# WHEEL CREEK GEOMORPHIC ASSESSMENT YEAR 3 FINAL REPORT

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HARFORD COUNTY MARYLAND

July 24, 2014

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# WHEEL CREEK
# GEOMORPHIC ASSESSMENT
# YEAR 3 FINAL REPORT

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# 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.

Restoration efforts in this watershed begain in 2012 with restoration/retrofit of a stormwater management pond (Pond A), located at the Gardens of Bel Air, which was completed in December of 2012. A second project, the Calvert's Walk stream restoration project, began in early 2013 and was completed that April. Additional stormwater retrofit and stream restoration projects within the watershed have been planned but have not yet been installed.

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 implement a total of 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 three years of 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).

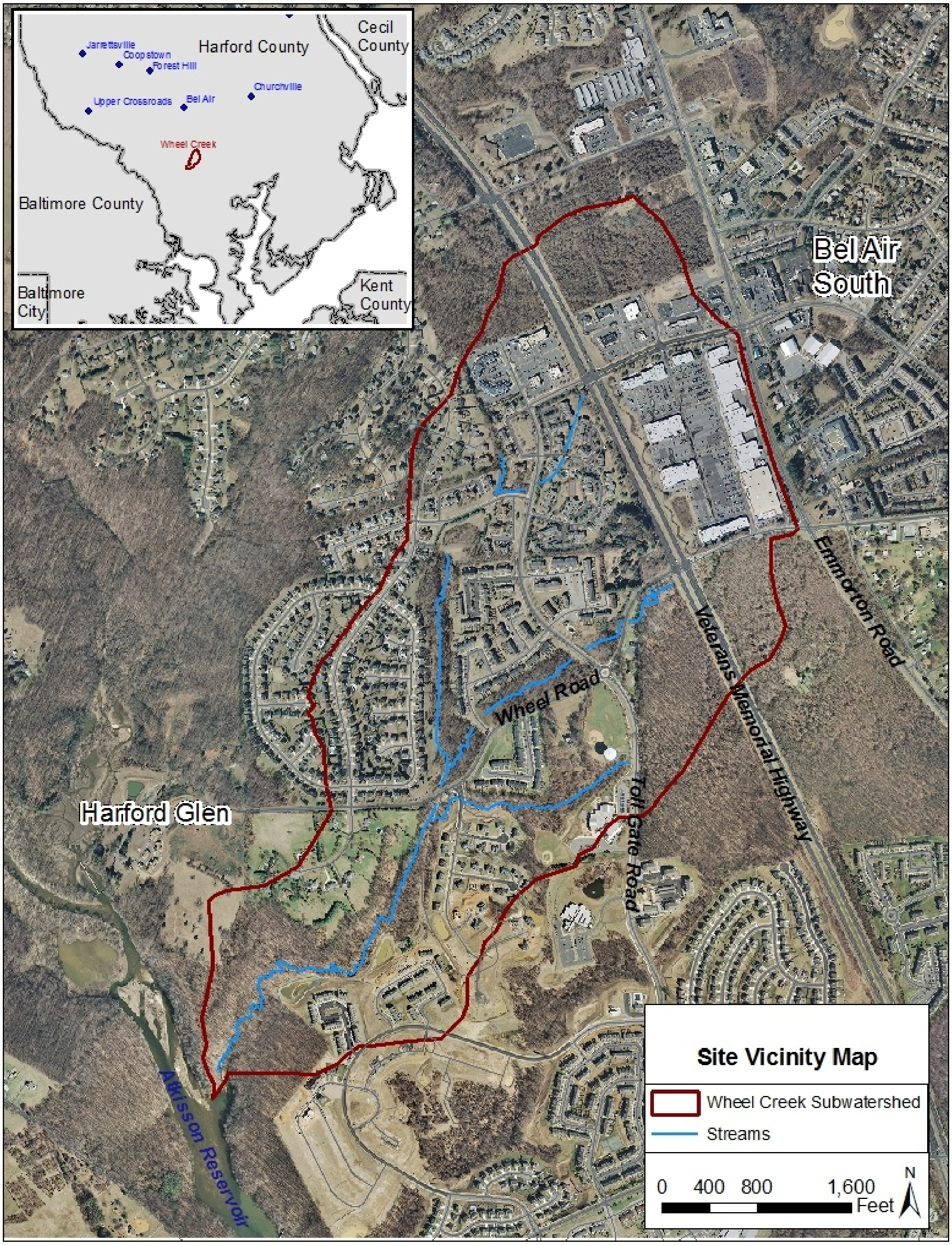


Figure 1-1. Site vicinity map

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 and 2013 (Year 3). 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). For a complete description of the Year 2 Study see *Wheel Creek Geomorphic Assessment Year 2* (Versar, 2013). This report focuses on continued geomorphic monitoring, including a comparison of data collected during Years 1, 2, and 3.

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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 and 2013 to provide additional monitoring data. Cross-sectional and longitudinal profile surveys were first conducted to establish baseline conditions of channel geometry and slope. Subsequent survey data can be compared to the baseline data to determine 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 3 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.

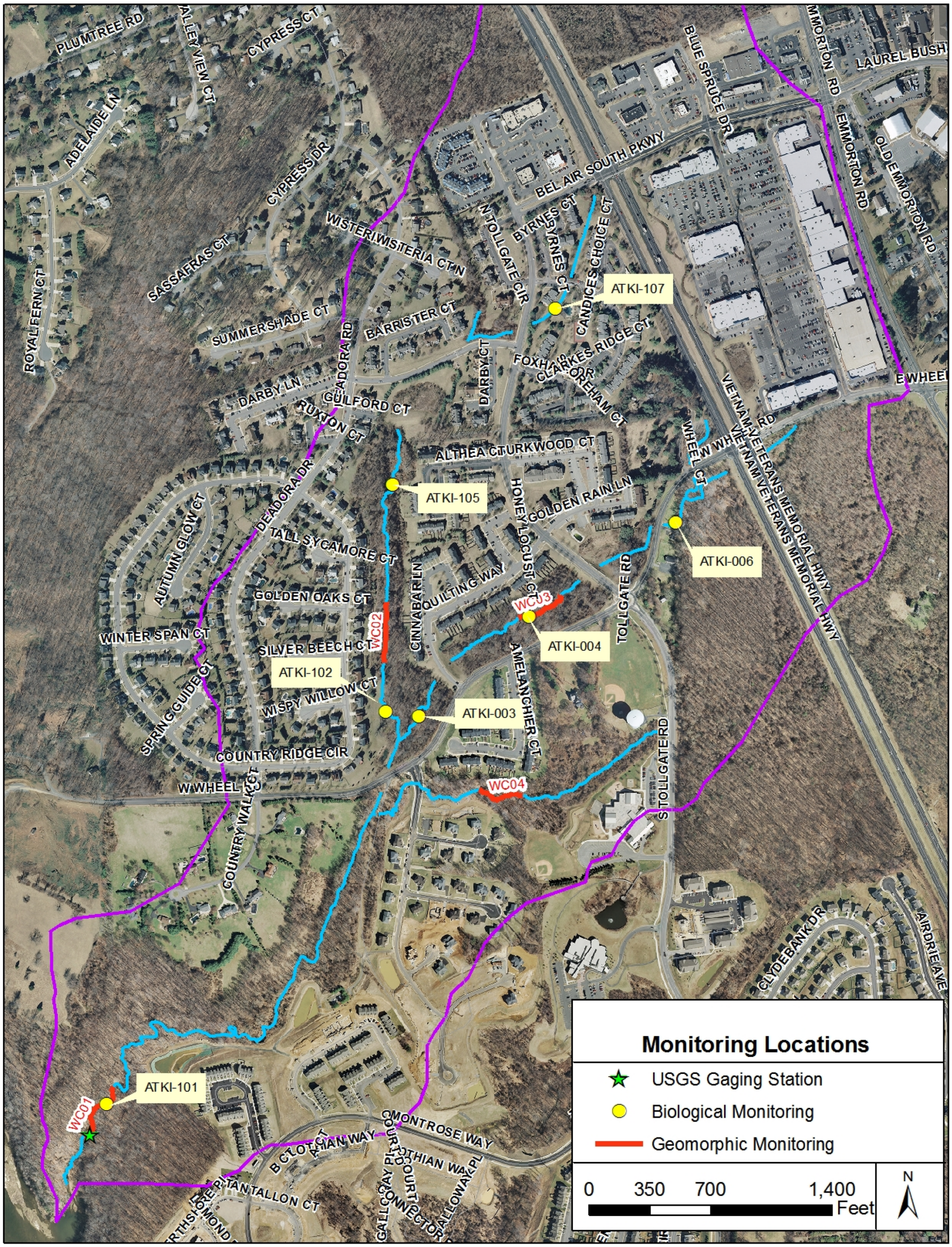


Figure 2-1. Wheel Creek monitoring locations

A survey of the bankfull elevation (where discernible), top of bank, and water surface was also performed. The plotted Year 3 longitudinal profile was overlaid with the plots from Years 1 and 2. These plots enable comparisons between years and are 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 during Year 1; 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 during Years 1, 2, and 3 within each reach at profile stations as shown in Table 2-1. Stationing differed slightly at several stations during Year 3 due to channel migration.

Table 2-1. Cross-sectional survey locations

| Reach | Profile Station (Year 1) | Profile Station (Year 2) | Profile Station (Year 3) | Feature |
|---|---|---|---|---|
| WC01 | 2+30 | 2+30 | 2+29 | Riffle |
| | 2+95 | 2+95 | 2+95 | Meander |
| WC02 | 1+37 | 1+38 | 1+38 | Riffle |
| | 3+24 | 3+24 | 3+25 | Meander |
| WC03 | 1+55 | 1+57 | 1+56 | Riffle |
| | 2+07 | 2+08 | 2+12 | Meander |
| WC04 | 1+08 | 1+08 | 1+08 | Meander |
| | 1+68 | 1+68 | 1+68 | Riffle |

During Year 3, 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, 2012, and 2013 provide three years of data 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 2013 geomorphic survey, Versar located and measured the exposed length of each pin along the upper surface of the pin. In two (2) cases, pins were found laying in the stream bed beside the bank where they were orginially installed. The two pins, both located at WC04, were reinserted into the stream bank and the 2013 length of exposure was recorded as 2 feet (the full length of the pins).

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 3 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+29 | 47 |
| | 2+29 | 50.7 |
| | 2+95 | 21.5 |
| WC02 | 1+38 | 12 |
| | 1+38 | 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 3 evaluations were compared to those found during the previous years 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 third year of baseline longitudinal profile and cross-sectional surveys were completed between October 9 to October 21, 2013. 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 3 baseline survey. Graphical depictions of each profile are presented in Appendix B. In addition, each surveyed profile was plotted, overlain and compared to the Years 1 and 2 profiles (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 3

| Reach | Length (ft) | Slope | Proportion of Features | | | |
|---|---|---|---|---|---|---|
| | | | Riffle | Run | Pool | Glide |
| WC01 | 420 | 2.2% | 55.7% | 8.2% | 23.8% | 12.3% |
| WC02 | 350 | 2.3% | 48.1% | 12.6% | 26.3% | 13.0% |
| WC03 | 306.3 | 1.6% | 37.2% | 15.9% | 30.4% | 16.5% |
| WC04 | 300 | 3.4% | 46.5% | 11.0% | 27.9% | 14.6% |

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 Years 1 and 2 graphs (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 3

| 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+29 | Crossover Riffle | 21.6 | 1.1 | 20.2 | 1.5 | 23.2 | 82.2 |
| | 2+95 | Meander/Riffle | 29.0 | 0.9 | 34.1 | 1.5 | 24.7 | 212.7 |
| WC02 | 1+38 | Crossover Riffle | 14.3 | 0.7 | 19.4 | 1.2 | 10.6 | 36.7 |
| | 3+25 | Meander/Riffle | 15.6 | 0.7 | 21.8 | 1.5 | 11.1 | 72.0 |
| WC03 | 1+56 | Crossover/Riffle | 10.1 | 0.9 | 11.8 | 1.2 | 8.6 | 38.2 |
| | 2+12 | Meander/Pool | 9.7 | 1.0 | 10.0 | 2.7 | 9.4 | 55.0 |
| WC04 | 1+08 | Meander/Pool | 13.0 | 0.6 | 23.5 | 2.2 | 7.2 | 99.9 |
| | 1+68 | Crossover Riffle | 10.4 | 0.5 | 20.4 | 1.4 | 5.3 | 56.3 |

### 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 mid-November 2012 to mid-October 2013. 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 48-week period between measurements and scaling it to a one-year period based on the standard of 52 weeks in a year. Also note that several profile station locations were updated between 2012 and 2013. Pins formerly located at profile station 2+73 in WC03 were relocated to 2+57 and 2+77, while pins located at profile stations 1+06.5 and 1+87.5 in WC04 were measured at stations 1+07.5 and 1+87 in 2013 as a result of channel migration. Complete data on pin measurements for each visit are included in Appendix B.

Measured erosion rates in reach WC01 ranged from 0.00 to 0.38 ft/year with the highest erosion occurring along the outer meander bend at profile station 3+80. Both pins installed within the meander bend at profile station 3+80 were hammered further into the bank after the completion of Year 3 measurements to prevent them from falling out of the bank. Deposition rates at WC01 ranged from -0.05 to -0.77 ft/yr with the most deposition occurring along the base of the inner meander bend at profile station 1+92. Erosion rates ranged from 0.00 to 1.13 ft/yr at WC02, while deposition rates ranged from -0.02 to -0.38 ft/yr. The upper left bank at profile station 0+24 continues to experience significant undercutting, and the lower left bank pin was still not able to be found. Erosion rates at site WC03 ranged from 0.00 to 0.09 ft/yr with the highest erosion occurring at profile station 2+57. Deposition rates at WC03 ranged from -0.05 to -0.11 ft/yr. At reach WC04, measured erosion rates ranged from 0.00 to 1.90 ft/yr, with the highest erosion rate occurring on the upper portion of the left bank at profile station 1+07.5. It should be noted that actual erosion rates may differ from measured erosion rates for the 1+07.5

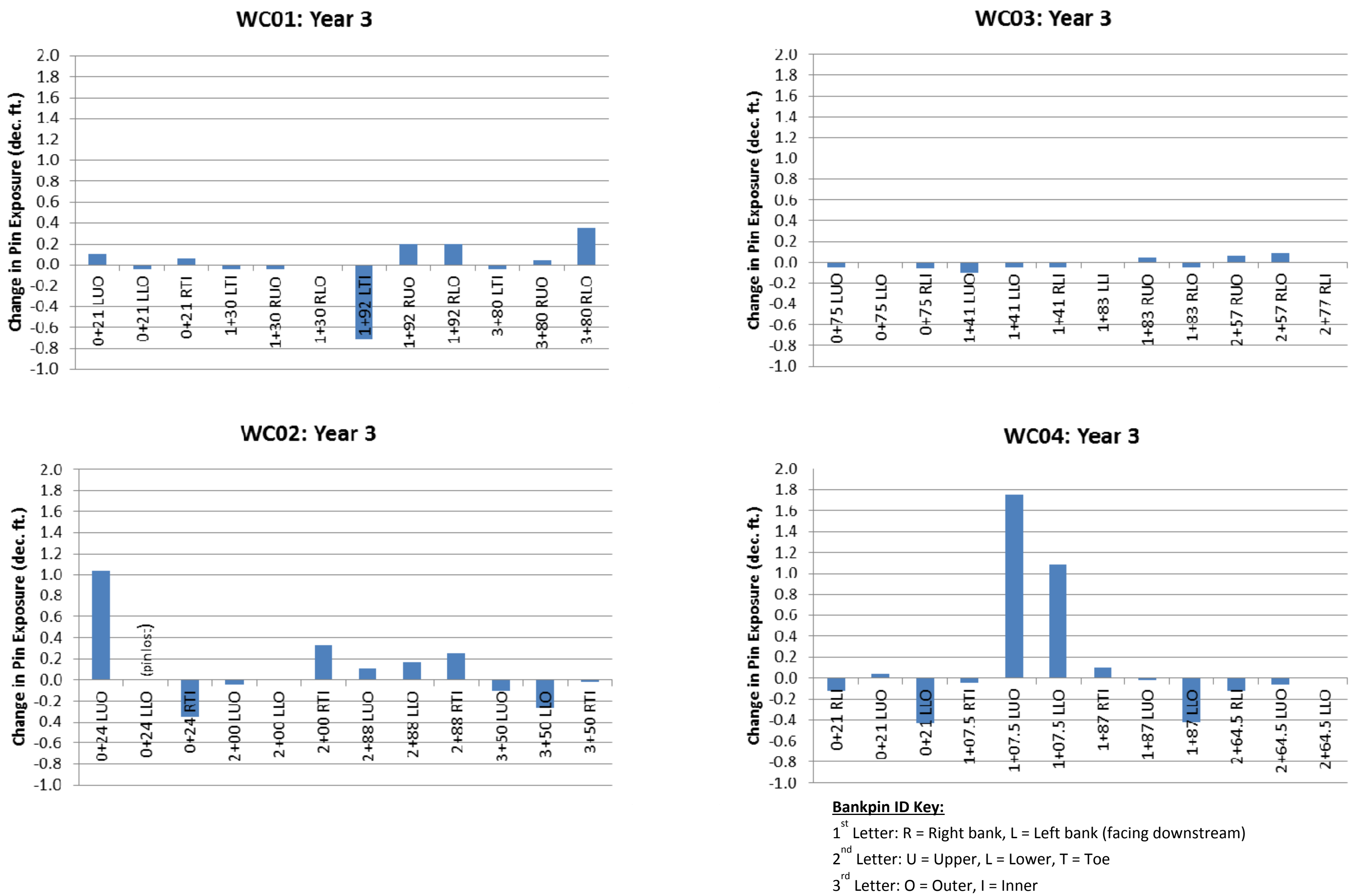


Figure 3-1. Cumulative change in Wheel Creek bankpin exposure by reach between mid-November 2012, and mid-October 2013. The pin lost at WC02 Station 0+24 LLO between Year 1 and Year 2 was not recovered in Year 3.

left bank pins; both of which fell after the bank experienced a significant amount of erosion. Depositional rates in this reach ranged from -0.02 to -0.47 ft/yr.

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

| Profile Station | Bank | Pin Location | Measured Erosion Rate (ft/yr) |
|---|---|---|---|
| 0+21 | Left - outer | Upper | 0.11 |
| | Left - outer | Lower | -0.05 |
| | Right - inner | Lower | 0.07 |
| 1+30 | Left - inner | Toe | -0.05 |
| | Right - outer | Upper | -0.05 |
| | Right - outer | Lower | 0.00 |
| 1+92 | Left - inner | Toe | -0.77 |
| | Right - outer | Upper | 0.21 |
| | Right - outer | Lower | 0.21 |
| 3+80 | Left - inner | Toe | -0.05 |
| | Right - outer | Upper | 0.05 |
| | Right - outer | Lower | 0.38 |

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

| Profile Station | Bank | Pin Location | Measured Erosion Rate (ft/yr) |
|---|---|---|---|
| 0+24 | Left - outer | Upper | 1.13 |
| | Left - outer | Lower | NA* |
| | Right - inner | Toe | -0.38 |
| 2+00 | Left - outer | Upper | -0.05 |
| | Left - outer | Lower | 0.00 |
| | Right - inner | Toe | 0.36 |
| 2+88 | Left - outer | Upper | 0.11 |
| | Left - outer | Lower | 0.18 |
| | Right - inner | Toe | 0.27 |
| 3+50 | Left - outer | Upper | -0.11 |
| | Left - outer | Lower | -0.29 |
| | Right - inner | Toe | -0.02 |

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

| Table 3-5. WC03 bank pin erosion – Year 3 | | | |
|---|---|---|---|
| **Profile Station** | **Bank** | **Pin Location** | **Measured Erosion Rate (ft/yr)** |
| 0+75 | Left - outer | Upper | -0.05 |
| | Left - outer | Lower | 0.00 |
| | Right - inner | Lower | -0.07 |
| 1+41 | Left - outer | Upper | -0.11 |
| | Left - outer | Lower | -0.05 |
| | Right - inner | Lower | -0.05 |
| 1+83 | Left - inner | Lower | 0.00 |
| | Right - outer | Upper | 0.05 |
| | Right - outer | Lower | -0.05 |
| 2+57 | Right - outer | Upper | 0.07 |
| | Right - outer | Lower | 0.09 |
| 2+77 | Right - inner | Lower | 0.00 |

| Table 3-6. WC04 bank pin erosion – Year 3 | | | |
|---|---|---|---|
| **Profile Station** | **Bank** | **Bank Location** | **Measured Erosion Rate (ft/yr)** |
| 0+21 | Right - inner | Lower | -0.14 |
| | Left - outer | Upper | 0.05 |
| | Left - outer | Lower | -0.47 |
| 1+07.5 | Right - inner | Toe | -0.05 |
| | Left - outer | Upper | 1.90 |
| | Left - outer | Lower | 1.17 |
| 1+87 | Right - inner | Toe | 0.11 |
| | Left - outer | Upper | -0.02 |
| | Left - outer | Lower | -0.45 |
| 2+64.5 | Right - inner | Toe | -0.14 |
| | Left - outer | Upper | -0.07 |
| | Left - outer | Lower | 0.00 |

Figure 3-2 displays the cumulative depth of scour for each scour chain during the mid-November 2012 to mid-October 2013 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 3 survey. Also of note, similar to Year 2, crews were unable to uncover the entire length of chain after excavating down half a foot to reach the buried chain at station 3+34 in WC02. In this case, field staff assumed no additional scour occurred. Complete data reflecting individual scour chain measurements are included in Appendix B.

During the period of mid-November 2012 to mid-October 2013, cumulative bed scour occurred within two reaches (WC02 and WC04). The largest amount of scour, 0.17 feet, was measured at station 1+38 in reach WC02. Cumulative deposition occurred at all other chains, with the most deposition occurring in reach WC03. Station 1+55 (WC03) had 1.67 feet of deposition, the most observed at any chain.

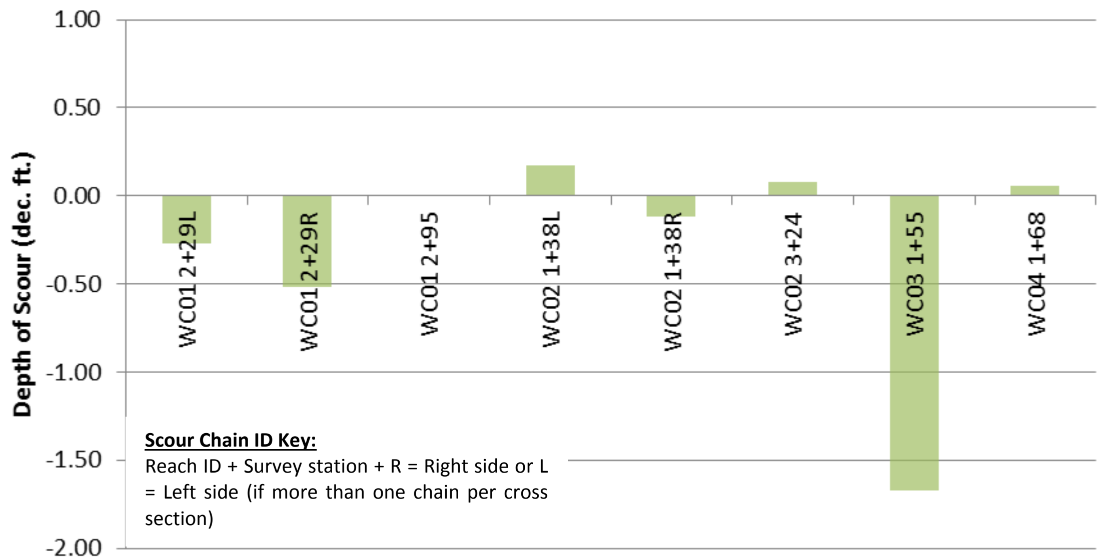


Figure 3-2. Bed scour in Wheel Creek between mid-November, 2012 and mid-October 2013 as measured through scour chain analysis at each reach. The scour chain at station 2+95 in WC01 was not able to be located for measurement.

Table 3-7 displays the location of scour chains within each reach as well as the corresponding annual scour rates as measured from mid-Novermber 2012 to mid-October 2013. It should be noted that annual scour rates, presented in feet per year, were derived by calculating the cumulative change over the 48-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 3

| Reach | Profile Station, 2013 | Feature, 2013 | Cross Section Station | Cumulative Change from November 2012 | Annual rate of scour (ft/yr) |
|---|---|---|---|---|---|
| WC01 | 2+29 | Riffle | 47 | -0.27 | -0.29 |
| | 2+29 | Riffle | 50.7 | -0.52 | -0.56 |
| | 2+95 | Meander | 21.5 | N/A* | N/A* |
| WC02 | 1+38 | Riffle | 12 | 0.17 | 0.18 |
| | 1+38 | Riffle | 15 | -0.12 | -0.13 |
| | 3+24 | Riffle | 25.5 | 0.08 | 0.09 |
| WC03 | 1+55 | Pool | 12 | -1.67 | -1.81 |
| WC04 | 1+68 | Riffle | 21 | 0.06 | 0.07 |

* 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 3 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 at WC01, WC02, and WC03 indicate a D50 ranging from coarse gravel to very coarse gravel. At WC04, the meander feature D50 is in the very coarse sand class, due to pool features yielding smaller particles. Riffle surface and reachwide D84 size classes range from small to large cobble at sites WC01, WC02, and WC03, with the largest particles found at site WC01. Site WC04 has the smallest particles, with riffle surface and meander surface D84 in the very coarse gravel and small cobble size classes, respectively. Meander feature surface pebble counts at all sites indicate a D84 median particle size class ranging from very coarse gravel to small cobble. Complete particle size distribution charts are included in Appendix B.

Table 3-8. Particle size distribution – Year 3

| ***Riffle Feature Surface*** | | | ***Meander Feature Surface*** | | | ***Reachwide*** | | |
|---|---|---|---|---|---|---|---|---|
| **Measure** | **Size (mm)** | **Size Class** | **Measure** | **Size (mm)** | **Size Class** | **Measure** | **Size (mm)** | **Size Class** |
| *WC01* | | | | | | | | |
| D50 | 49 | very coarse gravel | D50 | 37 | very coarse gravel | D50 | 55 | very coarse gravel |
| D84 | 130 | large cobble | D84 | 87 | small cobble | D84 | 130 | large cobble |
| *WC02* | | | | | | | | |
| D50 | 51 | very coarse gravel | D50 | 47 | very coarse gravel | D50 | 40 | very coarse gravel |
| D84 | 88 | small cobble | D84 | 86 | small cobble | D84 | 110 | medium cobble |
| *WC03* | | | | | | | | |
| D50 | 27 | coarse gravel | D50 | 29 | coarse gravel | D50 | 35 | very coarse gravel |
| D84 | 68 | small cobble | D84 | 59 | very coarse gravel | D84 | 130 | large cobble |
| *WC04* | | | | | | | | |
| D50 | 33 | very coarse gravel | D50 | 1.5 | very coarse sand | D50 | 36 | very coarse gravel |
| D84 | 57 | very coarse gravel | D84 | 64 | small cobble | D84 | 79 | small cobble |

# 4.0 COMPARISONS BETWEEN YEARS

## 4.1 WC01

This site exhibited the most drastic changes in longitudinal profile over the three 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 and third years of monitoring, the thalweg followed what had been the cutoff channel along the right bank and the previous thalweg channel had only minimal flows, if any. 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 and third years, the reach was 420 feet in length. Sinuosity above Cross-section 2 likely increased, adding length to the profile. Although there has been major changes in the longitudinal profile over the course of three years, there has been far less change shown between Year 2 and Year 3 of monitoring. (*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 and Year 3.*)

Changes in the cross-sections were also observed at WC01 between the three years of survey (Figures C-5, C-6). Bed scour was observed at Cross-section 1 (Crossover Riffle at Station 2+29) especially near the right bank between Years 1 and 2, while deposition is apparent near the left bank between Years 2 and 3. Significant bank erosion and undercutting along the left bank (almost 6 feet) was observed at Cross-Section 2 (Meander Bend at Station 2+95) during both second and third years' monitoring. This has resulted in increases, from Year 1, of bankfull cross-sectional area and top of bank cross-sectional area at this station. Between Years 1 and 2, a side-bar formed on the right bank, burying the scour chain at this cross-section. In addition, the thalweg pattern changed between Years 1 and 2 so that it 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 as the first two years, with the persistance of deposition at toe pins and erosion along meander bends (Table C-3). The erosion occurring in the upper-most portion of the reach (station 3+80) was less severe during the third year of study.

Annual rates of scour were estimated based on the change in scour chain exposure between Years 2 and 3 (November 2012 - October 2013) and between the June 2010 baseline measurement and Year 3 (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 48-week period between Year 2 and 3 measurements and 175-week period between the baseline and Year 3 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+29 (right) exhibited a high annual rate of deposition in Year 3 (-0.56 feet per year) after exhibiting the highest scour rate of all chains surveyed over the first two years of monitoring (0.09 feet per year).

At WC01, $D_{50}$ particle size classes remained the same between all three years of study at both cross-sections, and reachwide (Table C-5). $D_{84}$ particle size classes changed between Years 1 and 2, coarsening at Cross-section 1 (Crossover Riffle at Station 2+29) from medium to large cobble, and becoming slightly finer at Cross-Section 2 (Meander Bend at Station 2+95) from medium to small cobble. $D_{84}$ classes were unchanged between Years 2 and 3. Reachwide particle size class fluxtuated between large cobble during Year 1, to medium cobble during Year 2 and back to large cobble during Year 3.

## 4.2 WC02

Significant changes in profile were not observed at WC02 over the three years of study (Figure C-2). Reach length remained constant and stream slope measurements were fairly consistent overall. Feature porportions within the reach have fluctuated from year to year. While the percentage of glides increased from 0% to 16.7% between Years 1 and 2, the percentage of pools has declined each year. During the third year 39.3% of the surveyed reach was classified as pools and glides, the lowest percentage since monitoring began. In contrast, riffles and runs made up 60.7% of the surveyed reach which was the greatest percentage of all three years (Table C-1).

Following Year 1, bed aggradation occurred 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+25), as well as slight erosion of the upper portion of the right bank (Figure C-8). At this station, a bankfull bar exists along the left bank which has altered the cross-section bankfull dimensions as compared to the first year's survey. There was little change between Year 2 and Year 3 of the study.

Annual bank erosion rates as estimated from bank pin measurements in Year 3 were similar to Years 1 and 2, with exception of the upper portion of the reach. In Years 1 and 2 the pin data showed that the banks at station 3+50 were generally eroding, but deposition occurred at each of these pins between Years 2 and 3 (Table C-3). Also note that the erosion rate of the upper-left pin at profile station 0+24 increased significantly during the third year. All chains measured within WC02 exhibited a more stable stream bed than what was observed in Years 1 and 2. Chain exposure data from Years 1 and 2 showed heavy deposition within this reach (-0.12 to -0.35 feet per year), but -0.13 to 0.18 feet per year was the range of annual scour rates that occurred between Years 2 and 3 in WC02.

$D_{50}$ particle size classes remained the same between all three years of study at both cross-sections. The reachwide $D_{50}$ for Years 2 and 3 were categorized as coarse gravel which is slightly finer than the very coarse gravel observed in Year 1 (Table C-5). $D_{84}$ particle size classes became slightly finer at both cross sections,diminishing from medium-sized cobble to small cobble. Although reachwide $D_{84}$ particle sizes also reduced between Year 1 and Year 2, particles increased back to medium-sized cobble in Year 3.

### 4.3 WC03

Pool and glide features have previously dominated reach WC03, as 65.6% and 67.5% of the reach was made up of pools and glides during Years 1 and 2, respectively. During Year 3, however, riffles and runs made up more than half (53.1%) of the reach (Table C-1). Changes in longitudinal profile were noted between the three years' of study, most notably the deepening of most pools reachwide between the first two years (Figure C-3). Pool depth has stayed fairly consistent between Years 2 and 3.

Cross-section 1 (Station 1+56) had been a Crossover Riffle at Station 1+55 when initially established during Year 1 of the study and again in Year 3. 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, Year 2 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 throughout the three year study. Significant deepening also occurred at Cross-section 2 (Meander Bend at Station 2+12), and erosion of the outside (left) bank was also observed between Years 1 and 2 (Figure C-10). The left bank continued to erode between Year 2 and Year 3 while agraddation occurred in the stream bed near the left bank. Consequently, bankfull cross-sectional dimensions also differed significantly at this station between all three years (Table C-2).

Bank pin data collected within WC03 shows almost no lateral migration of stream banks between Years 2 and 3. This is consistent with Years 1 and 2, with the exception of the uppermost reach, which exhibited a large degree of lateral movement during Years 1 and 2 (Table C-3). When calculating an annual rate of scour between Years 2 and 3, this site had a rate of -1.81 feet per year at Cross-section 1 (Station 1+56), which is the highest amount of depositition that has occurred during the duration of this project (Table C-4).

Along with the changes in channel cross-section at Cross-section 1 (Crossover Riffle at Station 1+56), channel substrate became more fine, with the $D_{50}$ decreasing from very coarse gravel to coarse gravel between Year 1 and Year 3. The $D_{84}$ decreased from small cobble to very coarse gravel and back to small cobble over the three years (Table C-5). The $D_{84}$ also decreased at Cross-section 2 (Meander Bend at Station 2+12) from small cobble in Year 1 to very coarse gravel in Years 2 and 3. At Cross-section 2, $D_{50}$ particle size classes remained the same between the first two years of study (medium gravel) and increased during the third (coarse gravel). Reachwide, the $D_{50}$ (very coarse gravel) and $D_{84}$ (large cobble) particle size classes increased over the years with the change occurring between Years 2 and 3.

## 4.4 WC04

No significant changes were observed in the profile of the downstream portion of the reach at site WC04 between the three years' of study. However, during Years 2 and 3 survey, the stream channel was dry from above the pool feature at Station 1+80 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 initial year and Years 2 and 3 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 three years of study, with the exception of some lower bank erosion observed at Cross-section 1 (Meander at Station 1+08) between Year 1 and Years 2 and 3 (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 Years 2 and 3. The channel was actively widening and cutting into the bank at this station during the Year 3 survey, resulting in changes in cross-sectional dimensions (Table C-2).

Year 3 annual bank erosion rates and patterns at this reach differed from Years 1 and 2 (Table C-3). The left bank pins at station 1+07.5 experienced higher erosion rates that resulted in the pins falling out of the bank. The erosion rates at this station's upper and lower pins was estimated at 1.90 and 1.17 feet per year, respectively, which are much higher than what was observed in Years 1 and 2 (Table C-3). Banks along other sections of WC04 also showed signs of instability, most notabley at station 0+21, where a significant amount of aggradation occurred at the right (-0.14 feet per year) and left-lower (-0.47 feet per year) pins. The scour chain data at this site continued to exhibit evidence of a stable stream bed, with a Year 3 annual scour rate of 0.07 feet per year and a Year 1 through Year 3 scour rate of 0.02 feet per year (Table C-4).

$D_{84}$ particle size classes remained the same during all three years at Cross-section 1 and reachwide (small cobble, Table C-5). At Cross-section 2, $D_{84}$ decreased from small cobble to very coarse gravel. The $D_{50}$ particle size class increased from coarse gravel to very coarse gravel for the reachwide survey while Cross-section 1 decreased (very coarse sand) and Cross-section 2 remained the same (very coarse gravel) between Years 2 and 3.

# 5.0 CONCLUSIONS

The data presented herein provide a third year of assessment of conditions within the Wheel Creek watershed. During the sampling for the Year 1 and Year 2 study, none of the planned restoration projects had been completed within this watershed. For this Year 3 study, however, two of at least seven planned restoration projects had been constructed, while the remaining projects were still in the planning stages. 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 continued to be evident during this third year of monitoring, with significant changes seen in some channel cross sections and longitudinal profiles.

Additional geomorphic surveys following the completion of additional 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 pre-restoration 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 downstream at Station 4+25


WC01 - Facing downstream at Station 3+63


WC01 – Facing downstream at Station 2+85


WC01 – Facing upstream at Station 0+75

WC01 – Facing upstream from below Station 0+00

WC02 – Facing downstream at Station 3+50

WC02 – Facing downstream at Station 3+00

WC02 – Facing downstream at Station 2+00

WC02 – Facing downstream at Station 1+00

WC02 – Facing upstream at Station 0+00

WC03 – Facing downstream at Station 3+00

WC03 – Facing downstream at Station 2+00

WC03 – Facing downstream at Station 1+50

WC03 – Facing downstream at Station 1+00

WC03 – Facing upstream at station 0+00

WC04 – Facing downstream at Station 3+00

WC04 – Facing downstream at Station 2+00

WC04 – Facing downstream at Station 1+50

WC04 – Facing downstream at Station 0+50

WC04 – Facing upstream at Station 0+00

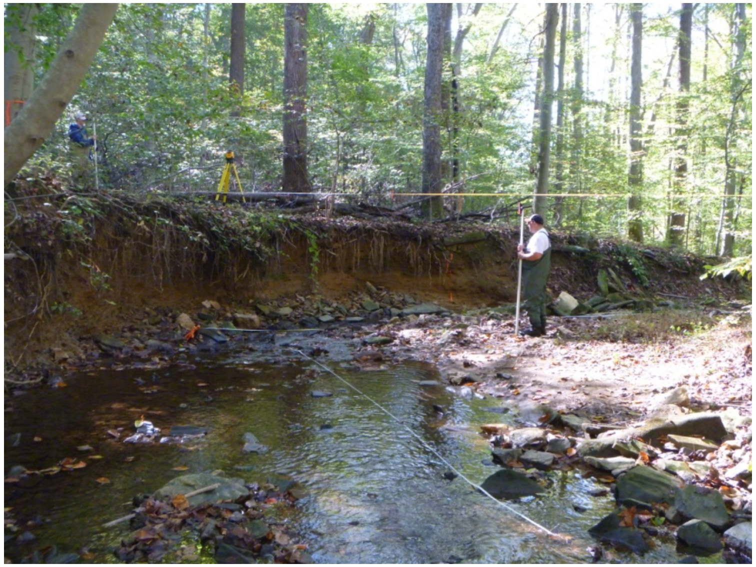
WC01 – XS-1 facing upstream

WC01 – XS-1 facing downstream

WC01 – XS-1 facing right bank

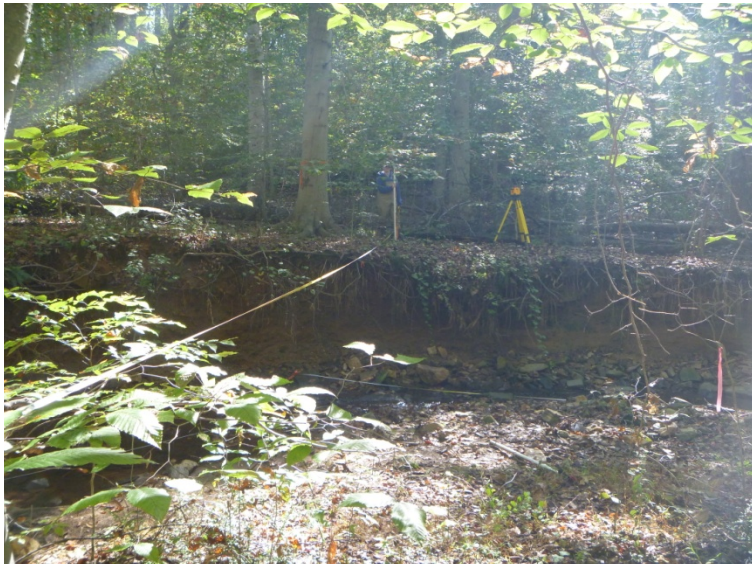
WC01 – XS-1 facing left bank

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 facing left bank

WC03 – XS-1 facing upstream

WC03 – XS-1 facing downstream

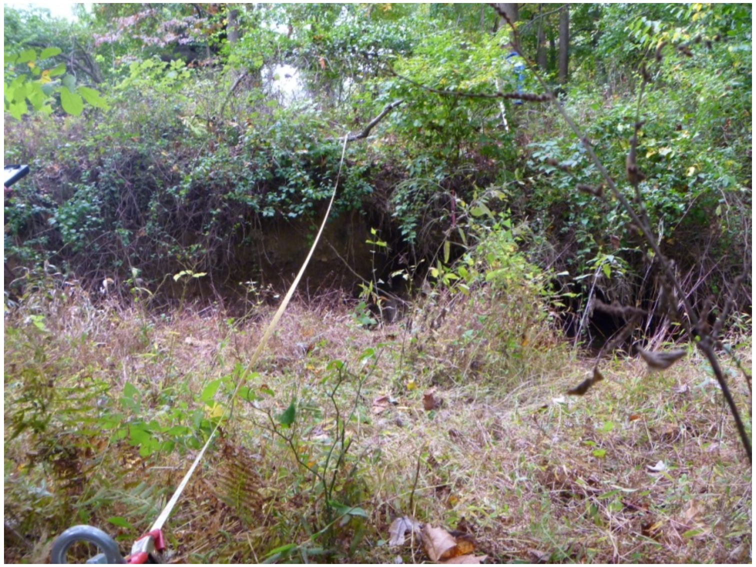
WC03 – XS-1 facing right bank

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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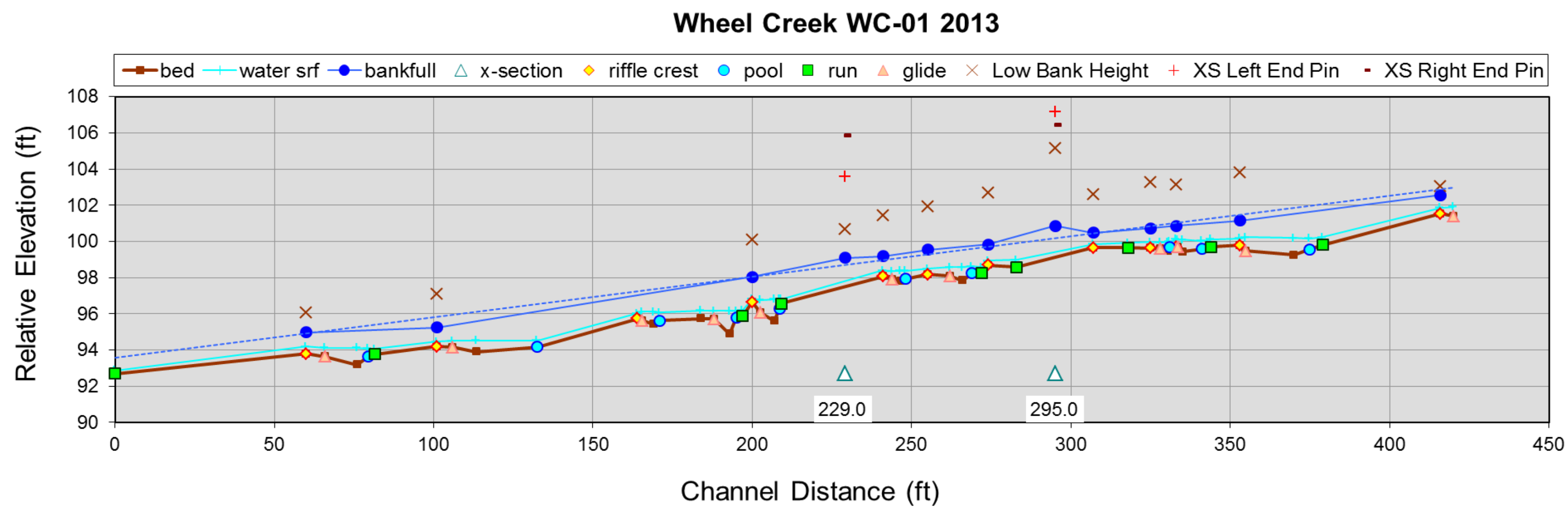
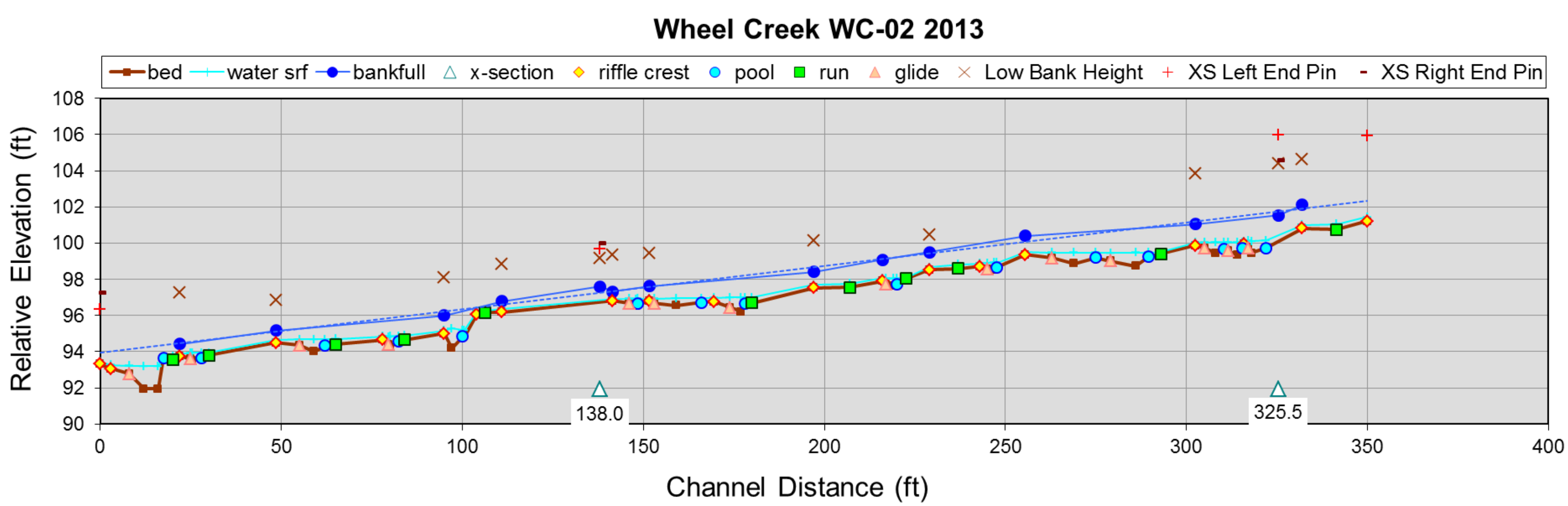
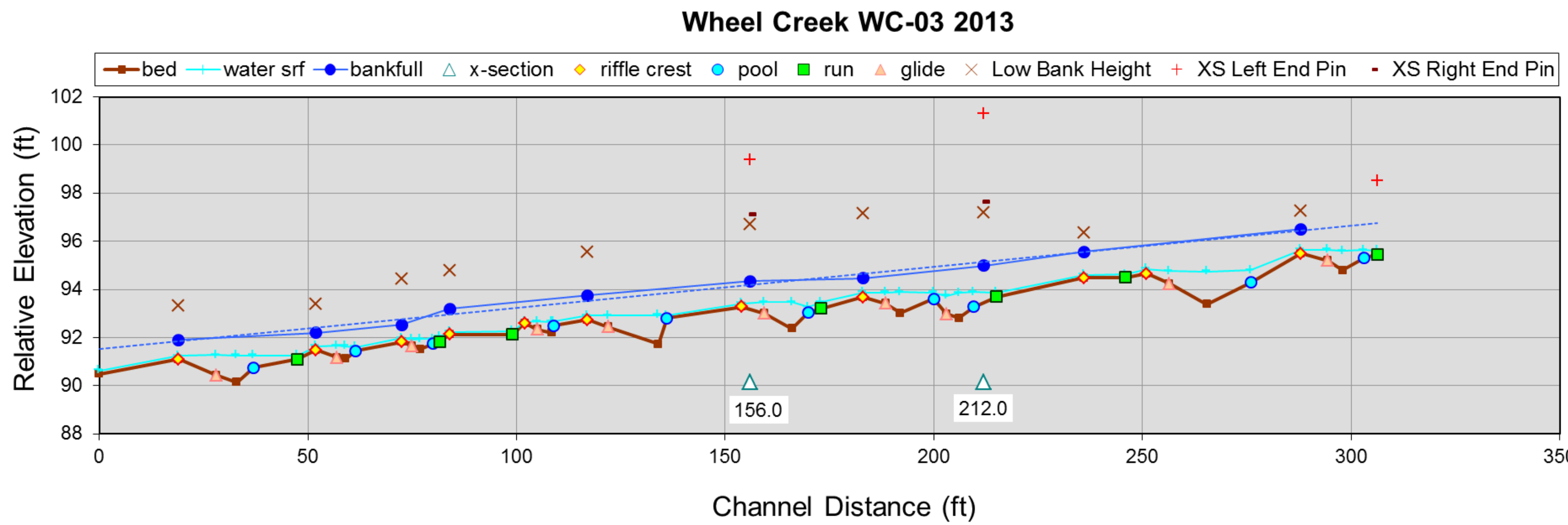
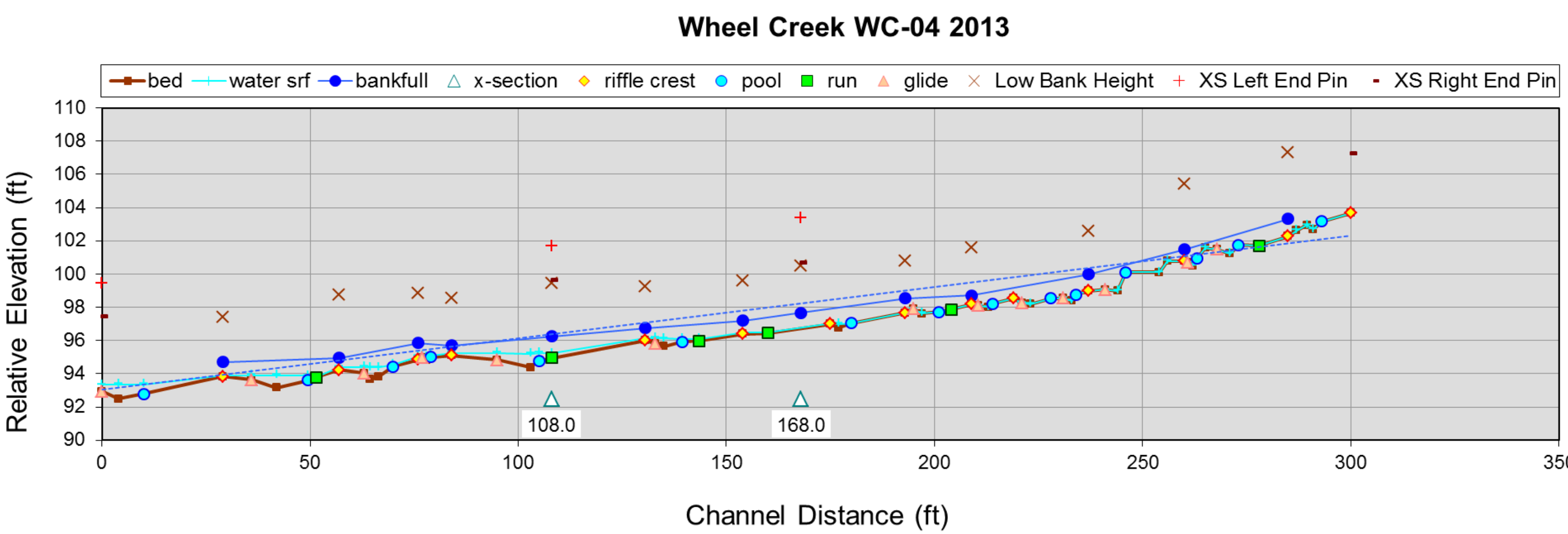
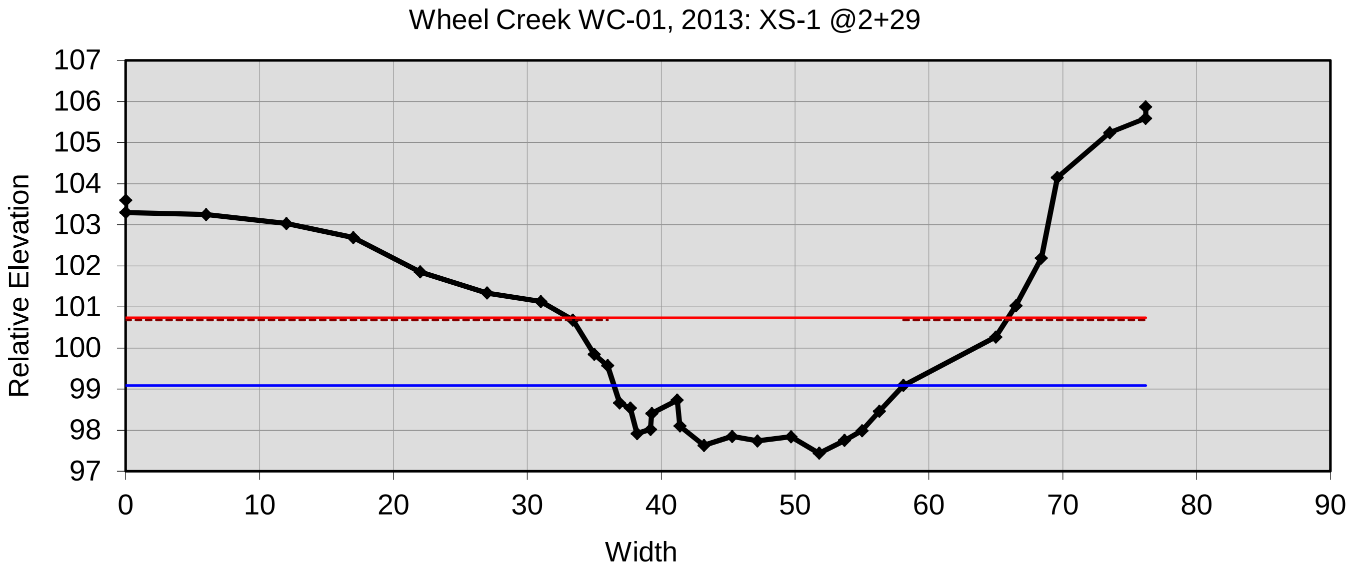

Wheel Creek WC-01 2013
bed
water srf
bankfull
x-section
riffle crest
pool
run
glide
Low Bank Height
XS Left End Pin
XS Right End Pin
Relative Elevation (ft)
Channel Distance (ft)
229.0
295.0

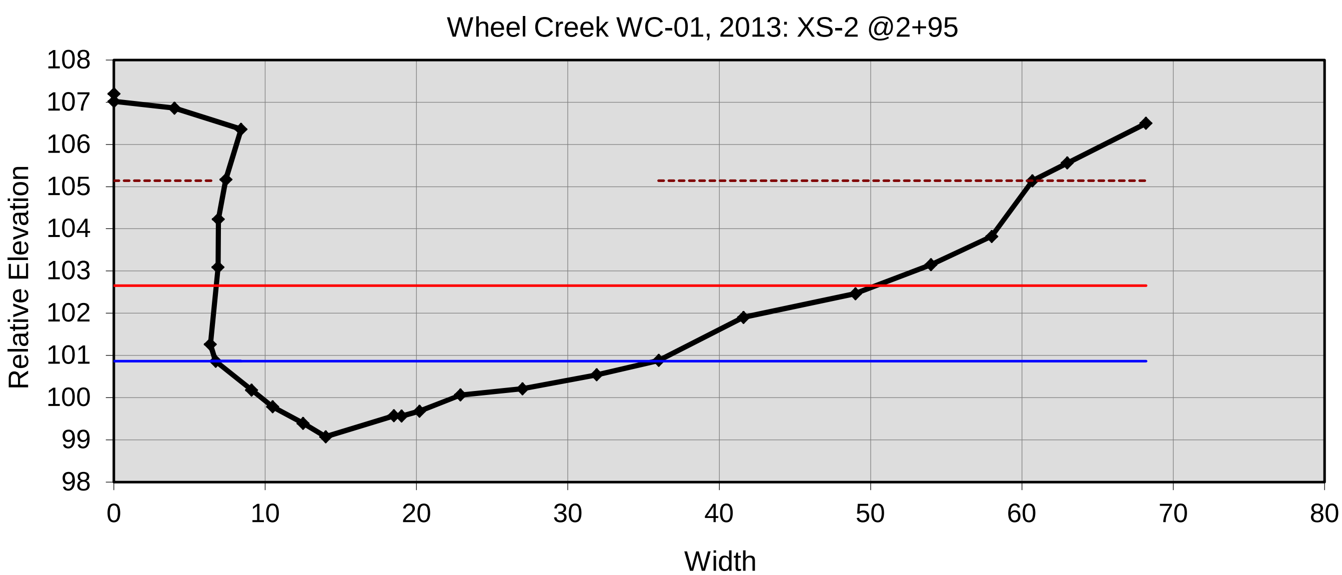

Wheel Creek WC-02 2013
bed
water srf
bankfull
x-section
riffle crest
pool
run
glide
Low Bank Height
XS Left End Pin
XS Right End Pin
Relative Elevation (ft)
Channel Distance (ft)
138.0
325.5


Wheel Creek WC-03 2013
bed
water srf
bankfull
x-section
riffle crest
pool
run
glide
Low Bank Height
XS Left End Pin
XS Right End Pin
Relative Elevation (ft)
Channel Distance (ft)
156.0
212.0

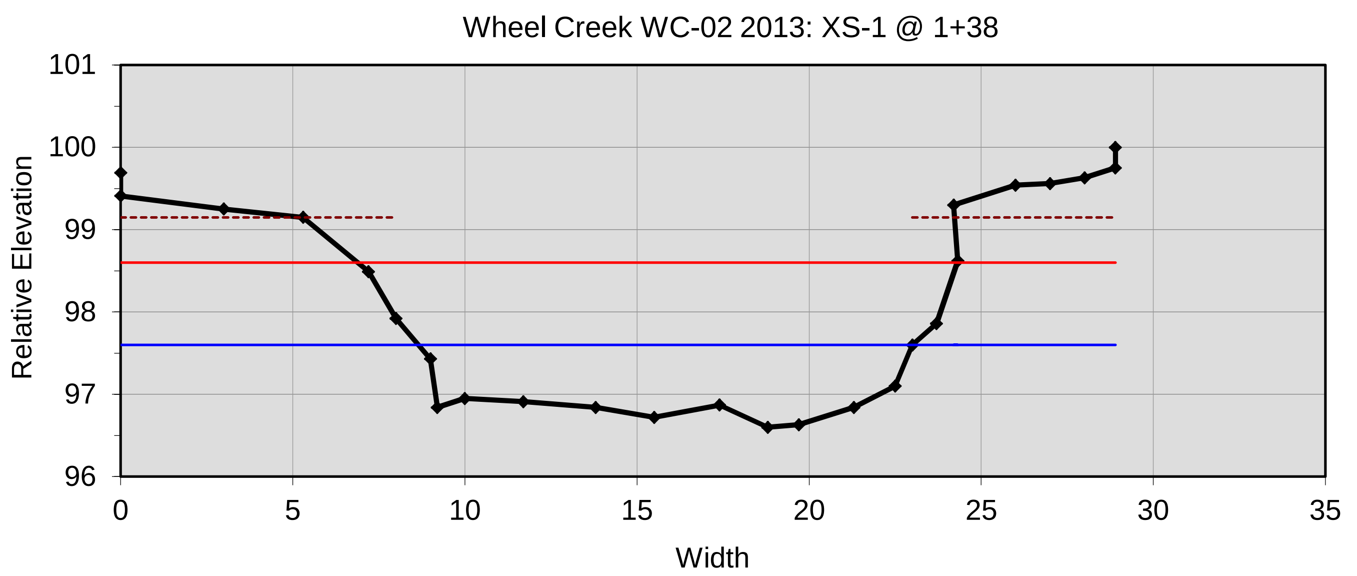

Wheel Creek WC-04 2013
bed
water srf
bankfull
x-section
riffle crest
pool
run
glide
Low Bank Height
XS Left End Pin
XS Right End Pin
Relative Elevation (ft)
Channel Distance (ft)
108.0
168.0



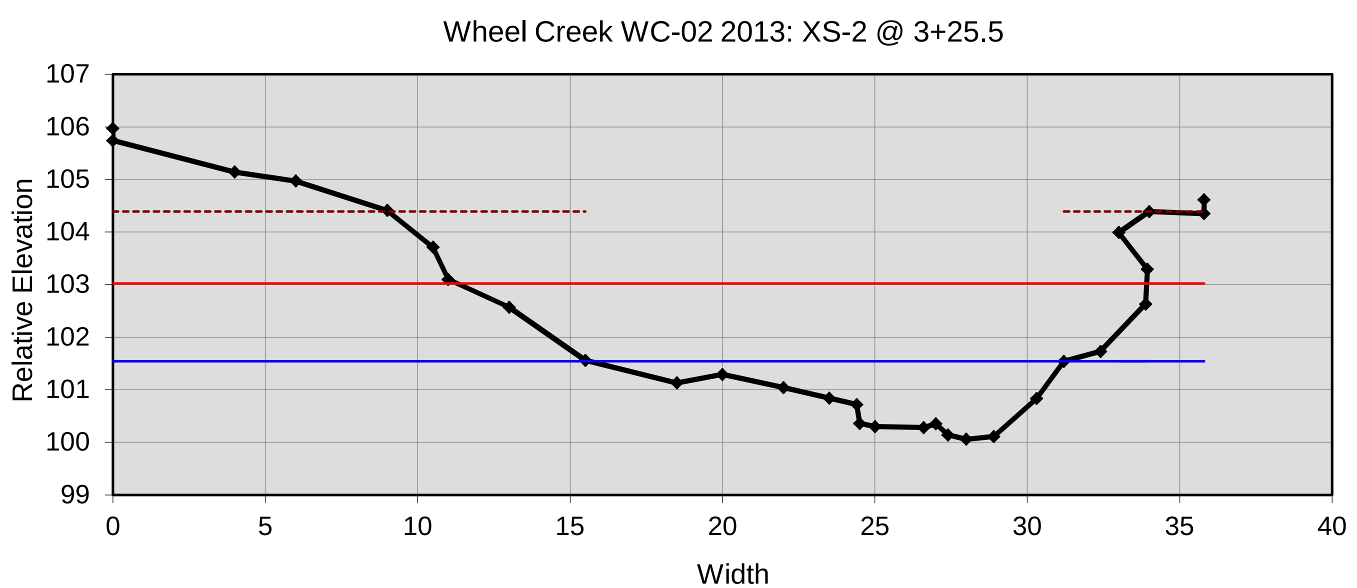

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 23.2 | x-section area (ft.sq.) | 32.8 | W flood prone area (ft) | 49 | D50 Riffle (mm) |
| 21.6 | width (ft) | 1.5 | entrenchment ratio | 130 | D84 Riffle (mm) |
| 1.1 | mean depth (ft) | 3.2 | low bank height (ft) | | |
| 1.6 | max depth (ft) | 2.0 | low bank height ratio | | |
| 23.3 | wetted parimeter (ft) | | | | |
| 1.0 | hyd radi (ft) | | | | |
| 20.2 | width-depth ratio | | | | |



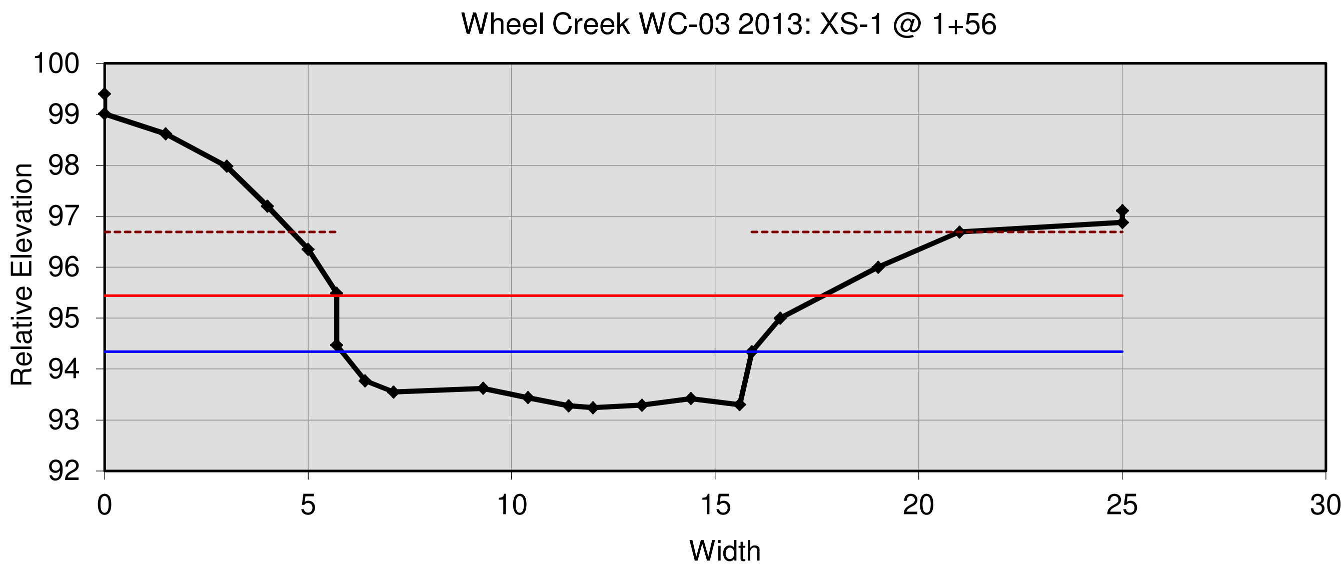

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 24.7 | x-section area (ft.sq.) | 43.6 | W flood prone area (ft) | 37 | D50 Riffle (mm) |
| 29.0 | width (ft) | 1.5 | entrenchment ratio | 87 | D84 Riffle (mm) |
| 0.9 | mean depth (ft) | 6.1 | low bank height (ft) | | |
| 1.8 | max depth (ft) | 3.4 | low bank height ratio | | |
| 29.3 | wetted parimeter (ft) | | | | |
| 0.8 | hyd radi (ft) | | | | |
| 34.1 | width-depth ratio | | | | |



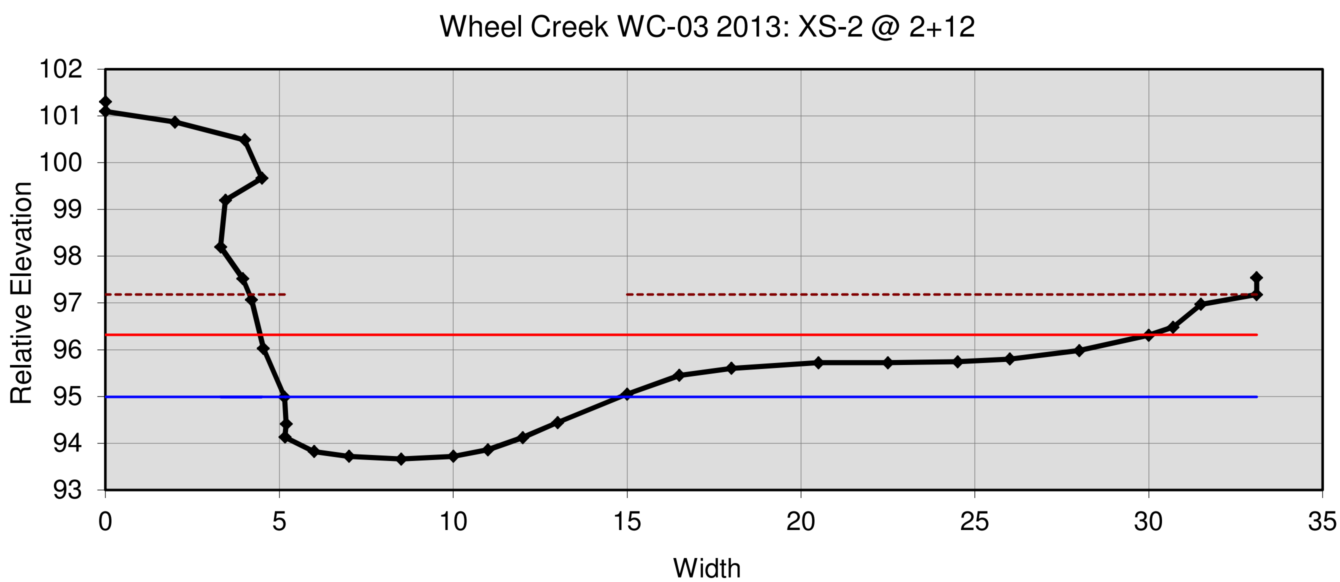

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 10.6 | x-section area (ft.sq.) | 17.4 | W flood prone area (ft) | 51 | D50 Riffle (mm) |
| 14.3 | width (ft) | 1.2 | entrenchment ratio | 88 | D84 Riffle (mm) |
| 0.7 | mean depth (ft) | 2.6 | low bank height (ft) | | |
| 1.0 | max depth (ft) | 2.6 | low bank height ratio | | |
| 15.1 | wetted parimeter (ft) | | | | |
| 0.7 | hyd radi (ft) | | | | |
| 19.4 | width-depth ratio | | | | |



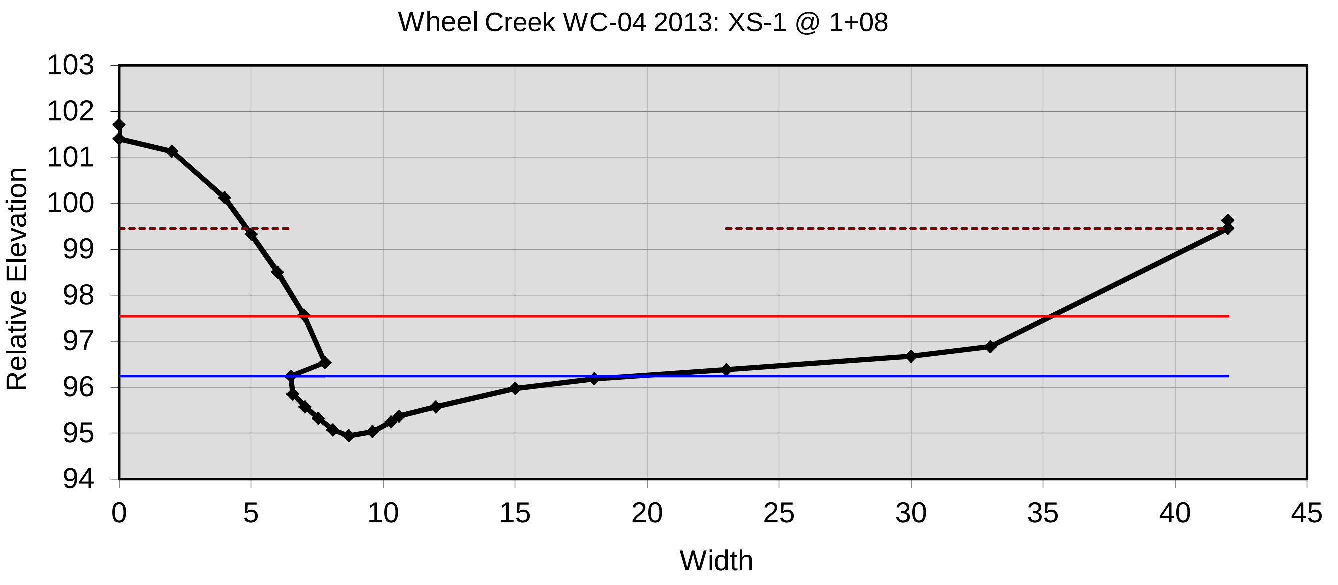

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 11.1 | x-section area (ft.sq.) | 22.6 | W flood prone area (ft) | 47 | D50 Riffle (mm) |
| 15.6 | width (ft) | 1.5 | entrenchment ratio | 86 | D84 Riffle (mm) |
| 0.7 | mean depth (ft) | 4.3 | low bank height (ft) | | |
| 1.5 | max depth (ft) | 2.9 | low bank height ratio | | |
| 16.4 | wetted parimeter (ft) | | | | |
| 0.7 | hyd radi (ft) | | | | |
| 21.8 | width-depth ratio | | | | |



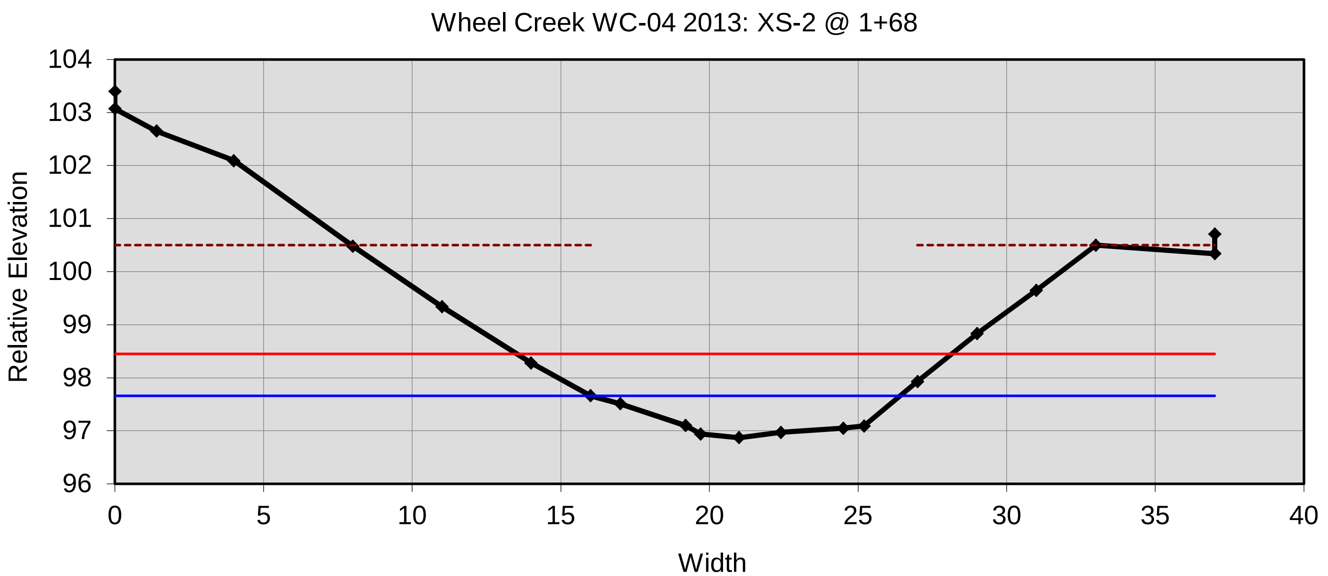

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 8.6 | x-section area (ft.sq.) | 12.0 | W flood prone area (ft) | 27 | D50 Riffle (mm) |
| 10.1 | width (ft) | 1.2 | entrenchment ratio | 68 | D84 Riffle (mm) |
| 0.9 | mean depth (ft) | 3.5 | low bank height (ft) | | |
| 1.1 | max depth (ft) | 3.1 | low bank height ratio | | |
| 11.2 | wetted parimeter (ft) | | | | |
| 0.8 | hyd radi (ft) | | | | |
| 11.8 | width-depth ratio | | | | |



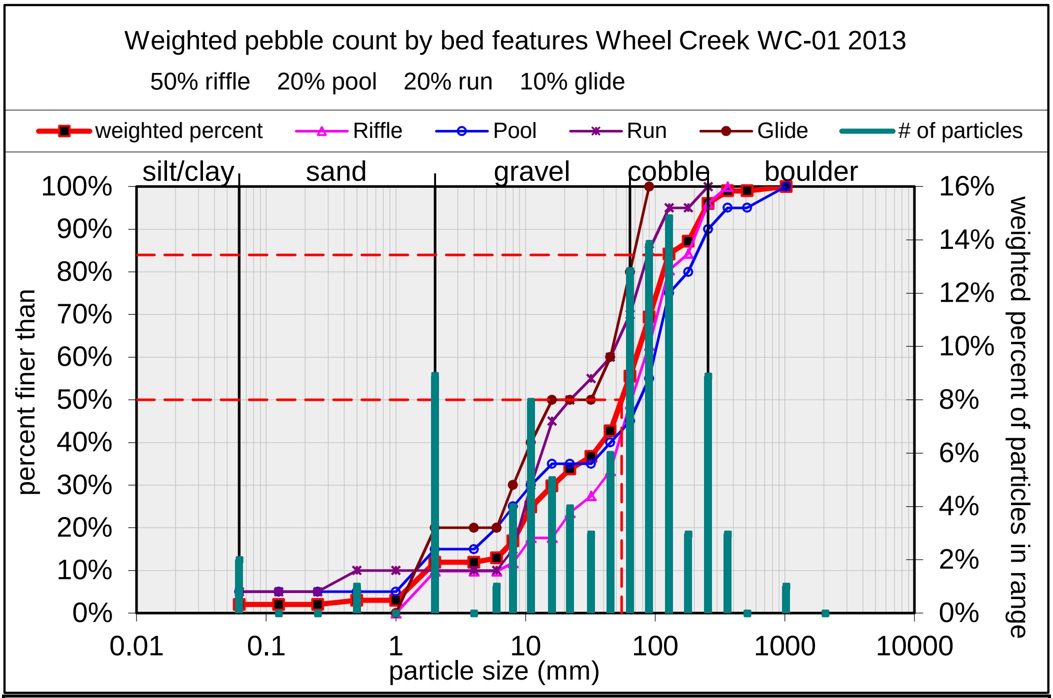

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 9.4 | x-section area (ft.sq.) | 25.6 | W flood prone area (ft) | 29 | D50 Riffle (mm) |
| 9.7 | width (ft) | 2.7 | entrenchment ratio | 59 | D84 Riffle (mm) |
| 1.0 | mean depth (ft) | 3.5 | low bank height (ft) | | |
| 1.3 | max depth (ft) | 2.6 | low bank height ratio | | |
| 10.7 | wetted parimeter (ft) | | | | |
| 0.9 | hyd radi (ft) | | | | |
| 10.0 | width-depth ratio | | | | |



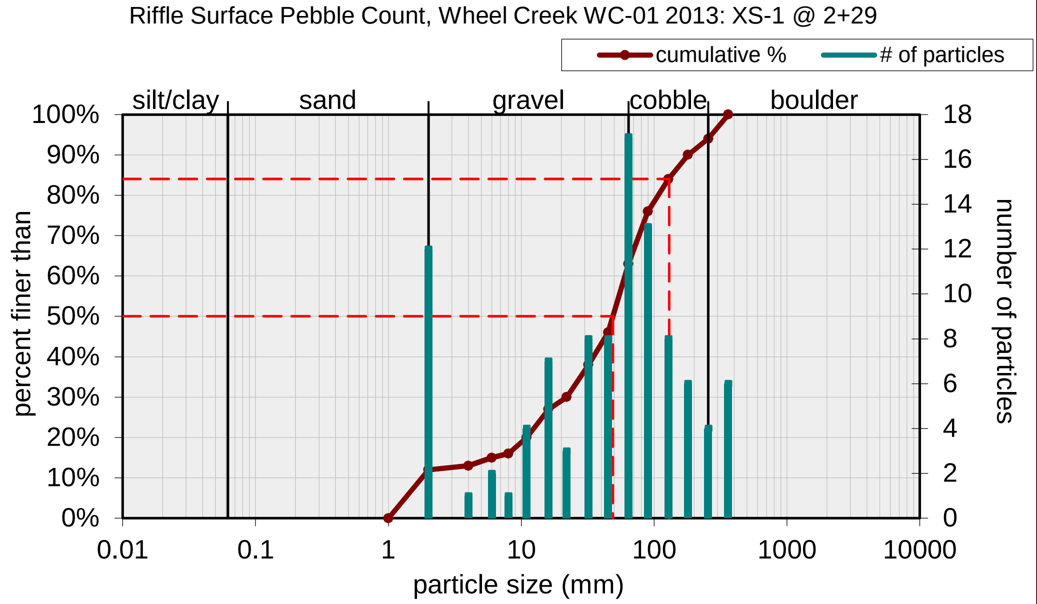

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 7.2 | x-section area (ft.sq.) | 28.3 | W flood prone area (ft) | 1.5 | D50 Riffle (mm) |
| 13.0 | width (ft) | 2.2 | entrenchment ratio | 64 | D84 Riffle (mm) |
| 0.6 | mean depth (ft) | 4.5 | low bank height (ft) | | |
| 1.3 | max depth (ft) | 3.5 | low bank height ratio | | |
| 13.6 | wetted parimeter (ft) | | | | |
| 0.5 | hyd radi (ft) | | | | |
| 23.5 | width-depth ratio | | | | |



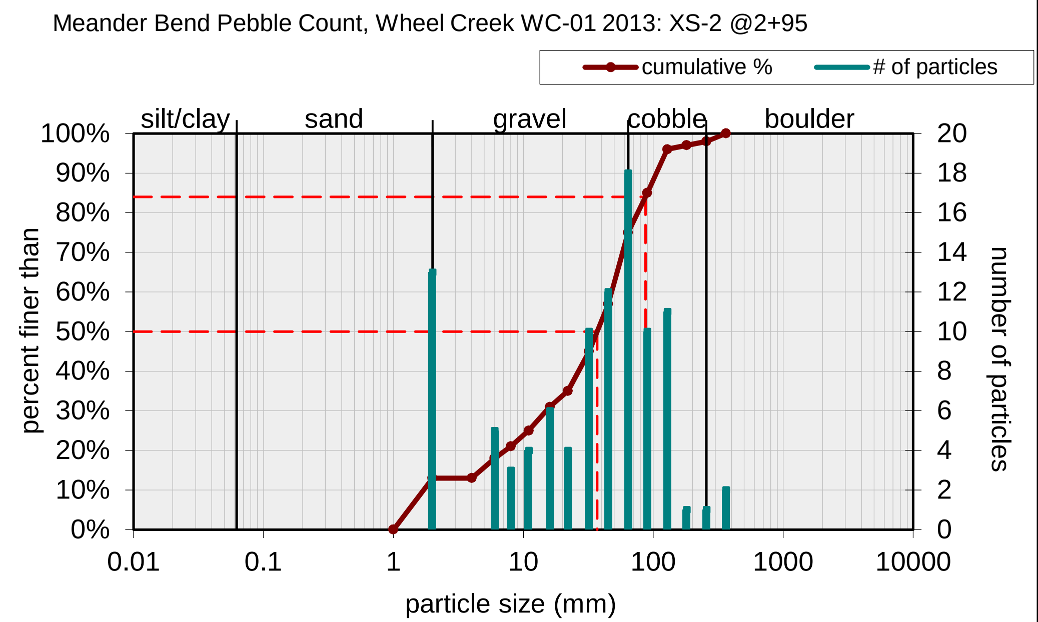

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 5.3 | x-section area (ft.sq.) | 14.6 | W flood prone area (ft) | 33 | D50 Riffle (mm) |
| 10.4 | width (ft) | 1.4 | entrenchment ratio | 57 | D84 Riffle (mm) |
| 0.5 | mean depth (ft) | 3.6 | low bank height (ft) | | |
| 0.8 | max depth (ft) | 4.6 | low bank height ratio | | |
| 10.6 | wetted parimeter (ft) | | | | |
| 0.5 | hyd radi (ft) | | | | |
| 20.4 | width-depth ratio | | | | |



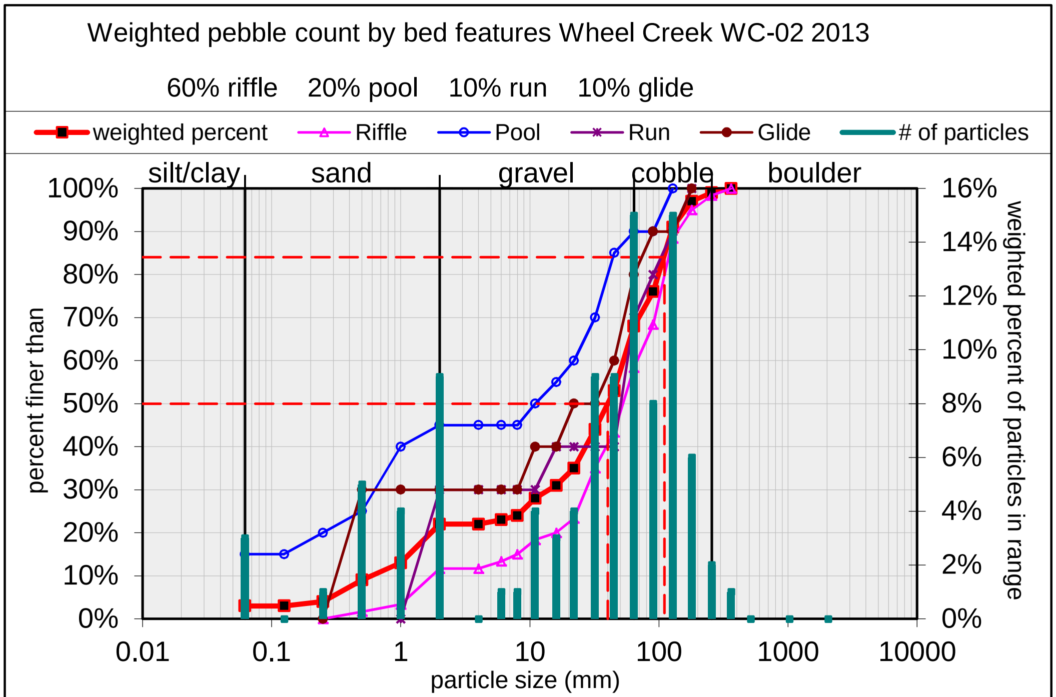

| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 7.5 | mean | 31.2 | silt/clay | 2% |
| D35 | 26 | dispersion | 4.8 | sand | 10% |
| D50 | 55 | skewness | -0.22 | gravel | 44% |
| D65 | 81 | | | cobble | 41% |
| D84 | 130 | | | boulder | 4% |
| D95 | 250 | | | | |




| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 8 | mean | 32.2 | silt/clay | 0% |
| D35 | 28 | dispersion | 4.4 | sand | 12% |
| D50 | 49 | skewness | -0.17 | gravel | 51% |
| D65 | 67 | | | cobble | 31% |
| D84 | 130 | | | boulder | 6% |
| D95 | 270 | | | | |

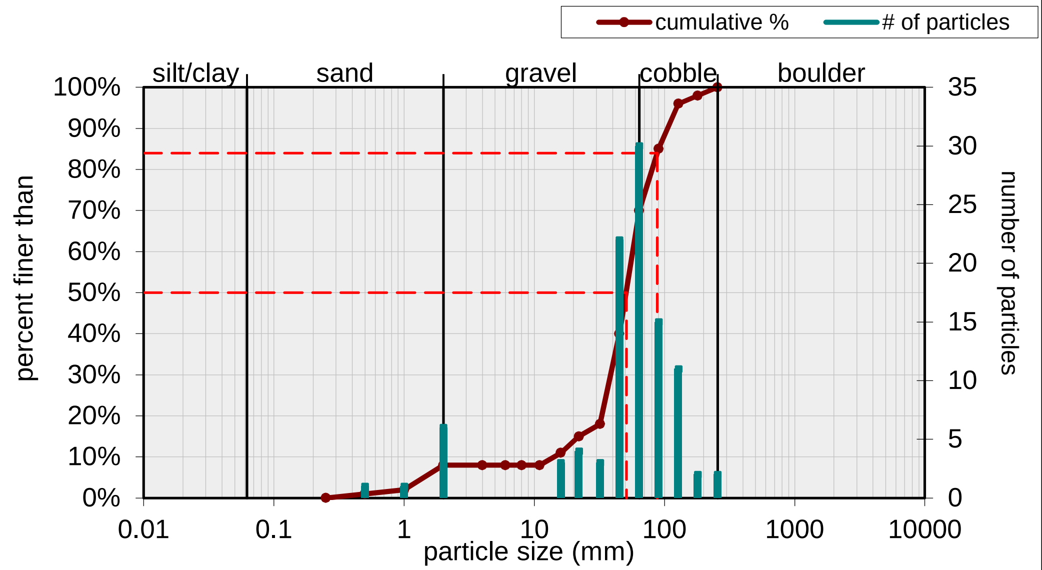



| Size (mm) | | | Size Distribution | | Type | |
|---|---|---|---|---|---|---|
| D16 | 5.1 | 3.4 | mean | 30.4 | silt/clay | 0% |
| D35 | 22 | 12 | dispersion | 2.6 | sand | 11% |
| D50 | 37 | 17 | skewness | -0.13 | gravel | 64% |
| D65 | 53 | 20 | | | cobble | 23% |
| D84 | 87 | 29 | | | boulder | 2% |
| D95 | 120 | 39 | | | | |



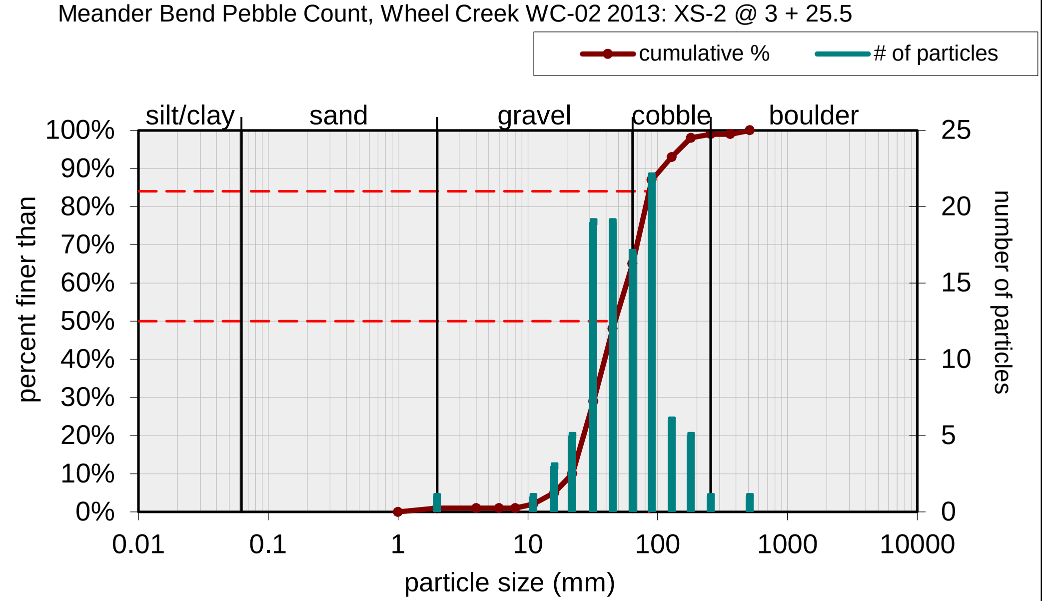

| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 1.3 | mean | 12.0 | silt/clay | 3% |
| D35 | 22 | dispersion | 16.8 | sand | 19% |
| D50 | 40 | skewness | -0.38 | gravel | 46% |
| D65 | 60 | | | cobble | 31% |
| D84 | 110 | | | boulder | 1% |
| D95 | 160 | | | | |

Riffle Surface Pebble Count, Wheel Creek WC-02 2013: XS-1 @ 1+38

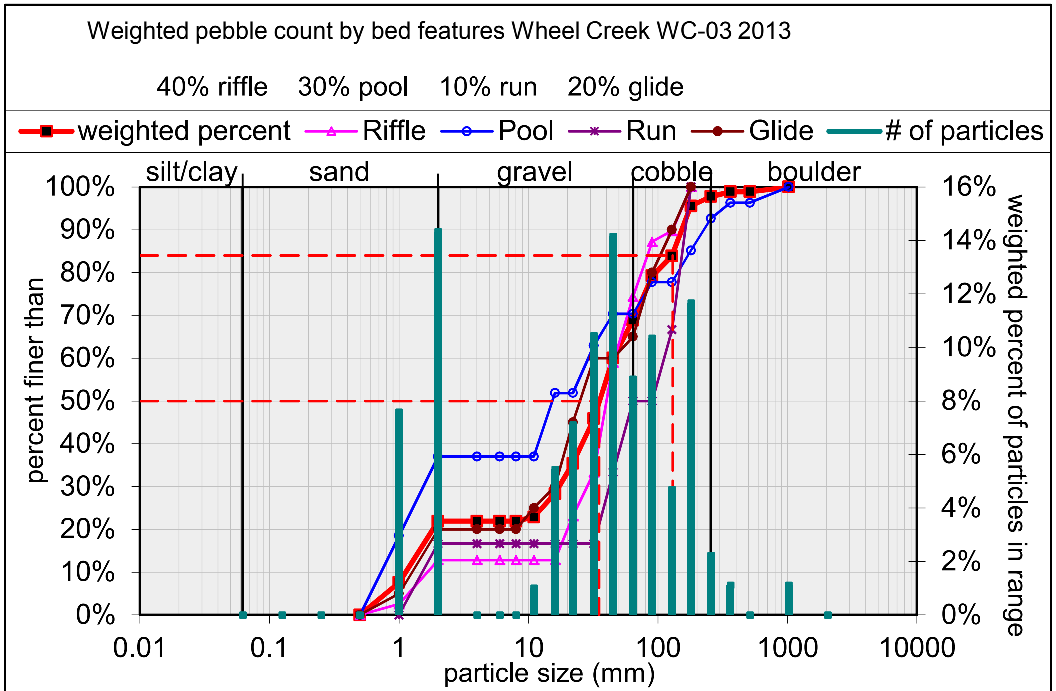



| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 25 | mean | 46.9 | silt/clay | 0% |
| D35 | 42 | dispersion | 1.9 | sand | 8% |
| D50 | 51 | skewness | -0.05 | gravel | 62% |
| D65 | 60 | | | cobble | 30% |
| D84 | 88 | | | boulder | 0% |
| D95 | 120 | | | | |

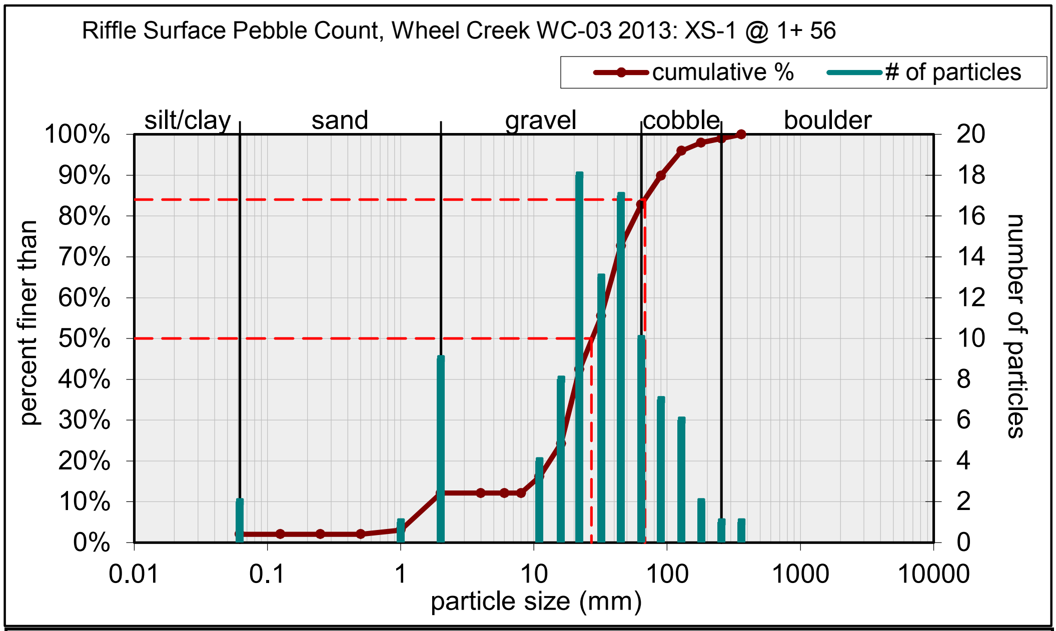
Meander Bend Pebble Count, Wheel Creek WC-02 2013: XS-2 @ 3 + 25.5



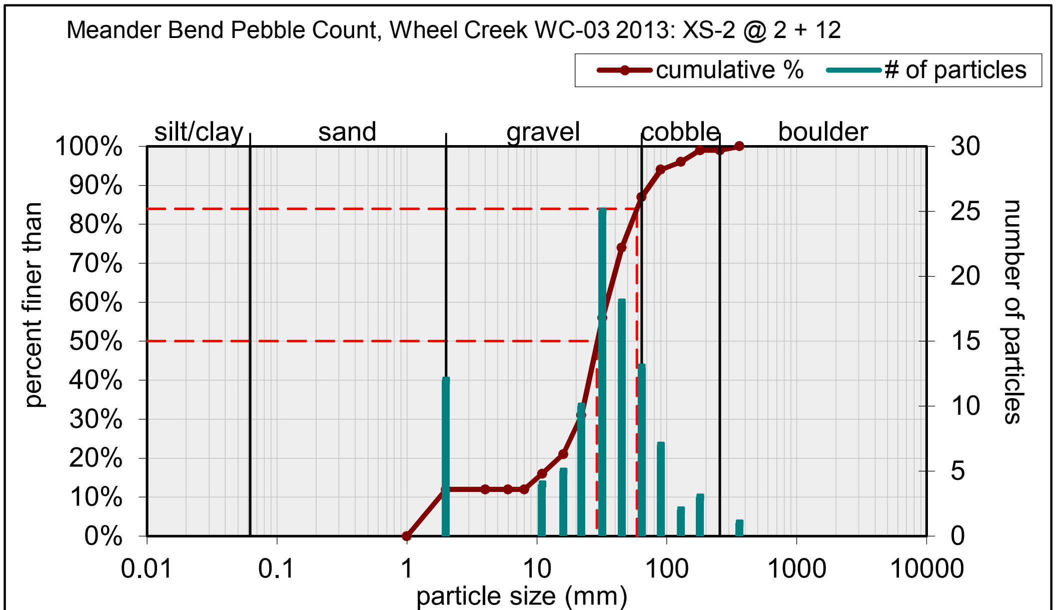

| Size (mm) | | | Size Distribution | | Type | |
|---|---|---|---|---|---|---|
| D16 | 25 | 3.4 | mean | 46.4 | silt/clay | 0% |
| D35 | 36 | 12 | dispersion | 1.9 | sand | 1% |
| D50 | 47 | 17 | skewness | -0.01 | gravel | 64% |
| D65 | 64 | 20 | | | cobble | 34% |
| D84 | 86 | 29 | | | boulder | 1% |
| D95 | 150 | 39 | | | | |



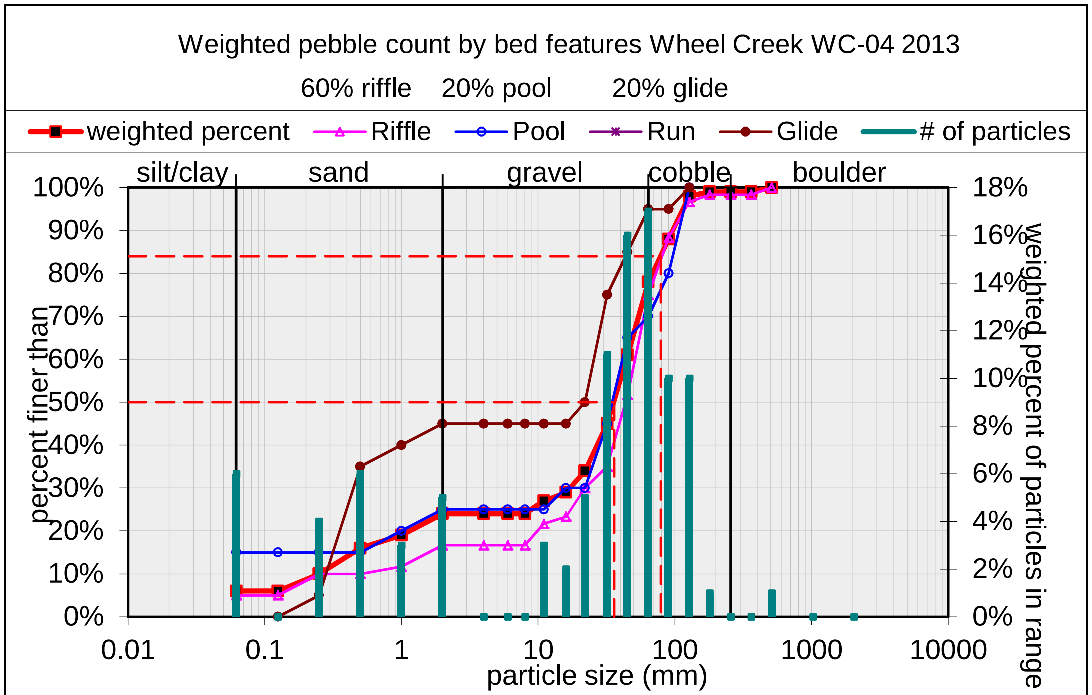

| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 1.5 | mean | 14.0 | silt/clay | 0% |
| D35 | 22 | dispersion | 13.5 | sand | 20% |
| D50 | 35 | skewness | -0.29 | gravel | 42% |
| D65 | 55 | | | cobble | 26% |
| D84 | 130 | | | boulder | 2% |
| D95 | 180 | | | bedrock | 10% |




| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 11 | mean | 27.3 | silt/clay | 2% |
| D35 | 19 | dispersion | 2.5 | sand | 10% |
| D50 | 27 | skewness | 0.01 | gravel | 70% |
| D65 | 39 | | | cobble | 16% |
| D84 | 68 | | | boulder | 1% |
| D95 | 120 | | | bedrock | 1% |

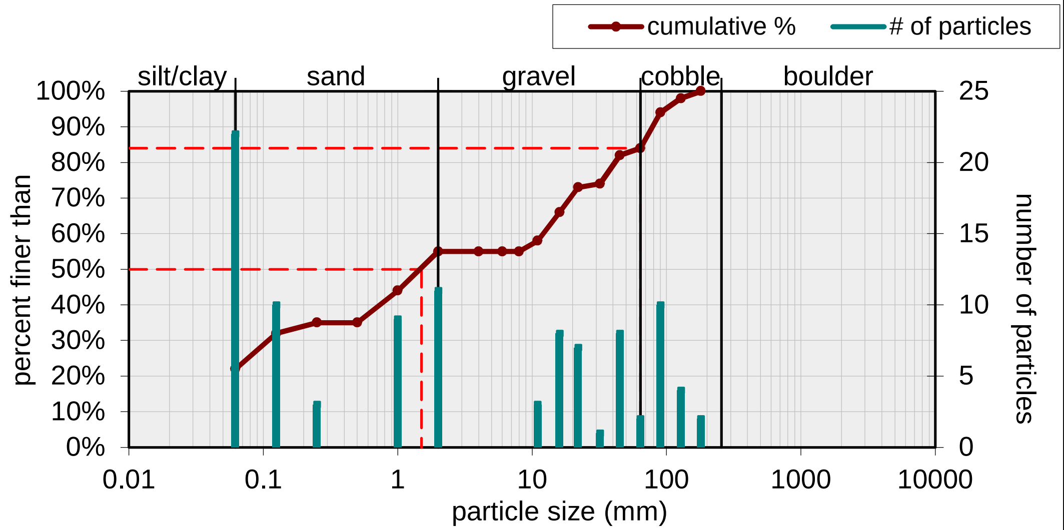



| Size (mm) | | | Size Distribution | | Type | |
|---|---|---|---|---|---|---|
| D16 | 11 | 3.4 | mean | 25.5 | silt/clay | 0% |
| D35 | 23 | 12 | dispersion | 2.3 | sand | 12% |
| D50 | 29 | 17 | skewness | -0.07 | gravel | 75% |
| D65 | 38 | 20 | | | cobble | 12% |
| D84 | 59 | 29 | | | boulder | 1% |
| D95 | 110 | 39 | | | | |



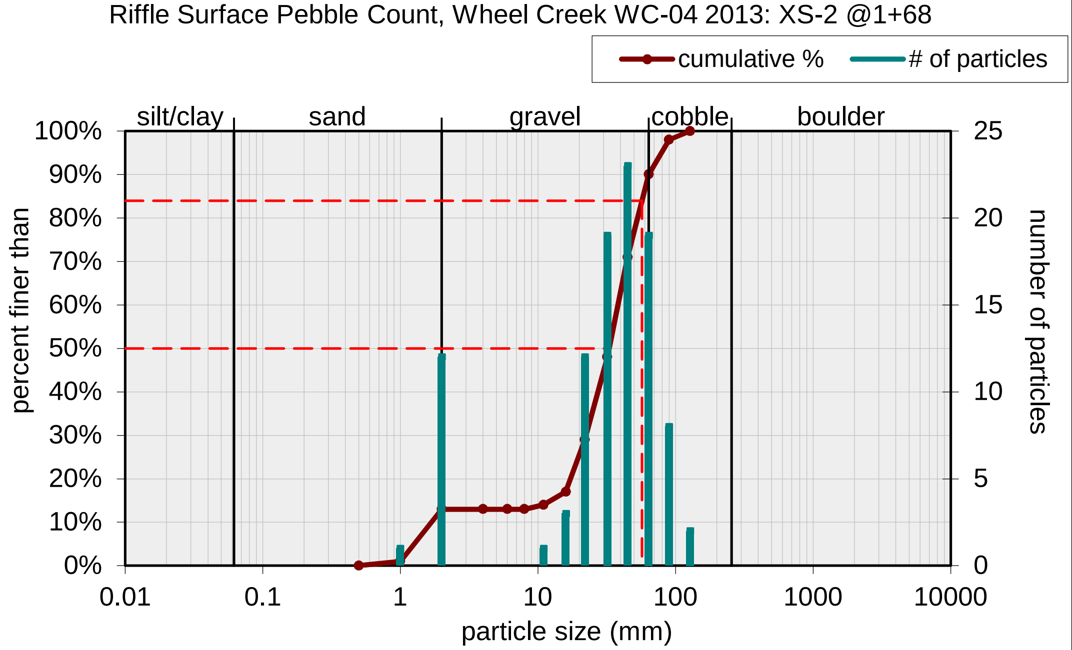

| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 0.5 | mean | 6.3 | silt/clay | 6% |
| D35 | 23 | dispersion | 37.1 | sand | 18% |
| D50 | 36 | skewness | -0.51 | gravel | 54% |
| D65 | 49 | | | cobble | 21% |
| D84 | 79 | | | boulder | 1% |
| D95 | 120 | | | | |

Meander Bend Pebble Count, Wheel Creek WC-04 2013: XS-1 @1+08




| Size (mm) | | | Size Distribution | | Type | |
|---|---|---|---|---|---|---|
| D16 | 0.062 | 3.4 | mean | 2.0 | silt/clay | 22% |
| D35 | 0.5 | 12 | dispersion | 33.4 | sand | 33% |
| D50 | 1.5 | 17 | skewness | 0.07 | gravel | 29% |
| D65 | 15 | 20 | | | cobble | 16% |
| D84 | 64 | 29 | | | boulder | 0% |
| D95 | 98 | 39 | | | | |

Riffle Surface Pebble Count, Wheel Creek WC-04 2013: XS-2 @1+68




| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 14 | mean | 28.2 | silt/clay | 0% |
| D35 | 25 | dispersion | 2.0 | sand | 13% |
| D50 | 33 | skewness | -0.09 | gravel | 77% |
| D65 | 41 | | | cobble | 10% |
| D84 | 57 | | | boulder | 0% |
| D95 | 79 | | | | |

| Reach | Profile Station | Bank Location | 3/30/2011 Length Exposed (dec. ft.) | November 2012 Length Exposed (dec. ft.) | October 2013 Length Exposed (dec. ft.) |
|---|---|---|---|---|---|
| WC01 | 0+21 | LB-UPPER | 0.54 | 0.58 | 0.69 |
| WC01 | 0+21 | LB-LOWER | 0.43 | 0.46 | 0.42 |
| WC01 | 0+21 | RB-PIN | 0.36 | 0.27 | 0.33 |
| WC01 | 1+30 | LB-TOE PIN | 0.59 | 0.38 | 0.33 |
| WC01 | 1+30 | RB-UPPER | 0.50 | 0.50 | 0.46 |
| WC01 | 1+30 | RB-LOWER | 0.32 | 0.31 | 0.31 |
| WC01 | 1+92 | LB-TOE PIN | N/A | N/A | -0.46 |
| WC01 | 1+92 | RB-UPPER | 0.40 | 0.34 | 0.54 |
| WC01 | 1+92 | RB-LOWER | 0.26 | 0.49 | 0.69 |
| WC01 | 3+80 | LB-TOE PIN | 0.24 | -0.17 | 0.21 |
| WC01 | 3+80 | RB-UPPER | 0.51 | 1.77 | 1.50 |
| WC01 | 3+80 | RB-LOWER | 0.66 | N/A | 1.08 |
| WC02 | 0+24 | LB-UPPER | 0.52 | 0.58 | N/A |
| WC02 | 0+24 | LB-LOWER | 0.39 | N/A | 1.63 |
| WC02 | 0+24 | RB-TOE PIN | 0.33 | -0.06 | -0.17 |
| WC02 | 2+00 | LB-UPPER | 0.32 | 0.29 | 0.25 |
| WC02 | 2+00 | LB-LOWER | 0.27 | 0.25 | 0.25 |
| WC02 | 2+00 | RB-TOE PIN | 0.69 | N/A | 0.92 |
| WC02 | 2+88 | LB-UPPER | 0.56 | 0.56 | 0.67 |
| WC02 | 2+88 | LB-LOWER | 0.64 | 0.75 | 0.92 |
| WC02 | 2+88 | RB-TOE PIN | 0.20 | -0.08 | 0.17 |
| WC02 | 3+50 | LB-UPPER | 0.36 | 0.65 | 0.54 |
| WC02 | 3+50 | LB-LOWER | 0.42 | 0.40 | 0.13 |
| WC02 | 3+50 | RB-TOE PIN | 0.38 | 0.63 | 0.60 |
| WC03 | 0+75 | LB-UPPER | 0.25 | 0.25 | 0.21 |
| WC03 | 0+75 | LB-LOWER | 0.33 | 0.33 | 0.33 |
| WC03 | 0+75 | RB-PIN | 0.23 | 0.25 | 0.19 |
| WC03 | 1+41 | LB-UPPER | 0.38 | 0.46 | 0.35 |
| WC03 | 1+41 | LB-LOWER | 0.33 | 0.46 | 0.42 |
| WC03 | 1+41 | RB-PIN | 0.32 | 0.38 | 0.33 |
| WC03 | 1+83 | LB-PIN | 0.20 | 0.13 | 0.13 |
| WC03 | 1+83 | RB-UPPER | 0.18 | 0.25 | 0.29 |
| WC03 | 1+83 | RB-LOWER | 0.17 | 0.21 | 0.17 |
| WC03 | 2+57 | RB-UPPER | 0.51 | N/A | 0.33 |
| WC03 | 2+57 | RB-LOWER | 0.79 | N/A | 0.38 |
| WC03 | 2+77 | RB-PIN | -0.7 | -0.19 | 0.17 |
| WC04 | 0+21 | RB-PIN | -0.3 | 0.17 | 0.04 |
| WC04 | 0+21 | LB-UPPER | -0.04 | 0.00 | 0.04 |
| WC04 | 0+21 | LB-LOWER | 0.15 | -0.25 | -0.25 |
| WC04 | 1+07.5 | RB-TOE PIN | 0.16 | 0.25 | 0.21 |
| WC04 | 1+07.5 | LB-UPPER | 0.18 | 0.25 | 2.00 |
| WC04 | 1+07.5 | LB-LOWER | 0.25 | 0.92 | 2.00 |

| Reach | Profile Station | Bank Location | 3/30/2011 Length Exposed (dec. ft.) | November 2012 Length Exposed (dec. ft.) | October 2013 Length Exposed (dec. ft.) |
|---|---|---|---|---|---|
| WC04 | 1+87 | RB-TOE PIN | 0.04 | 0.08 | 0.19 |
| WC04 | 1+87 | LB-UPPER | 0.18 | 0.17 | 0.15 |
| WC04 | 1+87 | LB-LOWER | -0.12 | -0.25 | -0.21 |
| WC04 | 2+64.5 | RB-TOE PIN | 0.20 | 0.17 | 0.04 |
| WC04 | 2+64.5 | LB-UPPER | 0.30 | 0.63 | 0.56 |
| WC04 | 2+64.5 | LB-LOWER | 0.08 | 0.33 | 0.33 |

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

| Reach | Profile Station, 2013 | Feature, 2013 | Cross Section Station | Baseline, June 2010 (dec. ft.) | 3/30/2011 (dec. ft.) | Nov 2012 (dec. ft.) | | Oct 2013 (dec. ft.) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Amount buried (dec. ft.) | Length exposed (dec. ft.) | Amount buried (dec. ft.) | Length exposed (dec. ft.) |
| WC01 | 2+29 | Riffle | 47 | 0.52 | 0.45 | 0.17 | 0.56 | 0.21 | 0.33 |
| | 2+29 | Riffle | 50.7 | 0.52 | 0.28 | 0.08 | 0.83 | 0.33 | 0.56 |
| | 2+95 | Meander | 21.5 | 0.60 | DNF[1] | DNF[1] | DNF[1] | DNF[1] | DNF[1] |
| WC02 | 1+38 | Riffle | 12 | 0.50 | 0.04 | 0.50 | N/A[2] | 0.33 | 0.00 |
| | 1+38 | Riffle | 15 | 0.32 | 0.32 | 0.15 | 0.27 | 0.17 | 0.17 |
| | 3+24 | Riffle | 25.5 | 0.52 | 0.69 | 0.58 | N/A[2] | 0.50 | 0.00 |
| WC03 | 1+55 | Pool | 12 | 1.60 | 1.76 | 0.42 | 2.08 | 0.42 | 0.42 |
| WC04 | 1+68 | Riffle | 21 | 0.50 | 0.45 | 0.00 | 0.50 | 0.00 | 0.56 |

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

[2]N/A= In 2012, 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

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# APPENDIX C

# ANNUAL COMPARISONS

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Table C-1. Comparisons of Longitudinal Profile Survey Year 1 – Year 3

| 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% |
| | *2013* | *420* | *2.2%* | *55.7%* | *8.2%* | *23.8%* | *12.3%* |
| WC02 | 2010 | 350 | 2.3% | 53.4% | 0% | 46.6% | 0% |
| | 2012 | 350 | 2.4% | 33.7% | 11.0% | 38.6% | 16.7% |
| | *2013* | *350* | *2.3%* | *48.1%* | *12.6%* | *26.3%* | *13.0%* |
| WC03 | 2010 | 300 | 1.7% | 34.4% | 0% | 65.6% | 0% |
| | 2012 | 300 | 1.8% | 24.0% | 8.5% | 54.9% | 12.6% |
| | *2013* | *306.3* | *1.6%* | *37.2%* | *15.9%* | *30.4%* | *16.5%* |
| WC04 | 2010 | 300 | 3.5% | 60.0% | 0% | 40.0% | 0% |
| | 2012 | 300 | 3.4% | 41.3% | 16.2% | 30.3% | 12.2% |
| | *2013* | *300* | *3.4%* | *46.5%* | *11.0%* | *27.9%* | *14.6%* |

Table C-2. Comparisons of Cross-sectional Survey Analyses Year 1 – Year 3

| 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 |
| | *2013* | *2+29* | *Crossover Riffle* | *21.6* | *1.1* | *20.2* | *1.5* | *23.2* | *66.9* |
| | 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 |
| | *2013* | *2+95* | *Meander/Riffle* | *29.0* | *0.9* | *34.1* | *1.5* | *24.7* | *212.7* |
| 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 |
| | *2013* | *1+38* | *Crossover Riffle* | *14.3* | *0.7* | *19.4* | *1.2* | *10.6* | *36.7* |
| | 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 |
| | *2013* | *3+25.5* | *Meander/Riffle* | *15.6* | *0.7* | *21.8* | *1.5* | *11.1* | *72.0* |
| 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 |
| | *2013* | *1+56* | *Crossover Riffle* | *10.1* | *0.9* | *11.8* | *1.2* | *8.6* | *38.2* |
| | 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 |
| | *2013* | *2+12* | *Meander/Pool* | *9.7* | *1.0* | *10.0* | *2.7* | *9.4* | *55.0* |
| 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 |
| | *2013* | *1+08* | *Meander/Pool* | *13* | *0.6* | *23.5* | *2.2* | *7.2* | *99.9* |
| | 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 |
| | *2013* | *1+68* | *Crossover Riffle* | *10.4* | *0.5* | *20.4* | *1.4* | *5.3* | *56.3* |

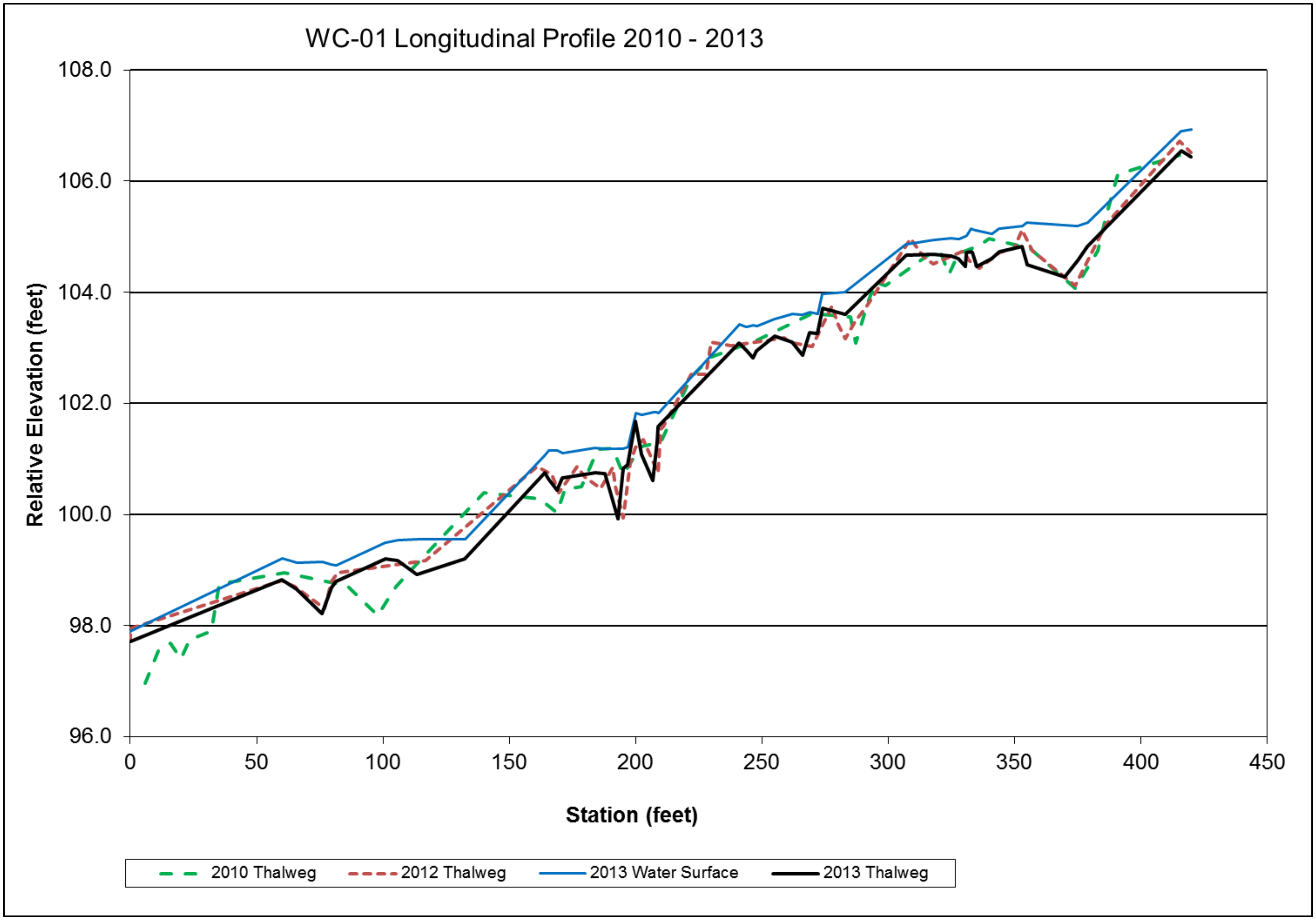


Figure C-1. WC-01 Chart

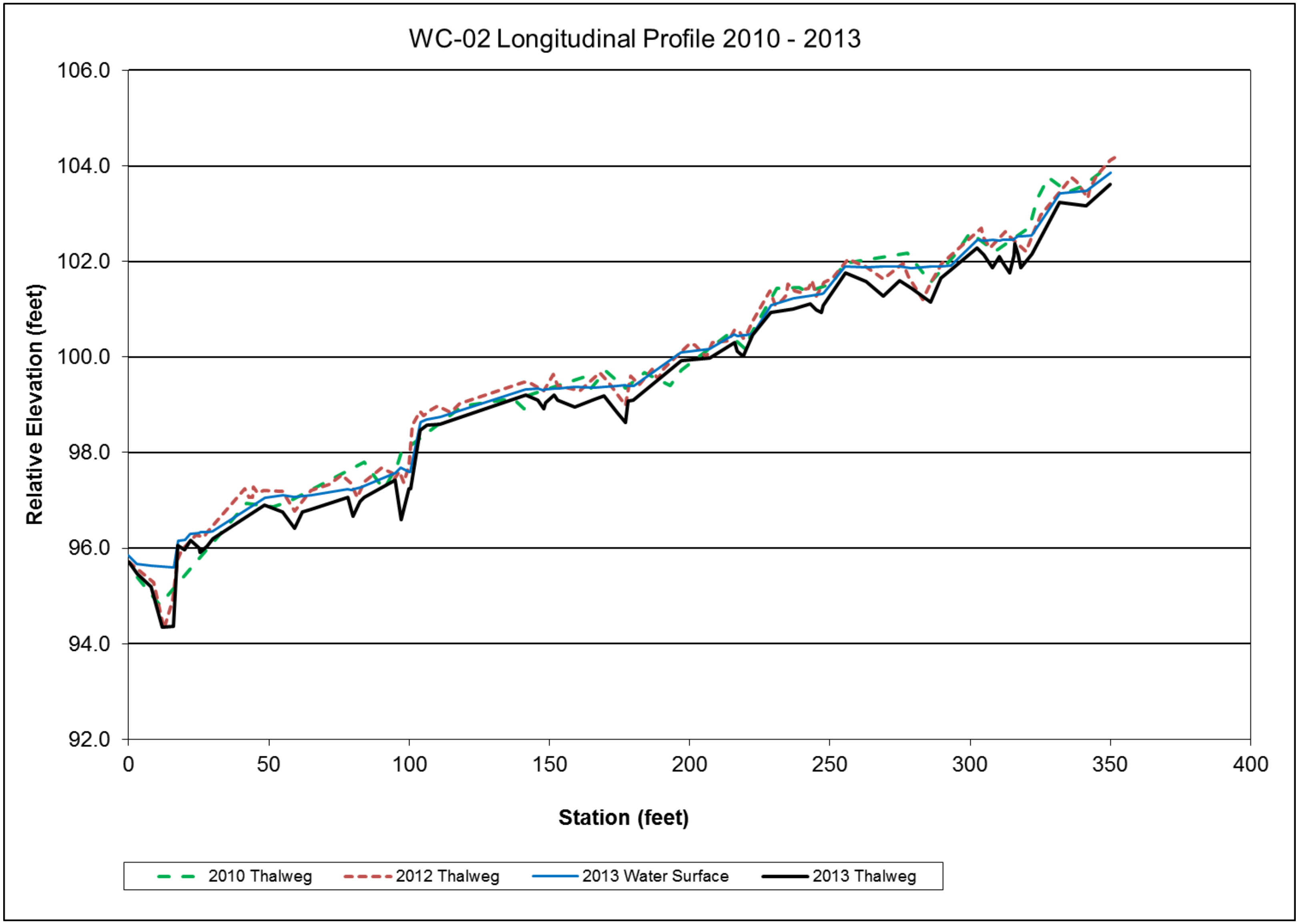


Figure C-2. WC-02 Chart

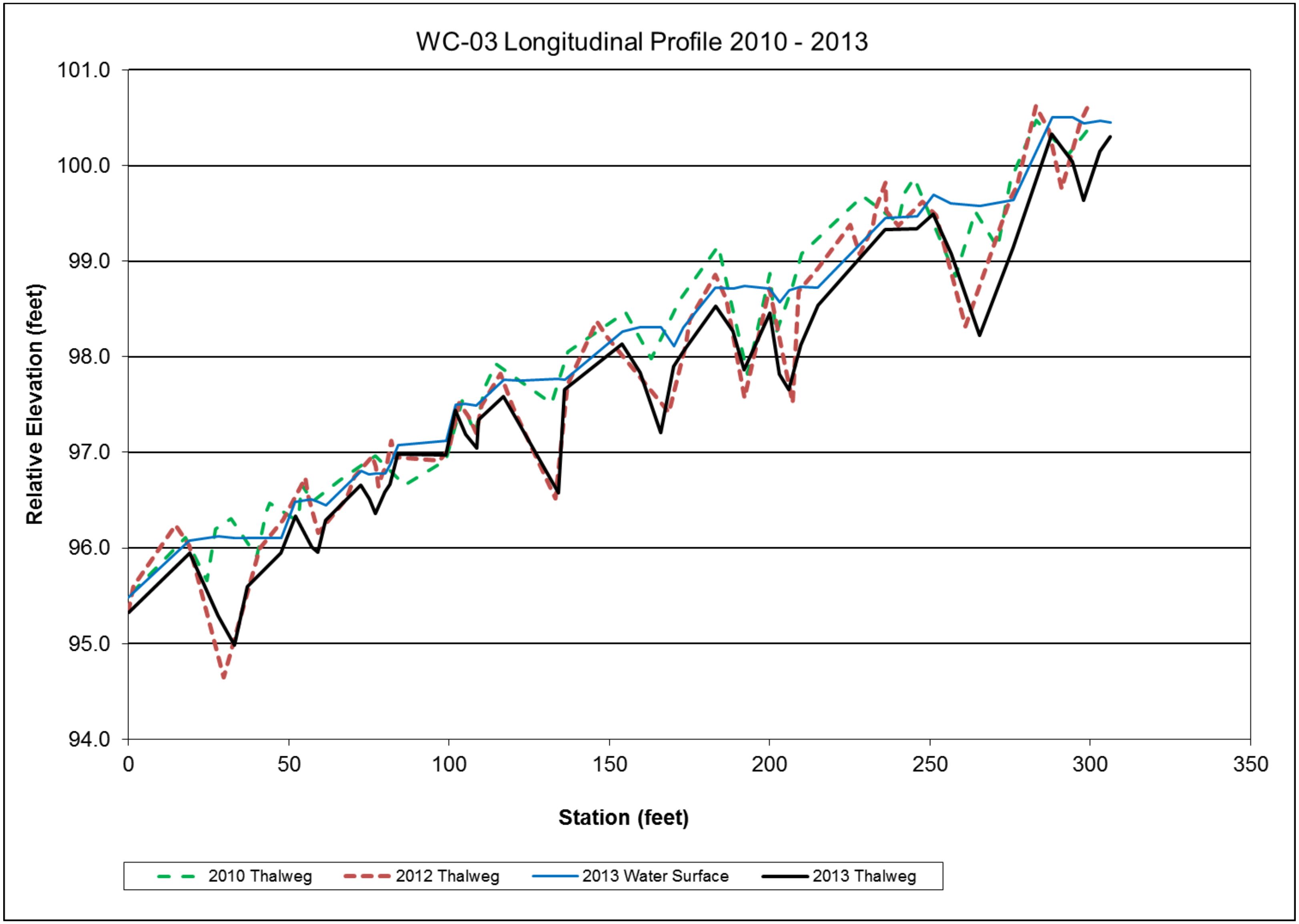


Figure C-3. WC-03 Chart

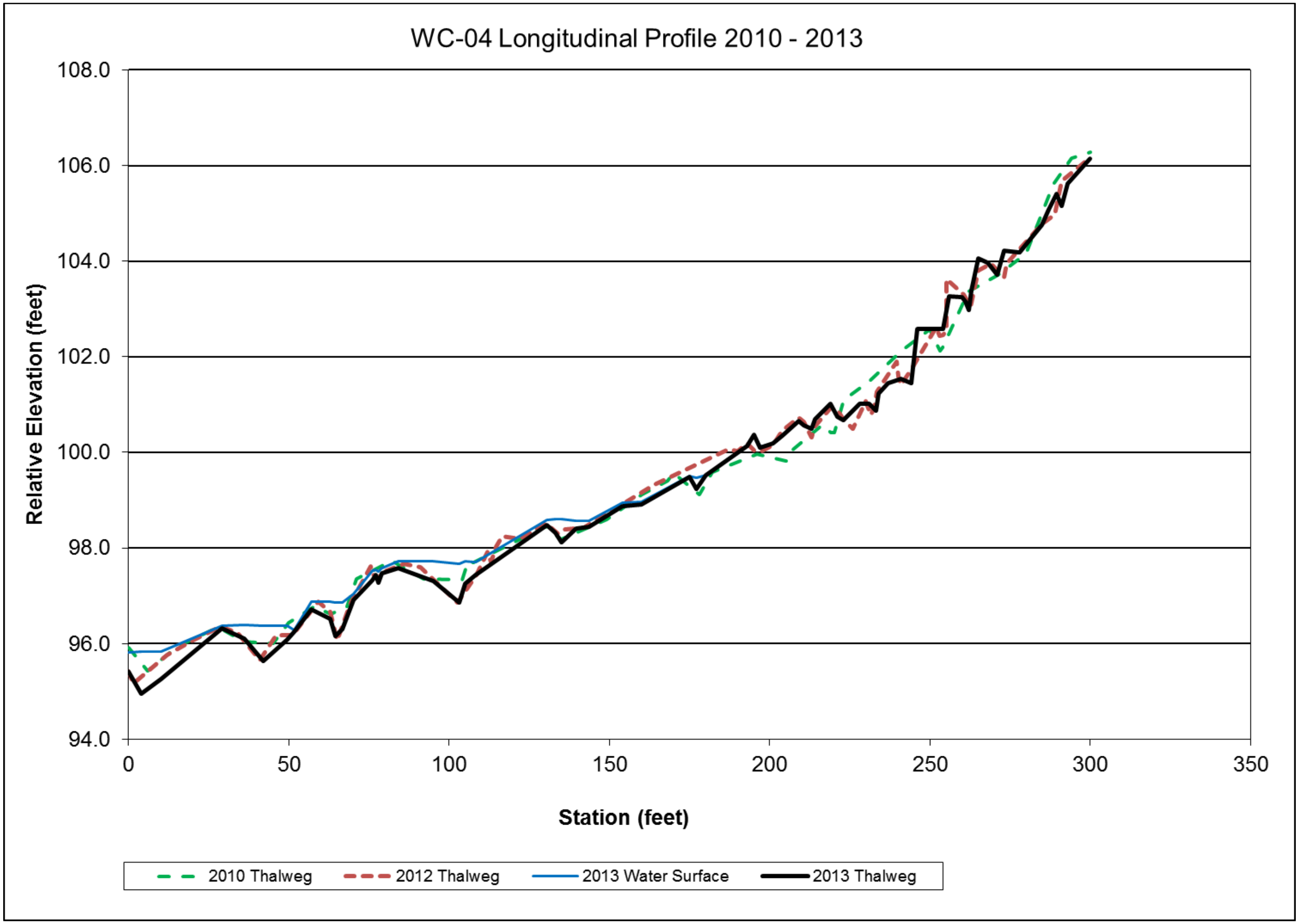


Figure C-4. WC-04 Chart

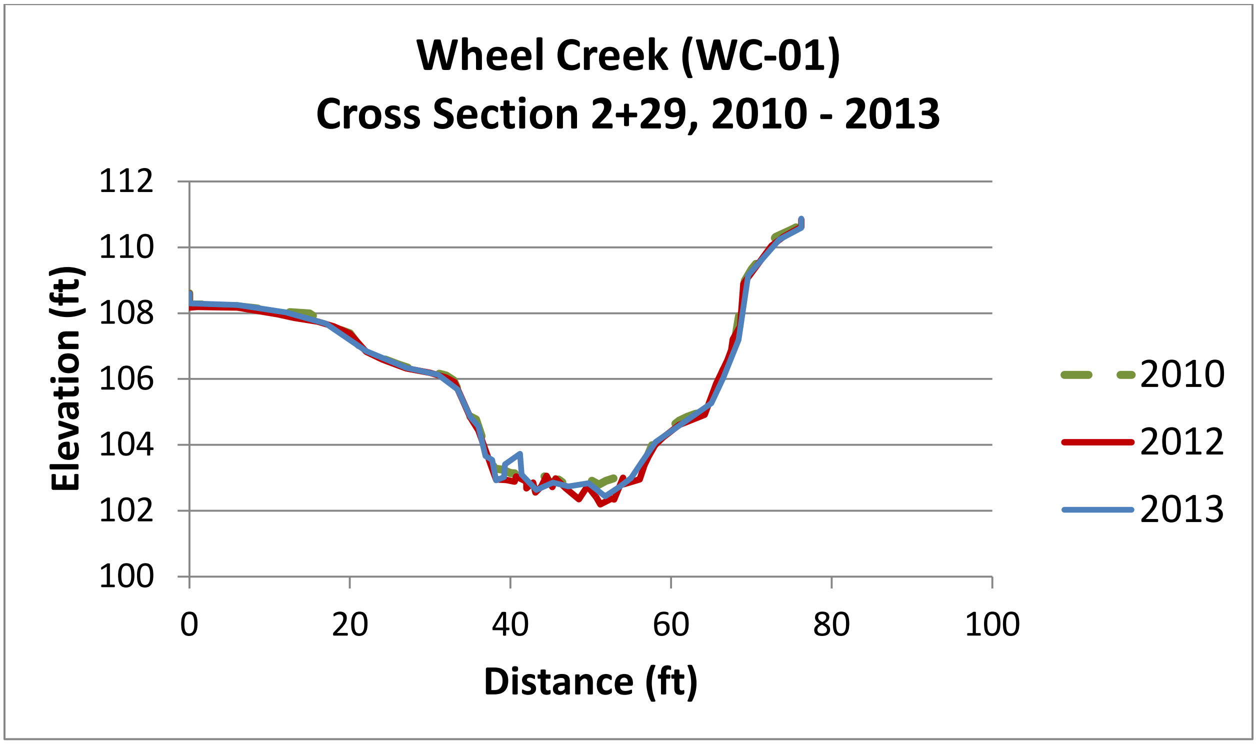


Figure C-5. WC01 Cross Section 1

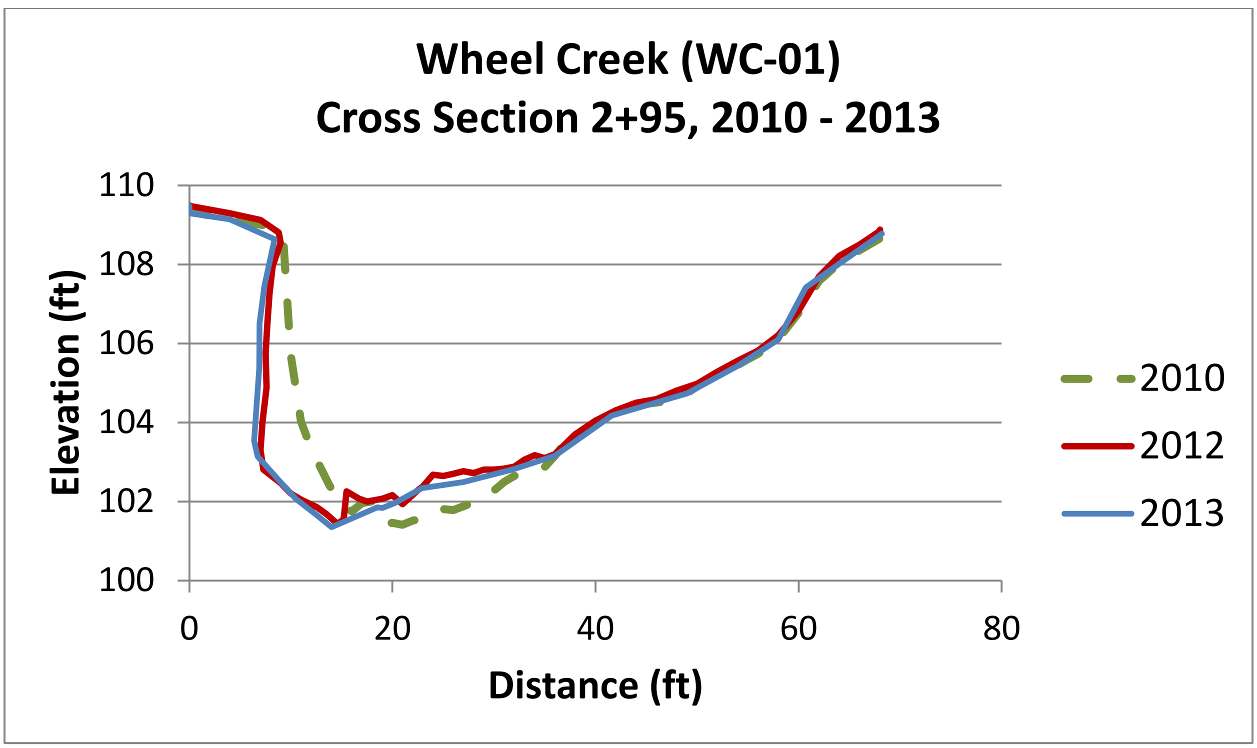


Figure C-6. WC01 Cross Section 2

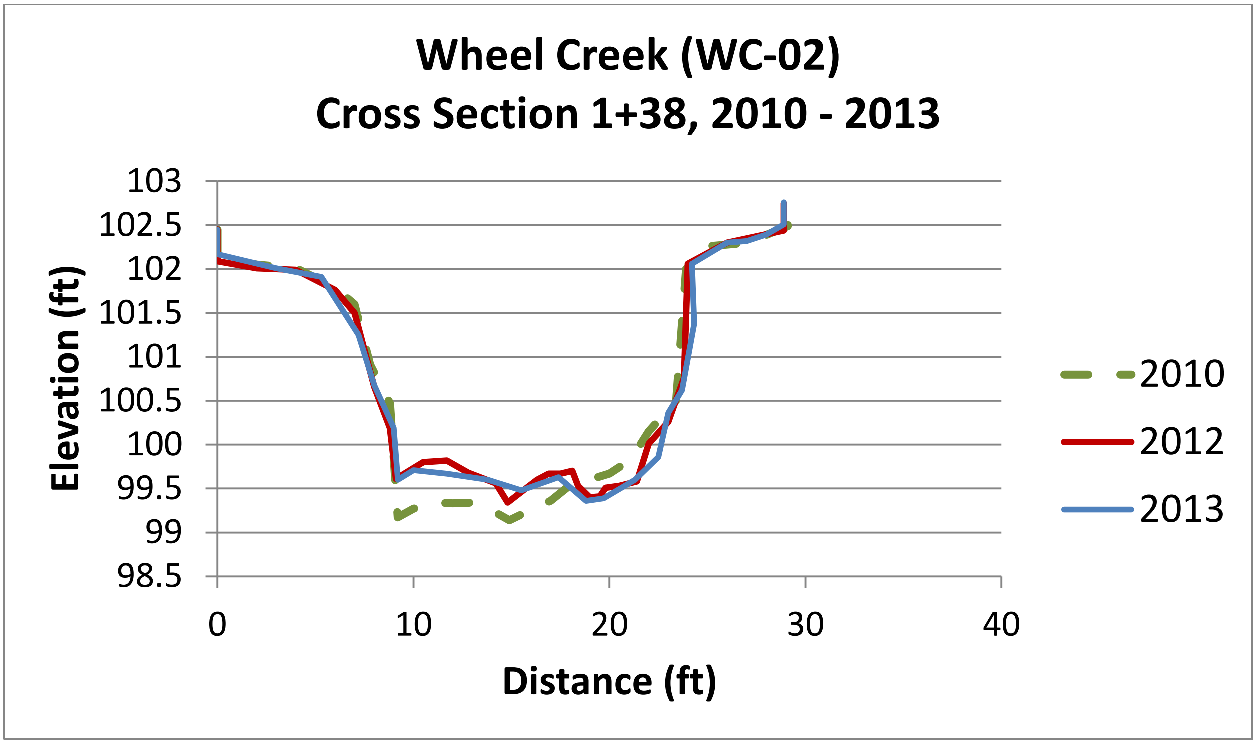


Figure C-7. WC02 Cross Section 1

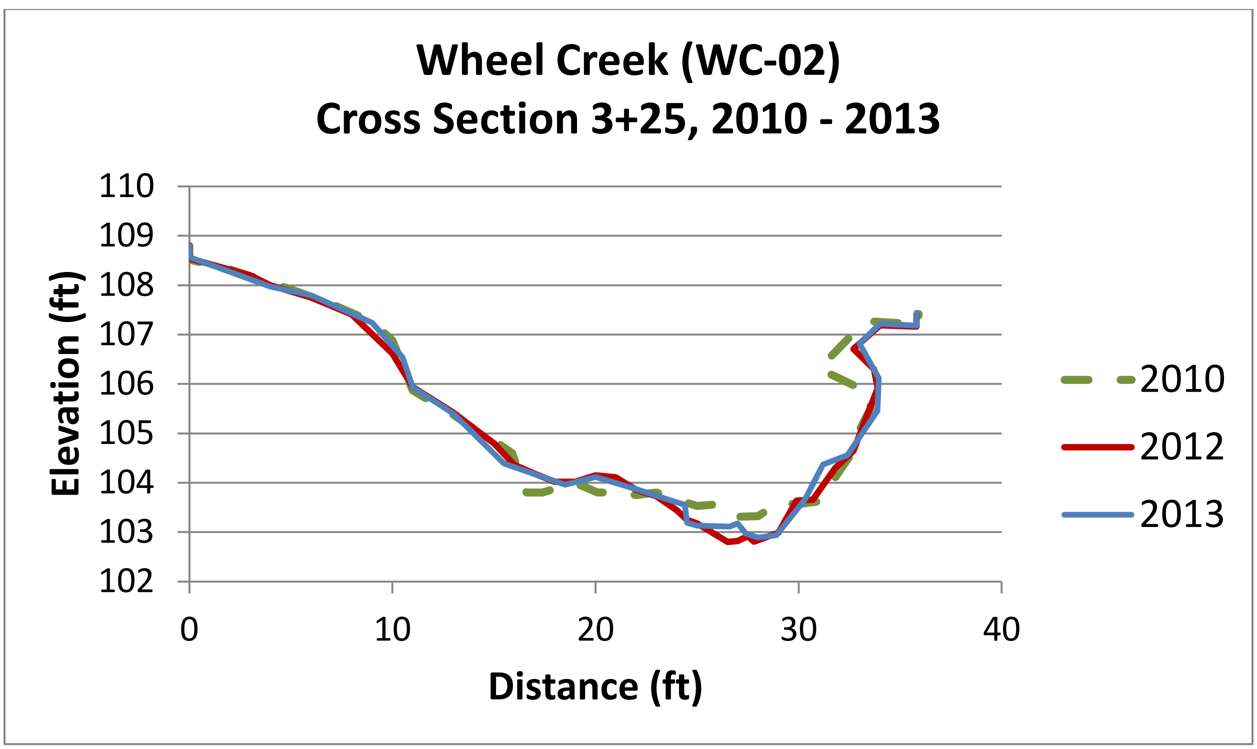


Figure C-8. WC02 Cross Section 2

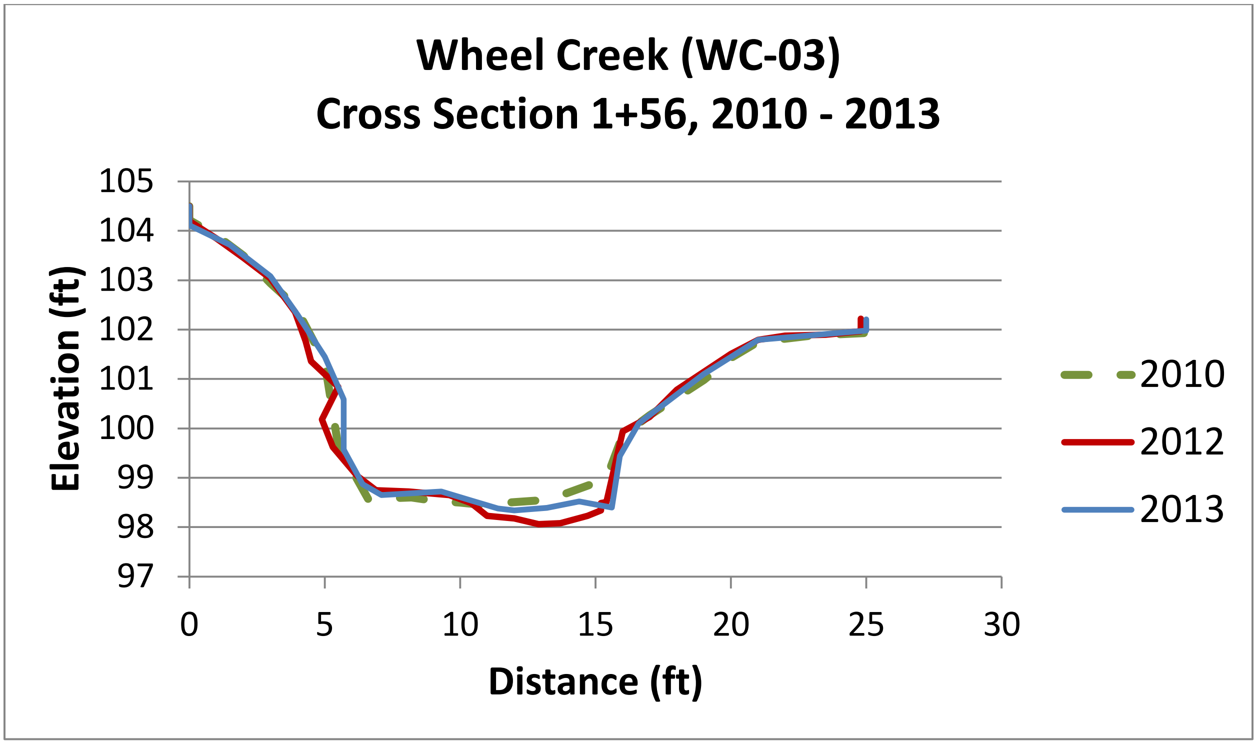


Figure C-9. WC03 Cross Section 1

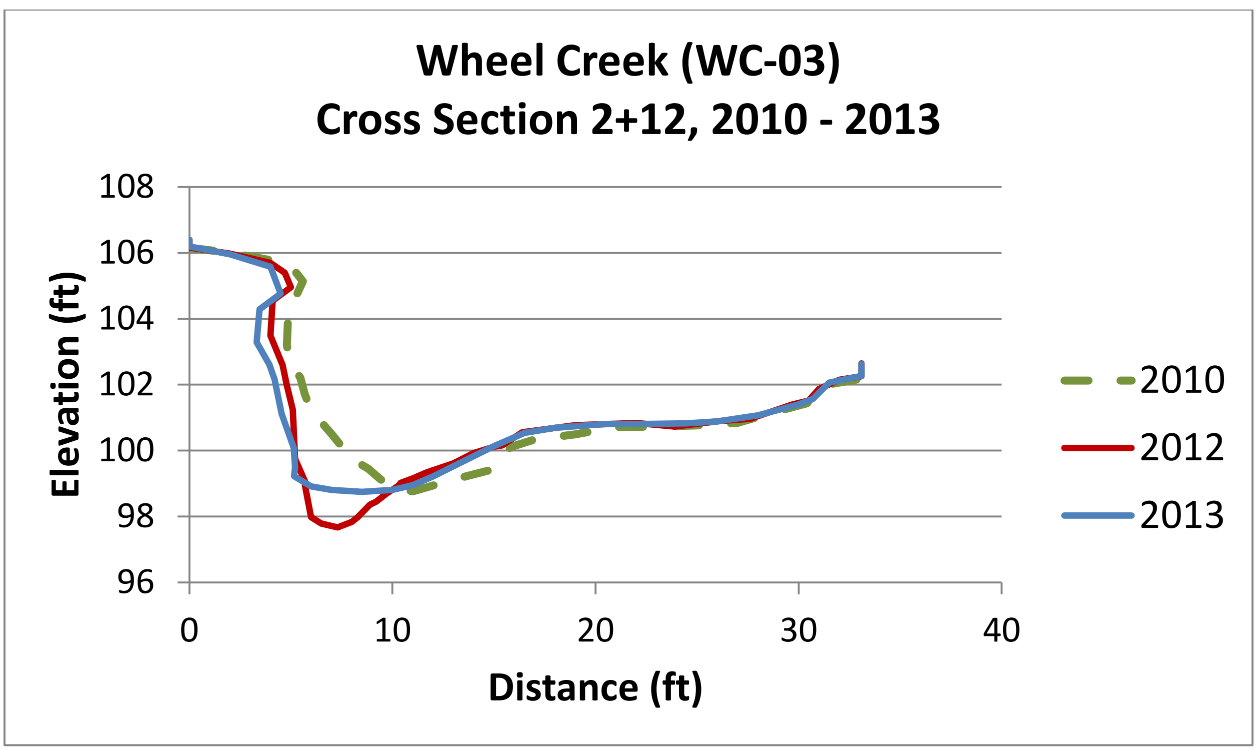


Figure C-10. WC03 Cross Section 2

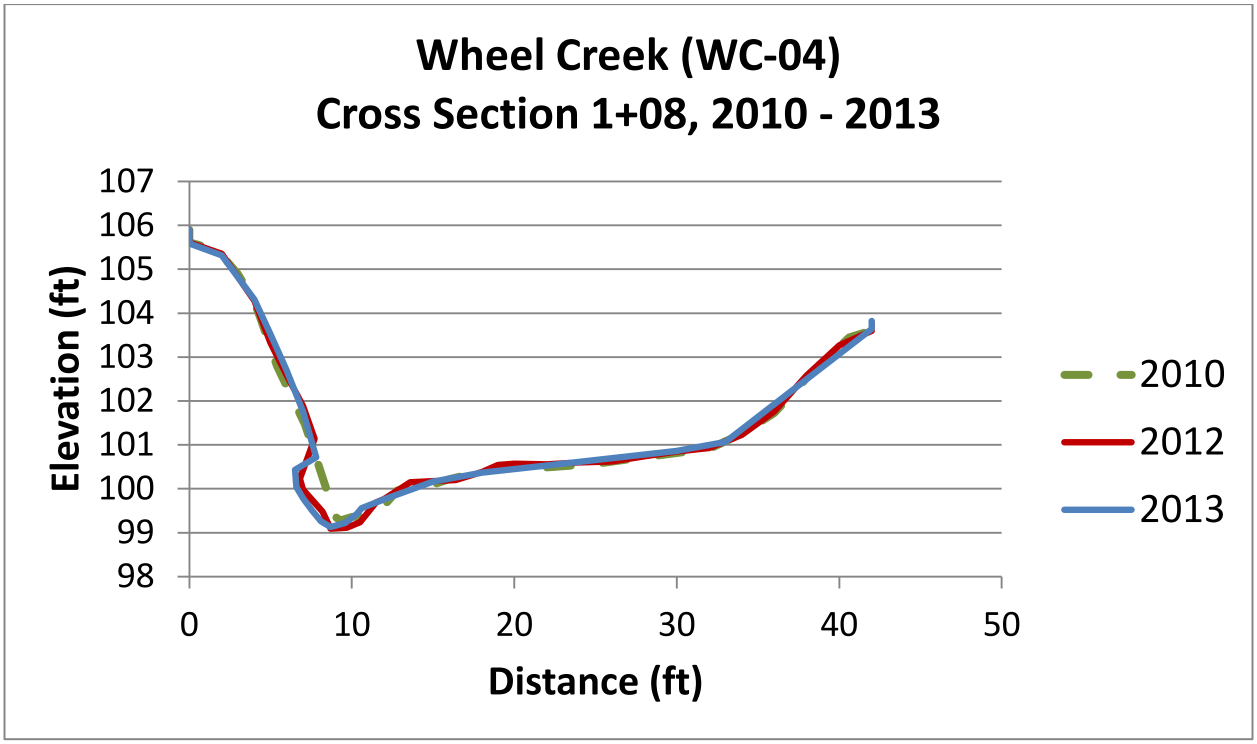


Figure C-11. WC04 Cross Section 1

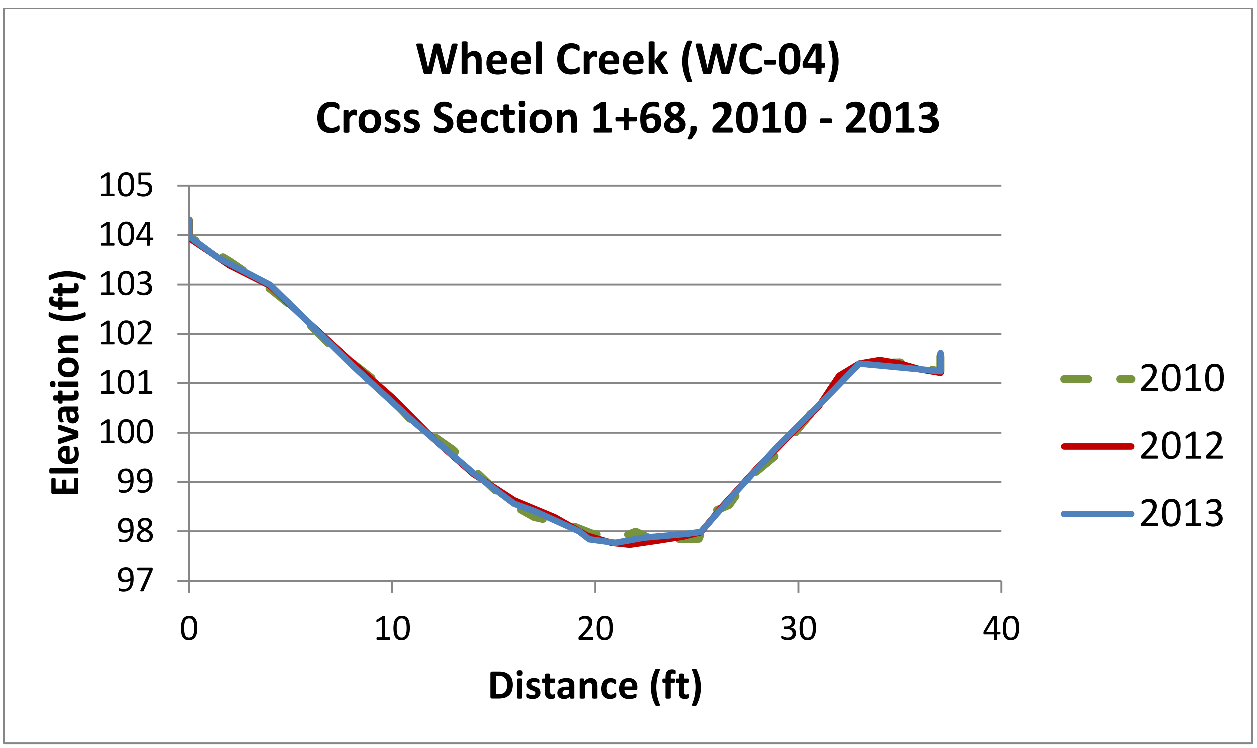


Figure C-12. WC04 Cross Section 2

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

| Site | Profile Station | Bank | Pin Location | Predicted Erosion Rate Year 1 (ft/yr) | Measured Erosion Rate Year 1 (ft/yr) | Measured Erosion Rate Year 2 (ft/yr) | Measured Erosion Rate Year 3 (ft/yr) | Total Measured Erosion Rate (ft/yr) |
|---|---|---|---|---|---|---|---|---|
| WC01 | 0+21 | Left - outer | Upper | 0.5 | 0.23 | 0.03 | 0.11 | 0.03 |
| | | Left - outer | Lower | 0.5 | 0.12 | 0.02 | -0.05 | -0.02 |
| | | Right - inner | Lower | 0.04 | 0.04 | -0.05 | 0.07 | 0.00 |
| | 1+30 | Left - inner | Toe | N/A* | 0.13 | -0.13 | -0.05 | -0.04 |
| | | Right - outer | Upper | 0.06 | 0.00 | 0.00 | -0.05 | -0.02 |
| | | Right - outer | Lower | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 1+92 | Left - inner | Toe | N/A* | -0.08 | N/A** | -0.77 | -0.77[a] |
| | | Right - outer | Upper | 0.28 | 0.14 | -0.03 | 0.21 | 0.08 |
| | | Right - outer | Lower | 0.28 | 0.08 | 0.14 | 0.21 | 0.13 |
| | 3+80 | Left - inner | Toe | N/A* | -0.02 | -0.25 | -0.05 | -0.20 |
| | | Right - outer | Upper | 0.125 | 1.03 | 0.77 | 0.05 | 0.49 |
| | | Right - outer | Lower | 0.125 | 0.98 | N/A** | 0.38 | 0.45[b] |
| WC02 | 0+24 | Left - outer | Upper | 0.375 | 0.24 | 0.04 | 1.13 | 0.40 |
| | | Left - outer | Lower | 0.375 | 0.11 | N/A** | N/A** | N/A** |
| | | Right - inner | Toe | 0.003 | 0.12 | -0.24 | -0.38 | -0.22 |
| | 2+00 | Left - outer | Upper | 0.04 | 0.06 | -0.02 | -0.05 | 0.00 |
| | | Left - outer | Lower | 0.04 | -0.03 | -0.01 | 0.00 | -0.01 |
| | | Right - inner | Toe | 0.03 | 0.47 | N/A** | 0.36 | 0.46[b] |
| | 2+88 | Left - outer | Upper | 0.2 | 0.30 | 0.00 | 0.11 | 0.12 |
| | | Left - outer | Lower | 0.2 | 0.36 | 0.07 | 0.18 | 0.19 |
| | | Right - inner | Toe | 0.06 | -0.04 | -0.17 | 0.27 | -0.04 |
| | 3+50 | Left - outer | Upper | 0.06 | 0.06 | 0.17 | -0.11 | 0.04 |
| | | Left - outer | Lower | 0.06 | 0.12 | -0.01 | -0.29 | -0.05 |
| | | Right - inner | Toe | 0.06 | 0.06 | 0.15 | -0.02 | 0.08 |
| WC03 | 0+75 | Left - outer | Upper | 0.06 | 0.02 | 0.00 | -0.05 | -0.01 |
| | | Left - outer | Lower | 0.06 | 0.11 | 0.00 | 0.00 | 0.03 |
| | | Right - inner | Lower | 0.03 | -0.04 | 0.01 | -0.07 | -0.03 |
| | 1+41 | Left - outer | Upper | 0.5 | 0.02 | 0.05 | -0.11 | -0.03 |
| | | Left - outer | Lower | 0.5 | 0.06 | 0.08 | -0.05 | 0.03 |
| | | Right - inner | Lower | 0.003 | 0.15 | 0.03 | -0.05 | 0.00 |
| | 1+83 | Left - inner | Lower | 0.003 | 0.08 | -0.05 | 0.00 | 0.00 |
| | | Right - outer | Upper | 0.125 | 0.02 | 0.04 | 0.05 | 0.04 |
| | | Right - outer | Lower | 0.125 | 0.05 | 0.02 | -0.05 | 0.01 |
| | 2+57 | Right - outer | Upper | 1.3 | 0.23 | N/A** | 0.07 | 0.07[c] |
| | | Right - outer | Lower | 1.3 | 0.63 | N/A** | 0.09 | 0.09[c] |
| | 2+77 | Right - inner | Lower | N/A* | -1.00 | 0.31 | 0.00 | -0.14 |

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

| Site | Profile Station | Bank | Pin Location | Predicted Erosion Rate Year 1 (ft/yr) | Measured Erosion Rate Year 1 (ft/yr) | Measured Erosion Rate Year 2 (ft/yr) | Measured Erosion Rate Year 3 (ft/yr) | Total Measured Erosion Rate (ft/yr) |
|---|---|---|---|---|---|---|---|---|
| WC04 | 0+21 | Right - inner | Lower | N/A* | -0.44 | 0.29 | -0.14 | -0.03 |
| | | Left - outer | Upper | 0.06 | -0.16 | 0.02 | 0.05 | -0.02 |
| | | Left - outer | Lower | 0.06 | 0.03 | -0.24 | -0.47 | -0.24 |
| | 1+07.5 | Right - inner | Toe | N/A* | -0.01 | 0.06 | -0.05 | 0.00 |
| | | Left - outer | Upper | 0.125 | 0.07 | 0.04 | 1.90 | 0.56 |
| | | Left - outer | Lower | 0.125 | 0.09 | 0.41 | 1.17 | 0.55 |
| | 1+87 | Right - inner | Toe | 0.0003 | -0.04 | 0.03 | 0.11 | 0.00 |
| | | Left - outer | Upper | 0.003 | -0.06 | -0.01 | -0.02 | -0.03 |
| | | Left - outer | Lower | 0.003 | -0.32 | -0.08 | -0.45 | -0.26 |
| | 2+64.5 | Right - inner | Toe | 0.01 | 0.14 | -0.02 | -0.14 | -0.01 |
| | | Left - outer | Upper | 0.2 | -0.14 | 0.20 | -0.07 | 0.11 |
| | | Left - outer | Lower | 0.2 | 0.00 | 0.15 | 0.00 | 0.03 |

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, calculated Measured Erosion Rate Year 3 using the difference between the October 2013 measurements and the November 2012 measurements, and calculated Total Measured Erosion Rate using the difference between the October 2013 measurements and the baseline measurements from 2010, except where noted.

*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 could not be calculated at these locations.

[a] Due to pin loss between Baseline and Year 1 assessments, and pin loss between Year 1 and Year 2 assessments, the Total Measured Erosion Rate was calculated using the Year 3 exposure measurement and elapsed time (48 weeks).

[b] Due to pin loss between the Year 1 and Year 2 assessments, the Total Measured Erosion Rate was calculated by using Year 1 and Year 3 exposure measurements and elapsed time (90 weeks).

[c] Pin lost between Year 1 and Year 2 measurements and could not be reinstalled in original bank location due to significant erosion. Pin placed in the next closest outside meander bend in 2012. The Total Measured Erosion Rate was calculated by using the Year 3 exposure measurement and elapsed time (48 weeks).

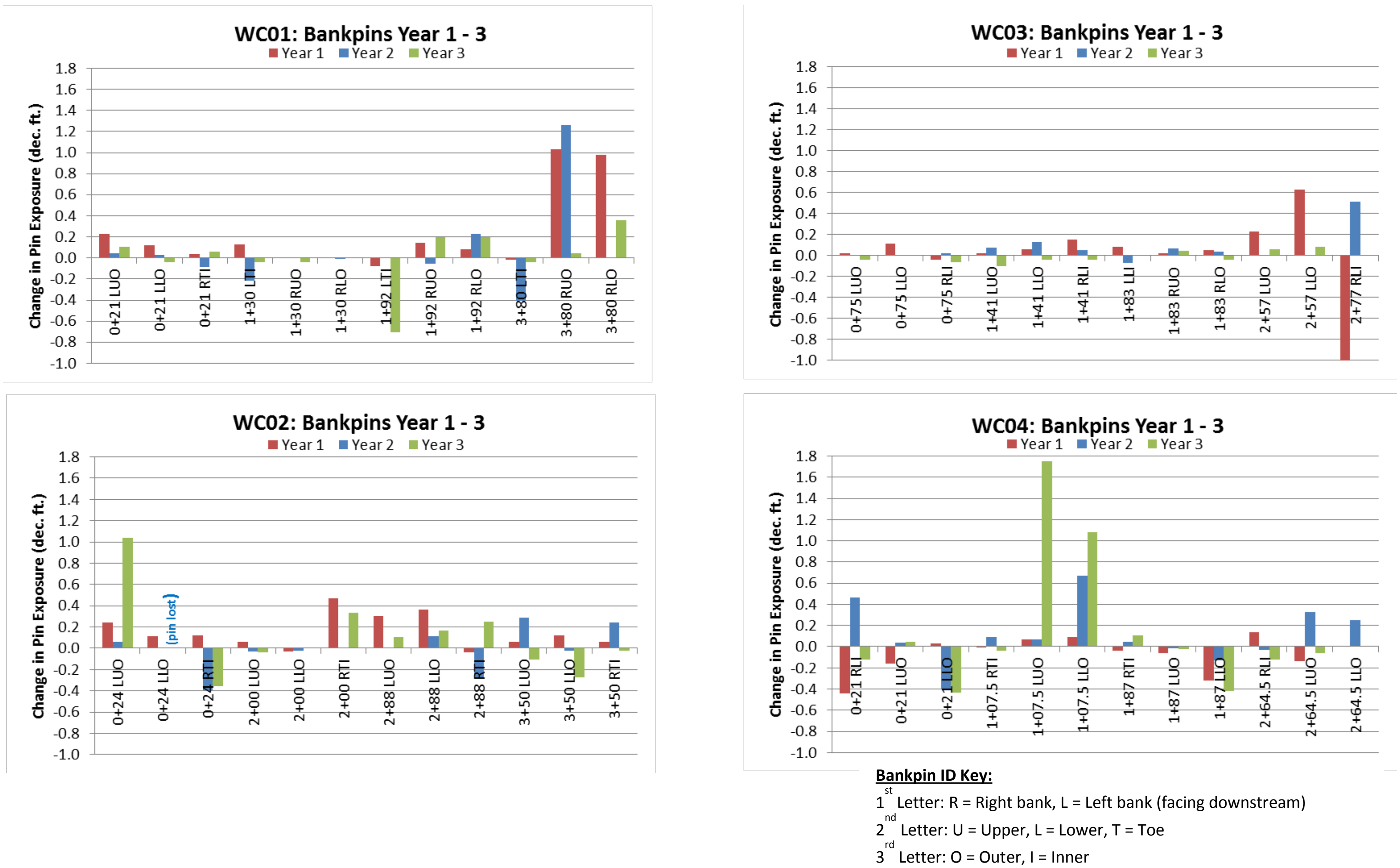


Figure C-13. Cumulative changes in Bank Pin Exposure Year 1-3. Between Year 1 and Year 2, a pin was lost at WC02 station 2+24 LLO, and was not recovered in Year 3.

| Table C-4. Scour Chain Evaluation Year 1 – Year 3 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Reach** | **Profile Station 2013** | **Feature 2013** | **Cross Section Station** | **Cumulative Change from November 2012 (dec. ft.)** | **Cumulative Change from June 2010 (dec. ft.)** | **Annual rate of scour (March 2011- November 2012) (ft/yr)** | **Annual rate of scour (November 2012- October 2013) (ft/yr)** | **Annual rate of scour (June 2010- October 2013) (ft/yr)** |
| WC01 | 2+29 | Riffle | 47 | -0.27 | -0.40 | -0.03 | -0.29 | -0.12 |
| | 2+29 | Riffle | 50.7 | -0.52 | -0.29 | 0.29 | -0.56 | -0.09 |
| | 2+95 | Meander | 21.5 | N/A* | N/A* | N/A* | N/A* | N/A* |
| WC02 | 1+38 | Riffle | 12 | 0.17 | -0.83 | -0.31 | 0.18 | -0.25 |
| | 1+38 | Riffle | 15 | -0.12 | -0.32 | -0.12 | -0.13 | -0.10 |
| | 3+24 | Riffle | 25.5 | 0.08 | -1.02 | -0.35 | 0.09 | -0.30 |
| WC03 | 1+55 | Pool | 12 | -1.67 | -1.60 | -0.06 | -1.81 | -0.48 |
| WC04 | 1+68 | Riffle | 21 | 0.06 | 0.06 | 0.03 | 0.07 | 0.02 |
| 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 3 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | ***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 |
| *2013* | *D50* | 49 | very coarse gravel | D50 | 37 | very coarse gravel | D50 | 55 | 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 |
| *2013* | *D84* | 130 | large cobble | D84 | 87 | small cobble | D84 | 130 | large 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 |
| *2013* | *D50* | 51 | very coarse gravel | D50 | 47 | very coarse gravel | D50 | 40 | 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 |
| *2013* | *D84* | 88 | small cobble | D84 | 86 | small cobble | D84 | 110 | medium cobble |

Table C-5. (Continued)

| Year | Riffle Feature Surface | | | Meander Feature Surface | | | Reachwide | | |
|---|---|---|---|---|---|---|---|---|---|
| | Measure | Size (mm) | Size Class | Measure | Size (mm) | Size Class | Measure | Size (mm) | Size Class |
| 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 |
| *2013* | *D50* | 27 | coarse gravel | D50 | 29 | coarse gravel | D50 | 35 | very 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 |
| *2013* | *D84* | 68 | small cobble | D84 | 59 | very coarse gravel | D84 | 130 | large cobble |
| *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 |
| 2013 | D50 | 33 | very coarse gravel | D50 | 1.5 | very coarse sand | D50 | 36 | very 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 |
| 2013 | D84 | 57 | very coarse gravel | D84 | 64 | small cobble | D84 | 79 | small cobble |