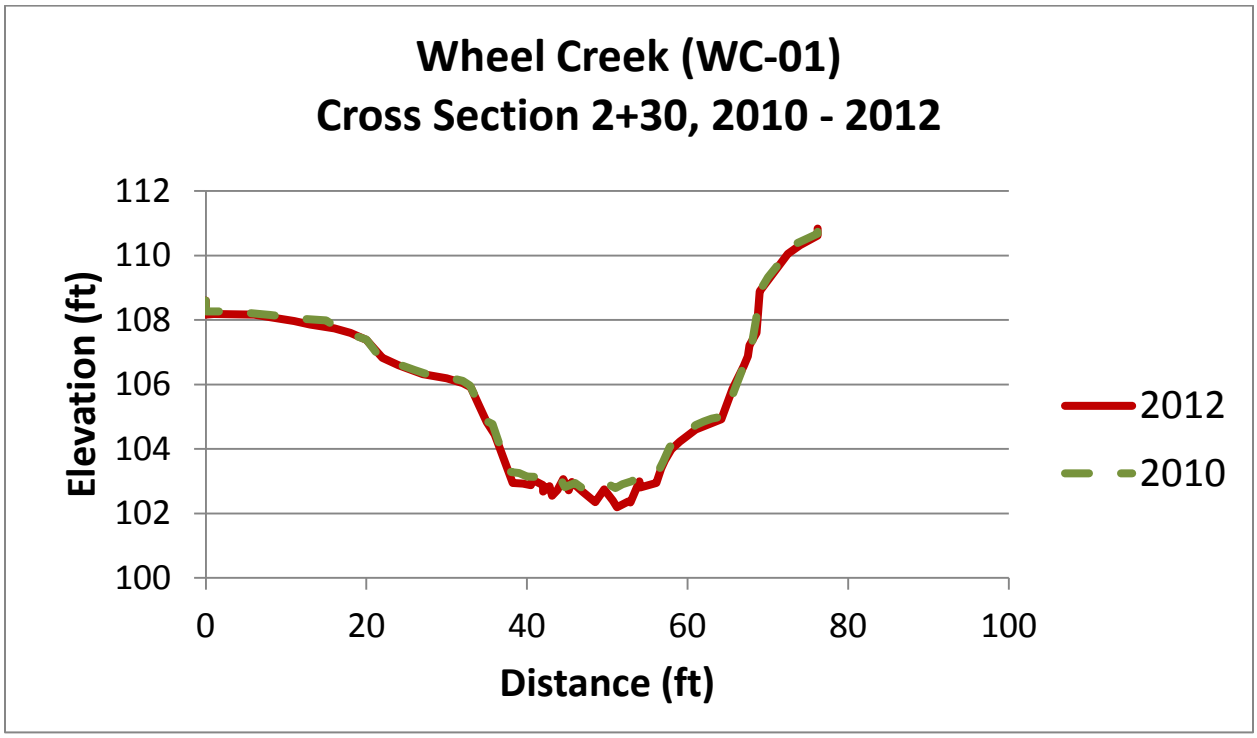


Figure C-5, WC01 Cross Section 1

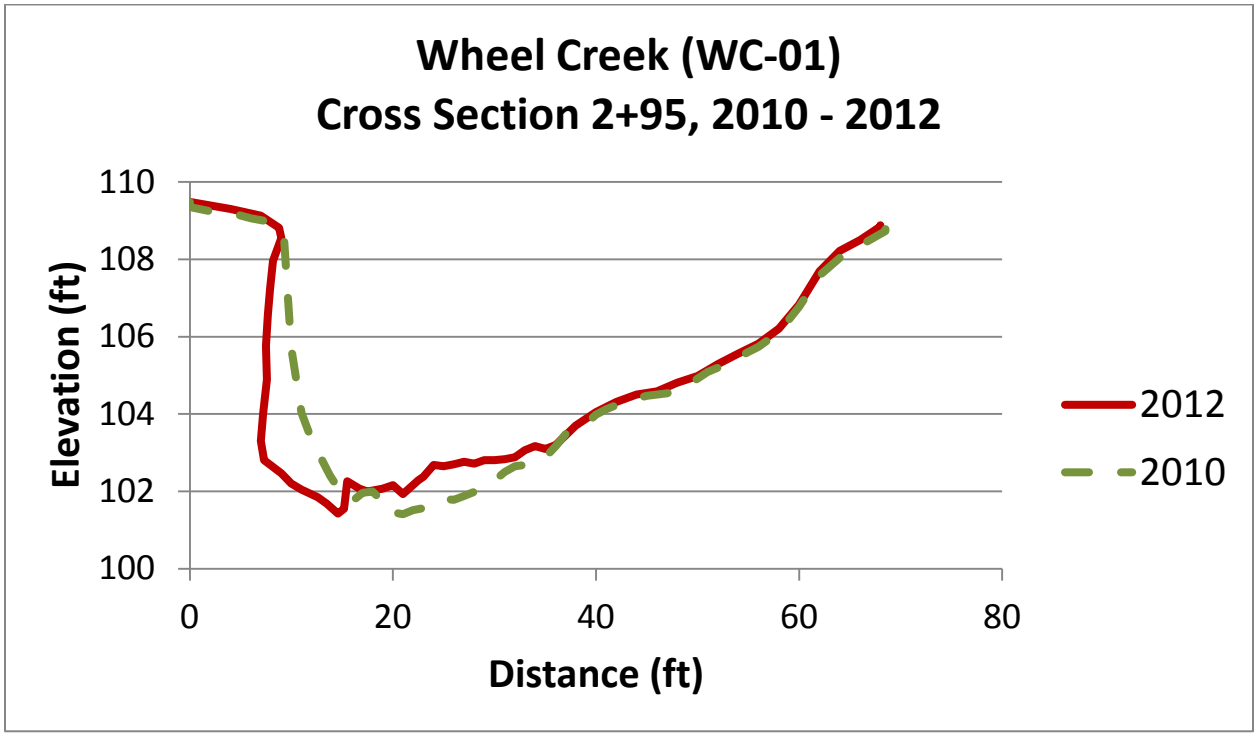


Figure C-6 WC01 Cross Section 2

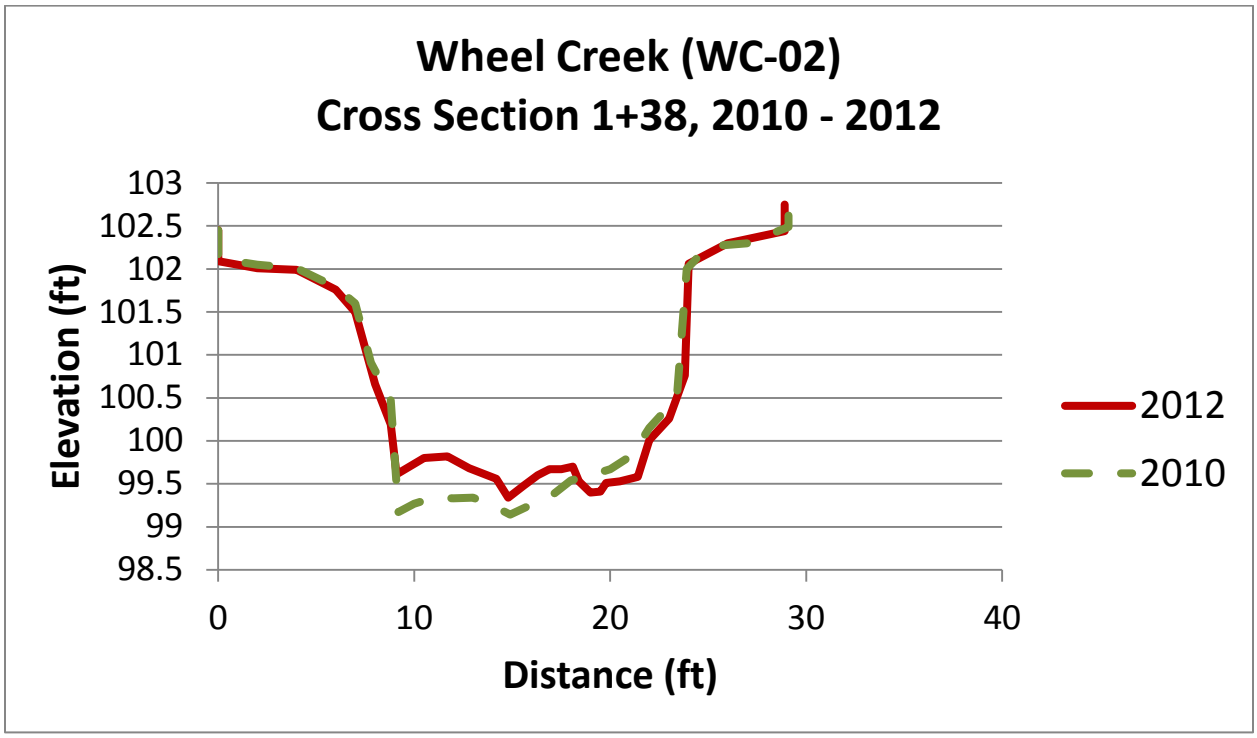


Figure C-7 WC02 Cross Section 1

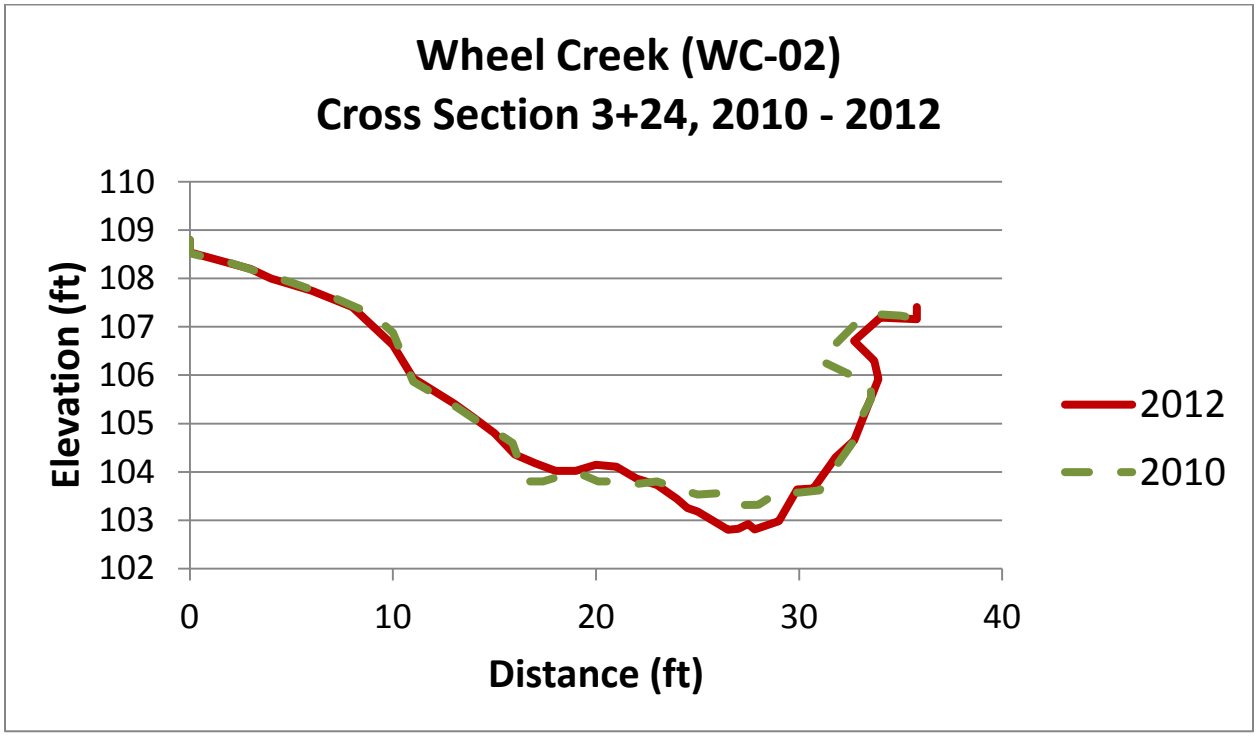


Figure C-8 WC02 Cross Section 2

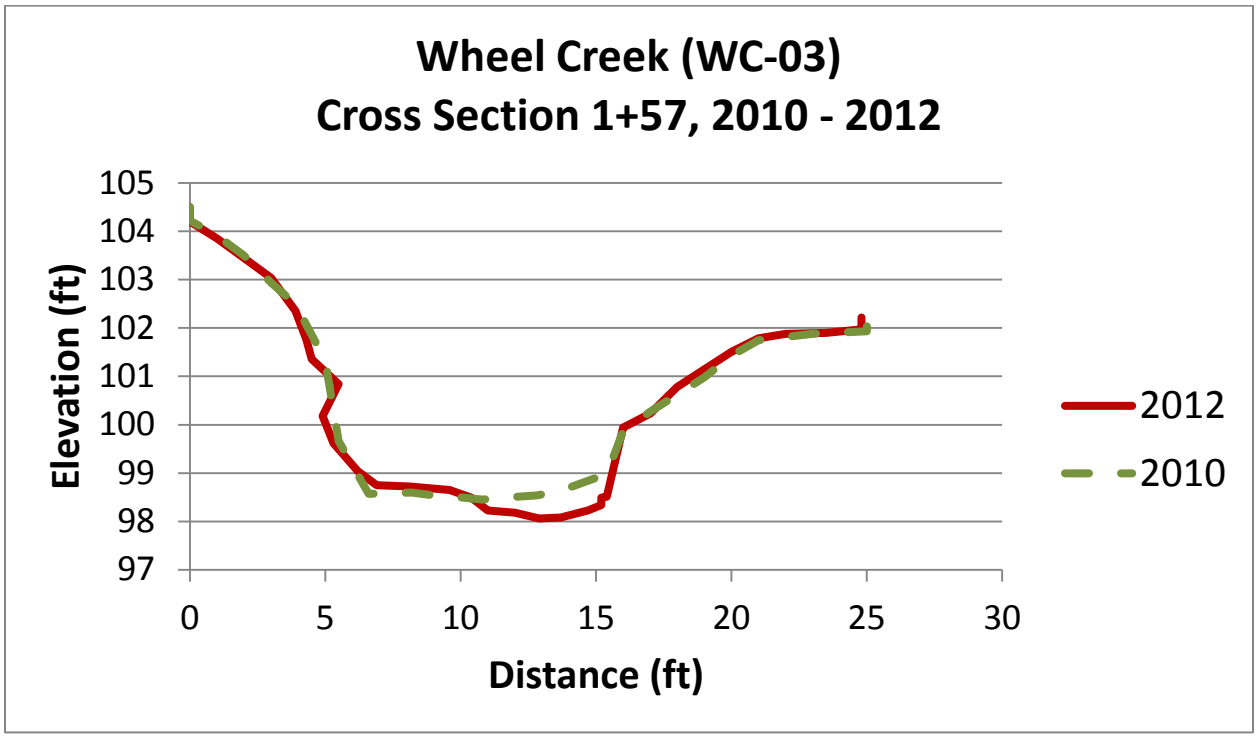


Figure C-9 WC03 Cross Section 1

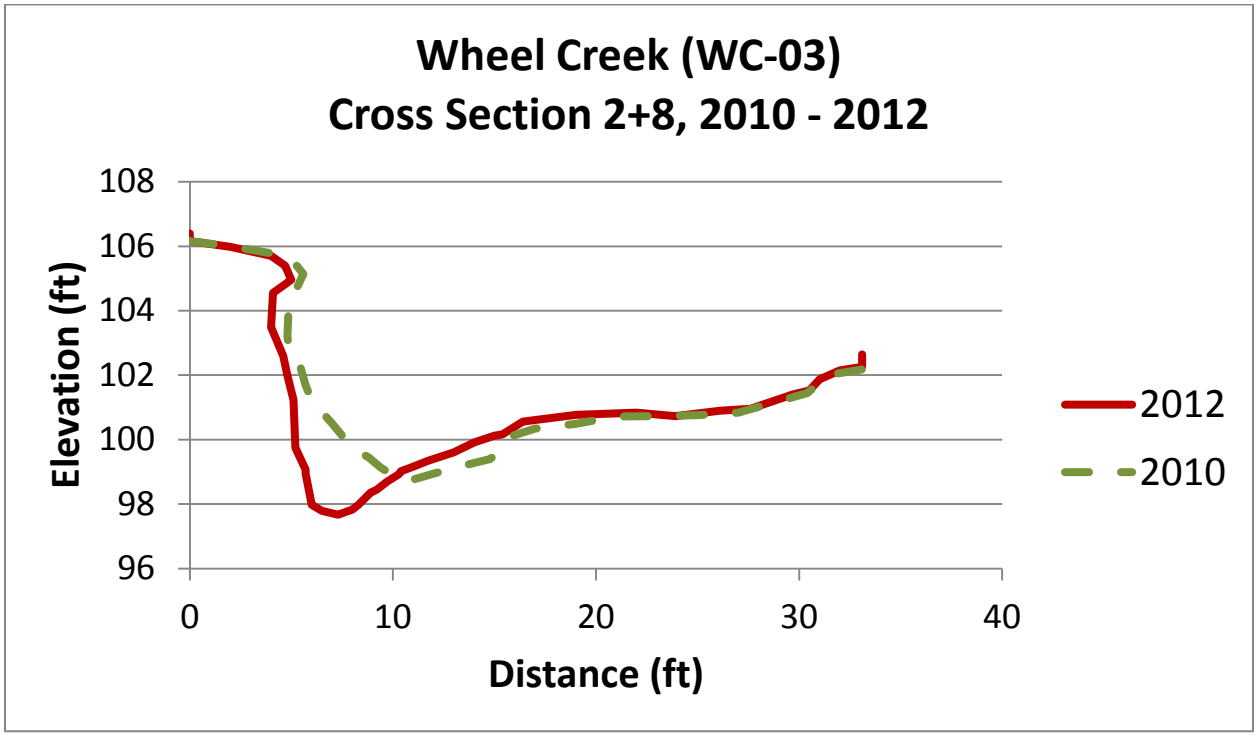


Figure C-10 WC03 Cross Section 2

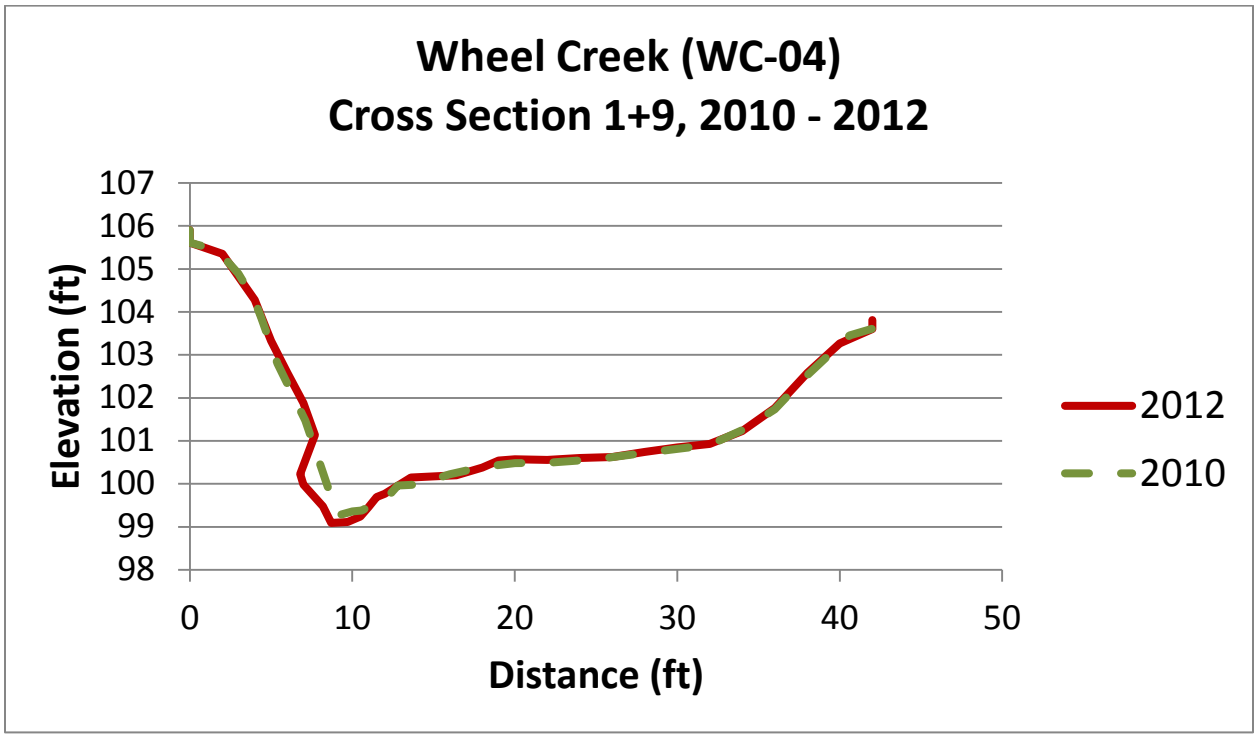


Figure C-11 WC04 Cross Section 1

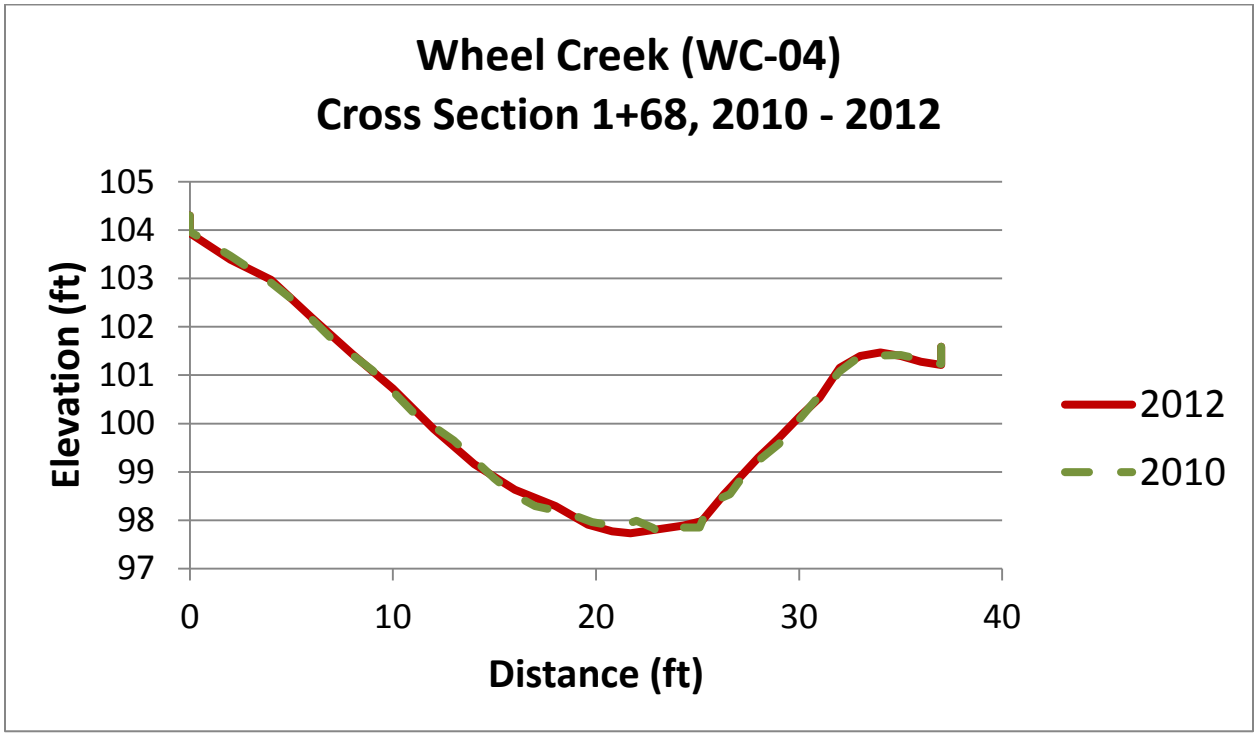


Figure C-12 WC04 Cross Section 2

Table C-3. Bank Pin Erosion Year 1 – Year 2

| Site | Profile Station 2012 | Bank | Pin Location | Predicted Erosion Rate Year 1 (ft/yr) | Measured Erosion Rate Year 1 (ft/yr) | Measured Erosion Rate Year 2 (ft/yr) | Total Measured Erosion Rate (ft/yr) |
|---|---|---|---|---|---|---|---|
| WC01 | 0+21 | Left - outer | Upper | 0.5 | 0.23 | 0.03 | -0.01 |
| | | Left - outer | Lower | 0.5 | 0.12 | 0.02 | -0.01 |
| | | Right - inner | Lower | 0.04 | 0.04 | -0.05 | -0.02 |
| | 1+30 | Left - inner | Toe | N/A* | 0.13 | -0.13 | -0.03 |
| | | Right - outer | Upper | 0.06 | 0.00 | 0.00 | -0.01 |
| | | Right - outer | Lower | 0.06 | 0.00 | 0.00 | 0.00 |
| | 1+92 | Left - inner | Toe | N/A* | -0.08 | N/A** | N/A** |
| | | Right - outer | Upper | 0.28 | 0.14 | -0.03 | 0.03 |
| | | Right - outer | Lower | 0.28 | 0.08 | 0.14 | 0.09 |
| | 3+80 | Left - inner | Toe | N/A* | -0.02 | -0.25 | -0.26 |
| | | Right - outer | Upper | 0.125 | 1.03 | 0.77 | 0.66 |
| | | Right - outer | Lower | 0.125 | 0.98 | N/A** | N/A** |
| WC02 | 0+24 | Left - outer | Upper | 0.375 | 0.24 | 0.04 | 0.12 |
| | | Left - outer | Lower | 0.375 | 0.11 | N/A** | N/A** |
| | | Right - inner | Toe | 0.003 | 0.12 | -0.24 | -0.16 |
| | 2+00 | Left - outer | Upper | 0.04 | 0.06 | -0.02 | 0.01 |
| | | Left - outer | Lower | 0.04 | -0.03 | -0.01 | -0.02 |
| | | Right - inner | Toe | 0.03 | 0.47 | N/A** | N/A** |
| | 2+88 | Left - outer | Upper | 0.2 | 0.30 | 0.00 | 0.12 |
| | | Left - outer | Lower | 0.2 | 0.36 | 0.07 | 0.19 |
| | | Right - inner | Toe | 0.06 | -0.04 | -0.17 | -0.16 |
| | 3+50 | Left - outer | Upper | 0.06 | 0.06 | 0.17 | 0.10 |
| | | Left - outer | Lower | 0.06 | 0.12 | -0.01 | 0.04 |
| | | Right - inner | Toe | 0.06 | 0.06 | 0.15 | 0.12 |
| WC03 | 0+75 | Left - outer | Upper | 0.06 | 0.02 | 0.00 | 0.00 |
| | | Left - outer | Lower | 0.06 | 0.11 | 0.00 | 0.05 |
| | | Right - inner | Lower | 0.03 | -0.04 | 0.01 | -0.02 |
| | 1+41 | Left - outer | Upper | 0.5 | 0.02 | 0.05 | 0.01 |
| | | Left - outer | Lower | 0.5 | 0.06 | 0.08 | 0.06 |
| | | Right - inner | Lower | 0.003 | 0.15 | 0.03 | 0.02 |
| | 1+83 | Left - inner | Lower | 0.003 | 0.08 | -0.05 | 0.00 |
| | | Right - outer | Upper | 0.125 | 0.02 | 0.04 | 0.04 |
| | | Right - outer | Lower | 0.125 | 0.05 | 0.02 | 0.04 |
| | 2+73 | Left - outer | Upper | 1.3 | 0.23 | N/A** | N/A** |
| | | Left - outer | Lower | 1.3 | 0.63 | N/A** | N/A** |
| | | Right - inner | Lower | N/A* | -1.00 | 0.31 | -0.20 |
| WC04 | 0+21 | Right - inner | Lower | N/A* | -0.44 | 0.29 | 0.01 |
| | | Left - outer | Upper | 0.06 | -0.16 | 0.02 | -0.05 |
| | | Left - outer | Lower | 0.06 | 0.03 | -0.24 | -0.15 |
| | 1+06.5 | Right - inner | Toe | N/A* | -0.01 | 0.06 | 0.02 |
| | | Left - outer | Upper | 0.125 | 0.07 | 0.04 | 0.06 |
| | | Left - outer | Lower | 0.125 | 0.09 | 0.41 | 0.31 |
| | 1+85.5 | Right - inner | Toe | 0.0003 | -0.04 | 0.03 | -0.04 |
| | | Left - outer | Upper | 0.003 | -0.06 | -0.01 | -0.03 |
| | | Left - outer | Lower | 0.003 | -0.32 | -0.08 | -0.18 |

Table C-3. (Continued)

| Site | Profile Station 2012 | Bank | Pin Location | Predicted Erosion Rate Year 1 (ft/yr) | Measured Erosion Rate Year 1 (ft/yr) | Measured Erosion Rate Year 2 (ft/yr) | Total Measured Erosion Rate (ft/yr) |
|---|---|---|---|---|---|---|---|
| | 2+64.5 | Right - inner | Toe | 0.01 | 0.14 | -0.02 | 0.04 |
| | | Left - outer | Upper | 0.2 | -0.14 | 0.20 | 0.17 |
| | | Left - outer | Lower | 0.2 | 0.00 | 0.15 | 0.05 |

Note: KCI calculated Measured Erosion Rate Year 1 using the difference between the maximum exposure values measured during the Year 1 monitoring period and the baseline measurements from 2010. Versar calculated Measured Erosion Rate Year 2 using the difference between the November 2012 measurements and the March 2011 measurements, and calculated Total Measured Erosion Rate using the difference between the November 2012 measurements and the baseline measurements fro 2010.

* Not Available – Erosion rate was not predicted at these locations.

** Not Available – Due to pin loss between the Year 1 and Year 2 assessments, Measured Erosion Rate Year 2 and Total Measured Erosion Rate could not be calculated at these locations.

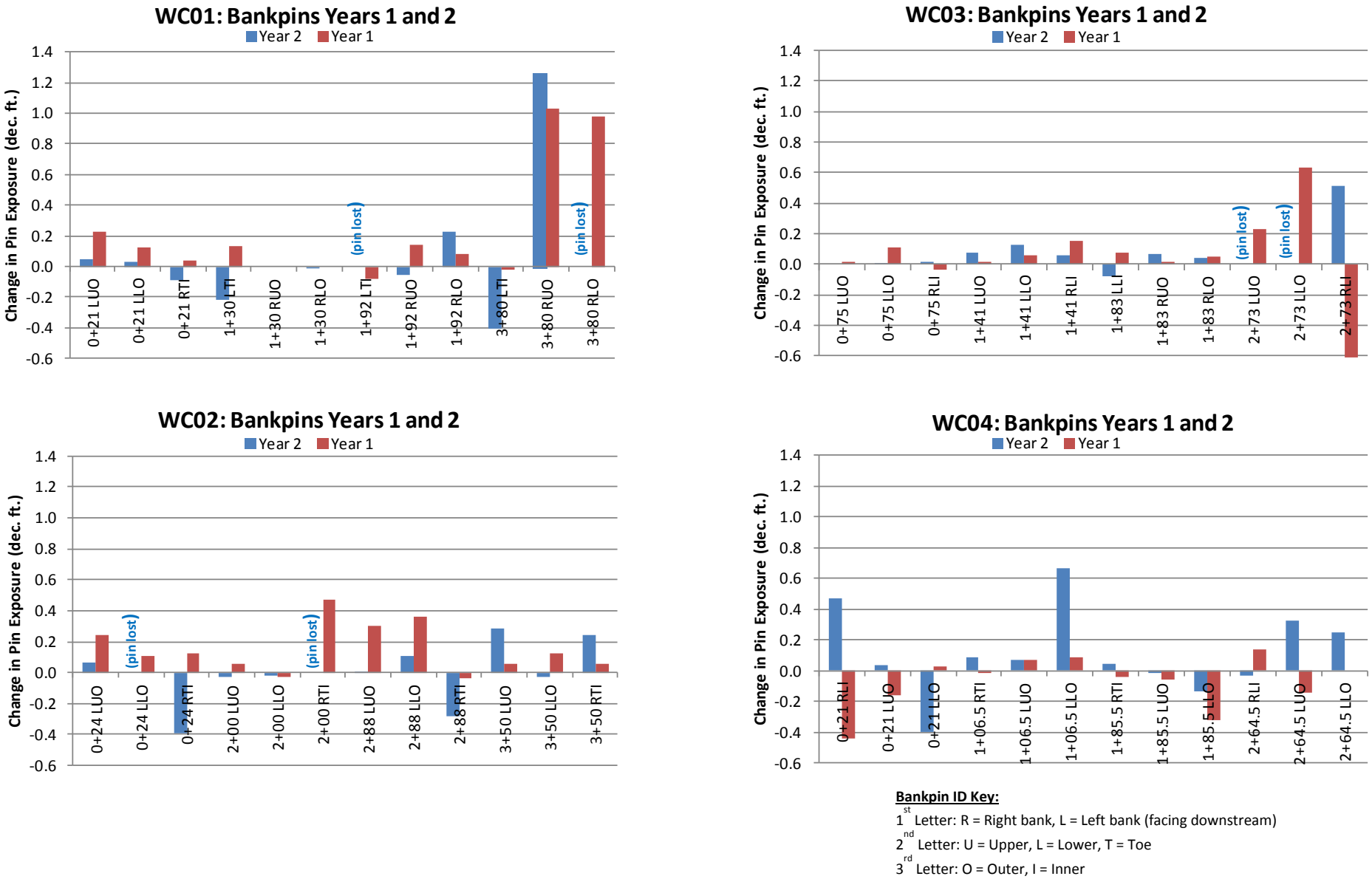


Figure C-13. Cumulative changes in Bank Pin Exposure Years 1 and 2. Between Year 1 and Year 2, pins were lost at WC01 Station 1+92 LTI and 3+80 RLO, at WC02 Stations 0+24 LLO and 2+00 RTI, and at WC03 Stations 2+73 LUO and 2+73 LLO.

Table C-4. Scour Chain Evaluation Years 1 and 2

| Reach | Profile Station, 2012 | Feature, 2012 | Cross Section Station | Cumulative Change from March 2011 (dec. ft.) | Cumulative Change from June 2010 (dec. ft.) | Annual rate of scour (March 2011-November 2012) (ft/yr) | Annual rate of scour (June 2010-November 2012) (ft/yr) |
|---|---|---|---|---|---|---|---|
| WC01 | 2+30 | Riffle | 47 | -0.05 | -0.12 | -0.03 | -0.05 |
| | 2+30 | Riffle | 50.7 | 0.47 | 0.23 | 0.29 | 0.09 |
| | 2+95 | Meander | 21.5 | N/A* | N/A* | N/A* | N/A* |
| WC02 | 1+38 | Riffle | 12 | -0.50 | -0.96 | -0.31 | -0.39 |
| | 1+38 | Riffle | 15 | -0.20 | -0.20 | -0.12 | -0.08 |
| | 3+24 | Riffle | 25.5 | -0.58 | -0.41 | -0.35 | -0.17 |
| WC03 | 1+57 | Pool | 12 | -0.09 | 0.07 | -0.06 | 0.03 |
| WC04 | 1+68 | Riffle | 21 | 0.05 | 0.00 | 0.03 | 0.00 |

* N/A = Not available – scour chain at WC01 station 2+95 was not able to be located.

Table C-5. Particle Size Distribution Year 1 – Year 2

| | *Riffle Feature Surface* | | | *Meander Feature Surface* | | | *Reachwide* | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | Measure | Size (mm) | Size Class | Measure | Size (mm) | Size Class | Measure | Size (mm) | Size Class |
| *WC01* | | | | | | | | | |
| 2010 | D50 | 39 | very coarse gravel | D50 | 38 | very coarse gravel | D50 | 44 | very coarse gravel |
| *2012* | *D50* | *56* | *very coarse gravel* | *D50* | *40* | *very coarse gravel* | *D50* | *51* | *very coarse gravel* |
| 2010 | D84 | 120 | medium cobble | D84 | 90 | medium cobble | D84 | 140 | large cobble |
| *2012* | *D84* | *180* | *large cobble* | *D84* | *77* | *small cobble* | *D84* | *120* | *medium cobble* |
| *WC02* | | | | | | | | | |
| 2010 | D50 | 50 | very coarse gravel | D50 | 45 | very coarse gravel | D50 | 49 | very coarse gravel |
| *2012* | *D50* | *40* | *very coarse gravel* | *D50* | *33* | *very coarse gravel* | *D50* | *28* | *coarse gravel* |
| 2010 | D84 | 98 | medium cobble | D84 | 94 | medium cobble | D84 | 100 | medium cobble |
| *2012* | *D84* | *80* | *small cobble* | *D84* | *69* | *small cobble* | *D84* | *80* | *small cobble* |
| *WC03* | | | | | | | | | |
| 2010 | D50 | 33 | very coarse gravel | D50 | 8.7 | medium gravel | D50 | 28 | coarse gravel |
| *2012* | *D50* | *27* | *coarse gravel* | *D50* | *15* | *medium gravel* | *D50* | *23* | *coarse gravel* |
| 2010 | D84 | 74 | small cobble | D84 | 72 | small cobble | D84 | 75 | small cobble |
| *2012* | *D84* | *59* | *very coarse gravel* | *D84* | *43* | *very coarse gravel* | *D84* | *72* | *small cobble* |

Table C-5. Particle Size Distribution Year 1 – Year 2

| | ***Riffle Feature Surface*** | | | ***Meander Feature Surface*** | | | ***Reachwide*** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **Measure** | **Size (mm)** | **Size Class** | **Measure** | **Size (mm)** | **Size Class** | **Measure** | **Size (mm)** | **Size Class** |
| *WC04* | | | | | | | | | |
| 2010 | D50 | 30 | coarse gravel | D50 | 18 | coarse gravel | D50 | 22 | coarse gravel |
| *2012* | *D50* | *36* | *very coarse gravel* | *D50* | *15* | *medium gravel* | *D50* | *24* | *coarse gravel* |
| 2010 | D84 | 80 | small cobble | D84 | 87 | small cobble | D84 | 71 | small cobble |
| *2012* | *D84* | *64* | *small cobble* | *D84* | *70* | *small cobble* | *D84* | *76* | *small cobble* |