# Appendix G1 - Assessment of Controls (BMP Effectiveness Monitoring)

# WHEEL CREEK
# WATER CHEMISTRY MONITORING
# YEAR 13 REPORT

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# 1.0 INTRODUCTION

Harford County conducts monitoring in the Wheel Creek watershed to evaluate the benefits of various improvement projects, including stormwater pond retrofits and stream restorations. Wheel Creek has been identified as the County's priority watershed to satisfy National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) permit-required monitoring.

Wheel Creek watershed drains 435 acres consisting of high density residential and commercial land uses in the headwaters, and medium and low density residential and forest land uses in the remainder. The streams in the watershed have been altered by changes in hydrology associated with recent urbanization and historical agricultural land use. Imperviousness has increased to 27% in the past three decades of development (Harford County DPW 2008). In total, eight individual construction projects have been completed in tributaries and stormwater facilities in the watershed during 2012 to 2017 in an effort to improve instream chemical, biological, and physical conditions.

Monitoring to assess the effectiveness of the restoration effort in the Wheel Creek watershed to comply with the requirement of the MS4 permit has been ongoing since 2009. Harford County contracted with Versar, Inc., to conduct water chemistry and continuous flow monitoring. Previously, monitoring was performed in conjunction with requirements associated with the Chesapeake and Atlantic Coastal Bays 2010 Trust Fund stream restoration initiative, which included funding for the restoration projects and continuous flow, biological, and physical monitoring performed by Maryland Department of Natural Resources (DNR). Monitoring requirements for the Trust Fund stream restoration initiative have since been satisfied. Baseflow water chemistry monitoring, previously undertaken by County staff, has been conducted by Versar from 2018 to the present. Continuous flow monitoring near all three of the water chemistry monitoring stations has been conducted by Versar from June 2016 to the present. Biological and physical monitoring have been conducted by KCI Technologies beginning in 2019. Geomorphological assessments have been conducted annually since 2010, first by the County and subsequently by Versar. United States Geological Survey (USGS) operates a stream flow gauging station near the mouth of Wheel Creek (USGS Station 0158175320) and a stage level gauging station and tipping bucket rain gauge in Atkisson Reservoir (USGS Station 01581753).

This report documents the water chemistry monitoring activities undertaken by Harford County, Versar, and USGS, and summarizes the data obtained from July 1, 2022 to June 30, 2023. The activities included capturing eight wet weather events, monthly baseflow monitoring, and continuous flow rate monitoring in the Wheel Creek watershed. An assessment of long-term pollutant concentration trends and reduction by the restoration projects is also presented.

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# 2.0 STUDY AREA AND STUDY DESIGN

Wheel Creek forms a portion of the Atkisson Reservoir Watershed and resides within the Bush River Basin. It consists of approximately 435 acres of watershed, 2.2 linear stream miles, and five stormwater management facilities. Four stream reaches were targeted for restoration and four stormwater facility retrofits were planned in the drainage area (Harford County DPW 2008). Restoration and retrofit activities began in 2012 and continued through April 2017 (Table 2-1). Pre-restoration and post-restoration data will be used to assess performance of portions of the stream restoration and stormwater BMP retrofit projects as well as for the overall watershed. The current monitoring period represents the sixth full year of post-restoration data collection and analyses.

Table 2-1. Timeline of restoration and retrofit projects in Wheel Creek watershed (M. Dobson pers. comm.)

| Construction Projects | Start Date | Completion Date |
|---|---|---|
| Gardens of Bel Air (Pond A) | September 8, 2012 | December 20, 2012 |
| Calverts Walk (UMS-1) | January 14, 2013 | April 4, 2013 |
| Festival of Bel Air (Pond C) | May 12, 2015 | August 7, 2015 |
| Country Walk 1A (Pond D) | September 21, 2015 | December 11, 2015 |
| MMS-5, MB-4, MB-1 | December 7, 2015 | February 26, 2016 |
| Water Quality Facilities (4) | December 7, 2015 | March 18, 2016 |
| Lower Wheel Creek | September 19, 2016 | March 2017 |
| Country Walk 1B (Pond E) | December 2016 | April 2017 |

The water chemistry monitoring study design employs before and after conditions assessments corresponding to comparisons of pre- and post-restoration and retrofit phases. The initiation, termination, and duration of the phases vary by station and the schedule of restoration construction.

Three long-term automated water chemistry sampling and flow logging stations were established at Stations WC002, WC003, and WC004 (Figure 2-1). Station WC004 is located on the middle branch, immediately downstream of the stormwater retrofit at Festival Shopping Center (Point C; Figure 2-2). Stations WC003 and WC004 bracket completed stormwater retrofits at Pond D and Pond E along the middle branch (Figure 2-2). Station WC002 is located on the mainstem and water chemistry data collected there will provide an overall assessment of the benefits of retrofit and restoration projects in upstream tributaries (Figure 2-2). Baseflow monitoring took place at three stations along the Wheel Creek mainstem and tributaries (WC002, WC003, and WC004).


Figure 2-1. Wheel Creek Watershed long-term water chemistry monitoring stations

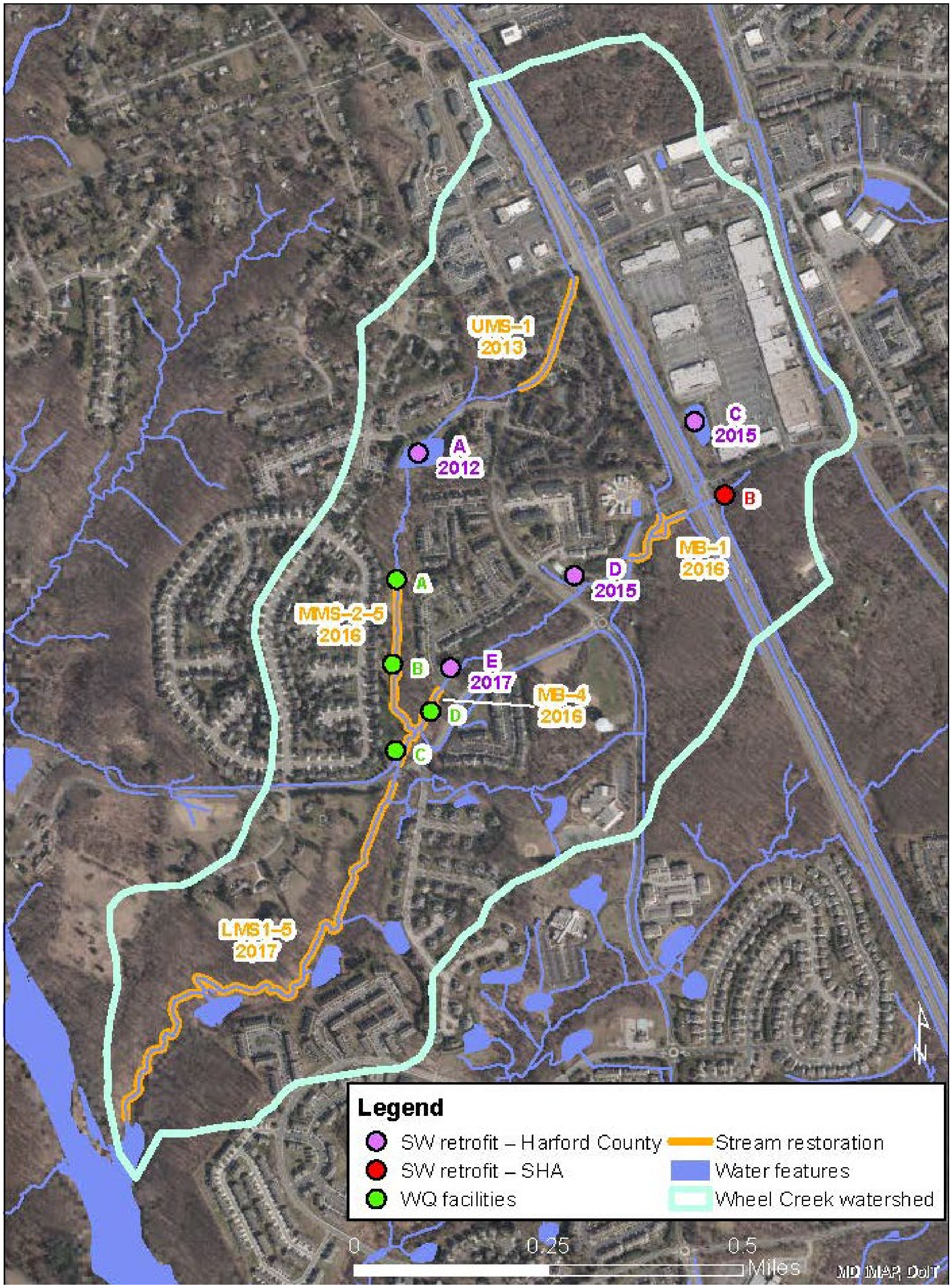


Figure 2-2. Stream restoration and stormwater retrofit sites in Wheel Creek watershed

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# 3.0 METHODS AND MATERIALS

## 3.1 STORMFLOW MONITORING

Fixed, automated stormflow monitoring and long-term flow logging stations were situated at the following locations:

- WC002 – Wheel Creek mainstem at Wheel Road
- WC003 – Middle branch at Cinnabar Lane
- WC004 – Middle branch off Wheel Court

Stormflow samples were collected by Versar staff using American Sigma 900Max samplers at Stations WC002, WC003, and WC004 working in conjunction with ISCO 4230 bubbler flow meters. Automated sampling equipment was installed in September 2010 at Station WC002 and Station WC003 and mid-October 2010 at Station WC004. During storms, bubbler flow meter tubing and carriers were secured at the downstream end of culverts at Station WC002 and Station WC003 while the bubbler tube at Station WC004 was secured instream. Automated samplers contained 24, one-liter polypropylene bottles and were programmed to start at a specific time (based on the storm forecast) by field staff to sample the rising, peak, and falling limbs of the storm on a time-paced basis. Separate composite samples were created on a discharge volume-proportional basis to represent the rising, peak, and falling limbs of the stream hydrograph.

Eight events were monitored between July 1, 2022 and June 30, 2023 (Table 3-1). Event rainfall duration was calculated from the first to the last measurable amounts of rain that triggered the tipping mechanism within the rain gauge. Antecedent dry time was calculated by determining the time interval between the initiation of rainfall for the monitored event and the cessation of rainfall for the prior event. Qualifying storm events required a minimum of 24 hours where there had been less than 0.03 inches total accumulated rainfall.

Flow rate during monitored storm events was determined using Manning's equations specific to each outfall pipe at Stations WC002 and WC003 and by rating curve at Station WC004. The rating curve at Station WC004 was prepared using directly-measured velocities, over a range of stages, along a stream channel cross-section (Appendix B). Versar field staff measured velocity and channel depth using a Marsh-McBirney Flowmate 2000 flowmeter, with sensor attached to a graduated wading rod (Jones and Hage 2011). Automated storm sampling procedures are described in fuller detail in the project's Quality Assurance and Quality Control Document (Corbin et al. 2021). The duration of a storm event was recorded as the time of elevated flow (Appendix A). Stations WC003 and WC004 were found to have flow levels above baseflow longer than Station WC002 for several monitored storm events. These prolonged periods of elevated flow for these stations were possibly due to the stormwater ponds upstream of them detaining and releasing water over an extended period of time, where the continued discharge from these stormwater ponds contributed to flows above baseflow in the smaller upstream station systems where channels are narrower, and flows elevate easier.

Stream water samples were tested for the analytes listed in Table 3-2. Since May 2013, samples were tested for an expanded suite of analytes that included turbidity and chloride. Analytes with multiple detection limits are presented as a range in Table 3-2.

Table 3-1. Statistics for monitored storms, July 2022 – June 2023

| Date | Rainfall Total (in.) | Rainfall Duration (hr.) | Antecedent Dry Time (hr.) |
|---|---|---|---|
| 24-Aug-22 | 4.75 | 30 | 154.50 |
| 7-Sep-22 | 1.97 | 24 | 151.00 |
| 14-Oct-22 | 0.91 | 28 | 173.50 |
| 1-Dec-22 | 0.31 | 24 | 58.25 |
| 13-Jan-23 | 0.21 | 24 | 166.25 |
| 24-Jan-23 | 0.50 | 30 | 58.25 |
| 24-Apr-23 | 0.58 | 20 | 131.75 |
| 26-Jun-23 | 1.58 | 74 | 212.50 |

Rainfall recorded by primary onsite rain gauge at Station WC002

Table 3-2. Parameters, methods, detection limits, and water quality criteria for Wheel Creek monitoring

| Parameter | Analytical Method | Reporting Limit (mg/L) | Method Detection Limit (mg/L) | MD Freshwater Criteria[a] | | EPA Recommended Ambient Water Quality Criteria[b] (mg/L) |
|---|---|---|---|---|---|---|
| | | | | Acute (µg/l) | Chronic (µg/l) | |
| BOD-5 | SM 5210 B | 1-2 | 0.2-1 | | | |
| Nitrate + Nitrite | SM 4500 NO3F | 0.2 | 0.01-0.02 | | | 0.69 (Total N)[c] |
| Total Kjeldahl Nitrogen | SM 4500 NorgD | 0.5 | 0.06-0.2 | | | |
| Orthophosphate | SM 4500 PE | 0.02-0.05 | 0.01-0.02 | | | |
| Total Suspended Solids | SM 2540D | 2-4 | 2.4 | | | |
| Copper | EPA 200.8 | 0.002-0.004 | 0.001-0.003 | 13 | 9 | |
| Lead | EPA 200.8 | 0.001-0.002 | 0.0003-0.0006 | 65 | 2.5 | |
| Zinc | EPA 200.8 | 0.01-0.02 | 0.004-0.007 | 120 | 120 | |
| Chloride[d] | EPA 300.0 | 5-50 | 5-50 | | | 860 (acute)<br>230 (chronic) |
| Ammonia | SM 4500 NH3H | 0.3 | 0.06-0.07 | | | |
| Total Phosphorus | SM 4500 PB&E | 0.05 | 0.005-0.1 | | | 0.03656 |
| Hardness | SM 2340C | 10-20 | 10-20 | | | |
| Turbidity | HACH 10258 | 0.01 | 0.01 | | | |
| Total Petroleum Hydrocarbons | EPA 1664A | 4.8-5 | 4.8-5 | | | |
| *E. coli* (reported as MPN/100 ml) | SM 9223B | 1 | 1 | | | |

(a) Values from COMAR 26.08.02.03-2 (undated).
(b) U.S. EPA 2000. Recommended criteria are derived from the 25th percentile of concentrations in all streams in the ecoregion.
(c) Total nitrogen concentration is the sum of total Kjeldahl nitrogen and combined nitrate plus nitrite.
(d) U.S. EPA 1988. Ambient Water Quality Criteria for Chloride.

Storm event mean concentrations (EMCs) were calculated individually for each storm by obtaining the concentration of each pollutant, weighted according to limb discharge volume. Limb discharges were determined by plotting the portion of the storm hydrograph represented by the composite sample and integrating under the curve using Flowlink software. For TPH and *E. coli*, which were collected by grab during irregular occasions during stormflow, a simple average concentration without flow weighting was calculated ("greater than" *E. coli* results were set to the numerical result).

Estimated pollutant loading values for each storm were determined by multiplying the storm EMCs by the total storm discharge in cubic feet. Total storm discharge was determined by plotting the storm hydrograph and integrating under the curve using Flowlink software.

## 3.2 BASEFLOW MONITORING

Baseflow monitoring was completed monthly by Versar staff. Grab samples were collected at the locations listed below.

- WC002 – Wheel Creek mainstem at Wheel Road
- WC003 – Middle branch at Cinnabar Lane
- WC004 – Middle branch off Wheel Court

## 3.3 LONG-TERM FLOW RATE LOGGING

Long-term flow rate logging was conducted at Stations WC002, WC003, and WC004 described above. Maryland DNR installed Solinst flow loggers in 2012 and maintained them through June 2016, at which point Versar assumed responsibility for monitoring and maintenance. Versar conducted monthly site inspections, logger downloads, and baseflow discharge measurements between July 2022 and June 2023. Storm discharge measurements were also collected whenever possible to verify the rating curve at each station.

During the winter months, the Solinst flow loggers were removed from service to prevent damage to the sensors due to icing if the threat of freezing was anticipated. During these periods, ISCO 4230 bubbler flow meters were installed to capture level data while the Solinst loggers were offline.

Complete flow series for each station were compiled from the Solinst and ISCO logger data. Staff performed quality control on the level time series to remove any anomalous data (e.g., resulting from manipulation during Solinst data offloads). Levels were corrected to reflect observed staff gauge readings, and linear corrections were applied to the time series at each station to compensate for logger drift. A rating curve was established at each of the three logging stations to convert each logger's level data to flow rate (Appendix B) and updated annually.

## 3.4 RAINFALL LOGGING

Rainfall was recorded by an Onset HOBO electronic, tipping-bucket rain gauge situated in an open area near Station WC002. The gauge was downloaded and maintained by Versar field staff and is the primary gauge used for storm event rainfall totals. Daily rainfall recorded by the gauge is presented in Appendix C. Rainfall records from USGS' Atkisson Reservoir gauge (0.8 miles away to the SW), the secondary rainfall recorder, were used to supplement the onsite data in cases where onsite gauge data were unavailable due to power interruptions or mechanical failures. When the onsite rain gauge experienced a malfunction, a local Weather Underground station (www.wunderground.com; Bel Air South Station) was used for storm event rainfall totals since it is closer to the monitoring stations than the USGS gauge; the USGS rain gauge represents the official totals used for comparison over the entire duration of the year.

## 3.5 DETERMINATION OF STORM EVENT POLLUTANT LOADS

Pollutant loads were determined by multiplying the pollutant event mean concentration (a stream flow volume-weighted mean of analytical results from laboratory analysis) by the total storm discharge at the point of sample collection. Stream discharge volume for a specific time interval (for a specific limb or the total event) is determined by integrating under the flow rate hydrograph over the time period of interest. The pollutant event mean concentration (EMC) for a given storm is determined by:

$$\text{EMC} = \frac{\sum_{i=1}^{3} C_i V_i}{\sum_{i=1}^{3} V_i}$$

Where:

EMC = Event Mean Concentration of specific pollutant

$i$ = Numerical representation of storm limb (1=rising, 2=peak, 3=falling)

$C_i$ = Pollutant concentration at limb $i$

$V_i$ = Corresponding discharge represented by composite sample collected for limb $i$.

The average pollutant EMC for the monitoring year is an arithmetic mean of individual storm EMCs.

Pollutant load for a given storm is calculated by:

$$L = (k_1 / k_2) \times (\text{EMC} \times V_T)$$

Where:

$L$ = estimated load in pounds
$k_1$ = conversion factor 28.317 liters per cubic foot
$k_2$ = conversion factor of 453,592.4 milligrams per pound
$V_T$ = estimated total storm runoff in stream in $ft^3$

The average pollutant load for the monitoring year is an arithmetic mean of individual storm loads.

## 3.6 DETERMINATION OF AVERAGE ANNUAL AND SEASONAL EMC AND TOTAL ANNUAL AND SEASONAL LOAD

Average annual storm EMCs for each pollutant at each station were determined by obtaining the arithmetic mean of individual storm EMC data for a given year. Average annual baseflow Mean Concentrations (MCs) were developed by calculating the arithmetic mean of concentration data. Average seasonal EMCs and MCs were obtained by using the same method, except on a seasonal basis. Below-reportable detection limit results were set to zero when determining average EMCs and determining baseflow MCs.

Total annual load was determined by (a) multiplying all stormflow volume in a given year at a given station by the corresponding average annual EMC for each pollutant, (b) multiplying all baseflow volume in the same year by the corresponding average annual MC, and (c) summing the result.

## 3.7 SUSPENDED SEDIMENT TRANSPORT MONITORING

Suspended sediment transport was monitored at all three Wheel Creek storm monitoring stations, WC002, WC003, and WC004 (Figure 2-1). Sediment samples were collected in conjunction with wet weather samples from July 2022 through December 2022. Suspended sediment monitoring was discontinued after the fourth sampled storm event after discussion with Harford County DPW due to weak and non-significant correlations between suspended sediment concentrations and stream flow over the past three reporting years. Suspended sediment was monitored during four wet weather sampling events using a modified siphon sampler (Diehl 2008) outfitted with a HOBO® U20 depth logger for continuous stage recording. The modified siphon sampler was developed by USGS to sample shallow water at closely spaced vertical intervals, enabling samples to be collected passively at multiple stages of the rising limb of the hydrograph. Each sampler included six 1000-mL sample containers oriented horizontally with an intake tube and an air vent, which allowed sample collection at up to six two-inch incremental stages. Samples collected were analyzed individually for suspended sediments following a standard method for total suspended solids (SM2540D; APHA 1999), with filtration of the full 1000-mL sample.

Since the sampler devices could not be deployed in the same location as the gauge recorders without causing interference, discharge corresponding to each sample was determined using depth data obtained from the HOBO® loggers. The loggers were set to record pressure and temperature data at 5-minute intervals for the full duration of their deployment. The logger data were then post-processed using HOBOware Pro 2.7.3 software, to correct for changes in barometric pressure. The resulting data were used to determine the approximate time that each sample bottle was filled, and the corresponding discharge from the time of sample collection was obtained from the storm event flow rate graphs for each station. The relationship between discharge and suspended sediment concentration was then plotted to create a sediment-transport curve (Glysson 1987) for each station.

## 3.8 STATISTICAL TEST FOR TREND

A Kendall's Tau-b statistical test (Kendall 1948) was performed on the compiled baseflow concentration and individual storm EMC data at the monitoring stations. This test is a non-parametric test that compares the ranks of parameter concentrations to the ranked collection dates. The test was used to determine whether a significant upward or downward trend in concentration occurred over time.

## 3.9 COMPARISON OF PRE- TO POST-RESTORATION DATA

The assessment of the effectiveness of restoration projects in Wheel Creek relies upon comparisons of pre-restoration conditions to post-restoration conditions. Because the implementation of restoration projects in the watershed was staggered, the effectiveness of groups of the projects was determined strategically using the location of the applicable monitoring station and construction timelines. The time periods for the pre-restoration and post-restoration conditions were appropriately defined at each station, so that the during-construction phases were eliminated from the comparisons. Note the following:

- Pre-restoration and post-restoration conditions evaluated using data from Station WC004 were governed only by the construction of Pond C at Festival of Bel Air,
- Pre-restoration phase for data collected at Station WC002 was governed by the earliest construction of projects on the mainstem (i.e., Pond A in September 2012),
- Pre-restoration phase for data collected at Station WC003 was governed by the start of construction at Pond C in May 2015 (same as at Station WC004) but was set to the same timeframe as Station WC002 for consistency, and
- Post-restoration phase at both Station WC002 and Station WC003 was set to the conclusion of construction of Pond E at Country Walk 1B in April 2017 since the effort was upstream of both stations.

The relationship between restoration construction schedule, which monitoring station data are used in efficiency evaluations, and the type of evaluations are provided in Table 3-3.

Comparisons were conducted in two ways: a) total annual load for fiscal years 2017-2023 (post-restoration) to 2010-2011 (pre-restoration); and b) post-restoration storm EMCs and baseflow MCs to pre-restoration storm EMCs and baseflow MCs.

### 3.9.1 Comparison of Ratios Between Stations WC002 and WC003

Because only one monitoring station is located on the mainstem, the assessment of the effectiveness of restoration projects in improving water quality in the mainstem, as well as projects on the middle branch located between Station WC002 and Station WC003 (e.g., MB-4 and one water quality facility), was isolated and performed indirectly by comparing ratios of pollutant loads and concentrations between the stations during the pre-restoration and post-restoration phases. The ratio (or relationship) of pollutant levels between the two stations during the pre-restoration period was taken as a baseline; a lowering of the ratio during the post-restoration period would indicate pollutant reduction between the stations as a result of implementation of the restoration projects.

The ratio of total load between the downstream station and the upstream station was calculated for the following pollutants: total nitrogen, total phosphorus, total suspended solids (TSS), ammonia, BOD, copper, lead, and zinc.

For this method, total loads were calculated using data from the pre-restoration period (2010-2011) and post-restoration period (FY 2017-2023) and then compared to one another. The ratio between stations is calculated from the following equation:

$$\text{Ratio} = (1 - (L_3/L_2)) * 100$$

Where:

$L_3$ = Load at Station WC003 (upstream)
$L_2$ = Load at Station WC002 (downstream)

To determine restoration effectiveness in terms of storm EMC and baseflow MC, the ratio between the average EMC or MC at the downstream Station WC002 and the upstream Station WC003 was calculated for the pre-restoration time period and the post-restoration time period. The ratios of average concentrations between the downstream station and the upstream station, during both periods, were compared for each analyte. The ratio between stations is calculated from the following equation:

$$\text{Ratio} = (1 - (C_3/C_2)) * 100$$

Where:

$C_3$ = Concentration at Station WC003 (upstream)
$C_2$ = Concentration at Station WC002 (downstream)

A paired Student's t test was used to determine significance of the difference in EMC or MC between the stations.

### 3.9.2 Comparison of Pre- and Post-Restoration Conditions at all Stations

Calculations of absolute pollutant removal efficiencies were used to characterize the aggregated effectiveness of restoration projects located within each station's subwatershed. Both storm EMC and baseflow MC data accumulated during the pre-restoration and post-restoration phases at each station, defined above, were compared. The efficiencies were calculated using the same percentage equation defined in Section 1.2.1. A Student's t test was used to determine the significance of the differences between the means of each pollutant EMC or MC.

Table 3-3. Restoration construction schedule, applicable monitoring stations, and recommended efficiency evaluation methods

| Construction Projects | Reach | Start Date | Completion Date | No. Storms | | No. Baseflows | | Efficiency Evaluation |
|---|---|---|---|---|---|---|---|---|
| | | | | Pre-restoration | Post-restoration | Pre-restoration | Post-restoration | |
| Gardens of Bel Air (Pond A) | Mainstem | September 8, 2012 | December 20, 2012 | 17 (WC002)<br>18 (WC003) | 57 (WC002)<br>56 (WC003) | 33 (WC002)<br>32 (WC003) | 86 (WC002)<br>86 (WC003) | Compare differences between WC002 & WC003 during pre- and post-conditions |
| Calverts Walk (UMS-1) | Mainstem | January 14, 2013 | April 4, 2013 | | | | | |
| MMS-5, MB-4 | Mainstem, Middle Branch | December 7, 2015 | February 26, 2016 | | | | | |
| Water Quality Facilities (4) | Mainstem (3), Middle Branch (1) | December 7, 2015 | March 18, 2016 | | | | | |
| Festival of Bel Air (Pond C) | Middle Branch | May 12, 2015 | August 7, 2015 | 42 | 66 | 52 | 93 | WC004 before & after |
| Country Walk 1A (Pond D) | Middle Branch | September 21, 2015 | December 11, 2015 | 17 (WC002)<br>18 (WC003) | 50 (WC002)<br>51 (WC003) | 33 (WC002)<br>32 (WC003) | 72 (WC002)<br>72 (WC003) | WC002 before & after; WC003 before & after |
| MB-1 | Middle Branch | December 7, 2015 | February 26, 2016 | | | | | |
| Country Walk 1B (Pond E) | Middle Branch | December 2016 | April 2017 | | | | | |

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# 4.0 RESULTS AND DISCUSSION

Results of stormflow and baseflow sampling performed from July 1, 2022 through June 30, 2023 are presented and discussed in this section. The individual sample analytical data are compiled into tables while annual average concentrations and loadings are presented in tabular and graphical form.

## 4.1 STORMFLOW CONCENTRATION RESULTS

Analytical results for storm samples collected at each of the three stations are presented in Table 4-1. Total nitrogen results were greater than the EPA recommended reference value of 0.69 mg/L (U.S. EPA 2000) in 100% of the samples in FY2023. Of the samples in which total phosphorus was detected in FY2023, 76.4% of the results were greater than the EPA recommended reference value of 0.03656 mg/L. Orthophosphate was detected in 52.8% of stormflow samples collected in FY2023. Ammonia results were above the detection limit in 29.2% of stormflow samples collected at all stations in FY2023. Ammonia concentrations were highest during the August storm event. BOD was detected in 86.1% of samples collected in FY2023, with the highest concentrations during the April storm event.

Zinc was detected in 100% of storm samples collected in FY2023. No zinc concentration was greater than MDE's acute criterion for surface water in samples collected during this reporting period (Table 3-2).[1] Zinc concentrations were highest during the April storm event. Lead concentrations were above the detection limit in 70.8% of the samples in FY2023, none of which were above the MDE acute criterion. Copper concentrations were above the detection limit in 94.4% of samples in FY2023; however, only 5.6% were greater than the MDE acute criterion for surface water.

*E. coli* concentrations were equal to or greater than the maximum reportable result (2,420 MPN/100ml) in 45.8% of stormflow grab samples in FY2023. *E. coli* concentrations were generally highest at Station WC002 in FY2023, with concentrations of *E. coli* decreasing at Station WC003 and WC004, respectively. TPH was not detected in any of the 24 stormflow grab samples collected at the monitoring stations. Hardness was generally the lowest at Station WC002. Turbidity was generally highest at Station WC002, probably due to the additive effects of suspended matter transported from the stormwater collection ponds upstream of this station. TSS was above the detection limit in 93.1% of samples in FY2023, with highest concentrations measured at Station WC004. Chloride was reported in 93.1% of the storm runoff samples in FY2023, but none of the reported results exceeded the acute criterion established by USEPA. Chloride concentrations were lower in FY2023 than in FY2022 and FY2021, and much less than those seen in FY2018 and FY2019, but higher than concentrations measured in FY2020; this is probably due to the moderate winter and smaller quantities of deicing compound applied on road surfaces in FY2023 compared to other years.

[1] The zinc, lead, and copper criteria are based on the dissolved form, while the laboratory analytical results are for total metal concentration. Comparisons to surface water criteria are for discussion purposes only and do not imply violations of surface water standards.

## 4.2 BASEFLOW CONCENTRATION RESULTS

Baseflow sample analytical results are presented in Table 4-2. Under baseflow conditions, concentration values for total phosphorus were above the detection limit in 97.2% of samples in FY2023. Orthophosphate was detected in 11.1% of the baseflow samples during this reporting period. Ammonia was detected in 50.0% of samples in FY2023, including 75.0% of Station WC002 samples, 50.0% of Station WC003 samples, and 25.0% of Station WC004 samples. TSS was detected in 38.9% of baseflow samples in FY2023. Total nitrogen was above the detection limit in all the baseflow samples, and all concentration levels were greater than the EPA reference value (0.69 mg/L). Total nitrogen concentrations tended to be lowest at Station WC003 and highest at Station WC004.

Zinc was detected in all FY2023 baseflow samples and had the highest concentrations at Station WC004. Lead and copper were detected in 11.1% and 5.6%, respectively, of FY2023 baseflow samples. Concentrations of zinc and lead were lower than MDE's applicable chronic surface water criteria (120 and 2.5 µg/L, respectively) in all samples. One sample, collected at Station WC002 on November 22, 2022, exceeded the MDE applicable chronic surface water criterion for copper (9 µg/L).

BOD was detected in 33.3% of samples in FY2023. Baseflow concentrations of nitrate plus nitrite were higher at Station WC004 than at the other stations. Turbidity was generally lowest in FY2023 baseflow samples collected at Station WC004 and highest in baseflow samples taken from Station WC003. Chloride concentrations were generally elevated from January through April for all stations. Chloride was highest at Station WC004 for a given baseflow sampling event and became gradually lower when progressing downstream to Station WC002. The maximum observed chloride concentrations for all stations occurred during the January sampling event. The lowest chloride concentrations occurred during the July sampling event at Station WC002, the October sampling event at Station WC003, and the August sampling event at Station WC004.

Hardness, a characteristic of surface waters, was quantified in all FY2023 baseflow samples. Concentrations greater than 120 mg/L are considered "Hard", while concentrations exceeding 180 mg/L are considered "Very Hard". All baseflow samples collected contained "Hard" water and 41.7% of all baseflow samples collected contained "Very Hard" water, and the highest hardness values were found at Station WC004, where 91.7% of collected samples were considered "Very Hard".

*E. coli* bacteria concentrations were detected in all FY2023 baseflow samples at all stations, ranging in concentration from 2 to 1,550 MPN/100ml. The maximum concentration during the monitoring period for Stations WC002 and WC003 occurred during the June sampling event, and the maximum concentration for Station WC004 occurred during the July sampling event. In general, *E. coli* concentrations were highest during the warmer months and lowest during the colder months. TPH was only detected in one (2.8%) of the baseflow samples collected from the study area in FY2023; this sample was collected at Station WC003 during the December 9, 2022 sampling event.

Table 4-1. Stormflow water chemistry results, July 2022 – June 2023. All concentrations are in units of mg/L unless indicated.

| Storm Date | Limb | Dis-charge (cf) | 5-Day BOD | Ammo-nia | Nitrate + Nitrite | Ortho-phos-phate | TKN | Total P | TSS | Copper (µg/l) | Lead (µg/l) | Zinc (µg/l) | TPH | *E. coli* (MPN/ 100 ml) | Total Nitro-gen | Hard-ness | Chlor-ide | Turbid-ity (NTU) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Station WC002** | | | | | | | | | | | | | | | | | | |
| 8/24/2022 | Rising | 1,021,246 | 5.0 | 0.17 | 0.5 | 0.04 | 1.0 | 0.180 | 41.0 | 13 | 1.0 | 26 | N.C. | N.C. | 1.5 | 54 | 34.40 | 11.70 |
| 8/24/2022 | Peak | 154,834 | 2.0 | 0.06 | 0.4 | 0.03 | 0.7 | 0.070 | 8.0 | 7 | 0.3 | 8 | <5.0 | >2,420.0 | 1.1 | 22 | <50.00 | 9.16 |
| 8/24/2022 | Falling | 52,377 | 2.0 | 0.08 | 0.4 | 0.03 | 0.7 | 0.070 | 7.0 | 8 | <1.0 | 10 | N.C. | N.C. | 1.1 | 32 | <25.00 | 8.31 |
| 9/7/2022 | Rising | 6,279 | <1.0 | 0.08 | 1.1 | 0.01 | 0.5 | 0.020 | <2.0 | 2 | <1.0 | 7 | N.C. | N.C. | 1.6 | 180 | 136.00 | 1.40 |
| 9/7/2022 | Peak | 752,201 | 3.0 | <0.30 | 0.4 | 0.04 | 0.8 | 0.110 | 23.0 | 6 | 0.7.0 | 15 | <5.0 | >2,420.0 | 1.2 | 36 | 12.80 | 9.40 |
| 9/7/2022 | Falling | 33,685 | 2.0 | 0.11 | 0.4 | 0.04 | 0.8 | 0.100 | 14.0 | 4 | 0.4.0 | 16 | N.C. | N.C. | 1.2 | 52 | 23.50 | 23.60 |
| 10/14/2022 | Rising | 7,459 | <2.0 | 0.07 | 1.3 | 0.03 | 0.5 | 0.006 | <4.0 | <2 | <1.0 | 7 | <5.0 | 1,550.0 | 1.8 | 156 | 137.00 | 0.96 |
| 10/14/2022 | Peak | 63,567 | 4.0 | <0.30 | 0.3 | 0.03 | 0.8 | 0.100 | 22.5 | 7 | 0.7 | 17 | N.C. | N.C. | 1.1 | 36 | 19.00 | 12.50 |
| 10/14/2022 | Falling | 6,137 | 2.5 | <0.30 | 0.4 | 0.04 | 0.7 | 0.060 | 5.0 | 4 | 0.3 | 10 | N.C. | N.C. | 1.1 | 52 | 30.80 | 16.30 |
| 12/1/2022 | Rising | 4,415 | <1.0 | <0.30 | 1.4 | <0.05 | 0.4 | 0.009 | 2.0 | <2 | <1.0 | 11 | <5.0 | 138.0 | 1.8 | 152 | 118.00 | 1.52 |
| 12/1/2022 | Peak | 20,232 | 3.0 | <0.30 | 0.6 | 0.01 | 0.6 | 0.050 | 6.0 | 4 | <1.0 | 12 | N.C. | N.C. | 1.2 | 84 | 60.90 | 5.93 |
| 12/1/2022 | Falling | 7,884 | 1.0 | <0.30 | 0.6 | 0.02 | 0.5 | 0.040 | 2.0 | 4 | <1.0 | 11 | N.C. | N.C. | 1.1 | 94 | 49.30 | 5.39 |
| 1/13/2023 | Rising | 3,285 | 1.0 | <0.30 | 1.6 | <0.05 | 0.5 | 0.020 | 4.0 | 3 | <1.0 | 13 | N.C. | N.C. | 2.1 | 160 | 135.00 | 2.10 |
| 1/13/2023 | Peak | 5,967 | 2.0 | <0.30 | 1.2 | 0.01 | 0.5 | 0.040 | 7.0 | 4 | <1.0 | 15 | N.C. | N.C. | 1.7 | 138 | 135.00 | 8.69 |
| 1/13/2023 | Falling | 5,223 | 1.0 | <0.30 | 0.9 | <0.05 | 0.5 | 0.020 | 3.0 | 4 | <1.0 | 13 | <5.0 | 411.0 | 1.4 | 114 | 195.00 | 3.18 |
| 1/24/2023 | Rising | 14,745 | 2.0 | 0.08 | 0.9 | 0.02 | 0.7 | 0.040 | <2.0 | 6 | <1.0 | 14 | N.C. | N.C. | 1.6 | 104 | 121.00 | 4.15 |
| 1/24/2023 | Peak | 32,489 | 2.0 | <0.30 | 0.5 | <0.05 | 0.6 | 0.030 | 4.0 | 9 | 0.3 | 15 | <5.0 | 866.0 | 1.1 | 52 | 82.60 | 8.03 |
| 1/24/2023 | Falling | 20,808 | 2.0 | <0.30 | 0.5 | 0.02 | 0.6 | 0.030 | 4.0 | 3 | 0.5 | 19 | N.C. | N.C. | 1.1 | 51 | 69.20 | 10.70 |
| 4/24/2023 | Rising | 18,600 | 2.0 | <0.30 | 1.1 | <0.05 | 0.9 | 0.050 | 14.0 | <2 | <1.0 | 15 | <5.0 | >2,420.0 | 2.0 | 166 | 135.00 | 2.21 |
| 4/24/2023 | Peak | 33,927 | 7.0 | <0.30 | 0.4 | 0.01 | 1.7 | 0.170 | 35.0 | 21 | 1.0 | 43 | N.C. | N.C. | 2.1 | 68 | 43.50 | 11.10 |
| 4/24/2023 | Falling | 6,610 | 3.0 | <0.30 | 0.4 | <0.05 | 0.9 | 0.060 | 4.0 | 16 | 0.3 | 19 | N.C. | N.C. | 1.3 | 76 | 59.80 | 4.71 |
| 6/26/2023 | Rising | 27,941 | 3.0 | 0.10 | 0.8 | <0.05 | 0.8 | 0.050 | 7.0 | 7 | <1.0 | 12 | N.C. | N.C. | 1.6 | 138 | 99.90 | 1.70 |
| 6/26/2023 | Peak | 274,132 | 2.0 | 0.10 | 0.3 | 0.01 | 0.8 | 0.070 | 20.0 | 8 | 0.7 | 20 | <5.0 | 23,800.0 | 1.1 | 44 | 19.70 | 2.84 |
| 6/26/2023 | Falling | 23,599 | 1.0 | <0.30 | 0.6 | <0.05 | 0.7 | 0.040 | 3.0 | 7 | <1.0 | 10 | N.C. | N.C. | 1.3 | 80 | 48.40 | 2.04 |

N.C. = Sample Not Collected

Table 4-1. (Continued)

| Storm Date | Limb | Dis-charge (cf) | 5-Day BOD | Ammo-nia | Nitrate + Nitrite | Ortho-phos-phate | TKN | Total P | TSS | Copper (µg/l) | Lead (µg/l) | Zinc (µg/l) | TPH | *E. coli* (MPN/ 100 ml) | Total Nitro-gen | Hard-ness | Chlor-ide | Turbid-ity (NTU) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Station WC003** | | | | | | | | | | | | | | | | | | |
| 8/24/2022 | Rising | 203,504 | 3.0 | <0.30 | 0.4 | <0.05 | 0.8 | 0.080 | 17.0 | 11 | 0.9 | 22 | N.C. | N.C. | 1.2 | 70 | 36.90 | 5.03 |
| 8/24/2022 | Peak | 65,296 | 2.0 | <0.30 | 0.3 | 0.02 | 0.6 | 0.050 | 13.0 | 6 | 0.4 | 10 | <5.0 | >2,420.0 | 0.9 | 36 | 15.70 | 3.67 |
| 8/24/2022 | Falling | 36,618 | 1.0 | <0.30 | 0.4 | 0.02 | 0.7 | 0.060 | 3.0 | 7 | <1.0 | 10 | N.C. | N.C. | 1.1 | 28 | 16.20 | 3.55 |
| 9/7/2022 | Rising | 4,007 | 1.0 | <0.30 | 0.7 | 0.02 | 0.5 | 0.030 | 9.0 | 3 | <1.0 | 10 | N.C. | N.C. | 1.2 | 196 | 162.00 | 6.67 |
| 9/7/2022 | Peak | 283,658 | 2.0 | <0.30 | 0.3 | 0.03 | 0.8 | 0.130 | 20.0 | 6 | 0.6 | 14 | <5.0 | >2,420.0 | 1.1 | 48 | 19.00 | 9.79 |
| 9/7/2022 | Falling | 28,203 | <1.0 | <0.30 | 0.2 | 0.02 | 0.6 | 0.060 | 6.0 | 6 | 0.3 | 10 | N.C. | N.C. | 0.8 | 64 | 24.70 | 5.33 |
| 10/14/2022 | Rising | 1,542 | 6.4 | <0.30 | 0.9 | 0.04 | 0.6 | 0.050 | 41.5 | 2 | 0.6 | 25 | <5.0 | 276.0 | 1.5 | 184 | 168.00 | 4.83 |
| 10/14/2022 | Peak | 74,904 | 2.9 | <0.30 | 0.3 | <0.02 | 0.9 | 0.090 | 21.5 | 7 | 0.8 | 19 | N.C. | N.C. | 1.2 | 48 | 33.60 | 14.80 |
| 10/14/2022 | Falling | 5,576 | 2.1 | <0.30 | 0.4 | <0.02 | 0.7 | 0.040 | 4.8 | 4 | 0.3 | 10 | N.C. | N.C. | 1.1 | 68 | 49.00 | 7.38 |
| 12/1/2022 | Rising | 2,928 | <1.0 | <0.30 | 0.7 | <0.05 | 0.8 | 0.080 | 6.0 | 3 | 1.0 | 30 | <5.0 | 48.8 | 1.5 | 158 | 126.00 | 4.13 |
| 12/1/2022 | Peak | 19,020 | 2.0 | <0.30 | 0.6 | <0.05 | 0.6 | 0.040 | 8.0 | 3 | <1.0 | 15 | N.C. | N.C. | 1.2 | 118 | 107.00 | 6.78 |
| 12/1/2022 | Falling | 4,236 | <1.0 | <0.30 | 0.4 | <0.05 | 0.5 | 0.030 | <2.0 | 5 | 0.5 | 13 | N.C. | N.C. | 0.9 | 88 | 70.70 | 4.40 |
| 1/13/2023 | Rising | 3,145 | 1.0 | <0.30 | 0.9 | <0.05 | 0.6 | 0.030 | 9.0 | 6 | 0.5 | 20 | N.C. | N.C. | 1.5 | 188 | 208.00 | 8.33 |
| 1/13/2023 | Peak | 4,312 | 1.0 | <0.30 | 0.7 | <0.05 | 0.5 | 0.030 | 11.0 | 5 | 0.3 | 17 | N.C. | N.C. | 1.2 | 153 | 363.00 | 4.49 |
| 1/13/2023 | Falling | 2,522 | <1.0 | 0.12 | 0.6 | <0.05 | 0.5 | 0.020 | 3.0 | 7 | <1.0 | 19 | <5.0 | 81.0 | 1.1 | 139 | 370.00 | 3.02 |
| 1/24/2023 | Rising | 13,868 | 2.0 | <0.30 | 0.6 | 0.01 | 0.5 | 0.040 | 6.0 | 9 | 0.3 | 18 | N.C. | N.C. | 1.1 | 62 | 153.00 | 5.50 |
| 1/24/2023 | Peak | 28,001 | 1.0 | 0.07 | 0.4 | <0.05 | 0.6 | 0.020 | 4.0 | 7 | 0.3 | 22 | <5.0 | 411.0 | 1.0 | 101 | 199.00 | 6.30 |
| 1/24/2023 | Falling | 16,401 | 2.0 | <0.30 | 0.4 | <0.05 | 0.6 | 0.030 | 3.0 | 3 | 0.3 | 13 | N.C. | N.C. | 1.0 | 64 | 132.00 | 6.71 |
| 4/24/2023 | Rising | 14,436 | 3.0 | <0.30 | 0.3 | 0.02 | 1.2 | 0.100 | 4.0 | 3 | 0.6 | 23 | <5.0 | >2,420.0 | 1.5 | 146 | 109.00 | 10.20 |
| 4/24/2023 | Peak | 21,845 | 4.0 | 0.06 | 0.3 | <0.05 | 1.4 | 0.150 | 35.0 | 16 | 1.0 | 32 | N.C. | N.C. | 1.7 | 84 | 62.00 | 10.60 |
| 4/24/2023 | Falling | 4,283 | 4.0 | <0.30 | 0.3 | 0.02 | 0.8 | 0.050 | 5.0 | 12 | 0.3 | 13 | N.C. | N.C. | 1.1 | 100 | 65.70 | 5.81 |
| 6/26/2023 | Rising | 8,514 | 3.0 | <0.30 | 0.5 | <0.05 | 0.9 | 0.050 | 22.0 | 10 | 0.9 | 36 | N.C. | N.C. | 1.4 | 156 | 117.00 | 2.44 |
| 6/26/2023 | Peak | 93,554 | 2.0 | <0.30 | 0.2 | <0.05 | 0.8 | 0.080 | 35.0 | 11 | 1.0 | 28 | <5.0 | 15,000.0 | 1.0 | 54 | 32.70 | 4.78 |
| 6/26/2023 | Falling | 7,785 | 1.0 | <0.30 | 0.3 | <0.05 | 0.6 | 0.030 | 5.0 | 8 | <1.0 | 9 | N.C. | N.C. | 0.9 | 82 | 59.50 | 1.92 |

N.C. = Sample Not Collected

Table 4-1. (Continued)

| Storm Date | Limb | Dis-charge (cf) | 5-Day BOD | Ammo-nia | Nitrate + Nitrite | Ortho-phos-phate | TKN | Total P | TSS | Copper (µg/l) | Lead (µg/l) | Zinc (µg/l) | TPH | *E. coli* (MPN/ 100 ml) | Total Nitro-gen | Hard-ness | Chlor-ide | Turbid-ity (NTU) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Station WC004** | | | | | | | | | | | | | | | | | | |
| 8/24/2022 | Rising | 137,600 | 3.0 | 0.25 | 0.4 | 0.03 | 1.1 | 0.100 | 10.0 | 6 | 0.7 | 20 | N.C. | N.C. | 1.5 | 64 | 50.80 | 4.24 |
| 8/24/2022 | Peak | 94,686 | 2.0 | <0.30 | 0.3 | 0.02 | 0.8 | 0.050 | 5.0 | 3 | 0.3 | 15 | <5.0 | 1,730.0 | 1.1 | 30 | <25.00 | 3.15 |
| 8/24/2022 | Falling | 29,853 | 2.0 | 0.07 | 0.2 | 0.02 | 0.7 | 0.040 | 3.0 | 4 | <1.0 | 14 | N.C. | N.C. | 0.9 | 36 | 27.00 | 2.65 |
| 9/7/2022 | Rising | 4,260 | 3.0 | 0.07 | 0.7 | 0.02 | 1.2 | 0.100 | 14.0 | 11 | 1.0 | 59 | N.C. | N.C. | 1.9 | 176 | 104.00 | 3.21 |
| 9/7/2022 | Peak | 104,556 | 2.0 | <0.30 | 0.2 | 0.02 | 0.7 | 0.060 | 11.0 | 7 | 0.7 | 21 | <5.0 | >2,420.0 | 0.9 | 32 | <25.00 | 4.64 |
| 9/7/2022 | Falling | 16,848 | 2.0 | <0.30 | 0.2 | 0.02 | 0.6 | 0.060 | 7.0 | 4 | 0.3 | 23 | N.C. | N.C. | 0.8 | 56 | 33.00 | 3.28 |
| 10/14/2022 | Rising | 546 | <2.0 | <0.30 | 2.9 | <0.02 | 0.5 | 0.020 | <4.0 | <2 | <1.0 | 20 | <5.0 | 435.0 | 3.4 | 326 | 346.00 | 0.37 |
| 10/14/2022 | Peak | 26,485 | 2.1 | <0.30 | 0.2 | 0.04 | 0.9 | 0.070 | 13.6 | 6 | 0.8 | 25 | N.C. | N.C. | 1.1 | 30 | 14.90 | 10.90 |
| 10/14/2022 | Falling | 1,311 | <2.0 | <0.30 | 0.6 | <0.02 | 0.7 | 0.040 | 4.0 | 4 | 0.3 | 19 | N.C. | N.C. | 1.3 | 70 | 64.50 | 9.82 |
| 12/1/2022 | Rising | 2,284 | 2.0 | <0.30 | 1.1 | 0.01 | 0.8 | 0.070 | 9.0 | 6 | 1.0 | 40 | <5.0 | 50.4 | 1.9 | 140 | 124.00 | 4.09 |
| 12/1/2022 | Peak | 7,899 | 2.0 | 0.07 | 0.3 | 0.02 | 0.8 | 0.070 | 16.0 | 6 | 0.9 | 25 | N.C. | N.C. | 1.1 | 44 | 21.00 | 5.96 |
| 12/1/2022 | Falling | 2,034 | <1.0 | <0.30 | 0.5 | 0.02 | 0.6 | 0.040 | 3.0 | 5 | 0.4 | 18 | N.C. | N.C. | 1.1 | 64 | 53.20 | 5.37 |
| 1/13/2023 | Rising | 589 | 2.0 | 0.10 | 1.6 | <0.05 | 0.7 | 0.040 | 10.0 | 7 | 0.5 | 65 | N.C. | N.C. | 2.3 | 230 | 671.00 | 4.79 |
| 1/13/2023 | Peak | 1,831 | 4.0 | 0.13 | 0.5 | <0.05 | 0.8 | 0.040 | 7.0 | 6 | 0.4 | 36 | N.C. | N.C. | 1.3 | 102 | 596.00 | 6.13 |
| 1/13/2023 | Falling | 1,100 | 1.0 | <0.30 | 0.5 | <0.05 | 0.6 | 0.040 | 4.0 | 6 | <1.0 | 29 | <5.0 | 129.0 | 1.1 | 96 | 544.00 | 3.62 |
| 1/24/2023 | Rising | 2,863 | 2.0 | 0.10 | 0.6 | <0.05 | 0.8 | 0.050 | 7.0 | 13 | 0.7 | 33 | N.C. | N.C. | 1.4 | 84 | 320.00 | 6.39 |
| 1/24/2023 | Peak | 5,641 | 2.0 | 0.09 | 0.2 | <0.05 | 0.7 | 0.030 | 5.0 | 11 | 0.6 | 23 | <5.0 | 345.0 | 0.9 | 39 | 210.00 | 5.72 |
| 1/24/2023 | Falling | 2,214 | 2.0 | 0.10 | 0.4 | <0.05 | 0.7 | 0.040 | 3.0 | 3 | 0.3 | 18 | N.C. | N.C. | 1.1 | 46 | 162.00 | 6.38 |
| 4/24/2023 | Rising | 3,816 | 7.0 | <0.30 | 2.3 | 0.01 | 2.1 | 0.180 | 72.0 | 7 | 2.0 | 66 | <5.0 | >2,420.0 | 4.4 | 340 | 293.00 | 5.07 |
| 4/24/2023 | Peak | 4,070 | 6.0 | <0.30 | 0.3 | 0.02 | 1.8 | 0.160 | 40.0 | 17 | 1.0 | 39 | N.C. | N.C. | 2.1 | 43 | 5.45 | 6.92 |
| 4/24/2023 | Falling | 837 | 3.0 | <0.30 | 0.2 | <0.05 | 1.0 | 0.050 | 4.0 | 12 | 0.4 | 20 | N.C. | N.C. | 1.2 | 55 | 70.80 | 6.47 |
| 6/26/2023 | Rising | 4,497 | 4.0 | <0.30 | 0.4 | <0.05 | 1.3 | 0.140 | 51.0 | 12 | 2.0 | 42 | N.C. | N.C. | 1.7 | 90 | 56.40 | 1.70 |
| 6/26/2023 | Peak | 13,830 | 2.0 | <0.30 | 0.2 | <0.05 | 1.1 | 0.090 | 41.0 | 10 | 2.0 | 32 | <5.0 | 9,090.0 | 1.3 | 30 | <25.00 | 2.33 |
| 6/26/2023 | Falling | 5,677 | 1.0 | <0.30 | 0.6 | 0.01 | 1.0 | 0.050 | 17.0 | 8 | 1.0 | 24 | N.C. | N.C. | 1.6 | 94 | 217.00 | 1.48 |

N.C. = Sample Not Collected

Table 4-2. Baseflow water chemistry results, July 2022 – June 2023. All concentrations are in units of mg/L unless indicated.

| Baseflow Date | 5-Day BOD | Ammo-nia | Nitrate + Nitrite | Ortho-phos-phate | TKN | Total P | TSS | Copper (µg/l) | Lead (µg/l) | Zinc (µg/l) | TPH | *E. coli* (MPN/ 100 ml) | Total Nitro-gen | Hard-ness | Chlor-ide | Turbid-ity (NTU) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Station WC002** | | | | | | | | | | | | | | | | |
| 7/21/2022 | <1.0 | 0.13 | 1.0 | <0.05 | 0.7 | 0.020 | <3.0 | <2 | <1.0 | 8 | <5.0 | 387.0 | 1.7 | 146 | 105.00 | 1.46 |
| 8/3/2022 | 1.0 | 0.13 | 1.0 | 0.02 | 2.3 | 0.080 | 4.0 | <2 | <1.0 | 9 | <5.0 | 219.0 | 3.3 | 144 | 110.00 | 1.34 |
| 9/29/2022 | <1.0 | 0.07 | 1.3 | 0.01 | 0.5 | 0.009 | <2.0 | <2 | 0.3 | 14 | <5.0 | 190.0 | 1.8 | 188 | 137.00 | 1.01 |
| 10/27/2022 | <1.0 | 0.17 | 1.1 | <0.05 | 0.3 | 0.010 | <2.0 | <2 | <1.0 | 7 | <5.0 | 613.0 | 1.4 | 132 | 104.00 | 1.17 |
| 11/22/2022 | <1.0 | <0.30 | 1.5 | <0.05 | 0.4 | 0.008 | <2.0 | 10 | <1.0 | 11 | <5.0 | 54.8 | 1.9 | 166 | 126.00 | 0.74 |
| 12/9/2022 | <1.0 | 0.14 | 1.3 | <0.05 | 0.4 | 0.007 | 3.0 | <2 | <1.0 | 5 | <5.0 | 52.9 | 1.7 | 146 | 116.00 | 1.96 |
| 1/11/2023 | 1.0 | 0.10 | 1.6 | <0.05 | 0.4 | 0.009 | <2.0 | <2 | <1.0 | 11 | <5.0 | 16.0 | 2.0 | 168 | 153.00 | 0.82 |
| 2/15/2023 | 1.0 | <0.30 | 1.5 | <0.05 | 0.5 | 0.010 | <2.0 | <2 | <1.0 | 12 | <5.0 | 56.0 | 2.0 | 160 | 135.00 | 0.97 |
| 3/6/2023 | <1.0 | 0.17 | 1.4 | <0.05 | 0.6 | 0.020 | <2.0 | <2 | <1.0 | 9 | <5.0 | 39.0 | 2.0 | 139 | 112.00 | 2.10 |
| 4/26/2023 | 1.0 | 0.18 | 1.2 | <0.05 | 0.5 | 0.010 | <2.0 | <2 | <1.0 | 9 | <4.9 | 56.0 | 1.7 | 170 | 126.00 | 1.25 |
| 5/23/2023 | 2.0 | 0.39 | 1.2 | <0.05 | 0.4 | 0.010 | 5.0 | <2 | <1.0 | 7 | <5.0 | 270.0 | 1.6 | 172 | 132.00 | 1.74 |
| 6/20/2023 | 1.0 | <0.30 | 1.0 | <0.05 | 0.4 | 0.010 | 6.0 | <2 | <1.0 | 7 | <5.0 | 770.0 | 1.4 | 176 | 119.00 | 1.00 |
| **Station WC003** | | | | | | | | | | | | | | | | |
| 7/21/2022 | <1.0 | <0.30 | 0.5 | <0.05 | 0.7 | 0.020 | <3.0 | <2 | <1.0 | 5 | <5.0 | 435.0 | 1.2 | 144 | 115.00 | 2.21 |
| 8/3/2022 | <1.0 | 0.08 | 0.5 | <0.05 | 1.1 | 0.020 | 5.0 | <2 | <1.0 | 6 | <5.0 | 199.0 | 1.6 | 156 | 128.00 | 2.35 |
| 9/29/2022 | <1.0 | <0.30 | 0.9 | <0.05 | 0.5 | 0.020 | 3.0 | <2 | <1.0 | 9 | <5.0 | 178.0 | 1.4 | 212 | 170.00 | 3.49 |
| 10/27/2022 | 1.0 | 0.07 | 0.7 | <0.05 | 0.5 | 0.010 | <2.0 | <2 | <1.0 | 9 | <5.0 | 135.0 | 1.2 | 140 | 112.00 | 1.40 |
| 11/22/2022 | <1.0 | 0.13 | 0.9 | <0.05 | 0.5 | 0.010 | <2.0 | <2 | <1.0 | 14 | <5.0 | 27.2 | 1.4 | 174 | 142.00 | 1.32 |
| 12/9/2022 | <1.0 | <0.30 | 0.8 | <0.05 | 0.4 | 0.009 | <2.0 | <2 | <1.0 | 5 | 19.9 | 8.6 | 1.2 | 150 | 132.00 | 2.96 |
| 1/11/2023 | 1.0 | <0.30 | 1.0 | <0.05 | 0.5 | 0.020 | <2.0 | <2 | <1.0 | 9 | <5.0 | 12.0 | 1.5 | 177 | 201.00 | 1.43 |
| 2/15/2023 | 2.0 | <0.30 | 1.0 | <0.05 | 0.4 | 0.010 | 14.0 | <2 | <1.0 | 9 | <5.0 | 28.0 | 1.4 | 172 | 170.00 | 1.92 |
| 3/6/2023 | <1.0 | 0.07 | 0.8 | <0.05 | 0.5 | 0.020 | 3.0 | <2 | <1.0 | 9 | <5.0 | 30.0 | 1.3 | 134 | 126.00 | 2.43 |
| 4/26/2023 | 1.0 | 0.07 | 0.7 | <0.05 | 0.4 | 0.008 | <2.0 | <2 | <1.0 | 10 | <4.8 | 52.0 | 1.1 | 178 | 171.00 | 2.97 |
| 5/23/2023 | 1.0 | 0.11 | 0.8 | <0.05 | 0.4 | 0.020 | 10.0 | <2 | 0.3 | 18 | <5.0 | 248.0 | 1.2 | 200 | 162.00 | 5.65 |
| 6/20/2023 | <1.0 | <0.30 | 0.7 | <0.05 | 0.4 | 0.020 | <2.0 | <2 | <1.0 | 7 | <5.0 | 1,550.0 | 1.1 | 186 | 142.00 | 2.15 |

Table 4-2.  (Continued)

| Baseflow Date | 5-Day BOD | Ammo-nia | Nitrate + Nitrite | Ortho-phos-phate | TKN | Total P | TSS | Copper (µg/l) | Lead (µg/l) | Zinc (µg/l) | TPH | *E. coli* (MPN/ 100 ml) | Total Nitro-gen | Hard-ness | Chlor-ide | Turbid-ity (NTU) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Station WC004** | | | | | | | | | | | | | | | | |
| 7/21/2022 | <1.0 | <0.30 | 2.4 | <0.05 | 0.7 | 0.008 | 4.0 | <2 | <1.0 | 23 | <5.0 | 980.0 | 3.1 | 338 | 320.00 | 0.40 |
| 8/3/2022 | <1.0 | <0.30 | 1.4 | <0.05 | 1.2 | 0.030 | 5.0 | 3 | 0.6 | 40 | <5.0 | 579.0 | 2.6 | 148 | 207.00 | 0.83 |
| 9/29/2022 | <1.0 | <0.30 | 3.0 | 0.02 | 0.6 | 0.020 | 4.0 | <2 | 0.3 | 24 | <5.0 | 108.0 | 3.6 | 392 | 383.00 | 1.65 |
| 10/27/2022 | <1.0 | <0.30 | 1.9 | <0.05 | 0.5 | 0.008 | <2.0 | <2 | <1.0 | 18 | <5.0 | 285.0 | 2.4 | 232 | 232.00 | 0.85 |
| 11/22/2022 | <1.0 | <0.30 | 3.0 | <0.05 | 0.4 | 0.006 | <2.0 | <2 | <1.0 | 20 | <5.0 | 10.6 | 3.4 | 340 | 327.00 | 0.22 |
| 12/9/2022 | <1.0 | <0.30 | 2.6 | <0.05 | 0.4 | 0.020 | 7.0 | <2 | <1.0 | 14 | <5.0 | 25.6 | 3.0 | 260 | 260.00 | 4.78 |
| 1/11/2023 | <1.0 | <0.30 | 2.7 | <0.05 | 0.3 | 0.008 | <2.0 | <2 | <1.0 | 19 | <5.0 | 2.0 | 3.0 | 302 | 411.00 | 0.78 |
| 2/15/2023 | 1.0 | <0.30 | 2.6 | 0.01 | 0.5 | 0.030 | 12.0 | <2 | <1.0 | 19 | <5.0 | 15.0 | 3.1 | 284 | 320.00 | 1.51 |
| 3/6/2023 | <1.0 | 0.06 | 2.5 | <0.05 | 0.6 | 0.020 | <2.0 | <2 | <1.0 | 21 | <5.0 | 167.0 | 3.1 | 258 | 277.00 | 0.81 |
| 4/26/2023 | <1.0 | 0.07 | 2.9 | <0.05 | 0.2 | 0.006 | <2.0 | <2 | <1.0 | 25 | <4.8 | 345.0 | 3.1 | 354 | 335.00 | 0.83 |
| 5/23/2023 | <1.0 | 0.07 | 2.9 | <0.05 | 0.4 | <0.050 | <2.0 | <2 | <1.0 | 23 | <5.0 | 89.0 | 3.3 | 356 | 363.00 | 1.43 |
| 6/20/2023 | <1.0 | <0.30 | 2.6 | <0.05 | 0.5 | 0.010 | <2.0 | <2 | <1.0 | 27 | <5.0 | 192.0 | 3.1 | 410 | 363.00 | 0.46 |

## 4.3 BASEFLOW MEAN AND STORM EVENT MEAN CONCENTRATION DATA

EMC values for each parameter were calculated at each station for each storm event (Table 4-3). Average annual baseflow concentration and storm EMC values were calculated for each pollutant at each station (Table 4-4). Average concentration data computed for storm and baseflows during this reporting period were used to characterize pollutant concentrations during average baseflow conditions or an average stormflow event (Figures 4-1 through 4-6). Total annual and seasonal baseflow mean concentrations, storm EMCs, and loads for each pollutant are presented in Appendix D and Appendix E, respectively.

Under baseflow conditions, average concentrations of combined nitrate plus nitrite, orthophosphate, chloride, lead, and zinc were highest at Station WC004 compared to the other two stations downstream (Figures 4-1 through 4-6). Samples collected at Station WC003 had the highest average concentrations of TSS, TPH, and *E. coli* during baseflow conditions, while Station WC002 samples had the highest average concentrations of BOD, ammonia, orthophosphate, TKN, total phosphorus, and copper during baseflow conditions. Concentrations of ammonia were disproportionally highest at Station WC002 at 300.0% higher than the next highest mean concentration. The higher concentration of ammonia at Station WC002 may indicate a continued nutrient or sewer input in the vicinity of the station, such as leakage from a sanitary sewer line. Higher average chloride values at Station WC004 may be the result of mobilization of chloride in groundwater as a result of runoff from legacy deicing compound application at the Festival of Bel Air Shopping Center and along Route 24.

Under stormflow conditions, average EMCs were highest at Station WC004 for ammonia, TKN, TSS, chloride, copper, lead, and zinc (Figures 4-1 through 4-6). Average EMCs for BOD, combined nitrate plus nitrite, orthophosphate, total phosphorus, and *E. coli* were highest at Station WC002. TPH was non-detect in all stormflow samples. All average stormflow EMCs exceeded corresponding baseflow mean concentrations at all stations except combined nitrate plus nitrite and chloride (all three stations), ammonia (Stations WC002 and WC003), and TPH (Station WC003). Average EMCs of all pollutants at all stations were lower than Maryland and national average values (Table 4-4).

Time-series plots of the annual average pollutant concentrations measured from 2010 to FY2023 are shown in Figure 4-7 through Figure 4-15, illustrating the change, on an annual basis, in pollutant concentrations as restoration projects were implemented in the watershed. Plots of average annual storm EMCs and baseflow MCs (with individual non-detect concentrations set to zero) are presented for nitrate-nitrite, TKN, total phosphorus, TSS, copper, zinc, lead, ammonia, and BOD. Note that data from the shortened reporting period comprising the first six months of calendar year 2015 were not included in the plots.

Table 4-3. Storm event mean concentration results (mg/L except where indicated), July 2022 – June 2023 (non-detects set to zero).

| Storm Date | Rainfall (inches) | 5-Day BOD | Ammonia | Nitrate + Nitrite | Orthophos-phate | TKN | Total P | TSS | Chloride | Copper (µg/l) | Lead (µg/l) | Zinc (µg/l) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Station WC002** | | | | | | | | | | | | |
| 8/24/2022 | 4.75 | 4.49 | 0.15 | 0.48 | 0.04 | 0.95 | 0.16 | 35.39 | 28.60 | 12.03 | 0.87 | 23.05 |
| 9/7/2022 | 1.97 | 2.93 | 0.01 | 0.41 | 0.04 | 0.80 | 0.11 | 22.43 | 14.23 | 5.88 | 0.68 | 14.98 |
| 10/14/2022 | 0.91 | 3.49 | 0.01 | 0.40 | 0.03 | 0.76 | 0.09 | 18.93 | 31.35 | 6.08 | 0.60 | 15.48 |
| 12/1/2022 | 0.31 | 2.11 | 0.00 | 0.71 | 0.01 | 0.55 | 0.04 | 4.49 | 65.84 | 3.46 | 0.00 | 11.62 |
| 1/13/2023 | 0.21 | 1.41 | 0.00 | 1.18 | 0.00 | 0.50 | 0.03 | 4.88 | 156.65 | 3.77 | 0.00 | 13.82 |
| 1/24/2023 | 0.50 | 2.00 | 0.02 | 0.59 | 0.01 | 0.62 | 0.03 | 3.13 | 86.82 | 6.52 | 0.30 | 16.01 |
| 4/24/2023 | 0.58 | 4.98 | 0.00 | 0.62 | 0.01 | 1.36 | 0.12 | 24.93 | 74.10 | 13.84 | 0.61 | 31.51 |
| 6/26/2023 | 1.58 | 2.01 | 0.09 | 0.36 | 0.01 | 0.79 | 0.07 | 17.65 | 28.66 | 7.84 | 0.59 | 18.59 |
| **Station WC003** | | | | | | | | | | | | |
| 8/24/2022 | 4.75 | 2.55 | 0.00 | 0.38 | 0.01 | 0.75 | 0.07 | 14.47 | 29.89 | 9.45 | 0.69 | 18.00 |
| 9/7/2022 | 1.97 | 1.81 | 0.00 | 0.30 | 0.03 | 0.78 | 0.12 | 18.61 | 21.32 | 5.96 | 0.57 | 13.59 |
| 10/14/2022 | 0.91 | 2.91 | 0.00 | 0.32 | 0.00 | 0.88 | 0.09 | 20.74 | 37.17 | 6.70 | 0.76 | 18.50 |
| 12/1/2022 | 0.31 | 1.45 | 0.00 | 0.58 | 0.00 | 0.61 | 0.04 | 6.48 | 103.25 | 3.32 | 0.19 | 16.35 |
| 1/13/2023 | 0.21 | 0.75 | 0.03 | 0.74 | 0.00 | 0.53 | 0.03 | 8.35 | 315.92 | 5.82 | 0.29 | 18.45 |
| 1/24/2023 | 0.50 | 1.52 | 0.03 | 0.45 | 0.00 | 0.58 | 0.03 | 4.19 | 169.19 | 6.35 | 0.30 | 18.51 |
| 4/24/2023 | 0.58 | 3.64 | 0.03 | 0.30 | 0.01 | 1.27 | 0.12 | 20.80 | 79.12 | 10.95 | 0.78 | 26.79 |
| 6/26/2023 | 1.58 | 2.01 | 0.00 | 0.23 | 0.00 | 0.79 | 0.07 | 31.87 | 41.13 | 10.71 | 0.92 | 27.27 |
| **Station WC004** | | | | | | | | | | | | |
| 8/24/2022 | 4.75 | 2.52 | 0.14 | 0.34 | 0.03 | 0.95 | 0.08 | 7.40 | 29.74 | 4.69 | 0.48 | 17.51 |
| 9/7/2022 | 1.97 | 2.03 | 0.00 | 0.22 | 0.02 | 0.70 | 0.06 | 10.57 | 7.95 | 6.73 | 0.66 | 22.56 |
| 10/14/2022 | 0.91 | 1.96 | 0.00 | 0.27 | 0.04 | 0.88 | 0.07 | 12.89 | 23.57 | 5.79 | 0.76 | 24.63 |
| 12/1/2022 | 0.31 | 1.67 | 0.05 | 0.48 | 0.02 | 0.77 | 0.07 | 12.53 | 45.62 | 5.83 | 0.84 | 26.64 |
| 1/13/2023 | 0.21 | 2.73 | 0.08 | 0.68 | 0.00 | 0.72 | 0.04 | 6.56 | 592.30 | 6.17 | 0.29 | 38.67 |
| 1/24/2023 | 0.50 | 2.00 | 0.09 | 0.35 | 0.00 | 0.73 | 0.04 | 5.12 | 229.47 | 9.88 | 0.56 | 24.64 |
| 4/24/2023 | 0.58 | 6.15 | 0.00 | 1.17 | 0.01 | 1.85 | 0.16 | 50.54 | 137.51 | 12.15 | 1.38 | 48.99 |
| 6/26/2023 | 1.58 | 2.14 | 0.00 | 0.33 | 0.00 | 1.11 | 0.09 | 37.20 | 61.89 | 9.90 | 1.76 | 31.98 |

Table 4-4. Average storm EMCs and baseflow mean concentrations, Wheel Creek Watershed, July 2022 – June 2023 (non-detects set to zero). All concentrations are in units of mg/L unless indicated.

| Station | 5-Day BOD | Ammonia | Nitrate + Nitrite | Ortho-phos-phate | TKN | Total P | TSS | Chlor-ide | Copper (µg/l) | Lead (µg/l) | Zinc (µg/l) | TPH | *E. coli* (MPN/ 100 ml) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Storm Event Mean Concentrations** | | | | | | | | | | | | | |
| WC002 | 2.93 | 0.03 | 0.59 | 0.02 | 0.79 | 0.08 | 16.48 | 60.78 | 7.43 | 0.46 | 18.13 | 0.00 | 4,253.13 |
| WC003 | 2.08 | 0.01 | 0.41 | 0.01 | 0.77 | 0.07 | 15.69 | 99.62 | 7.41 | 0.56 | 19.68 | 0.00 | 2,884.60 |
| WC004 | 2.65 | 0.05 | 0.48 | 0.01 | 0.96 | 0.07 | 17.85 | 141.01 | 7.64 | 0.84 | 29.45 | 0.00 | 2,077.43 |
| MD avg[a] | 14.44 | N.R. | 0.85 | N.R. | 1.94 | 0.33 | 66.57 | N.R. | 17.9 | 12.5 | 143.3 | N.R. | N.R. |
| NSQD[b] | 16.943 | N.R. | 1.587 | N.R. | 2.921 | 0.412 | 111.295 | N.R. | 42 | 41 | 250 | 2.759 | N.R. |
| NURP[c] | 9 | N.R. | 0.68 | N.R. | 1.5 | 0.33 | 100 | N.R. | 34 | 144 | 160 | N.R. | N.R. |
| **Baseflow Mean Concentrations** | | | | | | | | | | | | | |
| WC002 | 0.58 | 0.12 | 1.26 | 0.00 | 0.62 | 0.02 | 1.50 | 122.92 | 0.83 | 0.03 | 9.08 | 0.00 | 226.98 |
| WC003 | 0.50 | 0.04 | 0.78 | 0.00 | 0.53 | 0.02 | 2.92 | 147.58 | 0.00 | 0.03 | 9.17 | 1.66 | 241.90 |
| WC004 | 0.08 | 0.02 | 2.54 | 0.00 | 0.53 | 0.01 | 2.67 | 316.50 | 0.25 | 0.08 | 22.75 | 0.00 | 233.18 |

N.R. = Reference data not available.
[a] = Maryland State average values from Bahr 1997.
[b] = National Stormwater Quality Database values for Maryland from Pitt 2008.
[c] = National Urban Runoff Program values from U.S. EPA 1983.

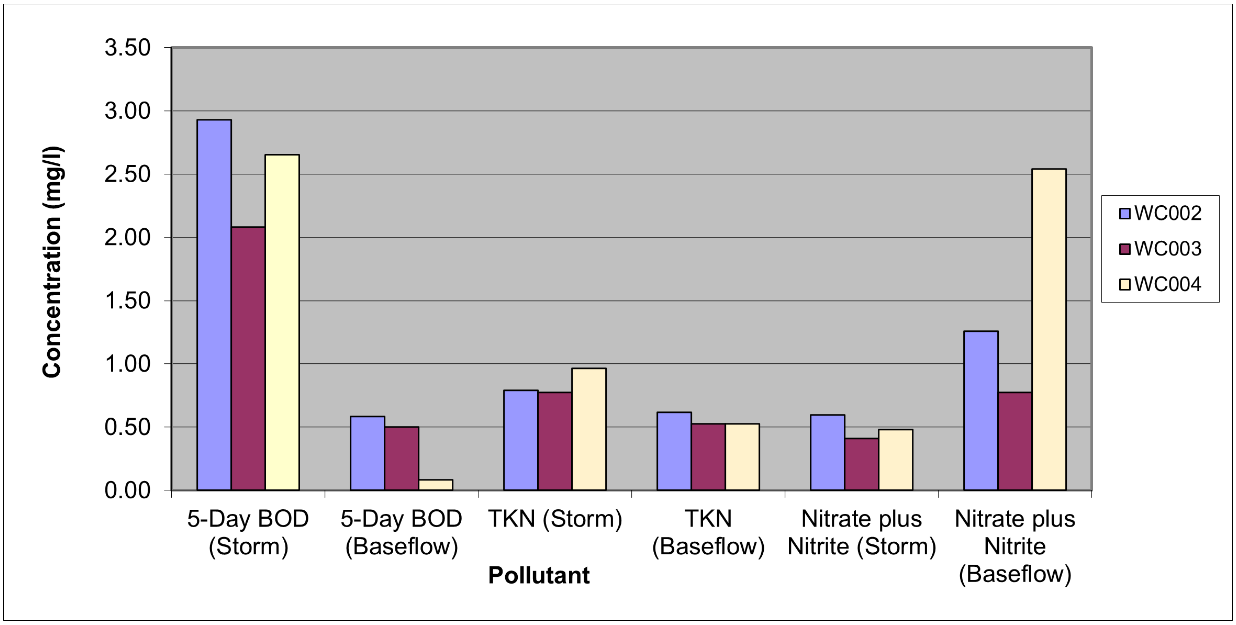


Figure 4-1. Nitrogen and 5-day BOD average storm event mean and baseflow mean concentrations in Wheel Creek, July 2022 – June 2023

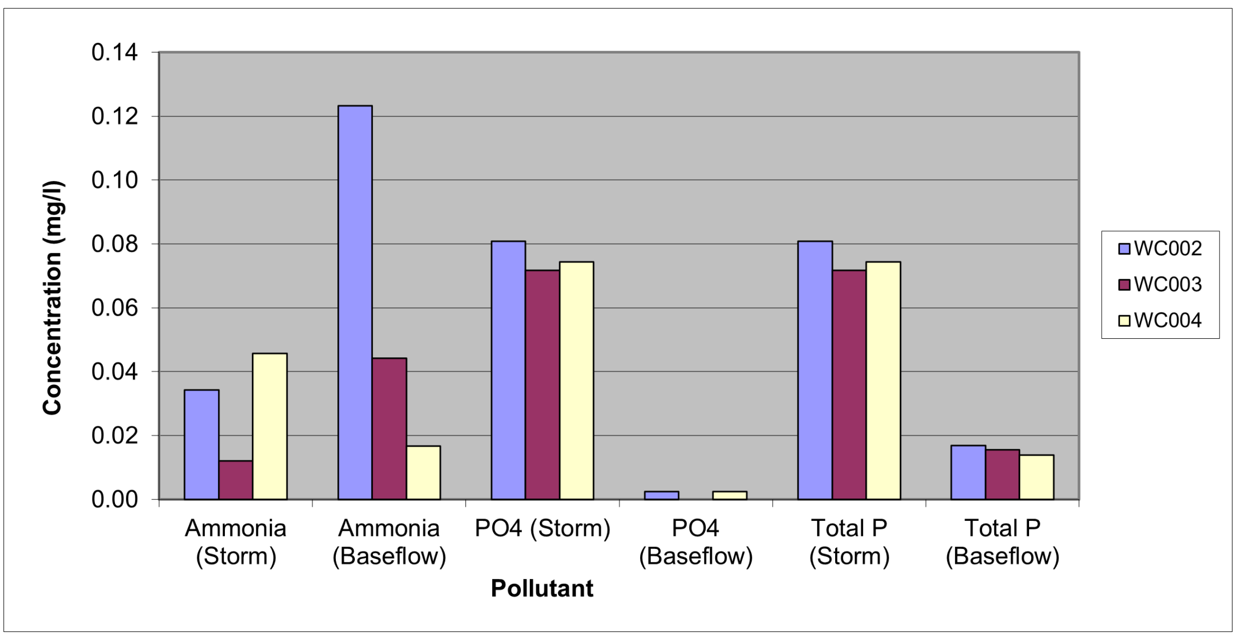


Figure 4-2. Ammonia and phosphorus average storm event mean and baseflow mean concentrations in Wheel Creek, July 2022 – June 2023

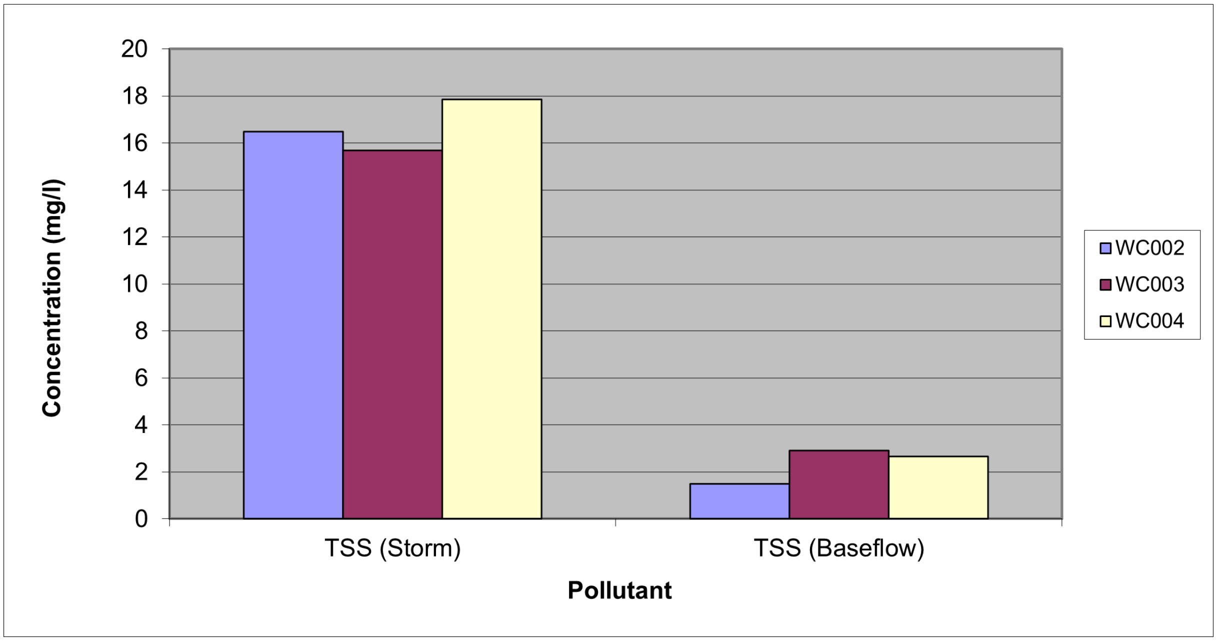


Figure 4-3. TSS average storm event and baseflow mean concentrations in Wheel Creek, July 2022 – June 2023

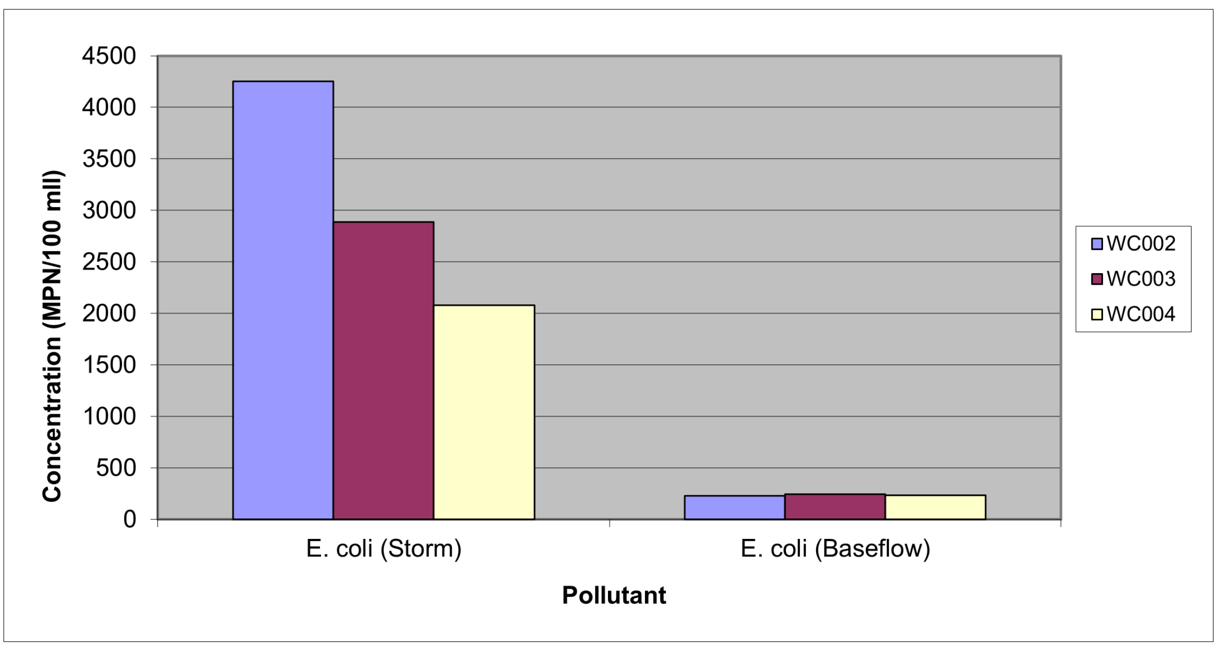


Figure 4-4. *E. coli* average storm and baseflow mean concentrations in Wheel Creek, July 2022 – June 2023

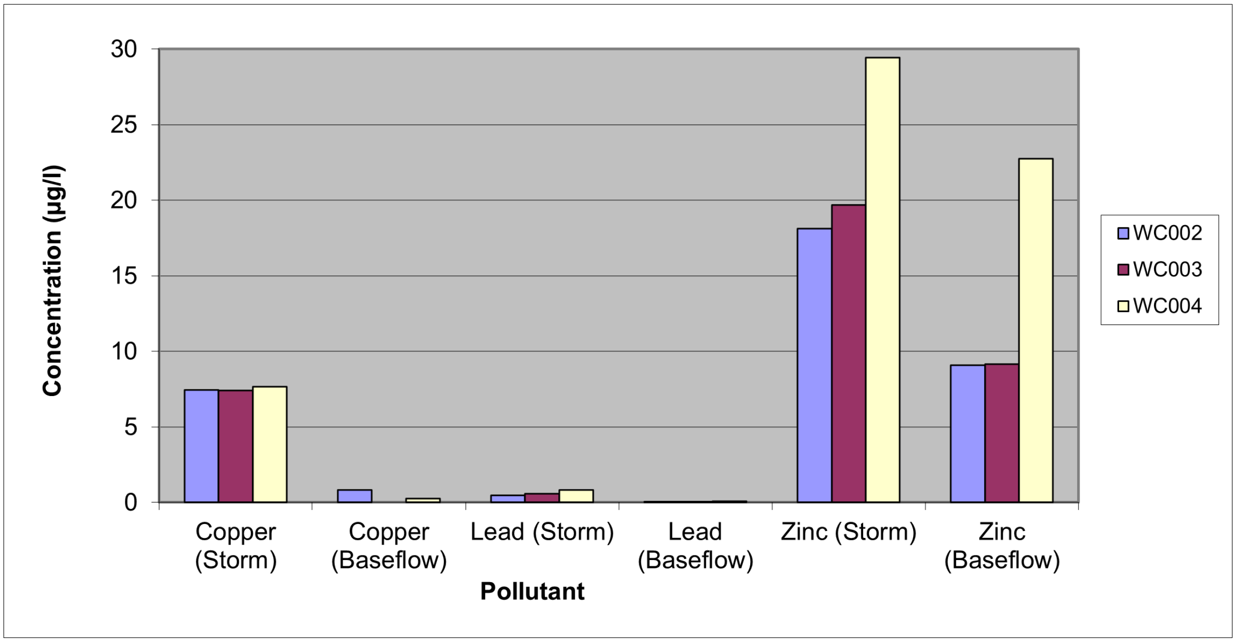


Figure 4-5. Metal average storm event mean and baseflow mean concentrations in Wheel Creek, July 2022 – June 2023

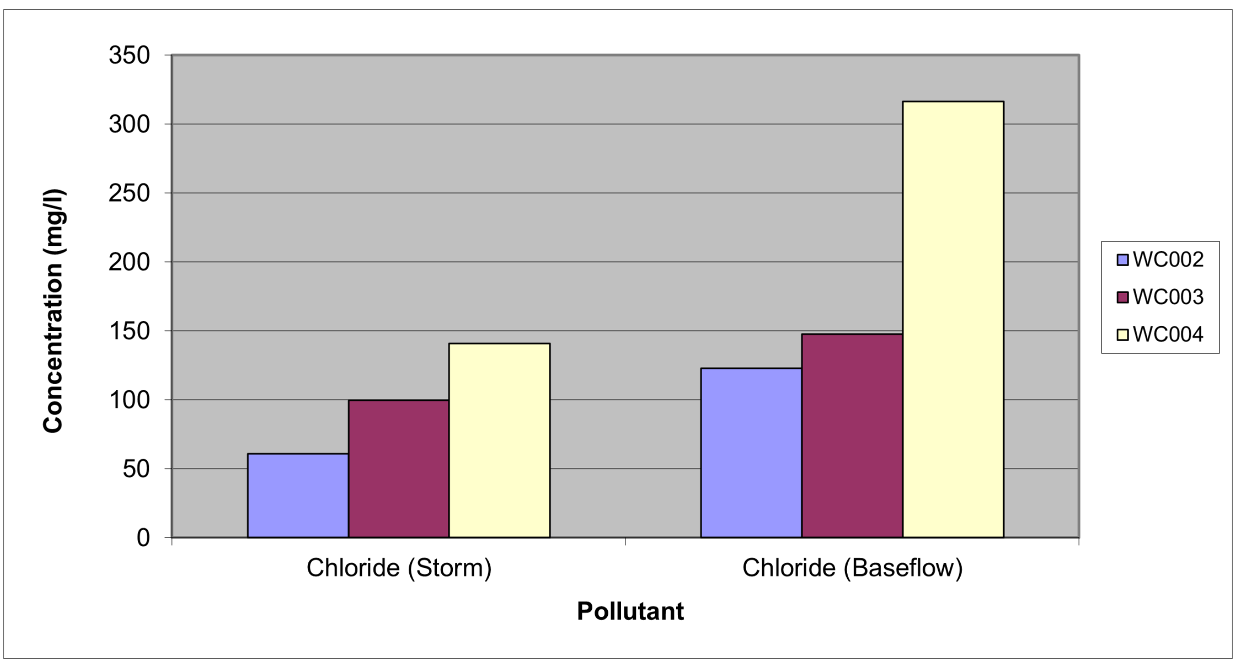


Figure 4-6. Chloride average storm event mean and baseflow mean concentrations in Wheel Creek, July 2022 – June 2023

As described below, some of the plots show a potential change in long-term trend in annual concentration data that can be associated with completion of restoration projects in the watershed. For nitrate plus nitrite through FY2023, the prevailing trend continues gradually downward at all stations since approximately 2014, coinciding with the completion of most of the restoration projects. Storm EMCs for several of the parameters, including total phosphorus, TSS, copper, and BOD show signs of gradually increasing trend until approximately FY2017 and then notably falling in FY2018 through FY2020. From FY2020 through FY2023, storm EMCs for total phosphorus, copper, and BOD largely remained stable and lower than pre-restoration conditions, with minor fluctuations noted for total phosphorus and copper. Storm EMCs for TSS continued to show a declining trend through FY2023. Average storm EMCs for TKN behaved similarly through FY2018 but, despite decreases in all calculated concentrations except baseflow at Station WC002 in FY2023, concentrations have shown an increasing trend from FY2019 through FY2023 at all stations. Similarly, EMCs for ammonia gradually decreased through FY2017, from which point there has been variability in average storm EMCs and baseflow MCs but still an increasing trend through FY2022. Drastic declines in all EMCs for ammonia were observed in FY2023, but the prevailing trend still appears to be increasing. Lead and zinc EMCs were higher and more variable from 2010 through FY2018 before showing reductions in FY2019. Since then, EMCs for both constituents have remained stable with only minor fluctuations in concentrations each year. The time series data may indicate that the restoration efforts are having the desired effect of reducing parameters under specific flow regimes except for total phosphorus, TKN, and ammonia.

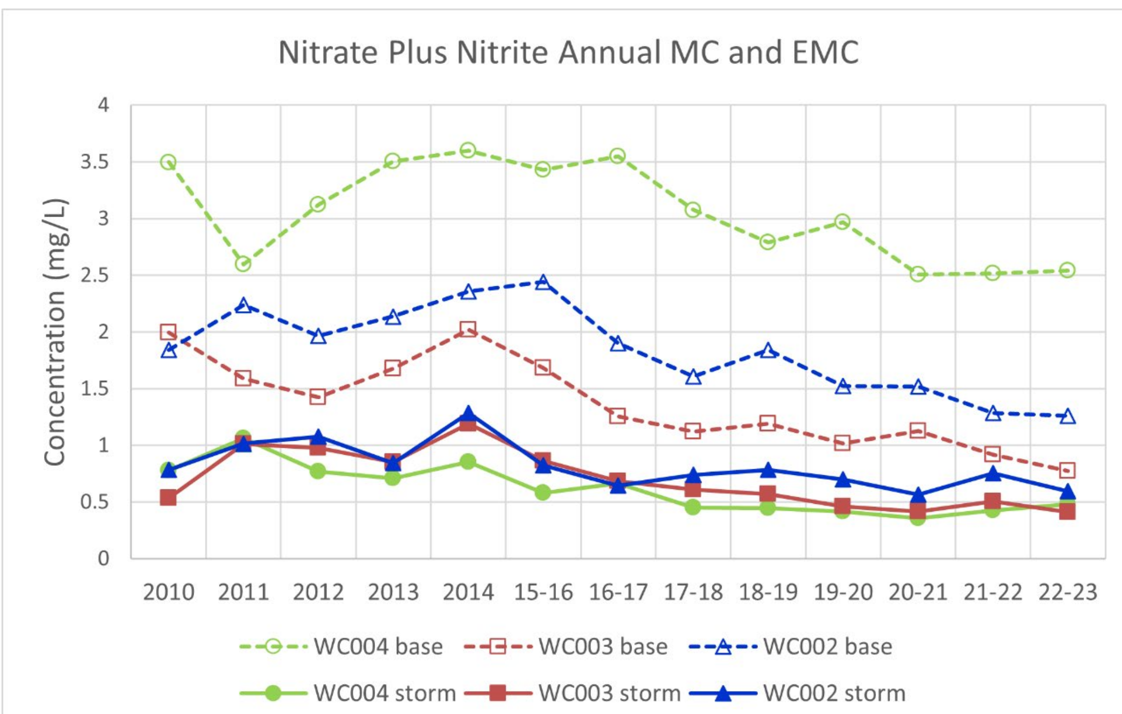


Figure 4-7. Time series plot of average annual baseflow MC and stormflow EMC for nitrate-nitrite (2010-FY2023)

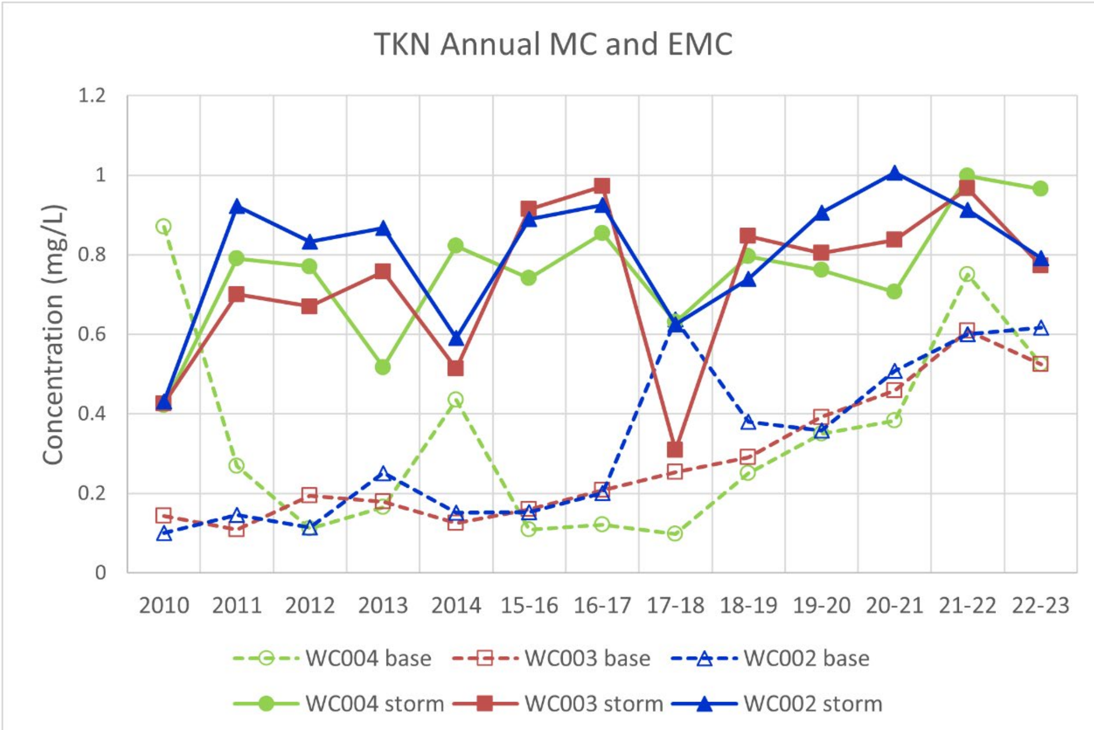


Figure 4-8. Time series plot of average annual baseflow MC and stormflow EMC for TKN (2010-FY2023)

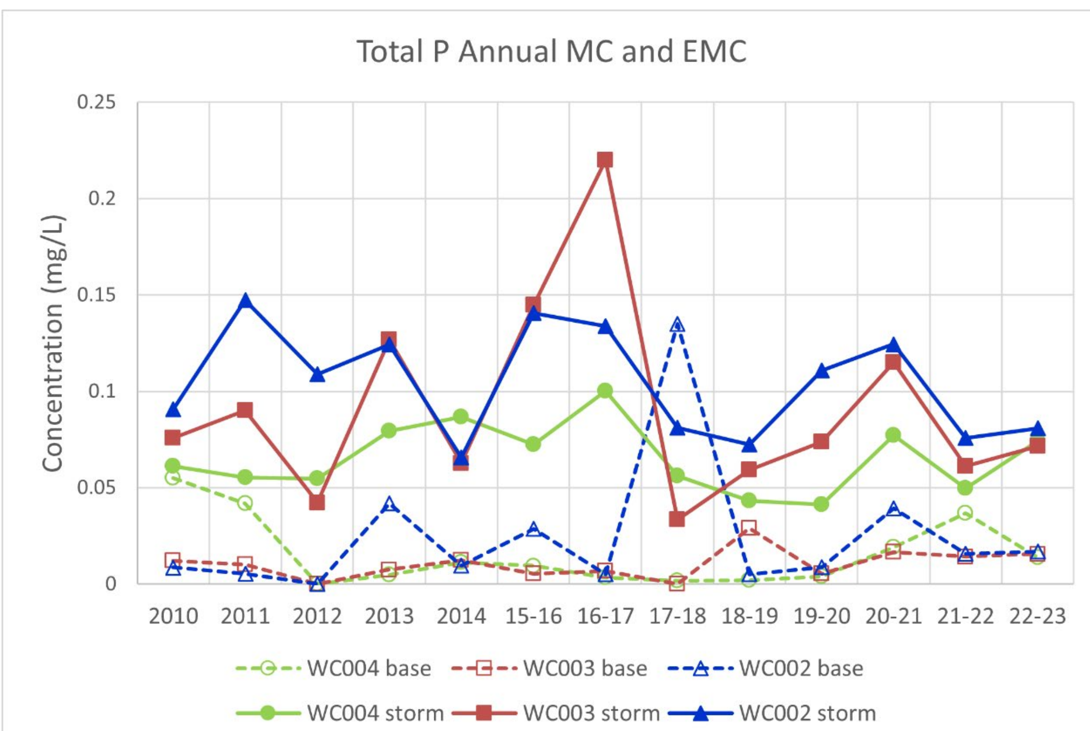


Figure 4-9. Time series plot of average annual baseflow MC and stormflow EMC for total phosphorus (2010-FY2023)

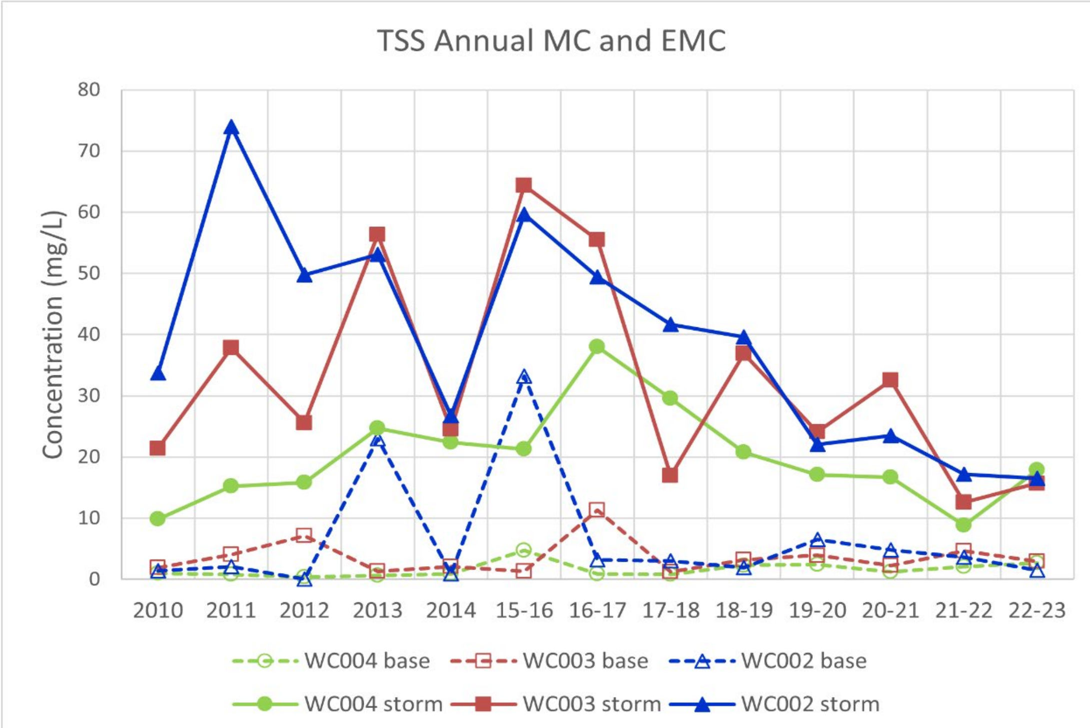


Figure 4-10. Time series plot of average annual baseflow MC and stormflow EMC for TSS (2010-FY2023)

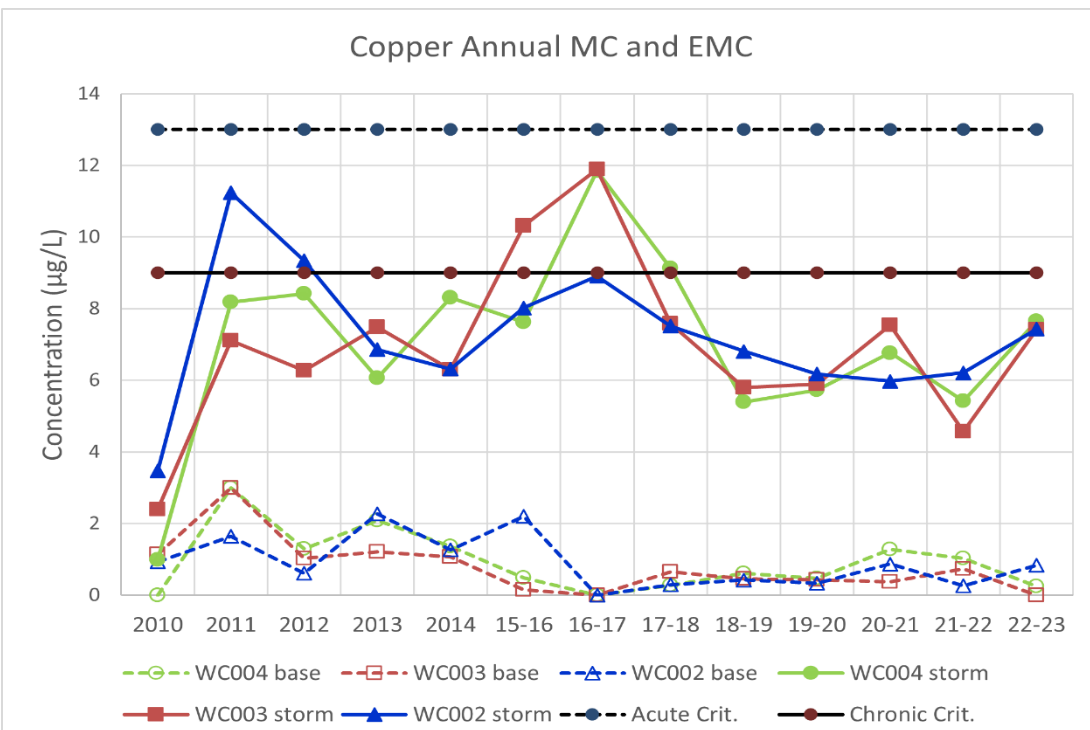


Figure 4-11. Time series plot of average annual baseflow MC and stormflow EMC for copper (2010-FY2023)

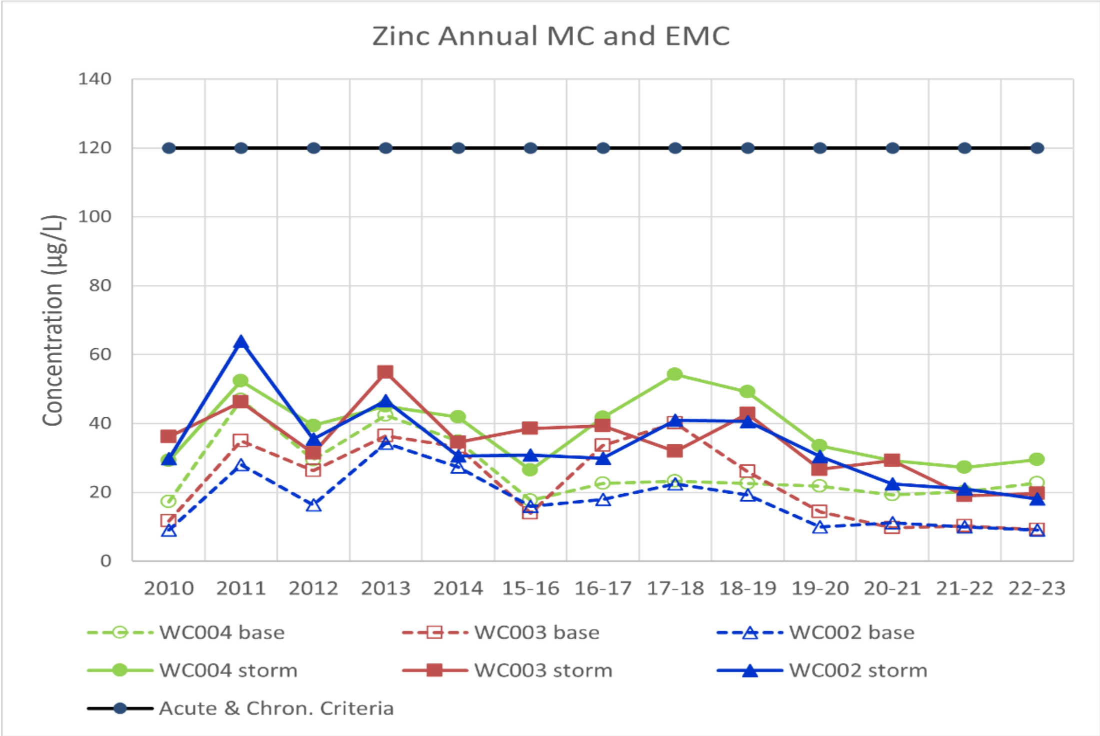


Figure 4-12. Time series plot of average annual baseflow MC and stormflow EMC for zinc (2010-FY2023)

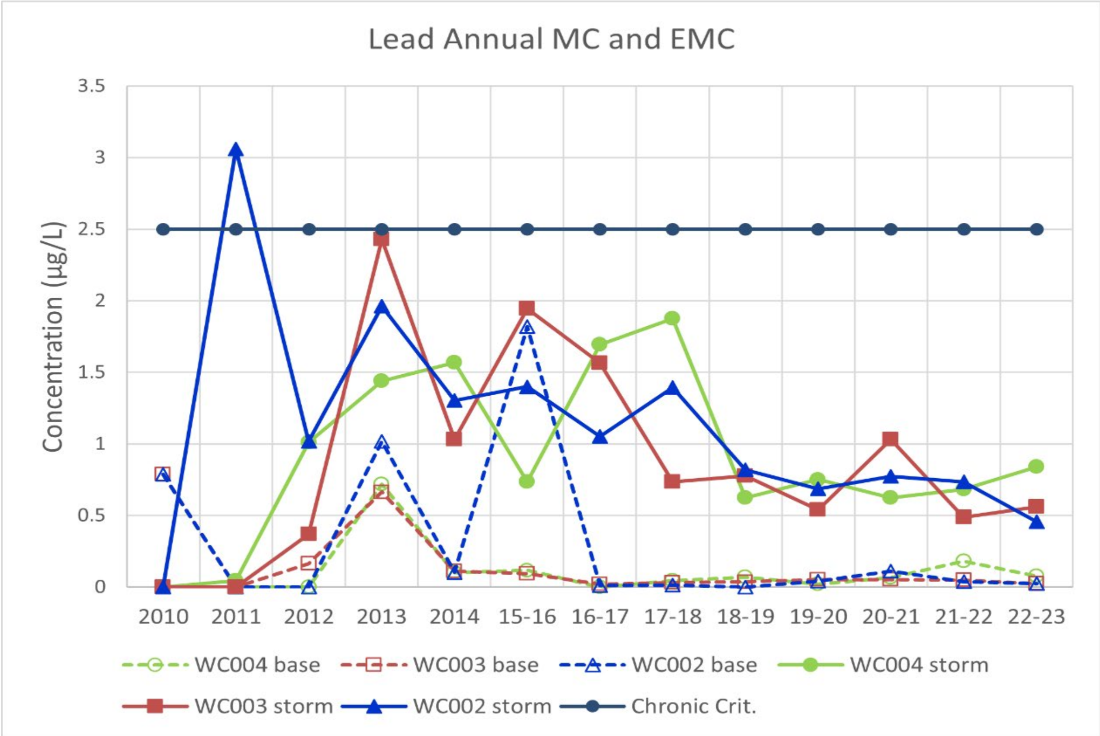


Figure 4-13. Time series plot of average annual baseflow MC and stormflow EMC for lead (2010-FY2023). Note: the acute criterion is not shown to maintain small scale.

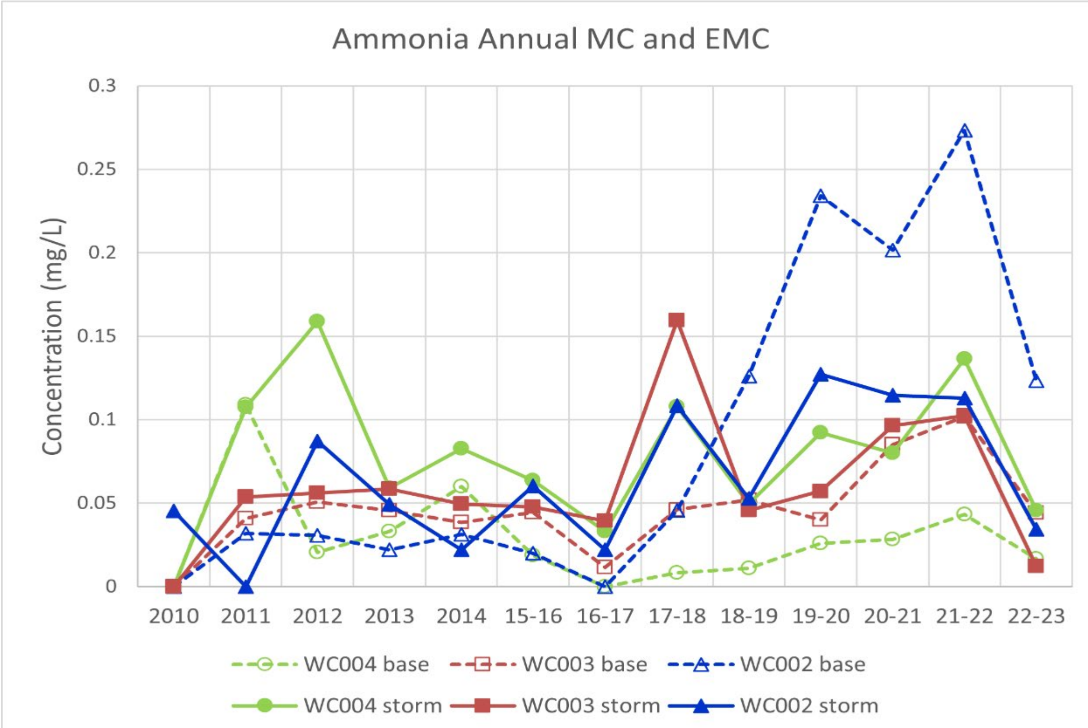


Figure 4-14. Time series plot of average annual baseflow MC and stormflow MC for ammonia (2010-FY2023)

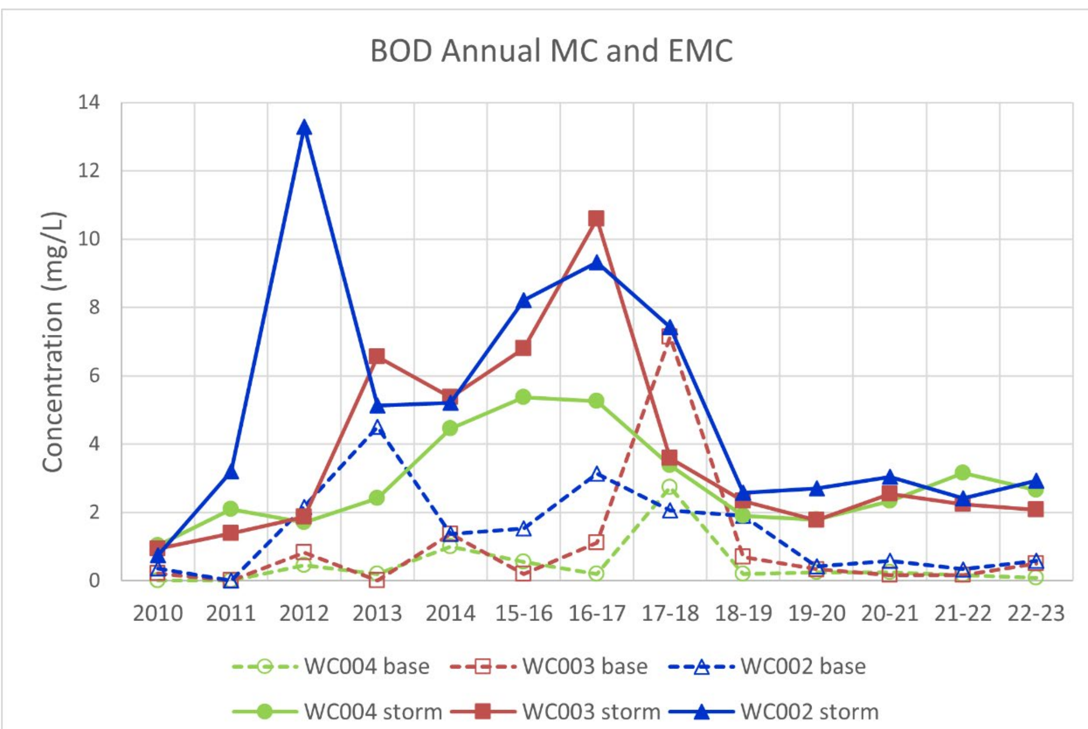


Figure 4-15. Time series plot of average annual baseflow MC and stormflow MC for BOD (2010-FY2023)

## 4.4 STORMFLOW POLLUTANT LOADING DATA

Pollutant loads for individual storms at each station were calculated from individual stormflow event mean concentration data (Table 4-5). Pollutant load represents the quantity of pollutant, in pounds, that was transported in the stream during the event. For discussion purposes, an average load was determined for each pollutant at each station for storms monitored from July 2022 through June 2023.

When comparing stations, average storm loads were highest at Station WC002 for all parameters (Table 4-6). Average loads were lowest at Station WC004 for all parameters, except for ammonia where Station WC003 was lowest. Since discharge volume for a given storm increases with distance downstream, maximum load results at Station WC002 are expected.

Table 4-5. Storm event pollutant loadings (lbs per event), July 2022 – June 2023 (non-detects set to zero)

| Storm Date | Discharge (cf) | 5-Day BOD | Ammonia | Nitrate + Nitrite | Ortho-phosphate | TKN | Total P | TSS | Chloride | Copper | Lead | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Station WC002** | | | | | | | | | | | | |
| 8/24/2022 | 3,922,960 | 1,100.58 | 37.30 | 118.32 | 9.38 | 232.51 | 39.54 | 8,667.36 | 7,003.61 | 2.946 | 0.213 | 5.645 |
| 9/7/2022 | 1,435,370 | 262.88 | 0.48 | 36.34 | 3.56 | 71.47 | 9.75 | 2,010.34 | 1,275.25 | 0.527 | 0.061 | 1.342 |
| 10/14/2022 | 136,853 | 29.85 | 0.06 | 3.46 | 0.26 | 6.52 | 0.75 | 161.75 | 267.79 | 0.052 | 0.005 | 0.132 |
| 12/1/2022 | 96,830 | 12.74 | 0.00 | 4.28 | 0.07 | 3.32 | 0.25 | 27.13 | 397.98 | 0.021 | 0.000 | 0.070 |
| 1/13/2023 | 71,388 | 6.29 | 0.00 | 5.27 | 0.02 | 2.23 | 0.13 | 21.73 | 698.13 | 0.017 | 0.000 | 0.062 |
| 1/24/2023 | 159,830 | 19.96 | 0.17 | 5.85 | 0.10 | 6.20 | 0.32 | 31.26 | 866.31 | 0.065 | 0.003 | 0.160 |
| 4/24/2023 | 130,447 | 40.56 | 0.00 | 5.05 | 0.05 | 11.07 | 0.98 | 203.02 | 603.44 | 0.113 | 0.005 | 0.257 |
| 6/26/2023 | 455,752 | 57.28 | 2.64 | 10.37 | 0.24 | 22.56 | 1.88 | 502.25 | 815.44 | 0.223 | 0.017 | 0.529 |
| **Station WC003** | | | | | | | | | | | | |
| 8/24/2022 | 1,318,430 | 209.59 | 0.00 | 31.16 | 0.55 | 61.34 | 5.86 | 1,190.68 | 2,459.81 | 0.778 | 0.056 | 1.481 |
| 9/7/2022 | 608,523 | 68.71 | 0.00 | 11.25 | 1.10 | 29.57 | 4.65 | 706.99 | 810.04 | 0.226 | 0.021 | 0.516 |
| 10/14/2022 | 182,900 | 33.24 | 0.00 | 3.63 | 0.01 | 10.06 | 0.98 | 236.82 | 424.45 | 0.077 | 0.009 | 0.211 |
| 12/1/2022 | 64,512 | 5.85 | 0.00 | 2.33 | 0.00 | 2.44 | 0.17 | 26.11 | 415.83 | 0.013 | 0.001 | 0.066 |
| 1/13/2023 | 30,298 | 1.41 | 0.06 | 1.40 | 0.00 | 1.01 | 0.05 | 15.79 | 597.54 | 0.011 | 0.001 | 0.035 |
| 1/24/2023 | 124,176 | 11.78 | 0.26 | 3.47 | 0.02 | 4.47 | 0.21 | 32.52 | 1,311.60 | 0.049 | 0.002 | 0.144 |
| 4/24/2023 | 83,566 | 19.01 | 0.17 | 1.57 | 0.05 | 6.60 | 0.63 | 108.51 | 412.74 | 0.057 | 0.004 | 0.140 |
| 6/26/2023 | 163,397 | 20.47 | 0.00 | 2.35 | 0.00 | 8.09 | 0.76 | 325.05 | 419.58 | 0.109 | 0.009 | 0.278 |
| **Station WC004** | | | | | | | | | | | | |
| 8/24/2022 | 905,402 | 142.71 | 7.87 | 19.28 | 1.43 | 53.48 | 4.25 | 418.08 | 1,681.00 | 0.265 | 0.027 | 0.990 |
| 9/7/2022 | 311,001 | 39.49 | 0.05 | 4.21 | 0.39 | 13.66 | 1.19 | 205.13 | 154.35 | 0.131 | 0.013 | 0.438 |
| 10/14/2022 | 63,929 | 7.83 | 0.00 | 1.08 | 0.15 | 3.52 | 0.27 | 51.46 | 94.08 | 0.023 | 0.003 | 0.098 |
| 12/1/2022 | 27,571 | 2.87 | 0.08 | 0.83 | 0.03 | 1.32 | 0.11 | 21.56 | 78.52 | 0.010 | 0.001 | 0.046 |
| 1/13/2023 | 12,549 | 2.14 | 0.07 | 0.54 | 0.00 | 0.56 | 0.03 | 5.14 | 464.01 | 0.005 | 0.000 | 0.030 |
| 1/24/2023 | 22,528 | 2.81 | 0.13 | 0.49 | 0.00 | 1.02 | 0.05 | 7.20 | 322.72 | 0.014 | 0.001 | 0.035 |
| 4/24/2023 | 17,147 | 6.58 | 0.00 | 1.25 | 0.01 | 1.99 | 0.17 | 54.11 | 147.20 | 0.013 | 0.001 | 0.052 |
| 6/26/2023 | 42,468 | 5.67 | 0.00 | 0.88 | 0.01 | 2.95 | 0.24 | 98.62 | 164.07 | 0.026 | 0.005 | 0.085 |

Table 4-6. Average storm pollutant loads (lbs/event), Wheel Creek monitoring, July 2022 – June 2023 (non-detects set to zero)

| Station | 5-Day BOD | Ammonia | Nitrate + Nitrite | Ortho-phosphate | TKN | Total P | TSS | Chloride | Copper | Lead | Zinc |
|---|---|---|---|---|---|---|---|---|---|---|---|
| WC002 | 191.27 | 5.08 | 23.62 | 1.71 | 44.48 | 6.70 | 1,453.10 | 1,490.99 | 0.495 | 0.038 | 1.025 |
| WC003 | 46.26 | 0.06 | 7.14 | 0.22 | 15.45 | 1.67 | 330.31 | 856.45 | 0.165 | 0.013 | 0.359 |
| WC004 | 26.26 | 1.02 | 3.57 | 0.25 | 9.81 | 0.79 | 107.66 | 388.24 | 0.061 | 0.006 | 0.222 |

## 4.5 SEDIMENT TRANSPORT SAMPLING RESULTS

A summary of suspended sediment transport data for Stations WC002, WC003, and WC004 (Tables 4-7 through 4-9) and suspended sediment transport curves for Stations WC002, WC003, and WC004 (Figures 4-16 through 4-18) are presented below. The discharges associated with each sediment sample were approximated from flow rate data recorded at the time when the stage at which the samplers filled, as shown by stage loggers attached to the siphon samplers, was achieved.

Four storm events were sampled from July 2022 to December 2022. Due to low historical correlations found with prior suspended sediment samples and discharge, Versar and County managers discontinued this monitoring at the end of 2022. From these four storms monitored in FY2023, a total of 18 samples were collected at Station WC002 (Table 4-7), 16 samples were collected at Station WC003 (Table 4-8), and 11 samples were collected at Station WC004 (Table 4-9). Note that bottles are numbered in sequence from the lowest to the highest point in the water column. Suspended sediment concentrations ranged from 21.7 to 1,340.0 mg/L at Station WC002, 8.8 to 771.0 mg/L at Station WC003, and 19.8 to 1,010.0 mg/L at Station WC004.

Table 4-7. Suspended sediment results at Station WC002, July 2022 – December 2022

| Date | Bottle Number | Suspended Sediment (mg/L) | Discharge (cfs) | Date | Bottle Number | Suspended Sediment (mg/L) | Discharge (cfs) |
|---|---|---|---|---|---|---|---|
| 21-Aug-22 | 2 | 1130.0 | 83.52 | 5-Sep-22 | 5 | 1340.0 | 0.45 |
| 21-Aug-22 | 3 | 431.0 | 83.52 | 13-Oct-22 | 1 | 46.9 | 0.51 |
| 21-Aug-22 | 4 | 560.0 | 83.52 | 13-Oct-22 | 2 | 173.0 | 0.51 |
| 21-Aug-22 | 5 | 786.0 | 83.52 | 13-Oct-22 | 3 | 107.0 | 0.51 |
| 21-Aug-22 | 6 | 519.0 | 83.52 | 13-Oct-22 | 4 | 77.2 | 0.51 |
| 5-Sep-22 | 1 | 130.0 | 0.45 | 13-Oct-22 | 5 | 42.6 | 0.51 |
| 5-Sep-22 | 2 | 660.0 | 0.45 | 30-Nov-22 | 1 | 21.7 | 0.62 |
| 5-Sep-22 | 3 | 224.0 | 0.45 | 30-Nov-22 | 2 | 34.0 | 1.79 |
| 5-Sep-22 | 4 | 376.0 | 0.45 | 30-Nov-22 | 4 | 109.0 | N.R. |

N.R. – Corresponding level data from logger and flow rate could not be determined for this sample.

Table 4-8. Suspended sediment results at Station WC003, July 2022 – December 2022

| Date | Bottle Number | Suspended Sediment (mg/L) | Discharge (cfs) | Date | Bottle Number | Suspended Sediment (mg/L) | Discharge (cfs) |
|---|---|---|---|---|---|---|---|
| 21-Aug-22 | 1 | 337.0 | 0.12 | 6-Sep-22 | 4 | 247.0 | 12.96 |
| 21-Aug-22 | 2 | 560.0 | 3.13 | 6-Sep-22 | 5 | 66.8 | 19.87 |
| 21-Aug-22 | 3 | 632.0 | 12.54 | 13-Oct-22 | 1 | 108.0 | 0.14 |
| 21-Aug-22 | 4 | 468.0 | 12.54 | 13-Oct-22 | 2 | 232.0 | 2.25 |
| 21-Aug-22 | 6 | 771.0 | 35.01 | 13-Oct-22 | 3 | 93.3 | 4.46 |
| 5-Sep-22 | 1 | 79.9 | 0.12 | 13-Oct-22 | 4 | 116.0 | 8.64 |
| 6-Sep-22 | 2 | 126.0 | 1.49 | 30-Nov-22 | 1 | 8.8 | 0.15 |
| 6-Sep-22 | 3 | 245.0 | 5.95 | 30-Nov-22 | 2 | 39.3 | 1.60 |

N.R. – Corresponding level data from logger and flow rate could not be determined for this sample.

Table 4-9. Suspended sediment results at Station WC004, July 2022 – December 2022

| Date | Bottle Number | Suspended Sediment (mg/L) | Discharge | Date | Bottle Number | Suspended Sediment (mg/L) | Discharge |
|---|---|---|---|---|---|---|---|
| 21-Aug-22 | 1 | 128.0 | 12.30 | 6-Sep-22 | 4 | 46.4 | N.R. |
| 21-Aug-22 | 2 | 177.0 | 24.00 | 13-Oct-22 | 1 | 34.0 | 1.68 |
| 21-Aug-22 | 4 | 123.0 | N.R. | 13-Oct-22 | 2 | 30.0 | N.R. |
| 6-Sep-22 | 1 | 1010.0 | 10.20 | 30-Nov-22 | 1 | 38.7 | 1.02 |
| 6-Sep-22 | 2 | 44.8 | N.R. | 30-Nov-22 | 2 | 19.8 | N.R. |
| 6-Sep-22 | 3 | 86.7 | N.R. | | | | |

N.R. – Corresponding level data from logger and flow rate could not be determined for this sample.

Sediment transport curves were created for each station using concentrations of suspended sediment in samples and corresponding flow rate values for storms monitored from July 2022 through December 2022. Average instantaneous discharges for each sample were similar to those reported in the previous year. Results at Station WC002 showed a low correlation between discharge and suspended sediment concentration ($r^2$ = 0.239; Figure 4-16). The sediment concentration correlation at Station WC002 was lower than reported last year and had higher concentrations per discharge. The sediment transport curve prepared for Station WC003 showed a moderate correlation between discharge and suspended sediment concentration ($r^2$ = 0.365; Figure 4-17). The sediment concentration correlation at Station WC003 was less than reported last year and had lower concentrations per discharge. Results at Station WC004 showed a very low correlation between discharge and suspended sediment concentration ($r^2$ = 0.159; Figure 4-18). The sediment concentration correlation at Station WC004 was much less than reported last year, likely due to less recorded sediment concentrations per discharge providing a less accurate representation of the relationship at this station.

The arithmetic mean of stormflow-associated suspended sediment concentrations, by station, exceeded corresponding average annual EMCs of TSS, suggesting that TSS results underestimate the actual transport of sediment during storms (Figure 4-19).

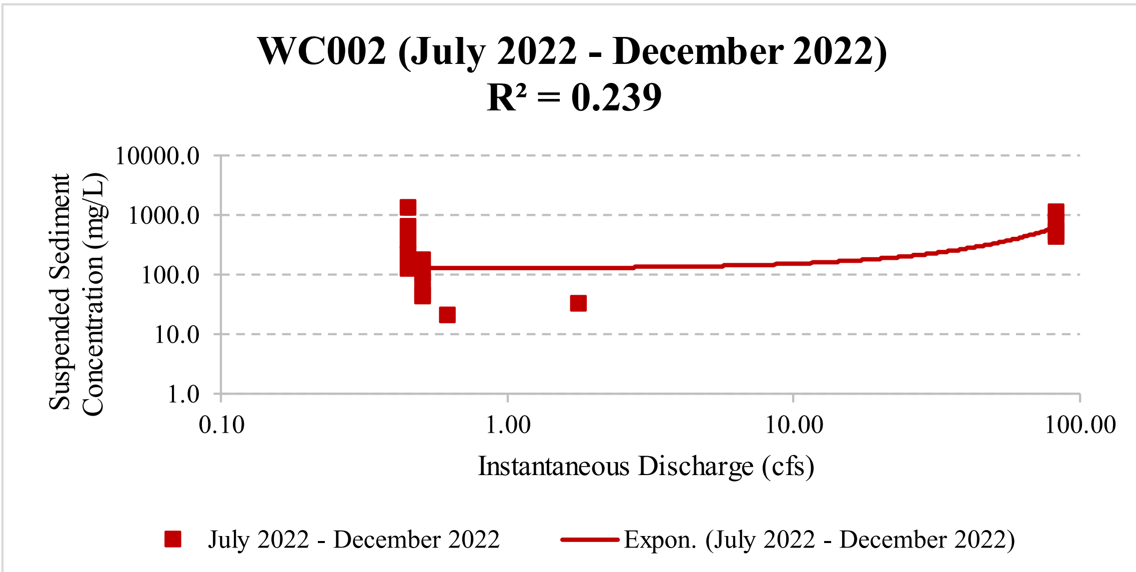


Figure 4-16. Suspended sediment curve for Wheel Creek Station 002 (July 2022 – December 2022)

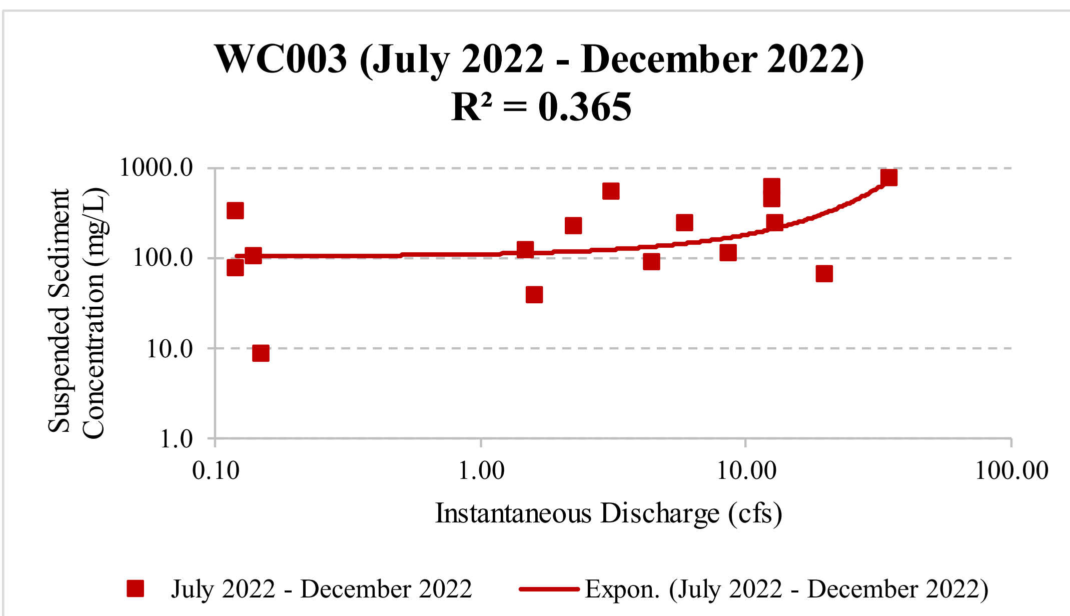


Figure 4-17. Suspended sediment curve for Wheel Creek Station 003 (July 2022 – December 2022)

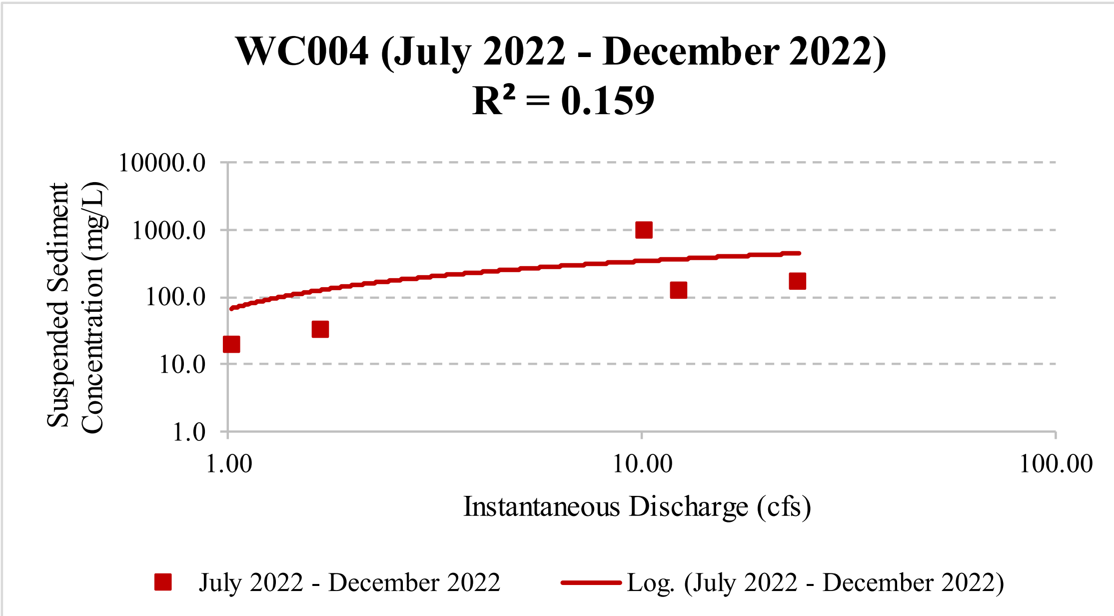


Figure 4-18. Suspended sediment curve for Wheel Creek Station 003 (July 2022 – December 2022)

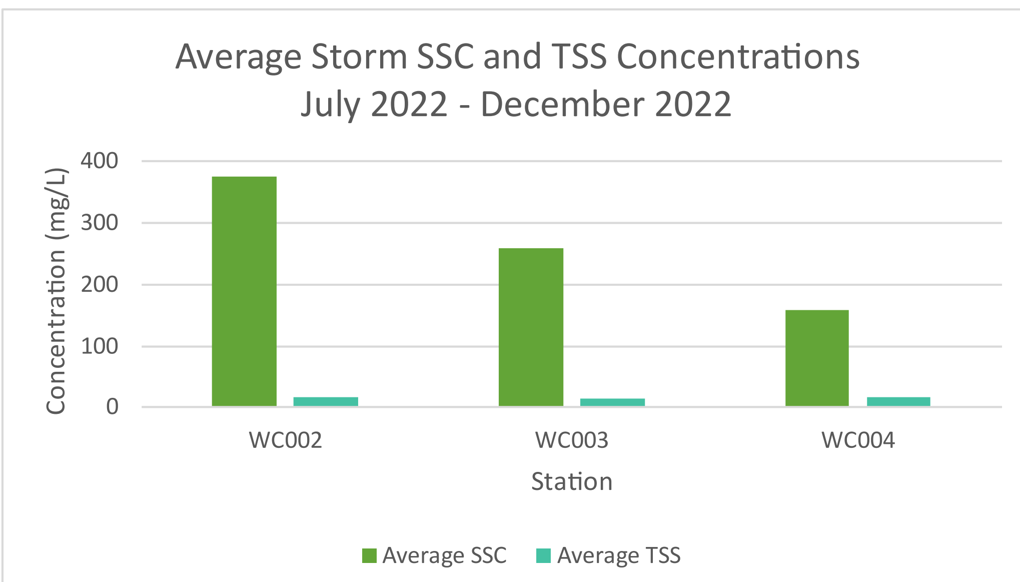


Figure 4-19. Average SSC and TSS concentrations in stormwater runoff (July 2022 – December 2022)

## 4.6 MONITORING PROBLEMS IDENTIFIED IN 2022-2023

### 4.6.1 Storm Events

During the October 13-14, 2022 storm event, the field crew noted that the Sigma sampler at Station WC003 was pulling inconsistent and low volumes of water in each discrete sample bottle during pre-program inspection. The field crew recalibrated the sample volume ahead of the event to ensure proper functionality. Also, due to the forecasted intensity of rainfall at the onset of the event, field staff collected rising limb samples in glass amber gallon containers at all three stations. This step was taken to mitigate the possibility of low discrete sample volume for the rising limb within the samplers, as the stream levels could have peaked before three discrete samples were pulled. Samples were retained on ice overnight to preserve the samples until composite with the remaining samples the following day.

During the January 12-13, 2023 storm event, Versar field staff planned to collect grab samples for *E. coli* and TPH during the rising limb. However, field staff experienced vehicle issues and decided to collect grab samples that coincided with the falling limb the next day, prior to compositing the automated samples.

### 4.6.2 Continuous Stage Logging

The Solinst level loggers at each station were downloaded monthly. Episodes of sensor drift due to presence of sediment after storm flows and leaf debris in the fall have been noted. The level loggers occasionally accumulate sediment in the sensor holes, which needs to be removed. Leaf debris buildup in the channels causes a temporary backwater condition, causing heightened stage and artificially inflated flow rate readings. Adjustments to correct for the drift and leaf buildup were performed to improve the flow record.

To account for data gaps, the following protocols were used to complete the stage records. All data from the Solinst level loggers were aggregated, and anomalous data encountered during data offloads and logger swapping were manually interpolated with the surrounding stage data. The level logger data were shifted to match observed actual staff gauge readings, and linear drift corrections were applied to correct periods of sensor drift. ISCO flowmeter data were also shifted to match staff gauge observations and Solinst level logger data; the ISCO level data were used when Solinst level loggers were offline. If equipment failures occurred, stream level data were modeled using a regression to determine the relationship between stations to estimate flow rate and fill in any resultant data gaps.

During the FY2023 reporting period, winter temperatures were not excessively low and staff did not remove the Solinst loggers during this time. The resultant dataset was continuous, and aside from normal seasonal drift corrections, no regressions were needed to complete the stage dataset.

## 4.7 COMPARISON OF PRE- AND POST-RESTORATION CONDITIONS

### 4.7.1 Comparison of Pollutant Ratios Between Stations WC002 and WC003

For this evaluation, a comparison of the ratios (in percent; see definition in section 3.9.1) of average pollutant concentrations and annual loads between Station WC003 and Station WC002 was employed to determine the benefit, in terms of pollution reduction, of restoration projects in the mainstem and in the middle branch between Station WC003 and Station WC002.

*Total Annual Load*

To facilitate comparison, samples collected in 2010 and 2011 were treated as fully "pre-restoration" and those collected in FY2017-2023 were treated as fully "post-restoration." If the ratio of pollutant load between the upstream station (WC003) and downstream station (WC002) during post-restoration conditions was less than the baseline ratio during pre-restoration conditions, then it may be concluded that the restoration projects reduced loading between the stations. Total loads and ratios are presented in Table 4-10. For comparison, intermediate post-restoration results using data collected in 2014, when no construction was in progress in the study area, are provided.

In terms of total annual load, the ratios of the downstream station (WC002) to the upstream station (WC003) for total nitrogen and ammonia were greater during post-restoration conditions than during pre-restoration conditions. Lead, copper, zinc, BOD, total phosphorus, and TSS ratios were lower during the post-restoration phase, indicating that the restoration between the stations succeeded in reducing loads for these pollutants. For total nitrogen and ammonia, the restoration projects between the two stations did not reduce loads.

*Storm EMCs*

The ratios of average EMCs of pollutants during storm events captured during pre-restoration conditions were compared to the ratios of average EMCs for storms captured during post-restoration conditions. The average EMCs during these periods, and comparisons between the periods, are provided in Table 4-11.

When assessing pre-restoration conditions, the average storm EMCs at Station WC002 exceeded those at Station WC003 for all pollutants except ammonia; however, none of the differences were significant. When assessing post-restoration conditions, the average storm EMCs at Station WC002 were greater than at Station WC003 for all pollutants except for zinc, with the differences for total nitrogen and total phosphorus being significantly greater. These changes in ratios suggest that the restoration in the contributing subwatersheds has reduced pollutant concentrations at Station WC002 under stormflow conditions for all parameters except for total nitrogen and ammonia.

Table 4-10. Comparison of Pre-Restoration and Post-Restoration Total Annual Loads

| Phase | Total Load (lbs) | | Ratio |
|---|---|---|---|
| | WC002 | WC003 | |
| Total Nitrogen | | | |
| Pre-Restoration (2010-2011) | 7,258 | 1,905 | 73.8% |
| Post-Restoration (2014) | 6,958 | 1,307 | 81.2% |
| Post-Restoration (FY 2017-23) | 32,662 | 8,024 | 75.4% |
| Total Phosphorus | | | |
| Pre-Restoration (2010-2011) | 281.8 | 73.9 | 73.8% |
| Post-Restoration (2014) | 171.5 | 33.4 | 80.5% |
| Post-Restoration (FY 2017-23) | 1401.8 | 389.6 | 72.2% |
| TSS | | | |
| Pre-Restoration (2010-2011) | 126,203 | 26,438 | 79.1% |
| Post-Restoration (2014) | 67,237 | 12,413 | 81.5% |
| Post-Restoration (FY 2017-23) | 337,026 | 120,638 | 64.2% |
| Ammonia | | | |
| Pre-Restoration (2010-2011) | 72.4 | 32.1 | 55.7% |
| Post-Restoration (2014) | 83.3 | 32.7 | 60.7% |
| Post-Restoration (FY 2017-23) | 2,084.6 | 415.5 | 80.1% |
| BOD | | | |
| Pre-Restoration (2010-2011) | 4,914 | 1,030 | 79.0% |
| Post-Restoration (2014) | 14,168 | 2,918 | 79.4% |
| Post-Restoration (FY 2017-23) | 53,362 | 15,703 | 70.6% |
| Copper | | | |
| Pre-Restoration (2010-2011) | 19.2 | 4.9 | 74.3% |
| Post-Restoration (2014) | 16.8 | 3.3 | 80.3% |
| Post-Restoration (FY 2017-23) | 77.5 | 30.3 | 60.9% |
| Lead | | | |
| Pre-Restoration (2010-2011) | 4.4 | 0.2 | 96.3% |
| Post-Restoration (2014) | 3.3 | 0.5 | 84.1% |
| Post-Restoration (FY 2017-23) | 13.2 | 4.7 | 64.6% |
| Zinc | | | |
| Pre-Restoration (2010-2011) | 137.9 | 43.7 | 68.3% |
| Post-Restoration (2014) | 101.1 | 24.2 | 76.1% |
| Post-Restoration (FY 2017-23) | 441.5 | 161.9 | 63.3% |

Table 4-11. Pre- and Post-Restoration Average Storm EMCs (shaded cells indicate significant results)

| Pollutant (mg/L) | Station | | Ratio | t test p-value (two-tailed) |
|---|---|---|---|---|
| | WC002 | WC003 | | |
| Pre-Restoration Conditions | | | | |
| Total N | 1.59 | 1.44 | 9% | 0.54 |
| Total P | 0.104 | 0.073 | 30% | 0.28 |
| TSS | 46.84 | 28.54 | 39% | 0.20 |
| Ammonia | 0.017 | 0.030 | -72% | 0.50 |
| BOD | 2.400 | 1.585 | 34% | 0.48 |
| Copper | 0.008 | 0.006 | 27% | 0.36 |
| Lead | 0.479 | 0.000 | 100% | 0.33 |
| Zinc | 0.043 | 0.038 | 11% | 0.59 |
| Post-Restoration Conditions | | | | |
| Total N | 1.56 | 1.33 | 15% | 0.002 |
| Total P | 0.098 | 0.086 | 13% | 0.05 |
| TSS | 31.55 | 26.59 | 16% | 0.29 |
| Ammonia | 0.085 | 0.076 | 11% | 0.80 |
| BOD | 4.530 | 3.419 | 25% | 0.06 |
| Copper | 0.00716 | 0.00712 | 1% | 0.69 |
| Lead | 0.0009 | 0.0008 | 17% | 0.55 |
| Zinc | 0.0291 | 0.0291 | -0.05% | 0.99 |
| Note: For all pollutants, α = 0.05 | | | | |

*Baseflow MCs*

The ratios of average baseflow MCs of pollutants during pre-restoration conditions were compared to the ratios of average baseflow MCs during post-restoration conditions. The average MCs during these periods, and comparisons between the periods, are provided in Table 4-12.

During pre-restoration phase baseflow conditions, total phosphorus, TSS, ammonia, copper, and zinc concentrations at the upstream station exceeded those at Station WC002, with TSS and zinc significant. Concentrations of BOD and total nitrogen were higher at Station WC002. After restoration, only BOD and zinc showed improvement in terms of lowering ratios between Station WC003 and Station WC002, relative to the baseline, with zinc showing a significant decrease. For the remaining parameters, concentrations at Station WC002 became greater in relation to Station WC003, with total nitrogen and ammonia showing significant increases. The significantly higher average ammonia concentrations at Station WC002 may be due to contributions of ammonia from a potential sanitary sewage source. The annual average

EMC for *E. coli* was highest at Station WC002. Additionally, it should be noted that during FY2023, average annual EMCs and MCs for ammonia declined to their lowest level since FY2017 at most stations and flow types.

Table 4-12. Pre- and Post-Restoration Average Baseflow MCs (shaded cells indicate significant results)

| Pollutant (mg/L) | Station WC002 | Station WC003 | Ratio | t test p-value (two-tailed) |
|---|---|---|---|---|
| Pre-Restoration Conditions | | | | |
| Total N | 2.14 | 1.88 | 12% | 0.22 |
| Total P | 0.006 | 0.040 | -617% | 0.28 |
| TSS | 1.38 | 3.36 | -144% | 0.04 |
| Ammonia | 0.016 | 0.030 | -86% | 0.19 |
| BOD | 0.900 | 0.387 | 57% | 0.25 |
| Copper | 0.001 | 0.002 | -55% | 0.23 |
| Lead | 0.0003 | 0.0003 | 0% | N/A |
| Zinc | 0.017 | 0.021 | -25% | 0.01 |
| Post-Restoration Conditions | | | | |
| Total N | 2.02 | 1.45 | 28% | <0.0001 |
| Total P | 0.032 | 0.012 | 62% | 0.30 |
| TSS | 3.48 | 4.17 | -20% | 0.58 |
| Ammonia | 0.141 | 0.058 | 59% | <0.0001 |
| BOD | 1.337 | 1.367 | -2% | 0.57 |
| Copper | 0.0005 | 0.0004 | 24% | 0.51 |
| Lead | 0.0001 | 0.00004 | 72% | 0.82 |
| Zinc | 0.014 | 0.020 | -43% | <0.0001 |

Note: For all pollutants, α = 0.05
N/A = not applicable

### 4.7.2 Subwatershed-level Evaluation of Pollutant Removal Efficiency

For this evaluation, average storm EMCs and baseflow MCs calculated during pre-restoration conditions were compared to those calculated during post-restoration conditions at each of the three monitoring stations to compute pollutant removal efficiency of restoration projects. The pollutant removal efficiency is a straightforward method to determine the net overall benefit of restoration projects in the contributing subwatershed to each station.

*Storm EMCs*

The average storm EMCs of pollutants during storm events captured during the pre-restoration period and post-restoration period at each station are provided in Table 4-13.

At Station WC002, EMCs of all parameters except ammonia and BOD were reduced from pre-restoration conditions. The reduction in lead was effectively 100%. The reductions in total nitrogen, total phosphorus, TSS, copper, and zinc were lower, at 3%, 9%, 38%, 10%, and 32%, respectively. Ammonia and BOD increased by 422% and 65% respectively, with the increase in ammonia being significant.

At Station WC003, stormflow total nitrogen, TSS, and zinc decreased between pre-restoration and post-restoration conditions by 11%, 11%, and 24%, respectively. Ammonia, BOD, copper, and lead increased between pre- and post-restoration phases, with ammonia and lead significant. Total phosphorus increased slightly by 0.4%.

At Station WC004, total nitrogen, total phosphorus, ammonia, and zinc decreased between pre-restoration and post-restoration conditions, by 17%, 5%, 18%, and 16%, respectively, with total nitrogen significant. TSS, BOD, copper, and lead increased by between 3% and 29% after completion of restoration activities.

*Baseflow MCs*

The average baseflow MCs of pollutants during pre-restoration conditions and post-restoration conditions at each station are provided in Table 4-14.

At Station WC002 baseflow MCs for total nitrogen, copper, lead, and zinc were reduced after completion of restoration projects in the contributing subwatershed by between 6% and 89%. The remaining parameters increased between pre-restoration and post-restoration by 8% for BOD, 157% for TSS, over six times for total phosphorus, and over 10 times for ammonia, with both TSS and ammonia significant.

At Station WC003, baseflow data show the restoration projects in the contributing subwatershed reduced pollutants by efficiencies ranging from 10% for zinc to 88% for lead. BOD dramatically increased by nearly four-fold, though not significantly. Ammonia increased by 110%.

At Station WC004, baseflow concentrations for six of eight parameters declined between pre-restoration and post-restoration conditions, with significant reductions for copper and zinc. Only TSS (258%) and BOD (52%) were greater during post-restoration than pre-restoration, with TSS significant.

Table 4-13. Pre- and Post-Restoration Average Storm EMCs (shaded cells indicate significant results)

| **Pollutant (mg/L)** | **Phase: Pre-Restoration** | **Phase: Post-Restoration** | **Percent Efficiency** | **t test p-value (two-tailed)** |
|---|---|---|---|---|
| Station WC002 | | | | |
| Total N | 1.59 | 1.54 | 3% | 0.79 |
| Total P | 0.104 | 0.095 | 9% | 0.72 |
| TSS | 46.84 | 29.13 | 38% | 0.18 |
| Ammonia | 0.017 | 0.090 | -422% | <0.0001 |
| BOD | 2.400 | 3.968 | -65% | 0.19 |
| Copper | 0.008 | 0.007 | 10% | 0.65 |
| Lead | 0.479 | 0.001 | 100% | 0.33 |
| Zinc | 0.043 | 0.029 | 32% | 0.07 |
| Station WC003 | | | | |
| Total N | 1.44 | 1.28 | 11% | 0.29 |
| Total P | 0.073 | 0.073 | -0.4% | 0.99 |
| TSS | 28.54 | 25.43 | 11% | 0.71 |
| Ammonia | 0.030 | 0.081 | -172% | 0.02 |
| BOD | 1.585 | 2.976 | -88% | 0.07 |
| Copper | 0.006 | 0.007 | -19% | 0.53 |
| Lead | 0.000 | 0.001 | N/A | <0.0001 |
| Zinc | 0.038 | 0.029 | 24% | 0.17 |
| Station WC004 | | | | |
| Total N | 1.55 | 1.29 | 17% | 0.04 |
| Total P | 0.068 | 0.064 | 5% | 0.67 |
| TSS | 18.42 | 21.50 | -17% | 0.37 |
| Ammonia | 0.093 | 0.077 | 18% | 0.44 |
| BOD | 2.536 | 3.273 | -29% | 0.20 |
| Copper | 0.007 | 0.007 | -6% | 0.63 |
| Lead | 0.001 | 0.001 | -3% | 0.91 |
| Zinc | 0.043 | 0.036 | 16% | 0.12 |

Note: For all pollutants, $\alpha = 0.05$
N/A = not applicable

Table 4-14. Pre- and Post-Restoration Average Baseflow MCs (shaded cells indicate significant results)

| Pollutant (mg/L) | Phase: Pre-Restoration | Phase: Post-Restoration | Percent Efficiency | t test p-value (two-tailed) |
|---|---|---|---|---|
| Station WC002 | | | | |
| Total N | 2.14 | 2.01 | 6% | 0.40 |
| Total P | 0.006 | 0.037 | -551% | 0.17 |
| TSS | 1.38 | 3.55 | -157% | 0.04 |
| Ammonia | 0.016 | 0.164 | -930% | <0.0001 |
| BOD | 0.900 | 0.972 | -8% | 0.89 |
| Copper | 0.001 | 0.0006 | 47% | 0.27 |
| Lead | 0.0003 | 0.00004 | 89% | 0.38 |
| Zinc | 0.017 | 0.014 | 19% | 0.33 |
| Station WC003 | | | | |
| Total N | 1.88 | 1.43 | 24% | 0.05 |
| Total P | 0.040 | 0.013 | 69% | 0.39 |
| TSS | 3.36 | 2.94 | 13% | 0.68 |
| Ammonia | 0.030 | 0.062 | -110% | 0.17 |
| BOD | 0.387 | 1.481 | -282% | 0.28 |
| Copper | 0.002 | 0.0004 | 74% | 0.07 |
| Lead | 0.0003 | 0.00004 | 88% | 0.39 |
| Zinc | 0.021 | 0.019 | 10% | 0.67 |
| Station WC004 | | | | |
| Total N | 3.49 | 3.23 | 8% | 0.19 |
| Total P | 0.017 | 0.011 | 34% | 0.51 |
| TSS | 0.66 | 2.35 | -258% | 0.04 |
| Ammonia | 0.052 | 0.020 | 62% | 0.11 |
| BOD | 0.353 | 0.535 | -52% | 0.58 |
| Copper | 0.002 | 0.0005 | 70% | 0.0003 |
| Lead | 0.0002 | 0.00009 | 50% | 0.36 |
| Zinc | 0.037 | 0.022 | 40% | 0.004 |

Note: For all pollutants, $\alpha = 0.05$
N/A = not applicable

## 4.8 LONG-TERM TREND ANALYSIS OF WATER CHEMISTRY DATA

The time-series statistical tests performed on baseflow concentration and individual storm EMC data collected showed significant, downward trends for both baseflow and storm flow nitrate plus nitrite and zinc at all stations. Additional constituents that significantly decreased included stormflow TSS at Station WC002 and baseflow copper at Station WC004. Constituents that significantly increased over time were the following: baseflow TSS at Stations WC002 and WC004, baseflow ammonia at all stations, stormflow ammonia at Stations WC002 and WC003, baseflow TKN at all stations, stormflow TKN at Stations WC003 and WC004, baseflow lead at Station WC004, and baseflow total phosphorus at all stations. Overall, the results were mixed, with 25 of the 54 EMCs and MCs examined under all flow conditions at all stations becoming lower over time. Reductions in 14 of the 25 decreasing EMCs and MCs were significant; significant upward trends were found in 17 of the 29 increasing EMCs and MCs. A summary of statistical test results for indicator parameters is presented in Table 4-15.

The reduction at all stations and flow types, much of it significant, for nitrate plus nitrite, copper, and zinc over time, occurred despite the reduction in detection limits by the analytical laboratory. A reduction in detection limits would potentially cause upward-trending data due to less non-detectible results, which are treated as zero in the data analysis in this report. Downward trending metals concentrations during baseflow conditions were in opposition to upward trending TSS concentrations during baseflow, which may be due to effects of changes in detection limits for some samples.

Table 4-15. Results and p values of Kendall's Tau-b significance tests for indicator parameters (2010-FY2023)

| Parameter | WC002 | | WC003 | | WC004 | |
|---|---|---|---|---|---|---|
| | Storm | Baseflow | Storm | Baseflow | Storm | Baseflow |
| Nitrate + Nitrite | 0.0003 (-) | < 0.0001 (-) | < 0.0001 (-) | < 0.0001 (-) | < 0.0001 (-) | 0.0009 (-) |
| Total Kjeldahl Nitrogen | N.S. | < 0.0001 (+) | 0.0116 (+) | < 0.0001 (+) | 0.0035 (+) | < 0.0001 (+) |
| Total Phosphorus | N.S. | < 0.0001 (+) | N.S. | < 0.0001 (+) | N.S. | 0.0001 (+) |
| TSS | 0.0152 (-) | < 0.0001 (+) | N.S. | N.S. | N.S. | 0.0016 (+) |
| Ammonia | 0.0002 (+) | < 0.0001 (+) | 0.0453 (+) | < 0.0001 (+) | N.S. | 0.0299 (+) |
| BOD | N.S. | N.S. | N.S. | 0.0318 (+) | N.S. | N.S. |
| Copper | N.S. | N.S. | N.S. | N.S. | N.S. | 0.0312 (-) |
| Lead | N.S. | N.S. | N.S. | N.S. | N.S. | 0.0271 (+) |
| Zinc | < 0.0001 (-) | < 0.0001 (-) | 0.0009 (-) | 0.0001 (-) | 0.0297 (-) | 0.0163 (-) |

Positive (+) symbols or orange shading indicate an increasing trend over time; negative (-) symbols or green shading indicate a decreasing trend over time
N.S. = not significant

# 5.0 CONCLUSIONS

In a cooperative effort, Harford County DPW, Versar, and USGS conducted water chemistry and long-term flow monitoring in the Wheel Creek watershed from July 1, 2022 through June 30, 2023. The monitoring effort included twelve baseflow sampling and eight wet weather sampling events, four of the eight storm events with suspended sediment transport sampling. Baseflow and stormflow monitoring consisted of sampling for suspended solids, copper, lead, zinc, BOD, ammonia, nitrate plus nitrite, chloride, orthophosphate, total phosphorous, TKN, turbidity, hardness, TPH, and *E. coli*.

## 5.1 SUMMARY OF MONITORING RESULTS

Federal and State reference values for certain nutrients were exceeded on several occasions, confirming detrimental stream chemistry impacts from development and changes in land use. Total nitrogen, calculated from the sum of nitrate plus nitrite and TKN, was present at concentrations exceeding the EPA reference values (0.69 mg/L) for both baseflow and stormflow in all detected samples. For total phosphorus, 2.9% of the detectible results in baseflow samples and 76.4% of the detectible results in stormflow samples were found to be above the corresponding EPA reference concentration (0.03656 mg/L). No reported chloride concentrations in stormflow samples exceeded the EPA acute criterion (860 mg/L), while 30.6% of baseflow samples exceeded the chronic criterion for chloride (230 mg/L). All baseflow samples that exceeded the chronic criterion for chloride were collected at Station WC004.

All baseflow samples had detectable amounts of zinc but none exceeded the MDE chronic surface water criterion (120 µg/L). Of the stormflow samples, all samples had detectable concentrations of zinc, but none exceeded the MDE acute criterion (120 µg/L). All lead concentrations fell below the MDE acute criterion (65 µg/L) for stormflow and the chronic criterion (2.5 µg/L) for baseflow during this monitoring period. Copper concentrations exceeded the MDE chronic criterion (9 µg/L) in one baseflow sample (November 22, 2022), while 5.6% of stormflow samples exceeded the acute criterion (13 µg/L).

*E. coli* bacteria concentrations were detected in all baseflow samples at all stations, ranging in concentration from 2.0 to 1,550.0 MPN/100ml. *E. coli* concentrations were equal to or greater than the maximum reportable result in 45.8% of stormflow grab samples, up from 18.5% in the FY2022 monitoring period. TPH was not detected above the reporting limit in any of the stormflow grab samples but was detected in one baseflow grab sample (2.8%) collected at Station WC003 on December 8, 2022.

Average baseflow concentrations of combined nitrate plus nitrite, orthophosphate, chloride, lead, and zinc were highest at Station WC004 compared to the other two stations downstream. Samples collected at Station WC003 had the highest average concentrations of TSS, TPH, and *E. coli* during baseflow conditions, while Station WC002 samples had the highest average concentrations of BOD, ammonia, orthophosphate, TKN, total phosphorus, and copper during baseflow conditions. Under stormflow conditions, average EMCs were highest at Station WC004 for ammonia, TKN, TSS, chloride, copper, lead, and zinc. Average EMCs for combined

BOD, nitrate plus nitrite, orthophosphate, total phosphorus, and *E. coli* were highest at Station WC002. At Station WC003, no pollutant EMCs were higher than the other stations. TPH was not recorded in any of the stormflow samples. Average EMCs of all pollutants at all stations were lower than Maryland and national average values.

All average stormflow loads were highest at Station WC002 and, with the exception of ammonia, lowest at Station WC004 for all parameters; stormflow load for ammonia was higher at Station WC003 than Station WC004 during the FY2023 monitoring period. Since discharge volume for a given storm increases with distance downstream, maximum load results at Station WC002 are expected.

Suspended sediment transport showed a low correlation with discharge at all three stations (Station WC002, $r^2$ = 0.239, Station WC003, $r^2$ = 0.365; Station WC004, $r^2$ = 0.159); due to low historical and current correlations found with suspended sediment samples and discharge, Versar and County managers discontinued this monitoring at the end of calendar year 2022.

## 5.2 SUMMARY OF RESTORATION EFFECTIVENESS

Comparisons of pre-restoration and post-restoration pollutant load and concentration data were performed to determine the benefit to watershed conditions as a result of the implementation of the several restoration projects. Restoration activity initiated in late summer 2012 and concluded in spring 2017, allowing a post-restoration collection of data to be accumulated. Subwatershed-level and total watershed benefits were evaluated by comparing concentration and loading data from specific stations during applicable pre-restoration and post-restoration timelines for projects within the catchments of those stations.

Comparing ratios of average concentrations and loads at Stations WC003 and WC002, determined first under pre-restoration conditions and then under post-restoration conditions, produced mixed results. Comparisons of total annual load ratios indicated that total phosphorus, TSS, BOD, copper, lead, and zinc were reduced by restoration. Concentration ratio results suggest that the restoration in the contributing subwatersheds has reduced total phosphorus, TSS, BOD, copper, lead, and zinc in the contributing drainage between Stations WC002 and WC003 under stormflow conditions. Under baseflow concentrations, only BOD and zinc showed improvement in terms of lowering percentage differences between the upstream and downstream stations.

Directly comparing both storm event and baseflow post-restoration concentrations to pre-restoration concentrations showed that at Station WC002, storm EMCs of total nitrogen, total phosphorus, TSS, copper, lead, and zinc were reduced from pre-restoration conditions. At Station WC003, stormflow total nitrogen, TSS, and zinc decreased between pre-restoration and post-restoration conditions. At Station WC004, total nitrogen, total phosphorus, ammonia, and zinc decreased between pre-restoration and post-restoration conditions. At Station WC002, baseflow total nitrogen, copper, lead, and zinc MCs were reduced after completion of restoration projects in the contributing subwatershed. At Station WC003, baseflow concentration data show the restoration projects in the contributing subwatershed reduced total nitrogen, total phosphorus, TSS, copper, lead, and zinc. At Station WC004, baseflow efficiency results showed that total nitrogen, total phosphorus, ammonia, copper, lead, and zinc were reduced between pre-restoration conditions and post-restoration. A summary of the results of tests of restoration effectiveness is provided in Table 5-1.

Table 5-1. Results of tests of restoration effectiveness (bullets indicate pollutant reduction between post- and pre-restoration conditions, shaded cells indicate significant results)

| Analysis Type | Target Sub-watershed | Parameter | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | BOD | Ammonia | Total P | TSS | Total N | Copper | Lead | Zinc |
| Ratio Loads | WC002 below WC003 | ● | | ● | ● | | ● | ● | ● |
| Ratio EMC | WC002 below WC003 | ● | | ● | ● | | ● | ● | ● |
| Ratio MC | WC002 below WC003 | ● | | | | | | | ● |
| Before After EMC | WC002 | | | ● | ● | ● | ● | ● | ● |
| Before After EMC | WC003 | | | | ● | ● | | | ● |
| Before After EMC | WC004 | | ● | ● | | ● | | | ● |
| Before After MC | WC002 | | | | | ● | ● | ● | ● |
| Before After MC | WC003 | | | ● | ● | ● | ● | ● | ● |
| Before After MC | WC004 | | ● | ● | | ● | ● | ● | ● |

The time-series statistical test performed on baseflow concentration and individual storm EMC data collected showed significant, downward trends for both baseflow and storm flow nitrate plus nitrite and zinc at all stations. Additional constituents that significantly decreased included stormflow TSS at Station WC002 and baseflow copper at Station WC004. Constituents that significantly increased over time were the following: baseflow TSS at Stations WC002 and WC004, baseflow ammonia at all stations, stormflow ammonia at Stations WC002 and WC003, baseflow TKN at all stations, stormflow TKN at Stations WC003 and WC004, baseflow lead at Station WC004, and baseflow total phosphorus at all stations. During the post-restoration period, the number of parameters trending downward (i.e., improving pollutant concentrations) has gradually increased over time and parameters trending significantly downward has increased year over year (Figure 5-1). The number of upward-trending (i.e., worsening pollutant concentrations) parameters has generally decreased while the number of significantly upward-trending parameters has only slightly increased since FY2018. While the increasing number of significantly trending parameters indicates data consistency, it can be argued that the continual increase in number of significantly downward trending parameters indicates effectiveness of the restoration projects is gradually improving over time.

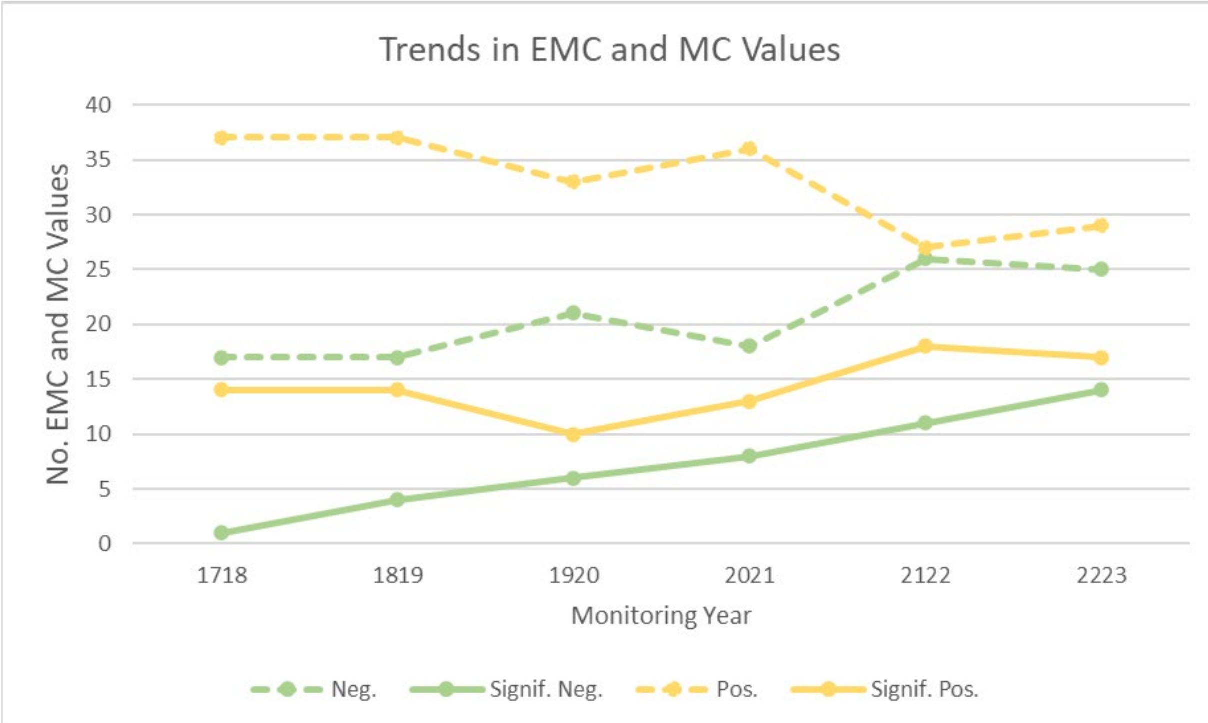


Figure 5-1. Time series plot of trend categories, FY2018 to FY2023

Time series plots of annual average EMCs and MCs for most parameters show continuing stabilization or apparent, downward short-term trends in TSS, copper, lead, zinc, BOD, and nitrate plus nitrite during the period after FY2017 and FY2018 to present. The timing of the above short-term concentration trends is coincident with the post-restoration period and a cause-and-effect relationship can be inferred between restoration completion and lowering concentrations. Exceptions to the above short-term trends include ammonia and TKN, which during the past four monitoring years have been generally trending higher, more consistently for baseflow MCs. Since ammonia is a component of TKN, an increase in ammonia would likely cause a corresponding increase in TKN. However, during FY2023, annual average ammonia EMCs and MCs at all stations fell by more than 60% and 50%, respectively; TKN values at most stations and flow conditions also fell, but not as precipitously. Annual baseflow TKN values continued to remain high, indicating the presence of a persistent organic nitrogen component in the watershed. Total phosphorus continued to demonstrate inter-annual variability but with no discernible trend.

Results of comparisons of post-restoration to pre-restoration concentrations show that effectiveness was roughly evenly distributed amongst the three stations, and mostly reflected in baseflow conditions (Table 5-1). When comparing ratios of concentrations at Stations WC002 and WC003 to isolate restoration work in contributing watersheds between the two stations, concentrations in storm runoff have been reduced for eight of 16 parameters. The results of analysis of ratios of loads show benefits in six of eight parameters. Annual EMCs and MCs were reduced between pre-restoration and post-restoration conditions for 29 of 48 parameters. Since the first full year of post-restoration monitoring in FY2018, the number of parameters that showed pollutant reductions amongst all the restoration effectiveness tests described above has gradually increased but stabilized in FY2023 at 43 out of a possible 72. Between FY2022 and FY2023, no additional parameters showed pollutant reductions, indicating reinforcement of established restoration effectiveness results. Note that zinc showed reductions for all nine tests. Overall, the results indicate that the restoration projects are performing as intended for most parameters.

An analysis of the effects of the change in analytical laboratory during FY2019 on the prevalence of censored results and their impact on apparent restoration effectiveness has not been conducted. The Wheel Creek Watershed comprehensive report will present a substitution method to potentially reduce bias introduced by using a value of zero for censored data, as has been employed for analyses of these data in annual reports. Additional statistical analysis methods will also be applied to the monitoring data to confirm the results of restoration effectiveness.

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# 6.0 REFERENCES

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# APPENDIX A

## STORM EVENT SUMMARY REPORTS

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# WHEEL CREEK STORM MONITORING SUMMARY REPORT

*AUGUST 21-23, 2022*

## INTRODUCTION

Versar field staff traveled to the site on August 21 to program the SIGMA automated samplers to sample the event. Rainfall initiated at approximately 8:52 p.m. the evening of Sunday, August 21. At the Wheel Creek Rain Gauge Station, 4.75 inches of rain was recorded for the duration of the storm.

On the afternoon of August 22, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the peak limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on August 24 to composite automated samples. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on August 24 for analysis. Siphon samples were delivered to Enviro-Chem Laboratories for analysis of SSC on August 24, 2022.

## RESULTS

Hydrographs for the August 21-23 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the August 21-23 event are shown in Table A-5.

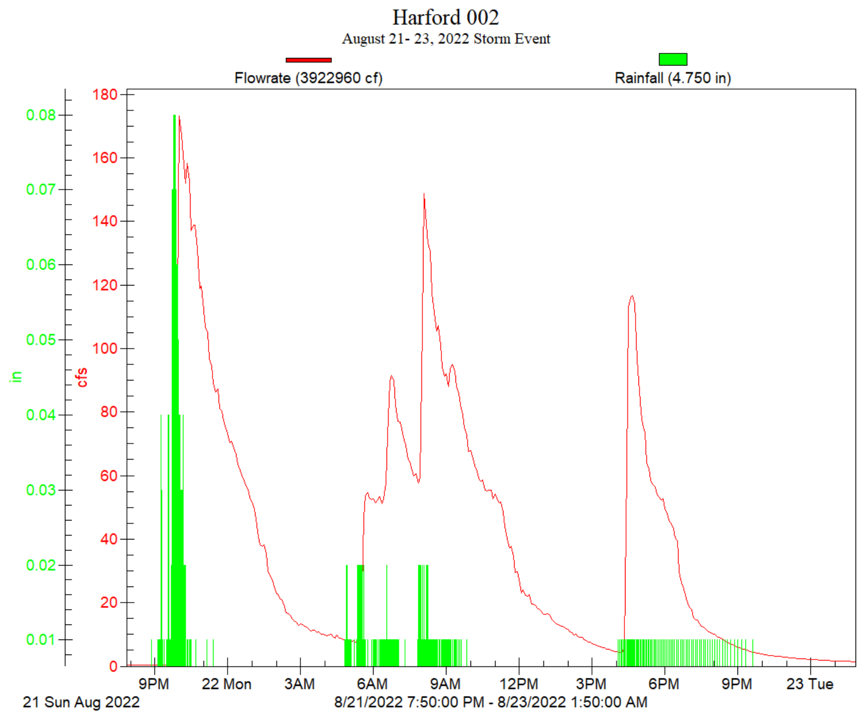


Figure A-1. Hydrograph at Station WC002 for August 21-23, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

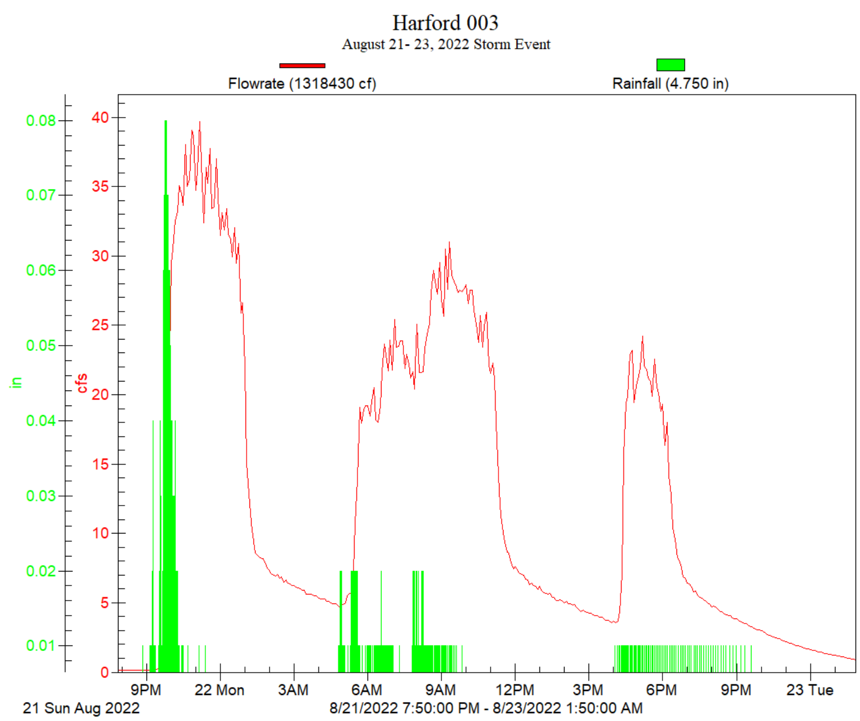


Figure A-2. Hydrograph at Station WC003 for August 21-23, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

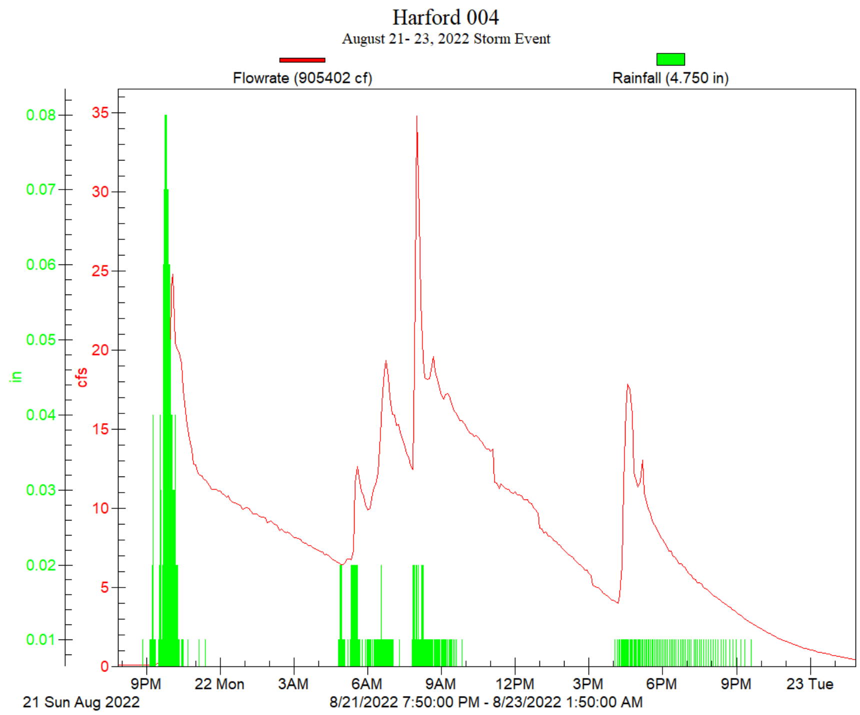


Figure A-3. Hydrograph at Station WC004 for August 21-23, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

| Constituent | 24-Aug-2022 | | |
|---|---|---|---|
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | 5.0 | 3.0 | 3.0 |
| Nitrate-Nitrite Nitrogen | 0.5 | 0.4 | 0.4 |
| Orthophosphate Phosphorus | 0.04 | <0.05 | 0.03 |
| Solids (Suspended) | 41.0 | 17.0 | 10.0 |
| Copper | 0.013 | 0.011 | 0.006 |
| Lead | 0.0010 | 0.0009 | 0.0007 |
| Zinc | 0.026 | 0.022 | 0.020 |
| Ammonia Nitrogen | 0.17 | <0.30 | 0.25 |
| Kjeldahl Nitrogen (Total) | 1.0 | 0.8 | 1.1 |
| Total Phosphorus | 0.180 | 0.080 | 0.100 |
| Hardness | 54.0 | 70.0 | 64.0 |
| Chloride | 34.4 | 36.9 | 50.8 |
| pH | 6.92 | 6.97 | 6.85 |

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb

| Constituent | 24-Aug-2022 | | |
|---|---|---|---|
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | 2.0 | 2.0 | 2.0 |
| Nitrate-Nitrite Nitrogen | 0.4 | 0.3 | 0.3 |
| Orthophosphate Phosphorus | 0.03 | 0.02 | 0.02 |
| Solids (Suspended) | 8.0 | 13.0 | 5.0 |
| Copper | 0.007 | 0.006 | 0.003 |
| Lead | 0.0003 | 0.0004 | 0.0003 |
| Zinc | 0.008 | 0.010 | 0.015 |
| Ammonia Nitrogen | 0.06 | <0.30 | <0.30 |
| Kjeldahl Nitrogen (Total) | 0.7 | 0.6 | 0.8 |
| Total Phosphorus | 0.070 | 0.050 | 0.050 |
| Hardness | 22.0 | 36.0 | 30.0 |
| Chloride | <50.0 | 15.7 | <25.0 |
| pH | 7.03 | 7.02 | 7.05 |

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb

| Constituent | 24-Aug-2022 | | |
|---|---|---|---|
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | 2.0 | 2.0 | 2.0 |
| Nitrate-Nitrite Nitrogen | 0.4 | 0.4 | 0.2 |
| Orthophosphate Phosphorus | 0.03 | 0.02 | 0.02 |
| Solids (Suspended) | 7.0 | 3.0 | 3.0 |
| Copper | 0.008 | 0.007 | 0.004 |
| Lead | <0.0010 | <0.0010 | <0.0010 |
| Zinc | 0.010 | 0.010 | 0.014 |
| Ammonia Nitrogen | 0.08 | <0.30 | 0.07 |
| Kjeldahl Nitrogen (Total) | 0.7 | 0.7 | 0.7 |
| Total Phosphorus | 0.070 | 0.060 | 0.040 |
| Hardness | 32.0 | 28.0 | 36.0 |
| Chloride | <25.0 | 16.2 | 27.0 |
| pH | 7.01 | 6.99 | 6.89 |

| Table A-4. Analytical Results – Wheel Creek Grab Sampling | | | |
|---|---|---|---|
| **Constituent** | **Station WC002** | **Station WC003** | **Station WC004** |
| August 24, 2022 (Peak) | | | |
| TPH (mg/L) | <5.0 | <5.0 | <5.0 |
| *E. coli* (MPN/100 ml) | >2420.0 | >2420.0 | 1730.0 |
| Temp (C) | 23.10 | 23.00 | 22.70 |
| DO (mg/L) | 8.97 | 8.40 | 8.04 |
| pH | 7.10 | 6.81 | 6.72 |
| Sp. Cond. (mS/cm) | 0.079 | 0.082 | 0.050 |

| Table A-5. Rainfall and flow statistics | | | |
|---|---|---|---|
| **Constituent** | **Station WC002** | **Station WC003** | **Station WC004** |
| Rainfall (in.) | 4.75 | 4.75 | 4.75 |
| Duration (hrs.) | 30 | 30 | 30 |
| Intensity (in./hr.) | 0.1583 | 0.1583 | 0.1583 |
| Discharge (cf.) | 3,922,960 | 1,318,430 | 905,402 |

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# WHEEL CREEK STORM MONITORING SUMMARY REPORT

*SEPTEMBER 5-6, 2022*

## INTRODUCTION

Versar field staff traveled to the site on September 5 to deploy siphon samplers and program the SIGMA automated samplers to sample the event. Rainfall initiated at approximately 11:19 p.m. the evening of Monday, September 5. At the Wheel Creek Rain Gauge Station, 1.97 inches of rain was recorded for the duration of the storm.

On the morning of September 6, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the peak limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on September 7 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were delivered to Enviro-Chem Laboratories for analysis of SSC on September 13. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on September 7.

## RESULTS

Hydrographs for the September 5-6 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the September 5-6 event are shown in Table A-5.

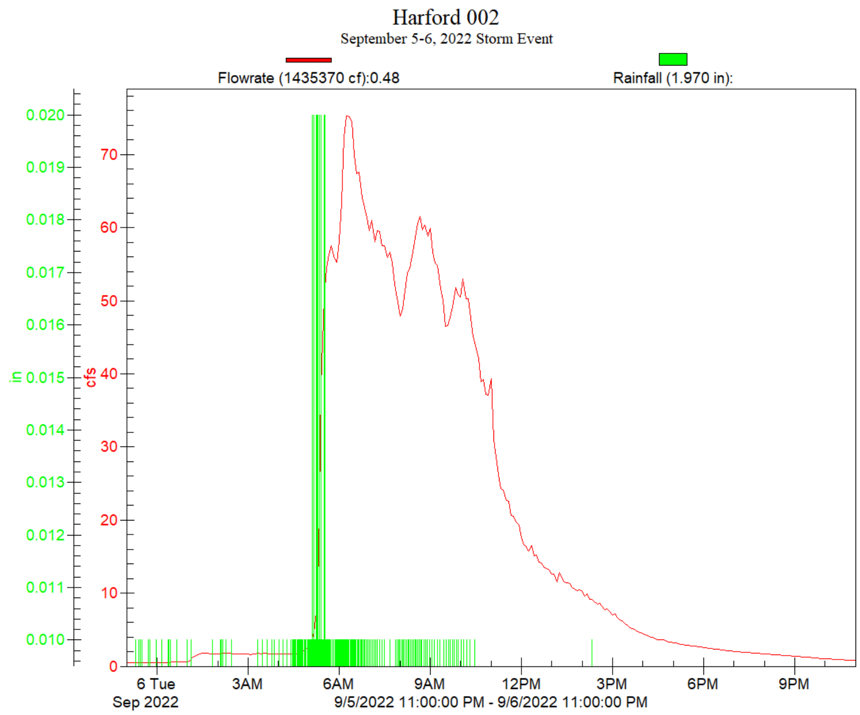


Figure A-1. Hydrograph at Station WC002 for September 5-6, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

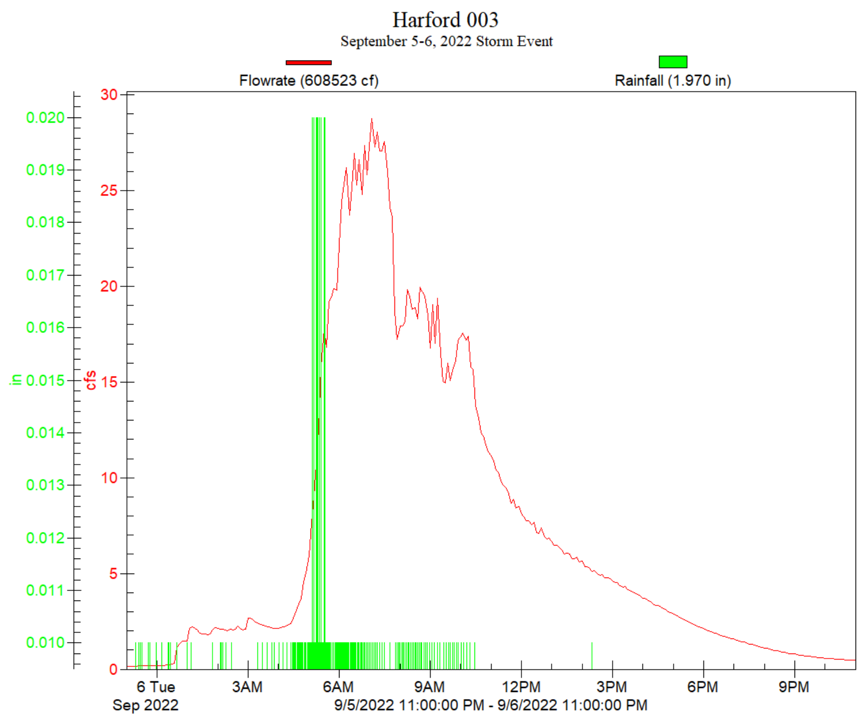


Figure A-2. Hydrograph at Station WC003 for September 5-6, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

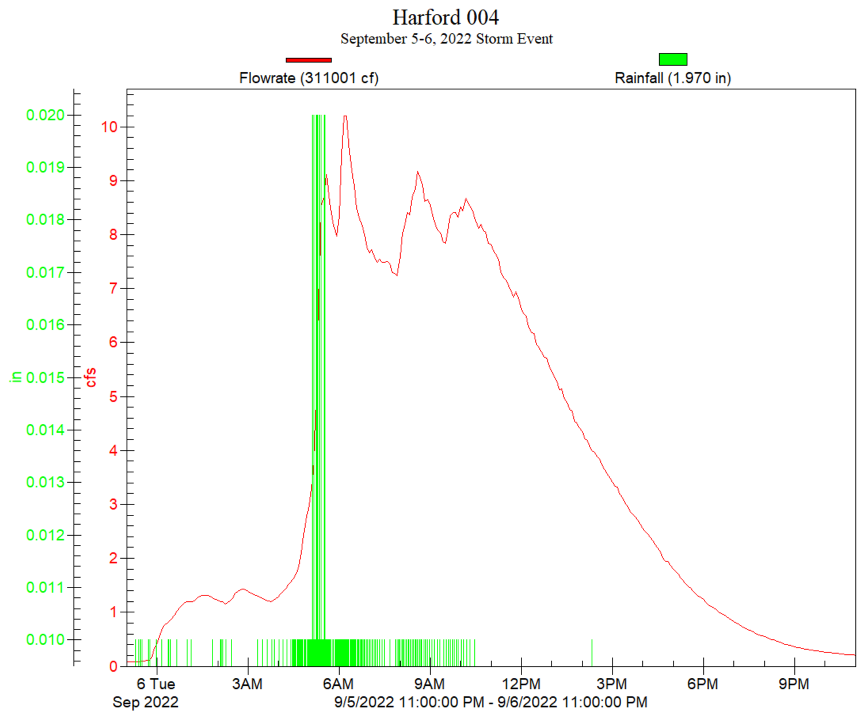


Figure A-3. Hydrograph at Station WC004 for September 5-6, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

| Constituent | 7-Sep-2022 | | |
|---|---|---|---|
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | <1.0 | 1.0 | 3.0 |
| Nitrate-Nitrite Nitrogen | 1.1 | 0.7 | 0.7 |
| Orthophosphate Phosphorus | 0.01 | 0.02 | 0.02 |
| Solids (Suspended) | <2.0 | 9.0 | 14.0 |
| Copper | 0.002 | 0.003 | 0.011 |
| Lead | <0.0010 | <0.0010 | 0.0010 |
| Zinc | 0.007 | 0.010 | 0.059 |
| Ammonia Nitrogen | 0.08 | <0.30 | 0.07 |
| Kjeldahl Nitrogen (Total) | 0.5 | 0.5 | 1.2 |
| Total Phosphorus | 0.020 | 0.030 | 0.100 |
| Hardness | 180.0 | 196.0 | 176.0 |
| Chloride | 136.0 | 162.0 | 104.0 |
| pH | 7.08 | 7.10 | 6.74 |

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb

| Constituent | 7-Sep-2022 Station WC002 (mg/L) | 7-Sep-2022 Station WC003 (mg/L) | 7-Sep-2022 Station WC004 (mg/L) |
|---|---|---|---|
| 5-Day BOD | 3.0 | 2.0 | 2.0 |
| Nitrate-Nitrite Nitrogen | 0.4 | 0.3 | 0.2 |
| Orthophosphate Phosphorus | 0.04 | 0.03 | 0.02 |
| Solids (Suspended) | 23.0 | 20.0 | 11.0 |
| Copper | 0.006 | 0.006 | 0.007 |
| Lead | 0.0007 | 0.0006 | 0.0007 |
| Zinc | 0.015 | 0.014 | 0.021 |
| Ammonia Nitrogen | <0.30 | <0.30 | <0.30 |
| Kjeldahl Nitrogen (Total) | 0.8 | 0.8 | 0.7 |
| Total Phosphorus | 0.110 | 0.130 | 0.060 |
| Hardness | 36.0 | 48.0 | 32.0 |
| Chloride | 12.8 | 19.0 | <25.0 |
| pH | 7.19 | 7.26 | 7.07 |

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb

| Constituent | 7-Sep-2022 Station WC002 (mg/L) | 7-Sep-2022 Station WC003 (mg/L) | 7-Sep-2022 Station WC004 (mg/L) |
|---|---|---|---|
| 5-Day BOD | 2.0 | 2.0 | 2.0 |
| Nitrate-Nitrite Nitrogen | 0.4 | 0.2 | 0.2 |
| Orthophosphate Phosphorus | 0.04 | 0.02 | 0.02 |
| Solids (Suspended) | 14.0 | 6.0 | 7.0 |
| Copper | 0.004 | 0.006 | 0.004 |
| Lead | 0.0004 | 0.0003 | 0.0003 |
| Zinc | 0.016 | 0.010 | 0.023 |
| Ammonia Nitrogen | 0.11 | <0.30 | <0.30 |
| Kjeldahl Nitrogen (Total) | 0.8 | 0.6 | 0.6 |
| Total Phosphorus | 0.100 | 0.060 | 0.060 |
| Hardness | 52.0 | 64.0 | 56.0 |
| Chloride | 23.5 | 24.7 | 33.0 |
| pH | 6.99 | 7.16 | 6.80 |

| Table A-4. Analytical Results – Wheel Creek Grab Sampling | | | |
|---|---|---|---|
| **Constituent** | **Station WC002** | **Station WC003** | **Station WC004** |
| September 7, 2022 (Peak) | | | |
| TPH (mg/L) | <5.0 | <5.0 | <5.0 |
| *E. coli* (MPN/100 ml) | >2420.0 | >2420.0 | >2420.0 |
| Temp (C) | 22.40 | 22.30 | 22.60 |
| DO (mg/L) | 8.34 | 8.24 | 8.53 |
| pH | 6.75 | 6.87 | 7.08 |
| Sp. Cond. (mS/cm) | 0.077 | 0.092 | 0.048 |

| Table A-5. Rainfall and flow statistics | | | |
|---|---|---|---|
| **Constituent** | **Station WC002** | **Station WC003** | **Station WC004** |
| Rainfall (in.) | 1.97 | 1.97 | 1.97 |
| Duration (hrs.) | 24 | 24 | 24 |
| Intensity (in./hr.) | 0.0821 | 0.0821 | 0.0821 |
| Discharge (cf.) | 1,435,370 | 608,523 | 311,001 |

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# Wheel Creek Storm Monitoring Summary Report
*October 13-14, 2022*

## INTRODUCTION

Versar field staff traveled to the site on October 13 to deploy siphon samplers and program the SIGMA automated samplers to sample the event. Rainfall initiated at approximately 5:54 a.m. the morning of Thursday, October 13. At the Wheel Creek Rain Gauge Station, 0.91 inches of rain was recorded for the duration of the storm.

On the morning of October 13, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the rising limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection. A rising limb grab sample was also obtained by the Versar field crew at all stations to accommodate for potential low volume samples due to the rapid increase in stream discharge and truncated period of rising flow before the peak. Grabs were used in the composite.

Field staff traveled to the sites on October 14, to composite automated and suspended sediment concentration samples (SSC). Siphon samples were delivered to Enviro-Chem Laboratories for analysis of SSC on October 14. Composite samples, including TPH samples were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on October 14.

The following problems occurred during the storm event:

Versar staff re-calibrated the SIGMA automated sampler at the Harford 003 station before programming for the storm due to a lack of volume being pulled through the tubing to the sampler bottles.

## RESULTS

Hydrographs for the October 13-14 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the October 13-14 storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the event are shown in Table A-5.

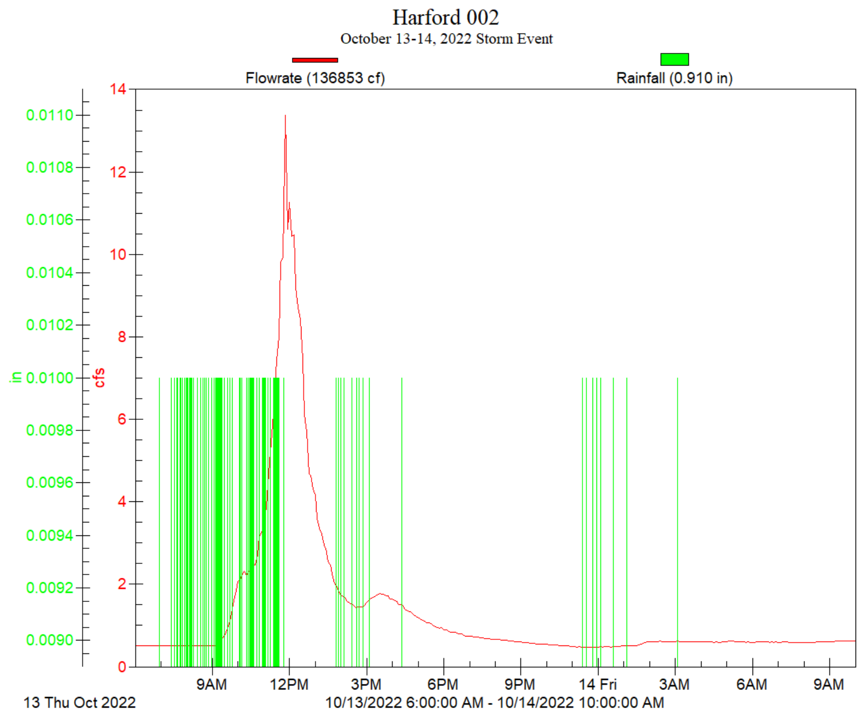


Figure A-1. Hydrograph at Station WC002 for October 13-14, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

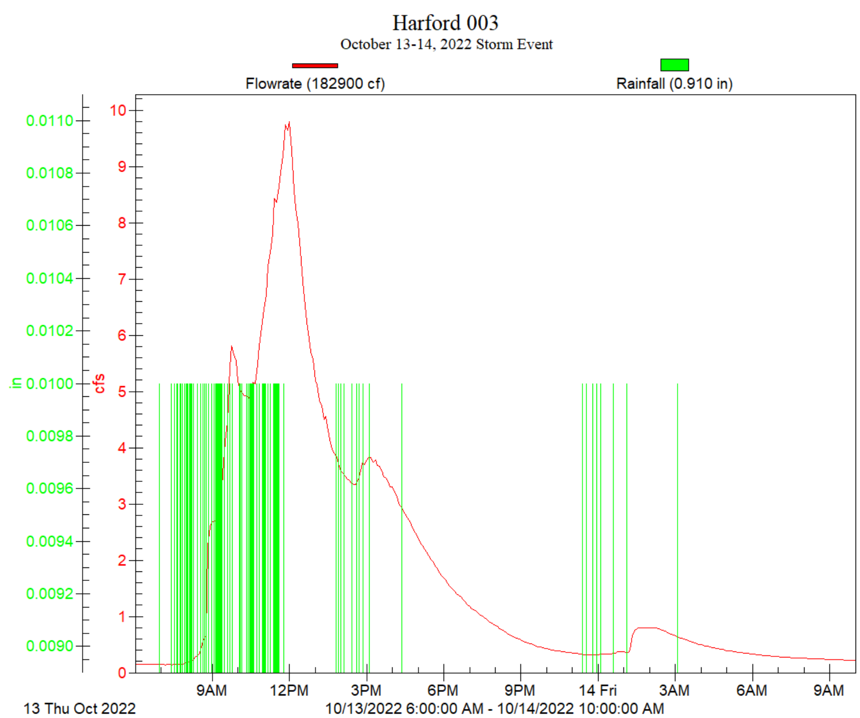


Figure A-2. Hydrograph at Station WC003 for October 13-14, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

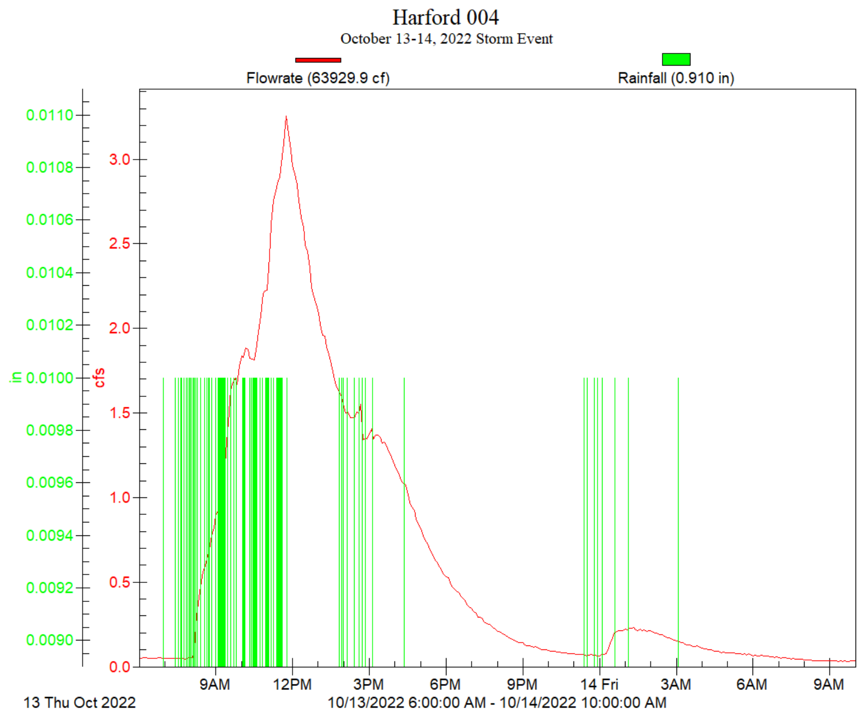


Figure A-3. Hydrograph at Station WC004 for October 13-14, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

| Constituent | 14-Oct-2022 | | |
|---|---|---|---|
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | <2.0 | 6.4 | <2.0 |
| Nitrate-Nitrite Nitrogen | 1.3 | 0.9 | 2.9 |
| Orthophosphate Phosphorus | 0.03 | 0.04 | <0.02 |
| Solids (Suspended) | <4.0 | 41.5 | <4.0 |
| Copper | <0.002 | 0.002 | <0.002 |
| Lead | <0.0010 | 0.0006 | <0.0010 |
| Zinc | 0.007 | 0.025 | 0.020 |
| Ammonia Nitrogen | 0.07 | <0.30 | <0.30 |
| Kjeldahl Nitrogen (Total) | 0.5 | 0.6 | 0.5 |
| Total Phosphorus | 0.006 | 0.050 | 0.020 |
| Hardness | 156.0 | 184.0 | 326.0 |
| Chloride | 137.0 | 168.0 | 346.0 |
| pH | 6.96 | 6.98 | 6.92 |

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb

| Constituent | 14-Oct-2022 | | |
|---|---|---|---|
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | 4.0 | 2.9 | 2.1 |
| Nitrate-Nitrite Nitrogen | 0.3 | 0.3 | 0.2 |
| Orthophosphate Phosphorus | 0.03 | <0.02 | 0.04 |
| Solids (Suspended) | 22.5 | 21.5 | 13.6 |
| Copper | 0.007 | 0.007 | 0.006 |
| Lead | 0.0007 | 0.0008 | 0.0008 |
| Zinc | 0.017 | 0.019 | 0.025 |
| Ammonia Nitrogen | <0.30 | <0.30 | <0.30 |
| Kjeldahl Nitrogen (Total) | 0.8 | 0.9 | 0.9 |
| Total Phosphorus | 0.100 | 0.090 | 0.070 |
| Hardness | 36.0 | 48.0 | 30.0 |
| Chloride | 19.0 | 33.6 | 14.9 |
| pH | 7.09 | 7.19 | 7.16 |

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb

| Constituent | 14-Oct-2022 | | |
|---|---|---|---|
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | 2.0 | 2.0 | 2.0 |
| Nitrate-Nitrite Nitrogen | 0.4 | 0.4 | 0.6 |
| Orthophosphate Phosphorus | 0.04 | <0.02 | <0.02 |
| Solids (Suspended) | 5.0 | 4.8 | 4.0 |
| Copper | 0.004 | 0.004 | 0.004 |
| Lead | 0.0003 | 0.0003 | 0.0003 |
| Zinc | 0.010 | 0.010 | 0.019 |
| Ammonia Nitrogen | <0.30 | <0.30 | <0.30 |
| Kjeldahl Nitrogen (Total) | 0.7 | 0.7 | 0.7 |
| Total Phosphorus | 0.060 | 0.040 | 0.040 |
| Hardness | 52.0 | 68.0 | 70.0 |
| Chloride | 30.8 | 49.0 | 64.5 |
| pH | 7.04 | 7.10 | 6.94 |

| Table A-4. Analytical Results – Wheel Creek Grab Sampling | | | |
|---|---|---|---|
| **Constituent** | **Station WC002** | **Station WC003** | **Station WC004** |
| October 14, 2022 (Rising) | | | |
| TPH (mg/L) | <5.0 | <5.0 | <5.0 |
| *E. coli* (MPN/100 ml) | 1550.0 | 276.0 | 435.0 |
| Temp (C) | 14.50 | 14.70 | 15.40 |
| DO (mg/L) | 9.40 | 9.28 | 8.30 |
| pH | 7.24 | 7.12 | 6.96 |
| Sp. Cond. (mS/cm) | 0.539 | 0.611 | 1.221 |

| Table A-5. Rainfall and flow statistics | | | |
|---|---|---|---|
| **Constituent** | **Station WC002** | **Station WC003** | **Station WC004** |
| Rainfall (in.) | 0.91 | 0.91 | 0.91 |
| Duration (hrs.) | 28 | 28 | 28 |
| Intensity (in./hr.) | 0.0325 | 0.0325 | 0.0325 |
| Discharge (cf.) | 136,853 | 182,900 | 63,929 |

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# WHEEL CREEK STORM MONITORING SUMMARY REPORT

*NOVEMBER 30-DECEMBER 1, 2022*

## INTRODUCTION

Versar field staff traveled to the site on November 29 to deploy siphon samplers and program the SIGMA automated samplers to sample the event. Rainfall initiated at approximately 6:45 am the morning of Friday, November 30. At the Wheel Creek Rain Gauge Station, 0.31 inches of rain was recorded for the duration of the storm.

On the morning of November 30, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the rising limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on December 1 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were delivered to Enviro-Chem Laboratories for analysis of SSC on December 1. Composite samples including THP were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on December 1.

## RESULTS

Hydrographs for the November 30-December 1 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the November 30-December 1 event are shown in Table A-5.

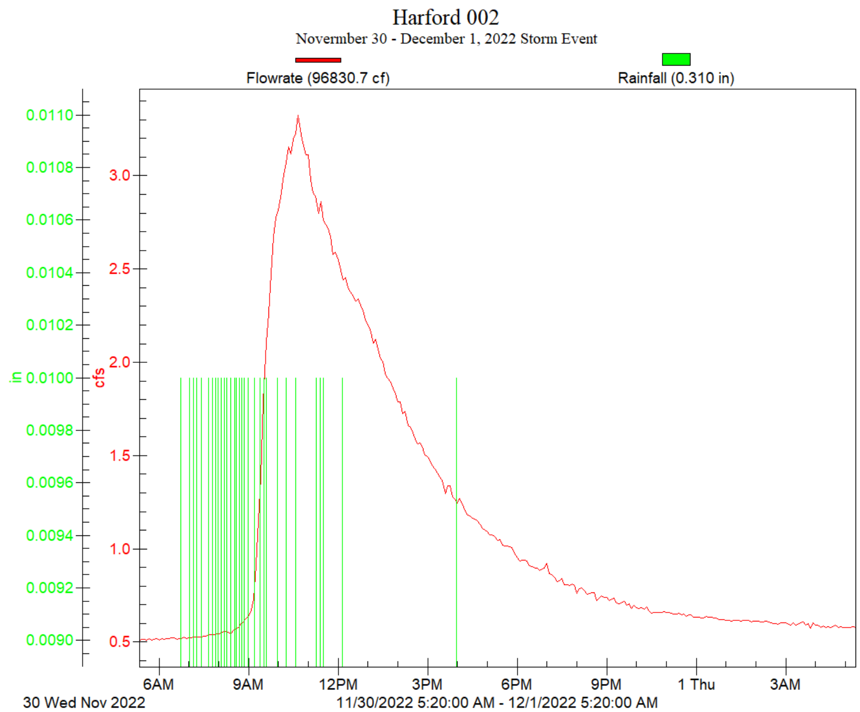


Figure A-1. Hydrograph at Station WC002 for November 30- December 1, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

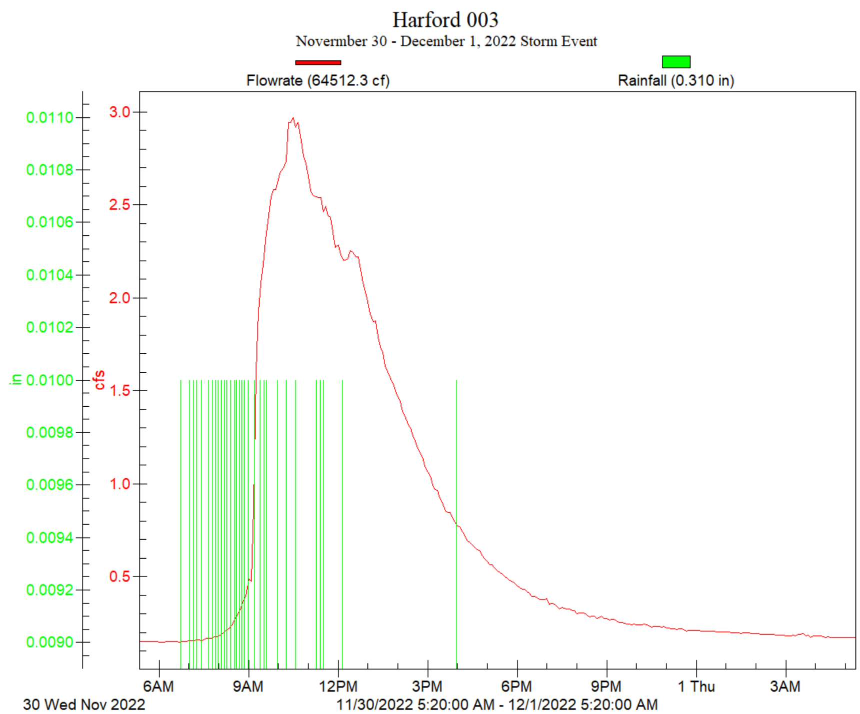


Figure A-2. Hydrograph at Station WC003 for November 30- December 1, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

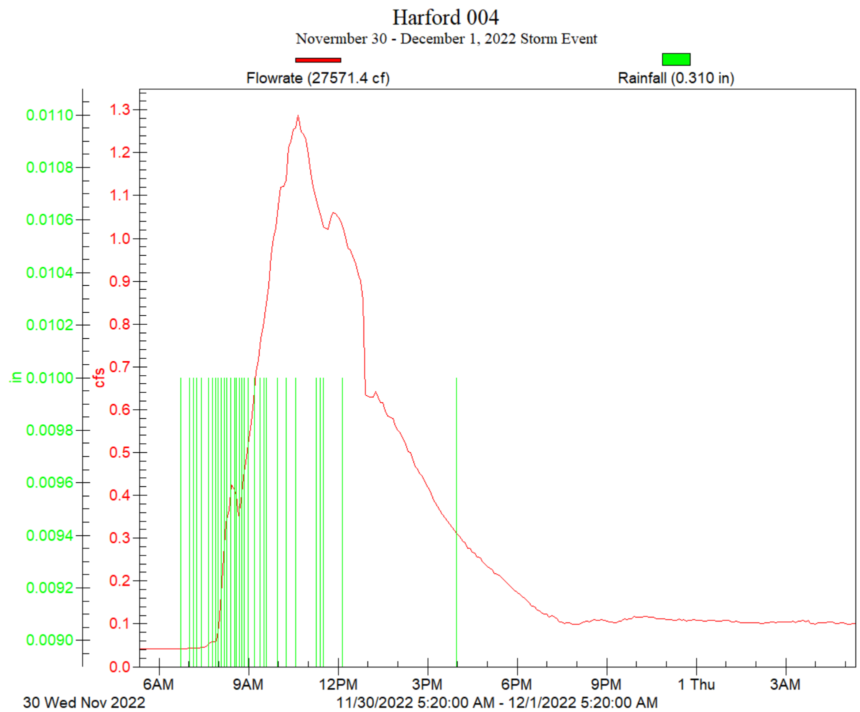


Figure A-3. Hydrograph at Station WC004 for November 30-December 1, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

| Constituent | 1-Dec-2022 | | |
|---|---|---|---|
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | <1.0 | <1.0 | 2.0 |
| Nitrate-Nitrite Nitrogen | 1.4 | 0.7 | 1.1 |
| Orthophosphate Phosphorus | <0.05 | <0.05 | 0.01 |
| Solids (Suspended) | 2.0 | 6.0 | 9.0 |
| Copper | <0.002 | 0.003 | 0.006 |
| Lead | <0.0010 | 0.0010 | 0.0010 |
| Zinc | 0.011 | 0.030 | 0.040 |
| Ammonia Nitrogen | <0.30 | <0.30 | <0.30 |
| Kjeldahl Nitrogen (Total) | 0.4 | 0.8 | 0.8 |
| Total Phosphorus | 0.010 | 0.080 | 0.070 |
| Hardness | 152.0 | 158.0 | 140.0 |
| Chloride | 118.0 | 126.0 | 124.0 |
| pH | 7.13 | 7.15 | 7.03 |

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb

| Constituent | 1-Dec-2022 | | |
|---|---|---|---|
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | 3.0 | 2.0 | 2.0 |
| Nitrate-Nitrite Nitrogen | 0.6 | 0.6 | 0.3 |
| Orthophosphate Phosphorus | 0.01 | <0.05 | 0.02 |
| Solids (Suspended) | 6.0 | 8.0 | 16.0 |
| Copper | 0.004 | 0.003 | 0.006 |
| Lead | <0.0010 | <0.0010 | 0.0010 |
| Zinc | 0.012 | 0.015 | 0.025 |
| Ammonia Nitrogen | <0.30 | <0.30 | 0.07 |
| Kjeldahl Nitrogen (Total) | 0.6 | 0.6 | 0.8 |
| Total Phosphorus | 0.050 | 0.040 | 0.070 |
| Hardness | 84.0 | 118.0 | 44.0 |
| Chloride | 60.9 | 107.0 | 21.0 |
| pH | 7.36 | 7.31 | 7.20 |

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb

| Constituent | 1-Dec-2022 | | |
|---|---|---|---|
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | 2.0 | 2.0 | 2.0 |
| Nitrate-Nitrite Nitrogen | 0.6 | 0.4 | 0.5 |
| Orthophosphate Phosphorus | 0.02 | <0.05 | 0.02 |
| Solids (Suspended) | 2.0 | <2.0 | 3.0 |
| Copper | 0.004 | 0.005 | 0.005 |
| Lead | <0.0010 | 0.0005 | 0.0004 |
| Zinc | 0.011 | 0.013 | 0.018 |
| Ammonia Nitrogen | <0.30 | <0.30 | <0.30 |
| Kjeldahl Nitrogen (Total) | 0.5 | 0.5 | 0.6 |
| Total Phosphorus | 0.040 | 0.030 | 0.040 |
| Hardness | 94.0 | 88.0 | 64.0 |
| Chloride | 49.3 | 70.7 | 53.2 |
| pH | 7.34 | 7.43 | 7.23 |

| Table A-4. Analytical Results – Wheel Creek Grab Sampling | | | |
|---|---|---|---|
| **Constituent** | **Station WC002** | **Station WC003** | **Station WC004** |
| December 1, 2022 (Rising) | | | |
| TPH (mg/L) | <5.0 | <5.0 | <5.0 |
| *E. coli* (MPN/100 ml) | 138.0 | 48.8 | 50.4 |
| Temp (C) | 8.30 | 8.20 | 10.00 |
| DO (mg/L) | 10.69 | 9.99 | 8.44 |
| pH | 7.11 | 7.08 | 6.80 |
| Sp. Cond. (mS/cm) | 0.495 | 0.525 | 1.073 |

| Table A-5. Rainfall and flow statistics | | | |
|---|---|---|---|
| **Constituent** | **Station WC002** | **Station WC003** | **Station WC004** |
| Rainfall (in.) | 0.31 | 0.31 | 0.31 |
| Duration (hrs.) | 24 | 24 | 24 |
| Intensity (in./hr.) | 0.0130 | 0.0130 | 0.0130 |
| Discharge (cf.) | 96,830 | 64,512 | 27,571 |

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# WHEEL CREEK STORM MONITORING SUMMARY REPORT

*JANUARY 12-13, 2023*

## INTRODUCTION

Versar field staff traveled to the site on January 12 to program the SIGMA automated samplers to sample the event. Rainfall initiated at approximately 9:37 p.m. the evening of Thursday, January 12. At the Wheel Creek Rain Gauge Station, 0.21 inches of rain was recorded for the duration of the storm.

On the morning of January 13, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. Field staff also composited automated samples. The *E. coli* samples were submitted to Martel Laboratories for analysis shortly after collection. Composite samples and TPH samples were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on January 13.

The following problems occurred during the storm event:

Versar field staff set up for the storm event with the intention of collecting a grab flush that would have coincided with the rising limb Thursday night. However, field staff experienced vehicle issues and decided to collect grab samples that coincided with the falling limb during the storm composite the very next day.

## RESULTS

Hydrographs for the January 12-13 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the January 12-13 event are shown in Table A-5.

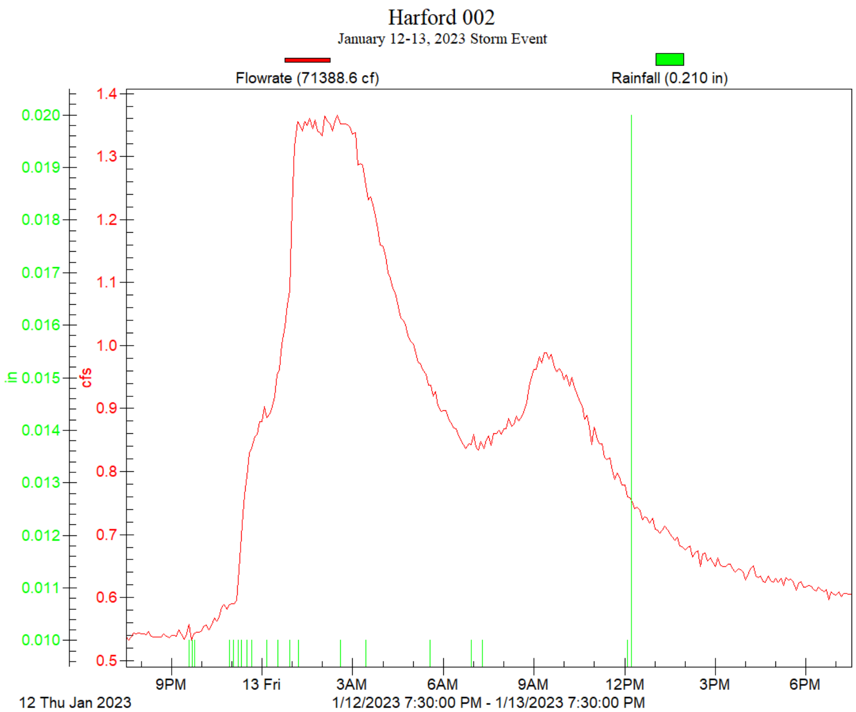


Figure A-1. Hydrograph at Station WC002 for January 12-13, 2023 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

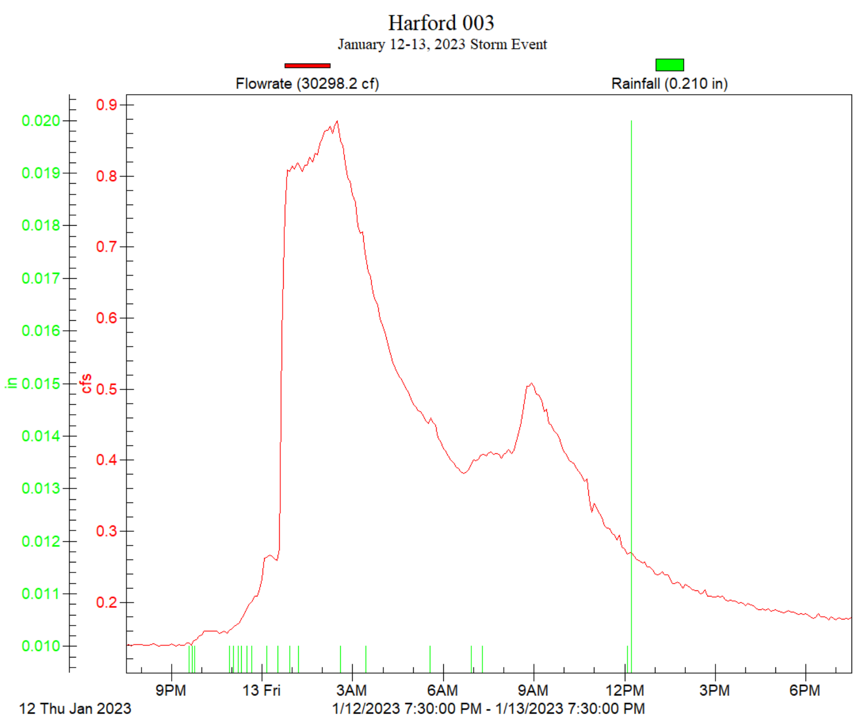


Figure A-2. Hydrograph at Station WC003 for January 12-13, 2023 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

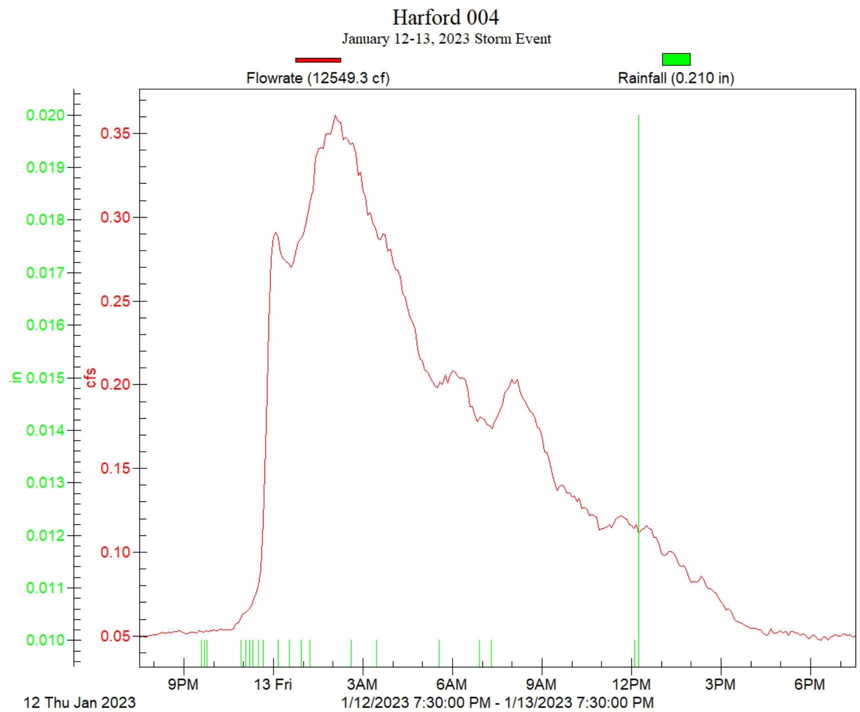


Figure A-3. Hydrograph at Station WC004 for January 12-13, 2023 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

| Constituent | 13-Jan-2023 | | |
|---|---|---|---|
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | 1.0 | 1.0 | 2.0 |
| Nitrate-Nitrite Nitrogen | 1.6 | 0.9 | 1.6 |
| Orthophosphate Phosphorus | <0.05 | <0.05 | <0.05 |
| Solids (Suspended) | 4.0 | 9.0 | 10.0 |
| Copper | 0.003 | 0.006 | 0.007 |
| Lead | <0.0010 | 0.0005 | 0.0005 |
| Zinc | 0.013 | 0.020 | 0.065 |
| Ammonia Nitrogen | <0.30 | <0.30 | 0.10 |
| Kjeldahl Nitrogen (Total) | 0.5 | 0.6 | 0.7 |
| Total Phosphorus | 0.020 | 0.030 | 0.040 |
| Hardness | 160.0 | 188.0 | 230.0 |
| Chloride | 135.0 | 208.0 | 671.0 |
| pH | 7.25 | 7.39 | 7.18 |

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb

| Constituent | 13-Jan-2023 | | |
|---|---|---|---|
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | 2.0 | 1.0 | 4.0 |
| Nitrate-Nitrite Nitrogen | 1.2 | 0.7 | 0.5 |
| Orthophosphate Phosphorus | 0.01 | <0.05 | <0.05 |
| Solids (Suspended) | 7.0 | 11.0 | 7.0 |
| Copper | 0.004 | 0.005 | 0.006 |
| Lead | <0.0010 | 0.0003 | 0.0004 |
| Zinc | 0.015 | 0.017 | 0.036 |
| Ammonia Nitrogen | <0.30 | <0.30 | 0.13 |
| Kjeldahl Nitrogen (Total) | 0.5 | 0.5 | 0.8 |
| Total Phosphorus | 0.040 | 0.030 | 0.040 |
| Hardness | 138.0 | 153.0 | 102.0 |
| Chloride | 135.0 | 363.0 | 596.0 |
| pH | 7.27 | 7.36 | 7.35 |

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb

| Constituent | 13-Jan-2023 | | |
|---|---|---|---|
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | 2.0 | 2.0 | 2.0 |
| Nitrate-Nitrite Nitrogen | 0.9 | 0.6 | 0.5 |
| Orthophosphate Phosphorus | <0.05 | <0.05 | <0.05 |
| Solids (Suspended) | 3.0 | 3.0 | 4.0 |
| Copper | 0.004 | 0.007 | 0.006 |
| Lead | <0.0010 | <0.0010 | <0.0010 |
| Zinc | 0.013 | 0.019 | 0.029 |
| Ammonia Nitrogen | <0.30 | 0.12 | <0.30 |
| Kjeldahl Nitrogen (Total) | 0.5 | 0.5 | 0.6 |
| Total Phosphorus | 0.020 | 0.020 | 0.040 |
| Hardness | 114.0 | 139.0 | 96.0 |
| Chloride | 195.0 | 370.0 | 544.0 |
| pH | 7.23 | 7.36 | 7.15 |

| Table A-4. Analytical Results – Wheel Creek Grab Sampling | | | |
|---|---|---|---|
| **Constituent** | **Station WC002** | **Station WC003** | **Station WC004** |
| January 13, 2023 (Falling) | | | |
| TPH (mg/L) | <5.0 | <5.0 | <5.0 |
| *E. coli* (MPN/100 ml) | 411.0 | 81.0 | 129.0 |
| Temp (C) | 8.20 | 8.10 | 9.50 |
| DO (mg/L) | 11.87 | 11.28 | 10.22 |
| pH | 7.25 | 7.30 | 7.17 |
| Sp. Cond. (mS/cm) | 1.069 | 1.184 | 1.698 |

| Table A-5. Rainfall and flow statistics | | | |
|---|---|---|---|
| **Constituent** | **Station WC002** | **Station WC003** | **Station WC004** |
| Rainfall (in.) | 0.21 | 0.21 | 0.21 |
| Duration (hrs.) | 24 | 24 | 24 |
| Intensity (in./hr.) | 0.0090 | 0.0090 | 0.0090 |
| Discharge (cf.) | 71,388 | 30,298 | 12,549 |

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# WHEEL CREEK STORM MONITORING SUMMARY REPORT

*JANUARY 22-23, 2023*

## INTRODUCTION

Versar field staff traveled to the site on January 22 to program the SIGMA automated samplers to sample the event. Rainfall initiated at approximately 2:37 p.m. the afternoon of Sunday, January 22. At the Wheel Creek Rain Gauge Station, 0.50 inches of rain was recorded for the duration of the storm.

On the morning of January 23, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the peak limb of the storm. The *E. coli* samples were submitted to Martel Laboratories for analysis shortly after collection.

Field staff traveled to the sites on January 24 to composite automated samples. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on January 24. During composite Versar field staff took a falling limb grab at all 3 stations due to high water levels to accommodate the falling limb discharge.

## RESULTS

Hydrographs for the January 22-23 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the January 22-23 event are shown in Table A-5.

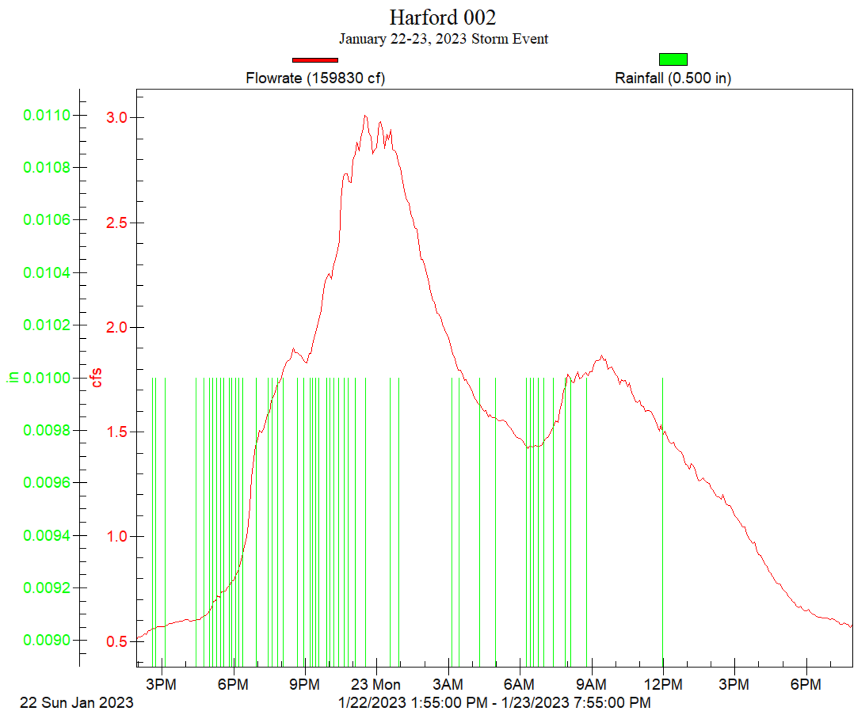


Figure A-1. Hydrograph at Station WC002 for January 22-23, 2023 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

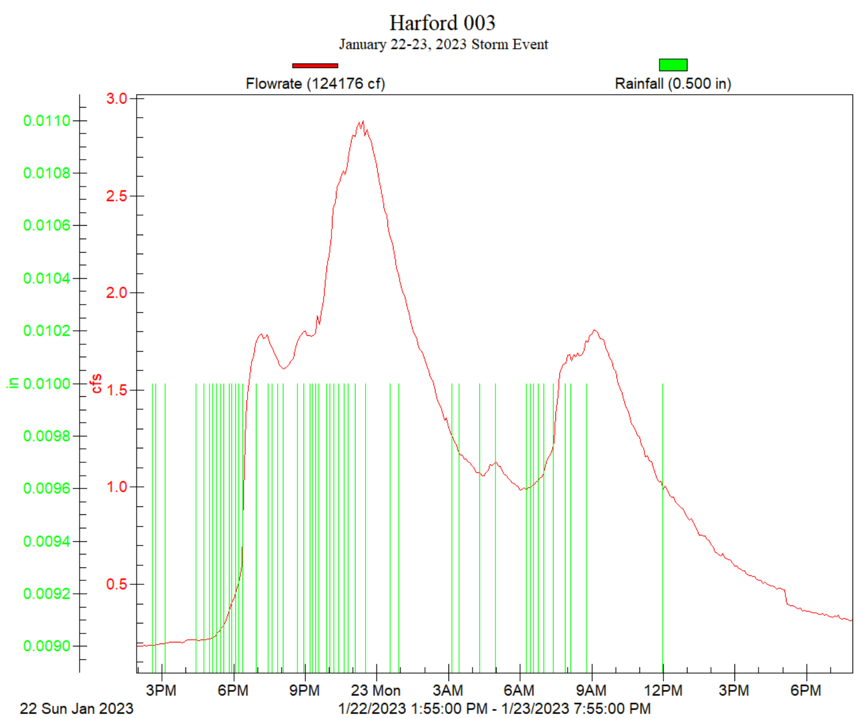


Figure A-2. Hydrograph at Station WC003 for January 22-23, 2023 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

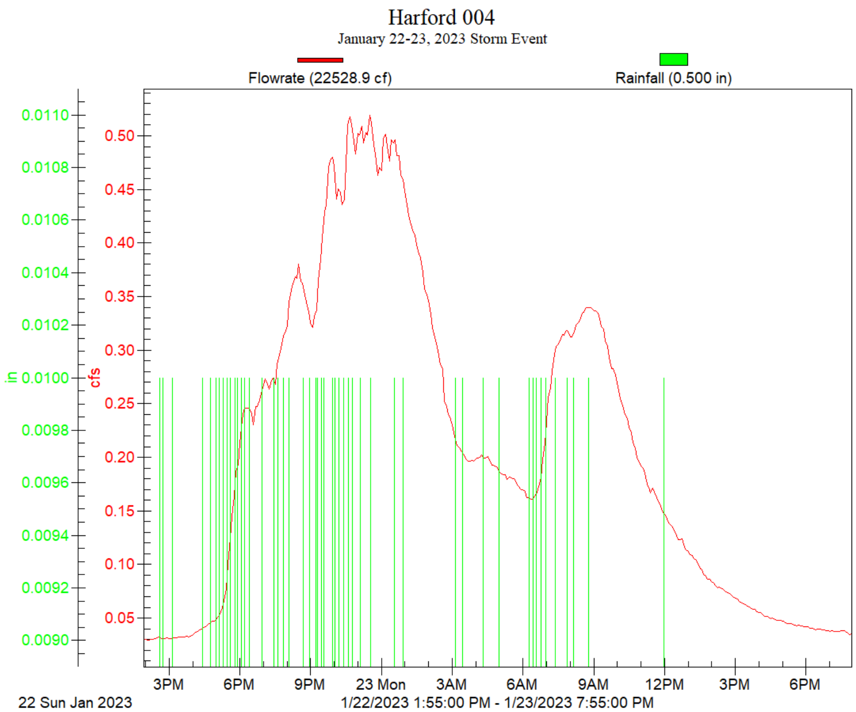


Figure A-3. Hydrograph at Station WC004 for January 22-23, 2023 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

| Constituent | 24-Jan-2023 | | |
|---|---|---|---|
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | 2.0 | 2.0 | 2.0 |
| Nitrate-Nitrite Nitrogen | 0.9 | 0.6 | 0.6 |
| Orthophosphate Phosphorus | 0.02 | 0.01 | <0.05 |
| Solids (Suspended) | <2.0 | 6.0 | 7.0 |
| Copper | 0.006 | 0.009 | 0.013 |
| Lead | <0.0010 | 0.0003 | 0.0007 |
| Zinc | 0.014 | 0.018 | 0.033 |
| Ammonia Nitrogen | 0.08 | <0.30 | 0.10 |
| Kjeldahl Nitrogen (Total) | 0.7 | 0.5 | 0.8 |
| Total Phosphorus | 0.040 | 0.040 | 0.050 |
| Hardness | 104.0 | 62.0 | 84.0 |
| Chloride | 121.0 | 153.0 | 320.0 |
| pH | 7.30 | 7.31 | 7.18 |

| Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb | | | |
|---|---|---|---|
| Constituent | 24-Jan-2023 | | |
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | 2.0 | 1.0 | 2.0 |
| Nitrate-Nitrite Nitrogen | 0.5 | 0.4 | 0.2 |
| Orthophosphate Phosphorus | <0.05 | <0.05 | <0.05 |
| Solids (Suspended) | 4.0 | 4.0 | 5.0 |
| Copper | 0.009 | 0.007 | 0.011 |
| Lead | 0.0003 | 0.0003 | 0.0006 |
| Zinc | 0.015 | 0.022 | 0.023 |
| Ammonia Nitrogen | <0.30 | 0.07 | 0.09 |
| Kjeldahl Nitrogen (Total) | 0.6 | 0.6 | 0.7 |
| Total Phosphorus | 0.030 | 0.020 | 0.030 |
| Hardness | 52.0 | 101.0 | 39.0 |
| Chloride | 82.6 | 199.0 | 210.0 |
| pH | 7.36 | 7.38 | 7.23 |

| Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb | | | |
|---|---|---|---|
| Constituent | 24-Jan-2023 | | |
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | 2.0 | 2.0 | 2.0 |
| Nitrate-Nitrite Nitrogen | 0.5 | 0.4 | 0.4 |
| Orthophosphate Phosphorus | 0.02 | <0.05 | <0.05 |
| Solids (Suspended) | 4.0 | 3.0 | 3.0 |
| Copper | 0.003 | 0.003 | 0.003 |
| Lead | 0.0005 | 0.0003 | 0.0003 |
| Zinc | 0.019 | 0.013 | 0.018 |
| Ammonia Nitrogen | <0.30 | <0.30 | 0.10 |
| Kjeldahl Nitrogen (Total) | 0.6 | 0.6 | 0.7 |
| Total Phosphorus | 0.030 | 0.030 | 0.040 |
| Hardness | 51.0 | 64.0 | 46.0 |
| Chloride | 69.2 | 132.0 | 162.0 |
| pH | 7.46 | 7.28 | 7.20 |

| Table A-4. Analytical Results – Wheel Creek Grab Sampling | | | |
|---|---|---|---|
| **Constituent** | **Station WC002** | **Station WC003** | **Station WC004** |
| January 24, 2023 (Peak) | | | |
| TPH (mg/L) | <5.0 | <5.0 | <5.0 |
| *E. coli* (MPN/100 ml) | 866.0 | 411.0 | 345.0 |
| Temp (C) | 5.70 | 5.60 | 5.50 |
| DO (mg/L) | 12.30 | 12.08 | 11.75 |
| pH | 7.20 | 7.33 | 7.08 |
| Sp. Cond. (mS/cm) | 0.298 | 0.504 | 0.604 |

| Table A-5. Rainfall and flow statistics | | | |
|---|---|---|---|
| **Constituent** | **Station WC002** | **Station WC003** | **Station WC004** |
| Rainfall (in.) | 0.50 | 0.50 | 0.50 |
| Duration (hrs.) | 30 | 30 | 30 |
| Intensity (in./hr.) | 0.0167 | 0.0167 | 0.0167 |
| Discharge (cf.) | 159,830 | 124,176 | 22,528 |

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# Wheel Creek Storm Monitoring
# Summary Report
*April 22-23, 2023*

## INTRODUCTION

Versar field staff traveled to the site on April 22 to program the SIGMA automated samplers to sample the event. Rainfall initiated at approximately 1:04 p.m. the afternoon of Wednesday, April 22. At the Wheel Creek Rain Gauge Station, 0.58 inches of rain was recorded for the duration of the storm.

On the afternoon of April 22, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the rising limb of the storm. The *E. coli* samples were submitted to Martel Laboratories for analysis shortly after collection. Due to a quick forecast change, Versar field staff also obtained a rising grab at all three stations for the composite near the same time as the first flush.

Field staff traveled to the sites on April 24 to composite automated samples. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on August 24.

## RESULTS

Hydrographs for the April 22-23 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the April 22-23 event are shown in Table A-5.

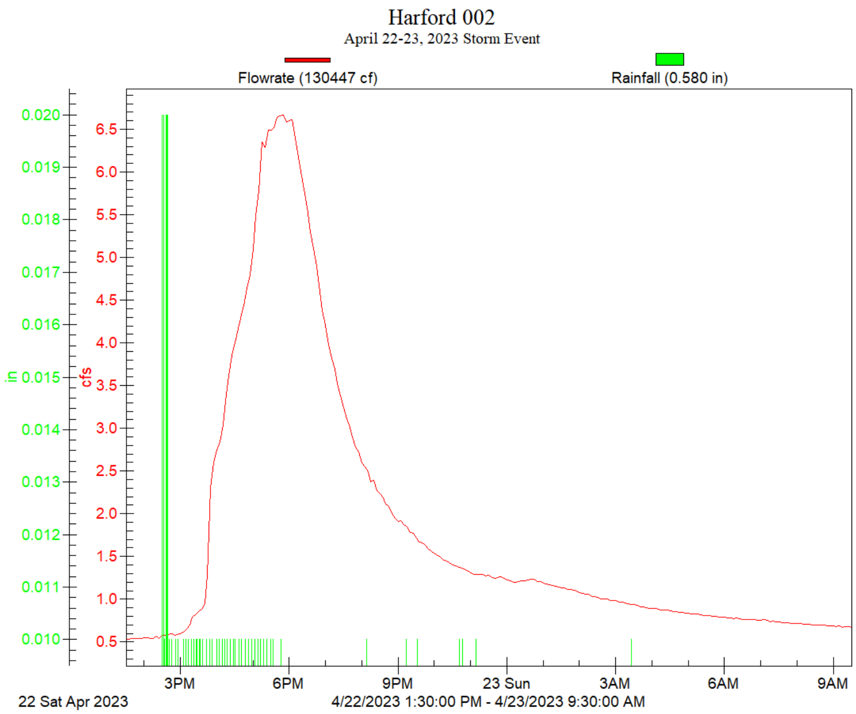


Figure A-1. Hydrograph at Station WC002 for April 22-23, 2023 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

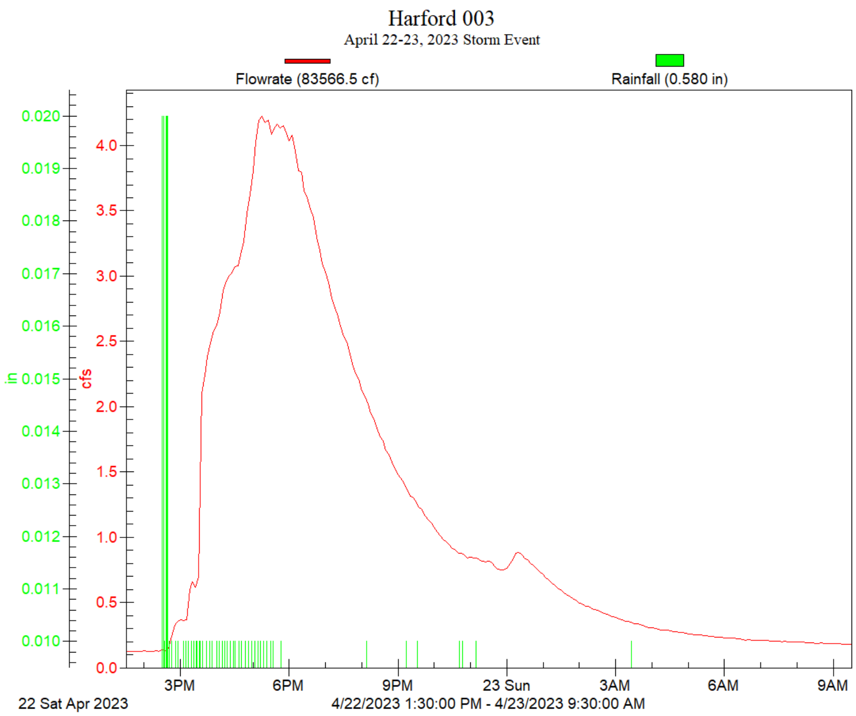


Figure A-2. Hydrograph at Station WC003 for April 22-23, 2023 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

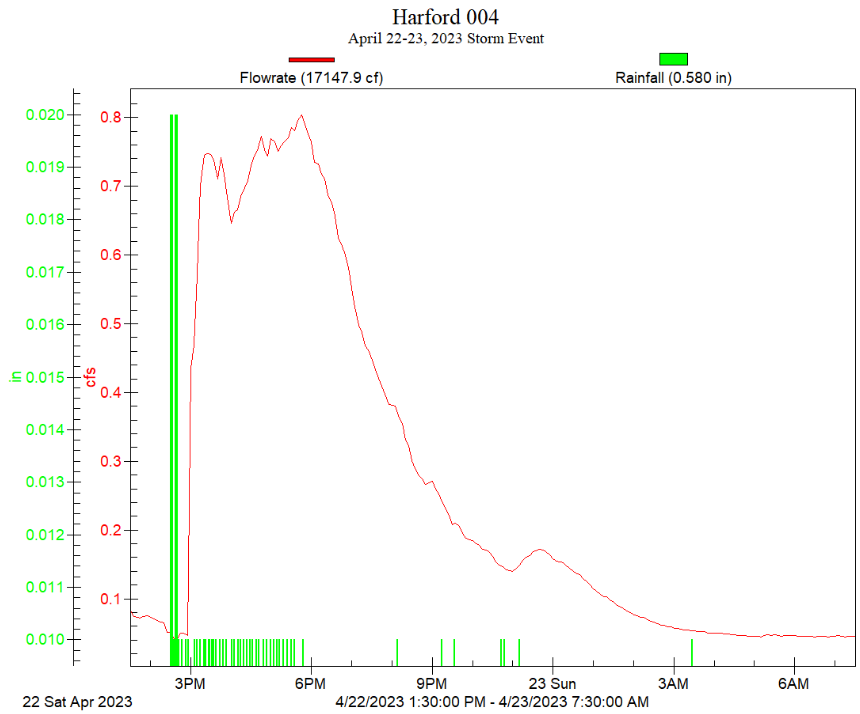


Figure A-3. Hydrograph at Station WC004 for April 22-23, 2023 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

| Constituent | 24-Apr-2023 | | |
|---|---|---|---|
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | 2.0 | 3.0 | 7.0 |
| Nitrate-Nitrite Nitrogen | 1.1 | 0.3 | 2.3 |
| Orthophosphate Phosphorus | <0.05 | 0.02 | 0.01 |
| Solids (Suspended) | 14.0 | 4.0 | 72.0 |
| Copper | <0.002 | 0.003 | 0.007 |
| Lead | <0.0010 | 0.0006 | 0.0020 |
| Zinc | 0.015 | 0.023 | 0.066 |
| Ammonia Nitrogen | <0.30 | <0.30 | <0.30 |
| Kjeldahl Nitrogen (Total) | 0.9 | 1.2 | 2.1 |
| Total Phosphorus | 0.050 | 0.100 | 0.180 |
| Hardness | 166.0 | 146.0 | 340.0 |
| Chloride | 135.0 | 109.0 | 293.0 |
| pH | 7.01 | 6.99 | 6.59 |

| Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb | | | |
|---|---|---|---|
| | 24-Apr-2023 | | |
| Constituent | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | 7.0 | 4.0 | 6.0 |
| Nitrate-Nitrite Nitrogen | 0.4 | 0.3 | 0.3 |
| Orthophosphate Phosphorus | 0.01 | <0.05 | 0.02 |
| Solids (Suspended) | 35.0 | 35.0 | 40.0 |
| Copper | 0.021 | 0.016 | 0.017 |
| Lead | 0.0010 | 0.0010 | 0.0010 |
| Zinc | 0.043 | 0.032 | 0.039 |
| Ammonia Nitrogen | <0.30 | 0.06 | <0.30 |
| Kjeldahl Nitrogen (Total) | 1.7 | 1.4 | 1.8 |
| Total Phosphorus | 0.170 | 0.150 | 0.160 |
| Hardness | 68.0 | 84.0 | 43.0 |
| Chloride | 43.5 | 62.0 | 5.45 |
| pH | 6.99 | 7.07 | 7.13 |

| Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb | | | |
|---|---|---|---|
| | 24-Apr-2023 | | |
| Constituent | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | 2.0 | 2.0 | 2.0 |
| Nitrate-Nitrite Nitrogen | 0.4 | 0.3 | 0.2 |
| Orthophosphate Phosphorus | <0.05 | 0.02 | <0.05 |
| Solids (Suspended) | 4.0 | 5.0 | 4.0 |
| Copper | 0.016 | 0.012 | 0.012 |
| Lead | 0.0003 | 0.0003 | 0.0004 |
| Zinc | 0.019 | 0.013 | 0.020 |
| Ammonia Nitrogen | <0.30 | <0.30 | <0.30 |
| Kjeldahl Nitrogen (Total) | 0.9 | 0.8 | 1.0 |
| Total Phosphorus | 0.060 | 0.050 | 0.050 |
| Hardness | 76.0 | 100.0 | 55.0 |
| Chloride | 59.8 | 65.7 | 70.8 |
| pH | 6.96 | 7.03 | 6.94 |

| Table A-4. Analytical Results – Wheel Creek Grab Sampling | | | |
|---|---|---|---|
| **Constituent** | **Station WC002** | **Station WC003** | **Station WC004** |
| April 24, 2023 (Rising) | | | |
| TPH (mg/L) | <5.0 | <5.0 | <5.0 |
| *E. coli* (MPN/100 ml) | >2420.0 | >2420.0 | >2420.0 |
| Temp (C) | 18.00 | 19.20 | 15.60 |
| DO (mg/L) | 8.55 | 8.16 | 5.79 |
| pH | 6.99 | 6.98 | 6.36 |
| Sp. Cond. (mS/cm) | 0.559 | 0.446 | 1.167 |

| Table A-5. Rainfall and flow statistics | | | |
|---|---|---|---|
| **Constituent** | **Station WC002** | **Station WC003** | **Station WC004** |
| Rainfall (in.) | 0.58 | 0.58 | 0.58 |
| Duration (hrs.) | 20 | 20 | 18 |
| Intensity (in./hr.) | 0.0290 | 0.0290 | 0.0320 |
| Discharge (cf.) | 130,447 | 83,566 | 17,147 |

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# WHEEL CREEK STORM MONITORING SUMMARY REPORT

*JUNE 21-24, 2023*

## INTRODUCTION

Versar field staff traveled to the site on June 21 to program the SIGMA automated samplers to sample the event. Rainfall initiated at approximately 1:16 p.m. the afternoon of Wednesday, June 21. At the Wheel Creek Rain Gauge Station, 0.58 inches of rain was recorded for the duration of the storm.

Due to a shift in rainfall for the system, on the morning of June 23, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the rising limb of the storm. The *E. coli* samples were submitted to Martel Laboratories for analysis shortly after collection.

On the morning of June 26, field staff traveled to the sites to composite automated samples. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on June 26.

## RESULTS

Hydrographs for the June 21-24 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the June 21-24 event are shown in Table A-5.

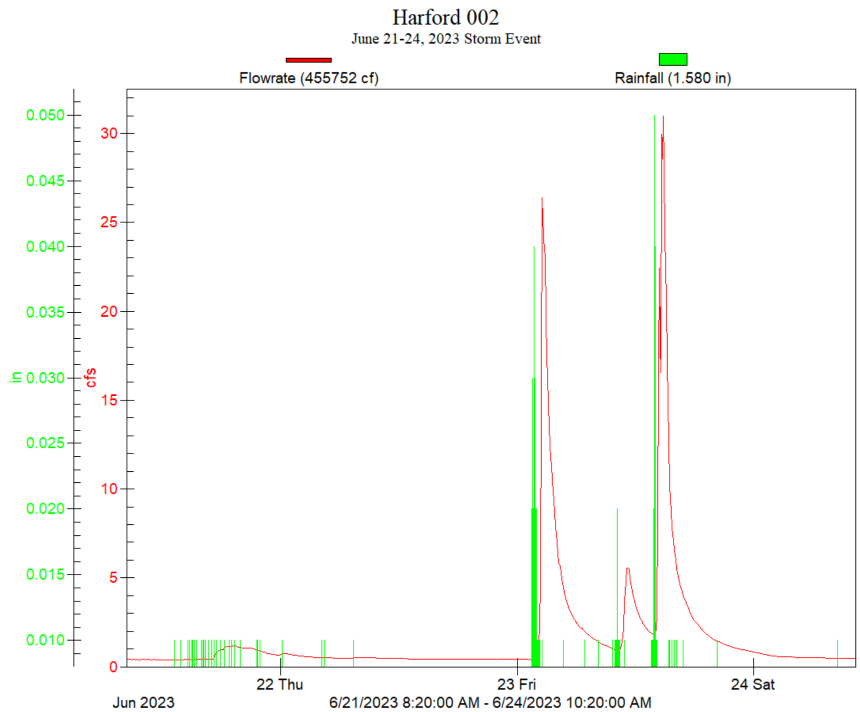


Figure A-1. Hydrograph at Station WC002 for June 21-24, 2023 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

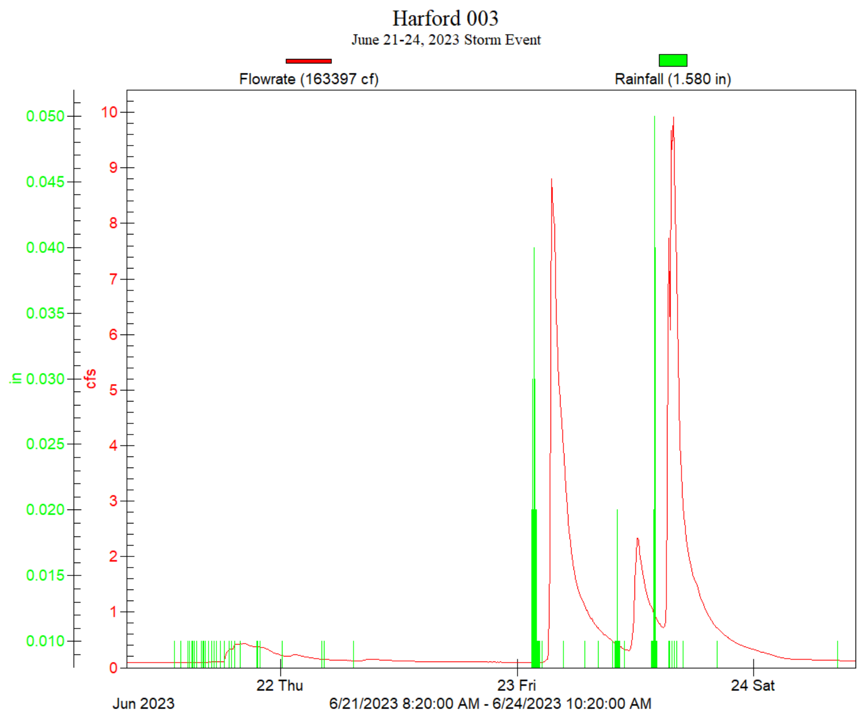


Figure A-2. Hydrograph at Station WC003 for June 21-24, 2023 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

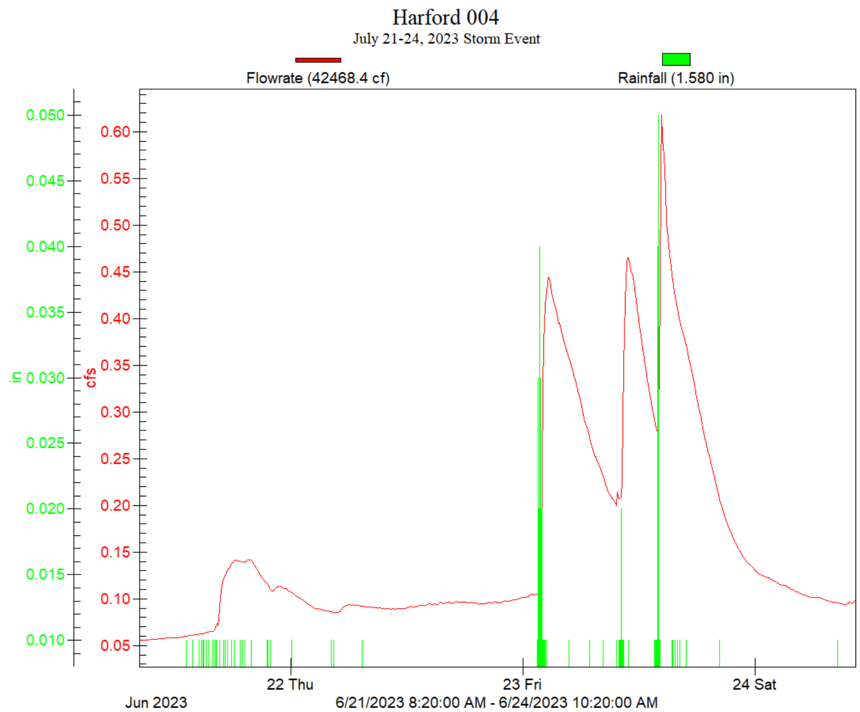


Figure A-3. Hydrograph at Station WC004 for June 21-24, 2023 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

| Constituent | 26-Jun-2023 | | |
|---|---|---|---|
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | 3.0 | 3.0 | 4.0 |
| Nitrate-Nitrite Nitrogen | 0.8 | 0.5 | 0.4 |
| Orthophosphate Phosphorus | <0.05 | <0.05 | <0.05 |
| Solids (Suspended) | 7.0 | 22.0 | 51.0 |
| Copper | 0.007 | 0.010 | 0.012 |
| Lead | <0.0010 | 0.0009 | 0.0020 |
| Zinc | 0.012 | 0.036 | 0.042 |
| Ammonia Nitrogen | 0.10 | <0.30 | <0.30 |
| Kjeldahl Nitrogen (Total) | 0.8 | 0.9 | 1.3 |
| Total Phosphorus | 0.050 | 0.050 | 0.140 |
| Hardness | 138.0 | 156.0 | 90.0 |
| Chloride | 99.9 | 117.0 | 56.4 |
| pH | 7.20 | 7.80 | 7.07 |

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb

| Constituent | 26-Jun-2023 | | |
|---|---|---|---|
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | 2.0 | 2.0 | 2.0 |
| Nitrate-Nitrite Nitrogen | 0.3 | 0.2 | 0.2 |
| Orthophosphate Phosphorus | 0.01 | <0.05 | <0.05 |
| Solids (Suspended) | 20.0 | 35.0 | 41.0 |
| Copper | 0.008 | 0.011 | 0.010 |
| Lead | 0.0007 | 0.0010 | 0.0020 |
| Zinc | 0.020 | 0.028 | 0.032 |
| Ammonia Nitrogen | 0.10 | <0.30 | <0.30 |
| Kjeldahl Nitrogen (Total) | 0.8 | 0.8 | 1.1 |
| Total Phosphorus | 0.070 | 0.080 | 0.090 |
| Hardness | 44.0 | 54.0 | 30.0 |
| Chloride | 19.7 | 32.7 | <25.0 |
| pH | 7.01 | 7.85 | 7.15 |

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb

| Constituent | 26-Jun-2023 | | |
|---|---|---|---|
| | Station WC002 (mg/L) | Station WC003 (mg/L) | Station WC004 (mg/L) |
| 5-Day BOD | 2.0 | 2.0 | 2.0 |
| Nitrate-Nitrite Nitrogen | 0.6 | 0.3 | 0.6 |
| Orthophosphate Phosphorus | <0.05 | <0.05 | 0.01 |
| Solids (Suspended) | 3.0 | 5.0 | 17.0 |
| Copper | 0.007 | 0.008 | 0.008 |
| Lead | <0.0010 | <0.0010 | 0.0010 |
| Zinc | 0.010 | 0.009 | 0.024 |
| Ammonia Nitrogen | <0.30 | <0.30 | <0.30 |
| Kjeldahl Nitrogen (Total) | 0.7 | 0.6 | 1.0 |
| Total Phosphorus | 0.040 | 0.030 | 0.050 |
| Hardness | 80.0 | 82.0 | 94.0 |
| Chloride | 48.4 | 59.5 | 217.0 |
| pH | 7.09 | 7.77 | 7.07 |

| Table A-4. Analytical Results – Wheel Creek Grab Sampling | | | |
| --- | --- | --- | --- |
| **Constituent** | **Station WC002** | **Station WC003** | **Station WC004** |
| June 26, 2023 (Peak) | | | |
| TPH (mg/L) | <5.0 | <5.0 | <5.0 |
| *E. coli* (MPN/100 ml) | 23,800.0 | 15,000.0 | 9,090.0 |
| Temp (C) | 17.90 | 18.60 | 18.00 |
| DO (mg/L) | 8.70 | 8.53 | 7.27 |
| pH | 7.12 | 7.21 | 6.80 |
| Sp. Cond. (mS/cm) | 0.222 | 0.284 | 0.197 |

| Table A-5. Rainfall and flow statistics | | | |
| --- | --- | --- | --- |
| **Constituent** | **Station WC002** | **Station WC003** | **Station WC004** |
| Rainfall (in.) | 1.58 | 1.58 | 1.58 |
| Duration (hrs.) | 74 | 74 | 74 |
| Intensity (in./hr.) | 0.0214 | 0.0214 | 0.0214 |
| Discharge (cf.) | 455,752 | 163,397 | 42,468 |

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# APPENDIX B

## RATING CURVES

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Table B-1. Station WC002 subset rating curve from data points collected in 2022-2023

| Level (ft) | Flow Rate (cfs) |
|---|---|
| 0.25 | 0.010 |
| 0.99 | 0.091 |
| 1.00 | 0.295 |
| 1.02 | 0.422 |
| 1.04 | 0.764 |
| 1.07 | 0.727 |
| 1.09 | 1.189 |
| 1.11 | 1.146 |
| 1.13 | 1.646 |
| 1.20 | 3.795 |
| 1.28 | 6.631 |
| 1.30 | 6.906 |
| 1.53 | 15.892 |
| 1.58 | 17.736 |

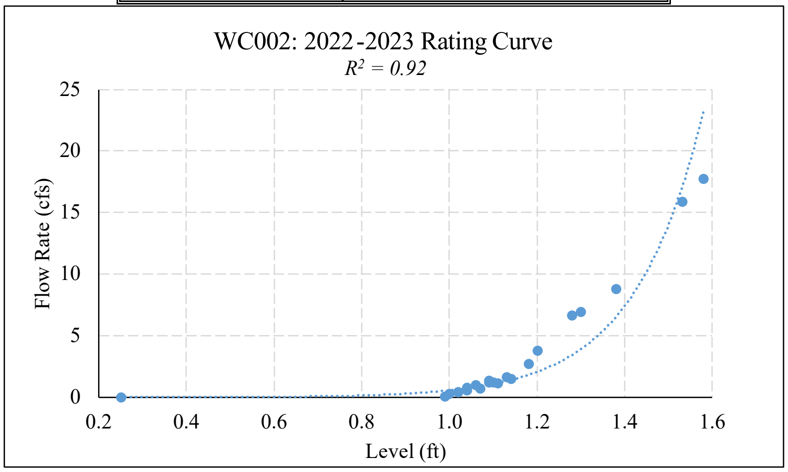
Table B-2. Station WC003 subset rating curve from data points collected in 2022-2023

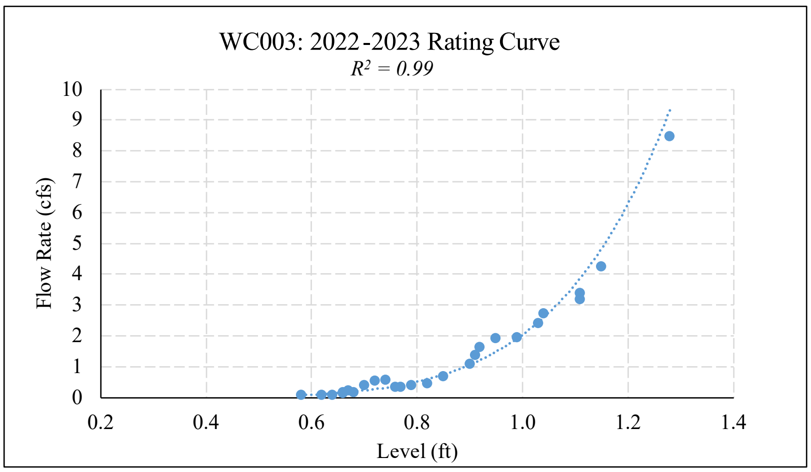
| Level (ft) | Flow Rate (cfs) |
|---|---|
| 0.58 | 0.067 |
| 0.66 | 0.154 |
| 0.70 | 0.397 |
| 0.79 | 0.389 |
| 0.82 | 0.439 |
| 0.85 | 0.664 |
| 0.90 | 1.093 |
| 0.92 | 1.637 |
| 0.99 | 1.929 |
| 1.03 | 2.389 |
| 1.04 | 2.726 |
| 1.11 | 3.189 |
| 1.15 | 4.250 |
| 1.28 | 8.454 |

Table B-3. Station WC004 subset rating curve from data points collected in 2022-2023

| Level (ft) | Flow Rate (cfs) |
|---|---|
| 0.43 | 0.010 |
| 0.54 | 0.032 |
| 0.56 | 0.037 |
| 0.58 | 0.216 |
| 0.61 | 0.311 |
| 0.64 | 0.281 |
| 0.80 | 0.727 |
| 0.89 | 2.063 |
| 0.92 | 2.308 |
| 0.95 | 2.770 |
| 0.96 | 2.895 |
| 1.00 | 3.623 |

| | |
|---|---|
| 1.17 | 6.878 |
| 1.20 | 7.914 |



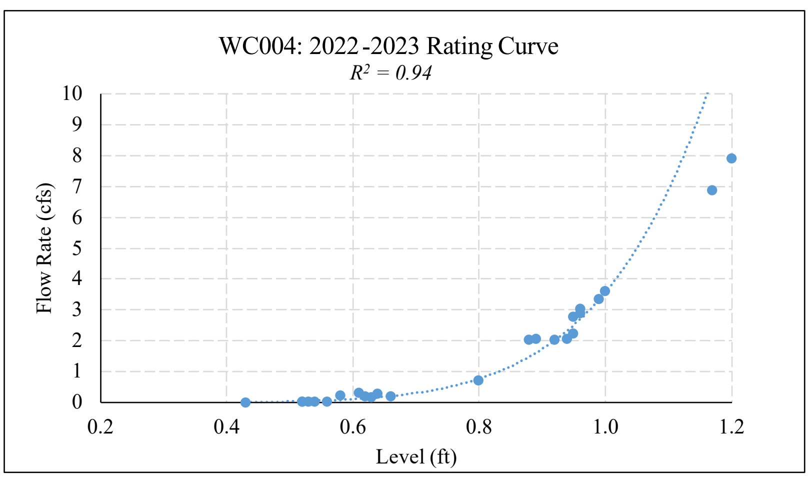




Figure B-1. Rating Curves for Stations WC002, WC003, and WC004

# APPENDIX C

## RAINFALL TOTALS

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Table C-1. July 2022 – June 2023 rainfall data from USGS Atkisson logger (inches)

| Day | July | Aug | Sept | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | June |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0.02 | 0 | 0.87 | 0.01 | 0 | 0.01 | 0 | 0 | 0.48 | 0.02 | 0 |
| 2 | 1.02 | 0.17 | 0 | 0.72 | 0 | 0 | 0 | 0 | 0 | 0 | 0.01 | 0 |
| 3 | 0 | 0 | 0 | 0.53 | 0 | 0.45 | 0 | 0 | 1.05 | 0 | 0.02 | 0 |
| 4 | 0 | 0.23 | 0 | 1.94 | 0 | 0 | 0.01 | 0 | 0.03 | 0 | 0 | 0 |
| 5 | 0.84 | 0.02 | 0.07 | 0.04 | 0 | 0 | 0.22 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0.32 | 0 | 1.71 | 0 | 0.07 | 0.27 | 0 | 0 | 0 | 0.05 | 0 | 0.12 |
| 7 | 0.36 | 0 | 0.07 | 0 | 0 | 0.02 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0.41 | 0.19 | 0 | 0 | 0 | 0 | 0.01 | 0 | 0 | 0 | 0.06 | 0.06 |
| 10 | 0 | 0.16 | 0 | 0 | 0 | 0 | 0 | 0 | 0.33 | 0 | 0 | 0.01 |
| 11 | 0 | 0.08 | 0.98 | 0 | 0.75 | 0.02 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0.39 | 0 | 0.04 | --- | 0.16 | 0 | 0.15 | 0.33 | 0.01 | 0 | 0 | 0.22 |
| 13 | 0 | 0 | 0 | --- | 0.01 | 0 | 0.09 | 0 | 0.01 | 0 | 0.26 | 0 |
| 14 | 0 | 0 | 0 | --- | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.01 |
| 15 | 0 | 0.14 | 0 | --- | 0.9 | 1.91 | 0 | 0 | 0 | 0.33 | 0 | 0 |
| 16 | 0.1 | 0 | 0 | --- | 0.03 | 0.22 | 0 | 0.41 | 0 | 0 | 0 | 0.06 |
| 17 | 0.01 | 0 | 0 | 0.27 | 0 | 0 | 0.09 | 0.71 | 0 | 0.07 | 0 | 0 |
| 18 | 0.87 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0.45 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0.01 | 0 | 0 | 0 | 0.05 | 0 |
| 21 | 0 | 1.83 | 0 | 0 | 0 | 0 | 0 | 0.06 | 0 | 0 | 0 | 0.27 |
| 22 | 0 | 2.69 | 0.03 | 0 | 0 | 1.61 | 0.34 | 0.06 | 0 | 0.56 | 0 | 0.03 |
| 23 | 0 | 0 | 0 | 1.39 | 0 | 0.47 | 0.14 | 0 | 0.26 | 0.03 | 0 | 1.14 |
| 24 | 0 | 0 | 0 | 0.46 | 0 | 0 | 0 | 0 | 0.19 | 0 | 0 | 0.67 |
| 25 | 0 | 0 | 0.07 | 0.01 | 0.06 | 0 | 0.98 | 0 | 0.22 | 0 | 0 | 0.09 |
| 26 | 0.01 | 0 | 0 | 0.07 | 0 | 0 | 0 | 0 | 0.01 | 0 | 0 | 1.15 |
| 27 | 0 | 0 | 0 | 0 | 0.38 | 0 | 0 | 0.23 | 0.06 | 0.02 | 0 | 0.99 |
| 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.02 | 0 | 1.31 | 0 | 0.01 |
| 29 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |  | 0 | 0.03 | 0 | 0 |
| 30 | 0.01 | 0.04 | 0.13 | 0 | 0.29 | 0 | 0 |  | 0 | 0.83 | 0 | 0.5 |
| 31 | 0.27 | 0 |  | 0.12 |  | 0.32 | 0.05 |  | 0 |  | 0 |  |
| **Total Rain** | **4.62** | **5.57** | **3.10** | **6.42** | **2.66** | **5.29** | **2.55** | **1.82** | **2.17** | **3.71** | **0.42** | **5.33** |
| **Annual Rainfall Total:** |  |  |  |  |  |  |  |  |  |  |  | **43.66** |

Table C-2. July 2022 – June 2023 rainfall data from Wheel Creek HOBO logger (inches)

| Day | July | Aug | Sept | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | June |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.00 | 0.02 | 0.00 | 0.81 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.45 | 0.02 | 0.00 |
| 2 | 0.87 | 0.18 | 0.00 | 0.64 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3 | 0.00 | 0.00 | 0.00 | 0.43 | 0.00 | 0.43 | 0.01 | 0.00 | 0.98 | 0.00 | 0.02 | 0.00 |
| 4 | 0.00 | 0.24 | 0.00 | 1.19 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 |
| 5 | 0.82 | 0.02 | 0.09 | 0.78 | 0.00 | 0.00 | 0.22 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 6 | 0.33 | 0.00 | 1.90 | 0.00 | 0.07 | 0.29 | 0.02 | 0.00 | 0.00 | 0.05 | 0.00 | 0.12 |
| 7 | 0.36 | 0.00 | 0.09 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 8 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 9 | 0.39 | 0.14 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.06 | 0.06 |
| 10 | 0.00 | 0.15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.33 | 0.00 | 0.00 | 0.00 |
| 11 | 0.00 | 0.06 | 0.96 | 0.00 | 0.67 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 12 | 0.35 | 0.00 | 0.04 | 0.00 | 0.13 | 0.00 | 0.10 | 0.34 | 0.01 | 0.00 | 0.00 | 0.27 |
| 13 | 0.01 | 0.00 | 0.00 | 0.88 | 0.01 | 0.00 | 0.12 | 0.00 | 0.00 | 0.00 | 0.27 | 0.00 |
| 14 | 0.00 | 0.00 | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 |
| 15 | 0.00 | 0.13 | 0.00 | 0.00 | 0.89 | 1.75 | 0.00 | 0.00 | 0.00 | 0.30 | 0.00 | 0.00 |
| 16 | 0.11 | 0.00 | 0.00 | 0.00 | 0.03 | 0.20 | 0.00 | 0.41 | 0.00 | 0.01 | 0.00 | 0.03 |
| 17 | 0.00 | 0.00 | 0.00 | 0.31 | 0.00 | 0.00 | 0.09 | 0.71 | 0.00 | 0.05 | 0.00 | 0.00 |
| 18 | 1.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 19 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.47 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.05 | 0.00 |
| 21 | 0.00 | 2.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.25 |
| 22 | 0.00 | 2.55 | 0.03 | 0.00 | 0.00 | 1.30 | 0.34 | 0.05 | 0.00 | 0.59 | 0.00 | 0.04 |
| 23 | 0.00 | 0.01 | 0.00 | 1.19 | 0.00 | 0.65 | 0.16 | 0.00 | 0.24 | 0.01 | 0.00 | 1.28 |
| 24 | 0.00 | 0.00 | 0.00 | 0.45 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.00 | 0.00 | 0.55 |
| 25 | 0.00 | 0.00 | 0.05 | 0.02 | 0.05 | 0.01 | 1.01 | 0.00 | 0.23 | 0.00 | 0.00 | 0.08 |
| 26 | 0.00 | 0.00 | 0.01 | 0.06 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 1.20 |
| 27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.38 | 0.01 | 0.00 | 0.24 | 0.06 | 0.02 | 0.00 | 1.00 |
| 28 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 1.28 | 0.00 | 0.00 |
| 29 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | | 0.00 | 0.03 | 0.00 | 0.00 |
| 30 | 0.00 | 0.08 | 0.12 | 0.00 | 0.31 | 0.00 | 0.00 | | 0.00 | 0.83 | 0.00 | 0.75 |
| 31 | 0.24 | 0.01 | | 0.10 | | 0.32 | 0.04 | | 0.00 | | 0.00 | |
| **Total Rain** | **4.49** | **5.79** | **3.30** | **6.91** | **2.56** | **5.00** | **2.62** | **1.84** | **2.08** | **3.62** | **0.42** | **5.65** |
| | | | | | | | | | | | **Annual Rainfall Total:** | **44.28** |

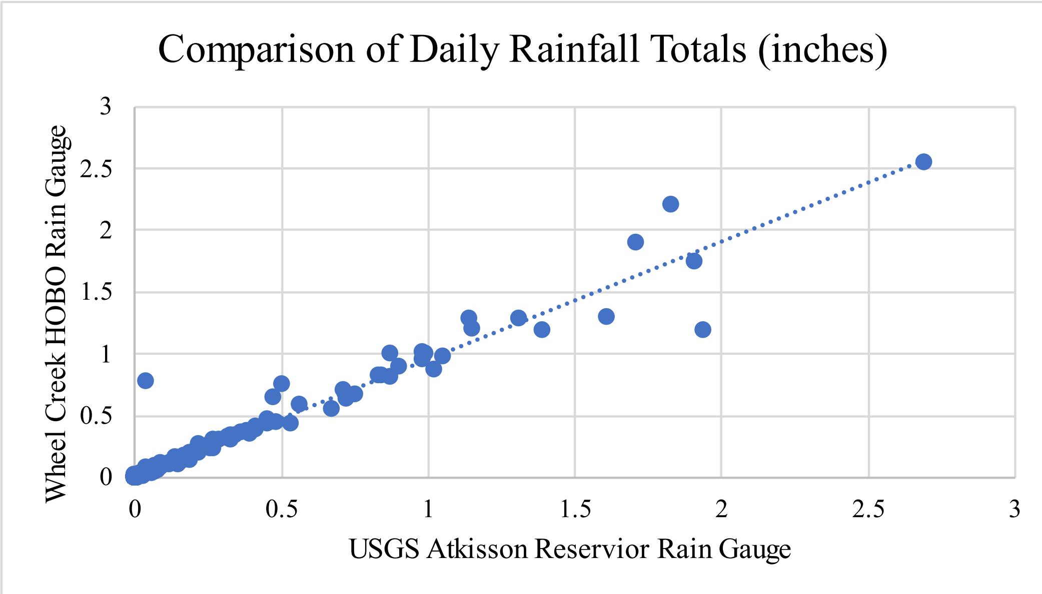


Figure C-1. Comparison of Daily Rainfall Totals for the USGS and Wheel Creek gauges

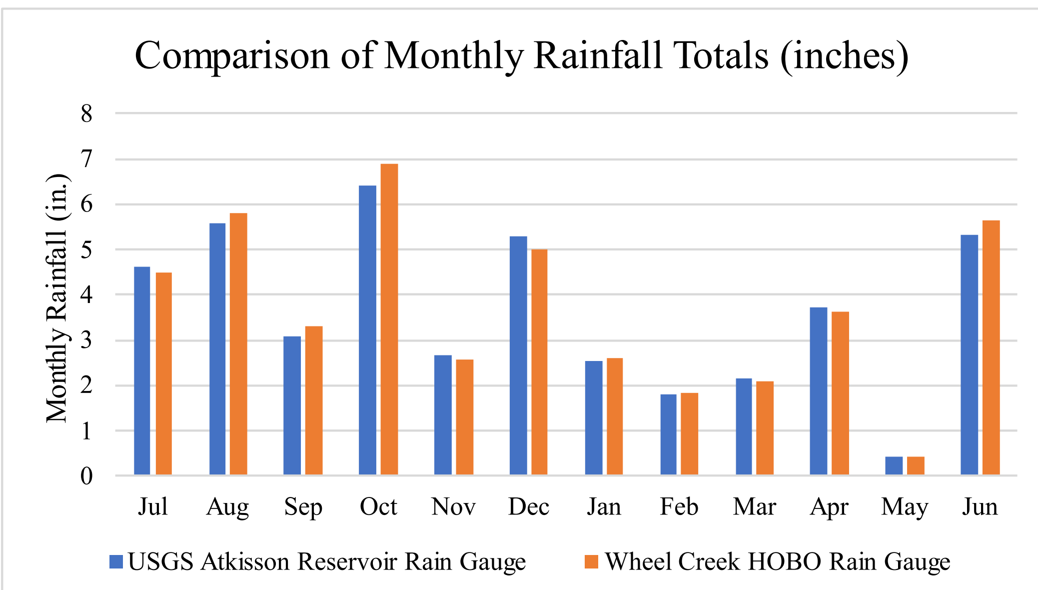


Figure C-2. Comparison of Monthly Rainfall Totals for the USGS and Wheel Creek gauges

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# APPENDIX D

## TOTAL ANNUAL LOADS AND YIELDS OF POLLUTANTS AT WHEEL CREEK STUDY STATIONS

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| Table D-1. Baseflow and storm flow MCs and EMCs, total annual loads, and annual yields (July 2022-June 2023) | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Analyte** | **Station** | **Storm EMC (mg/L)** | **Baseflow MC (mg/L)** | **Annual Storm Load (lbs)** | **Annual Baseflow Load (lbs)** | **Annual Total Load (lbs)** | **Yield (lbs/ac/yr)** |
| Ammonia | WC002 | 0.034 | 0.123 | 54.226 | 103.746 | 157.972 | 0.471 |
| | WC003 | 0.012 | 0.044 | 7.976 | 9.802 | 17.778 | 0.153 |
| | WC004 | 0.046 | 0.017 | 10.875 | 1.487 | 12.362 | 0.317 |
| BOD | WC002 | 2.972 | 1.083 | 4,696.757 | 911.281 | 5,608.038 | 16.725 |
| | WC003 | 2.157 | 1.083 | 1,429.238 | 240.435 | 1,669.672 | 14.344 |
| | WC004 | 2.688 | 1.000 | 639.008 | 89.223 | 728.231 | 18.673 |
| Chloride | WC002 | 61.702 | 122.917 | 97,523.258 | 103,395.394 | 200,918.652 | 599.221 |
| | WC003 | 99.625 | 147.583 | 66,025.244 | 32,754.586 | 98,779.831 | 848.624 |
| | WC004 | 146.535 | 316.500 | 34,839.520 | 28,238.978 | 63,078.498 | 1,617.397 |
| Nitrate + Nitrite | WC002 | 0.594 | 1.258 | 939.619 | 1,058.488 | 1,998.107 | 5.959 |
| | WC003 | 0.411 | 0.775 | 272.334 | 172.003 | 444.337 | 3.817 |
| | WC004 | 0.480 | 2.542 | 114.154 | 226.774 | 340.928 | 8.742 |
| TKN | WC002 | 0.792 | 0.617 | 1,251.025 | 518.729 | 1,769.755 | 5.278 |
| | WC003 | 0.772 | 0.525 | 511.743 | 116.518 | 628.262 | 5.397 |
| | WC004 | 0.964 | 0.525 | 229.289 | 46.842 | 276.131 | 7.080 |
| Total P | WC002 | 0.081 | 0.017 | 127.736 | 14.230 | 141.966 | 0.423 |
| | WC003 | 0.072 | 0.016 | 47.485 | 3.459 | 50.944 | 0.438 |
| | WC004 | 0.074 | 0.018 | 17.672 | 1.606 | 19.278 | 0.494 |
| Ortho-phosphate | WC002 | 0.030 | 0.044 | 47.010 | 37.152 | 84.162 | 0.251 |
| | WC003 | 0.039 | 0.050 | 26.177 | 11.097 | 37.274 | 0.320 |
| | WC004 | 0.033 | 0.044 | 7.760 | 3.941 | 11.701 | 0.300 |
| TSS | WC002 | 16.584 | 2.917 | 26,212.493 | 2,453.450 | 28,665.943 | 85.493 |
| | WC003 | 15.729 | 4.167 | 10,424.233 | 924.748 | 11,348.981 | 97.500 |
| | WC004 | 17.861 | 3.833 | 4,246.532 | 342.020 | 4,588.553 | 117.655 |
| Copper | WC002 | 7.428 | 0.833 | 11.740 | 0.701 | 12.441 | 0.037 |
| | WC003 | 7.409 | - | 4.910 | - | 4.910 | 0.042 |
| | WC004 | 7.643 | 0.250 | 1.817 | 0.022 | 1.839 | 0.047 |
| Lead | WC002 | 0.810 | 0.942 | 1.280 | 0.792 | 2.072 | 0.006 |
| | WC003 | 0.710 | 0.942 | 0.471 | 0.209 | 0.680 | 0.006 |
| | WC004 | 0.897 | 0.908 | 0.213 | 0.081 | 0.294 | 0.008 |
| Zinc | WC002 | 18.132 | 9.083 | 28.659 | 7.641 | 36.300 | 0.108 |
| | WC003 | 19.684 | 9.167 | 13.045 | 2.034 | 15.080 | 0.130 |
| | WC004 | 29.451 | 22.750 | 7.002 | 2.030 | 9.032 | 0.232 |

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# APPENDIX E

## TOTAL SEASONAL LOADS OF POLLUTANTS AT WHEEL CREEK STUDY STATIONS

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Table E-1. Baseflow and storm flow MCs and EMCs and total seasonal load (July 2022-June 2023)

| Sample Year | Season | Station | Storm EMC (mg/L) | Baseflow MC (mg/L) | Seasonal Storm Load (lbs) | Seasonal Baseflow Load (lbs) | Seasonal Total Load (lbs) |
|---|---|---|---|---|---|---|---|
| **Ammonia** | | | | | | | |
| 2022 | Summer | WC002 | 0.079 | 0.110 | 35.936 | 18.678 | 54.614 |
| | | WC003 | - | 0.027 | - | 1.365 | 1.365 |
| | | WC004 | 0.070 | - | 7.827 | - | 7.827 |
| | Fall | WC002 | 0.003 | 0.103 | 2.296 | 21.358 | 23.653 |
| | | WC003 | - | 0.067 | - | 3.596 | 3.596 |
| | | WC004 | 0.023 | - | 1.922 | - | 1.922 |
| 2023 | Winter | WC002 | 0.009 | 0.090 | 1.823 | 23.589 | 25.412 |
| | | WC003 | 0.032 | 0.023 | 3.155 | 1.433 | 4.588 |
| | | WC004 | 0.090 | 0.020 | 2.469 | 0.432 | 2.901 |
| | Spring | WC002 | 0.046 | 0.190 | 10.933 | 38.493 | 49.426 |
| | | WC003 | 0.016 | 0.060 | 2.104 | 3.324 | 5.429 |
| | | WC004 | - | 0.047 | - | 1.185 | 1.185 |
| **BOD** | | | | | | | |
| 2022 | Summer | WC002 | 3.718 | 1.000 | 1,695.361 | 169.799 | 1,865.160 |
| | | WC003 | 2.222 | 1.000 | 463.289 | 51.169 | 514.458 |
| | | WC004 | 2.266 | 1.000 | 253.864 | 19.544 | 273.408 |
| | Fall | WC002 | 2.966 | 1.000 | 2,012.156 | 206.686 | 2,218.842 |
| | | WC003 | 2.319 | 1.000 | 522.590 | 53.937 | 576.526 |
| | | WC004 | 1.963 | 1.000 | 166.785 | 22.684 | 189.469 |
| 2023 | Winter | WC002 | 1.706 | 1.000 | 358.811 | 262.101 | 620.912 |
| | | WC003 | 1.260 | 1.333 | 124.268 | 81.905 | 206.173 |
| | | WC004 | 2.364 | 1.000 | 65.181 | 21.594 | 86.775 |
| | Spring | WC002 | 3.497 | 1.333 | 824.339 | 270.128 | 1,094.467 |
| | | WC003 | 2.825 | 1.000 | 368.013 | 55.405 | 423.418 |
| | | WC004 | 4.144 | 1.000 | 54.811 | 25.401 | 80.212 |
| **Chloride** | | | | | | | |
| 2022 | Summer | WC002 | 25.098 | 117.333 | 11,445.208 | 19,923.133 | 31,368.341 |
| | | WC003 | 25.604 | 137.667 | 5,338.006 | 7,044.250 | 12,382.255 |
| | | WC004 | 32.368 | 303.333 | 3,625.622 | 5,928.447 | 9,554.068 |
| | Fall | WC002 | 48.592 | 115.333 | 32,969.154 | 23,837.827 | 56,806.981 |
| | | WC003 | 70.213 | 128.667 | 15,823.199 | 6,939.880 | 22,763.079 |
| | | WC004 | 34.595 | 273.000 | 2,938.629 | 6,192.622 | 9,131.250 |
| 2023 | Winter | WC002 | 121.737 | 133.333 | 25,602.302 | 34,946.844 | 60,549.147 |
| | | WC003 | 242.557 | 165.667 | 23,927.413 | 10,176.636 | 34,104.048 |
| | | WC004 | 410.884 | 336.000 | 11,329.436 | 7,255.586 | 18,585.023 |
| | Spring | WC002 | 51.381 | 125.667 | 12,112.498 | 25,459.532 | 37,572.031 |
| | | WC003 | 60.125 | 158.333 | 7,831.429 | 8,772.529 | 16,603.958 |
| | | WC004 | 106.902 | 353.667 | 1,413.991 | 8,983.397 | 10,397.388 |

| Table E-1. (Continued) | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Sample Year** | **Season** | **Station** | **Storm EMC (mg/L)** | **Baseflow MC (mg/L)** | **Seasonal Storm Load (lbs)** | **Seasonal Baseflow Load (lbs)** | **Seasonal Total Load (lbs)** |
| **Nitrate + Nitrite** | | | | | | | |
| 2022 | Summer | WC002 | 0.444 | 1.100 | 202.625 | 186.779 | 389.404 |
| | | WC003 | 0.337 | 0.633 | 70.338 | 32.407 | 102.745 |
| | | WC004 | 0.273 | 2.267 | 30.527 | 44.300 | 74.827 |
| | Fall | WC002 | 0.557 | 1.300 | 377.648 | 268.692 | 646.340 |
| | | WC003 | 0.448 | 0.800 | 101.063 | 43.150 | 144.213 |
| | | WC004 | 0.377 | 2.500 | 31.997 | 56.709 | 88.706 |
| 2023 | Winter | WC002 | 0.885 | 1.500 | 186.040 | 393.152 | 579.192 |
| | | WC003 | 0.593 | 0.933 | 58.466 | 57.333 | 115.799 |
| | | WC004 | 0.516 | 2.600 | 14.231 | 56.144 | 70.375 |
| | Spring | WC002 | 0.492 | 1.133 | 116.079 | 229.609 | 345.687 |
| | | WC003 | 0.265 | 0.733 | 34.539 | 40.631 | 75.170 |
| | | WC004 | 0.749 | 2.800 | 9.903 | 71.122 | 81.025 |
| **Orthophosphate** | | | | | | | |
| 2022 | Summer | WC002 | 0.039 | 0.027 | 17.802 | 4.528 | 22.330 |
| | | WC003 | 0.034 | 0.050 | 7.189 | 2.558 | 9.748 |
| | | WC004 | 0.023 | 0.040 | 2.534 | 0.782 | 3.316 |
| | Fall | WC002 | 0.024 | 0.050 | 16.504 | 10.334 | 26.838 |
| | | WC003 | 0.035 | 0.050 | 7.930 | 2.697 | 10.627 |
| | | WC004 | 0.028 | 0.050 | 2.413 | 1.134 | 3.547 |
| 2023 | Winter | WC002 | 0.034 | 0.050 | 7.133 | 13.105 | 20.238 |
| | | WC003 | 0.045 | 0.050 | 4.463 | 3.071 | 7.534 |
| | | WC004 | 0.050 | 0.037 | 1.379 | 0.792 | 2.170 |
| | Spring | WC002 | 0.022 | 0.050 | 5.113 | 10.130 | 15.243 |
| | | WC003 | 0.043 | 0.050 | 5.611 | 2.770 | 8.381 |
| | | WC004 | 0.030 | 0.050 | 0.390 | 1.270 | 1.661 |
| **TKN** | | | | | | | |
| 2022 | Summer | WC002 | 0.874 | 1.167 | 398.331 | 198.099 | 596.430 |
| | | WC003 | 0.762 | 0.767 | 158.819 | 39.229 | 198.048 |
| | | WC004 | 0.823 | 0.833 | 92.174 | 16.287 | 108.461 |
| | Fall | WC002 | 0.656 | 0.367 | 444.980 | 75.785 | 520.765 |
| | | WC003 | 0.743 | 0.467 | 167.550 | 25.171 | 192.720 |
| | | WC004 | 0.825 | 0.433 | 70.068 | 9.830 | 79.897 |
| 2023 | Winter | WC002 | 0.561 | 0.500 | 117.949 | 131.051 | 248.999 |
| | | WC003 | 0.554 | 0.467 | 54.636 | 28.667 | 83.303 |
| | | WC004 | 0.724 | 0.467 | 19.956 | 10.077 | 30.033 |
| | Spring | WC002 | 1.076 | 0.433 | 253.623 | 87.791 | 341.415 |
| | | WC003 | 1.030 | 0.400 | 134.098 | 22.162 | 156.260 |
| | | WC004 | 1.484 | 0.367 | 19.631 | 9.314 | 28.944 |

Table E-1. (Continued)

| Sample Year | Season | Station | Storm EMC (mg/L) | Baseflow MC (mg/L) | Seasonal Storm Load (lbs) | Seasonal Baseflow Load (lbs) | Seasonal Total Load (lbs) |
|---|---|---|---|---|---|---|---|
| **Total Phosphorous** | | | | | | | |
| 2022 | Summer | WC002 | 0.135 | 0.036 | 61.632 | 6.169 | 67.801 |
| | | WC003 | 0.097 | 0.020 | 20.188 | 1.023 | 21.212 |
| | | WC004 | 0.068 | 0.019 | 7.584 | 0.378 | 7.962 |
| | Fall | WC002 | 0.065 | 0.008 | 44.015 | 1.722 | 45.738 |
| | | WC003 | 0.064 | 0.010 | 14.502 | 0.521 | 15.024 |
| | | WC004 | 0.066 | 0.011 | 5.634 | 0.257 | 5.891 |
| 2023 | Winter | WC002 | 0.030 | 0.013 | 6.353 | 3.407 | 9.760 |
| | | WC003 | 0.028 | 0.017 | 2.715 | 1.024 | 3.739 |
| | | WC004 | 0.039 | 0.019 | 1.067 | 0.417 | 1.485 |
| | Spring | WC002 | 0.093 | 0.010 | 21.932 | 2.026 | 23.958 |
| | | WC003 | 0.098 | 0.016 | 12.750 | 0.886 | 13.637 |
| | | WC004 | 0.124 | 0.022 | 1.641 | 0.559 | 2.200 |
| **TSS** | | | | | | | |
| 2022 | Summer | WC002 | 28.921 | 3.000 | 13,188.302 | 509.398 | 13,697.701 |
| | | WC003 | 16.538 | 3.667 | 3,447.921 | 187.619 | 3,635.541 |
| | | WC004 | 9.125 | 4.333 | 1,022.127 | 84.692 | 1,106.819 |
| | Fall | WC002 | 11.904 | 2.333 | 8,076.666 | 482.268 | 8,558.935 |
| | | WC003 | 13.773 | 2.000 | 3,103.932 | 107.874 | 3,211.806 |
| | | WC004 | 12.749 | 3.667 | 1,082.947 | 83.173 | 1,166.121 |
| 2023 | Winter | WC002 | 4.221 | 2.000 | 887.761 | 524.203 | 1,411.963 |
| | | WC003 | 6.271 | 6.333 | 618.631 | 389.046 | 1,007.678 |
| | | WC004 | 5.843 | 5.333 | 161.105 | 115.168 | 276.273 |
| | Spring | WC002 | 21.291 | 4.333 | 5,019.245 | 877.915 | 5,897.160 |
| | | WC003 | 26.333 | 4.667 | 3,429.973 | 258.559 | 3,688.531 |
| | | WC004 | 43.871 | 2.000 | 580.279 | 50.801 | 631.081 |

Table E-1. (Continued)

| Sample Year | Season | Station | Storm EMC (µg/L) | Baseflow MC (µg/L) | Seasonal Storm Load (lbs) | Seasonal Baseflow Load (lbs) | Seasonal Total Load (lbs) |
|---|---|---|---|---|---|---|---|
| **Copper** | | | | | | | |
| 2022 | Summer | WC002 | 8.957 | - | 4.084 | - | 4.084 |
| | | WC003 | 7.707 | - | 1.607 | - | 1.607 |
| | | WC004 | 5.796 | 1.000 | 0.649 | 0.020 | 0.669 |
| | Fall | WC002 | 4.771 | 3.333 | 3.237 | 0.689 | 3.926 |
| | | WC003 | 5.013 | - | 1.130 | - | 1.130 |
| | | WC004 | 5.813 | - | 0.494 | - | 0.494 |
| 2023 | Winter | WC002 | 5.144 | - | 1.082 | - | 1.082 |
| | | WC003 | 6.085 | - | 0.600 | - | 0.600 |
| | | WC004 | 8.025 | - | 0.221 | - | 0.221 |
| | Spring | WC002 | 10.839 | - | 2.555 | - | 2.555 |
| | | WC003 | 10.831 | - | 1.411 | - | 1.411 |
| | | WC004 | 11.024 | - | 0.146 | - | 0.146 |
| **Lead** | | | | | | | |
| 2022 | Summer | WC002 | 0.801 | 0.767 | 0.365 | 0.130 | 0.495 |
| | | WC003 | 0.692 | 1.000 | 0.144 | 0.051 | 0.195 |
| | | WC004 | 0.638 | 0.633 | 0.071 | 0.012 | 0.084 |
| | Fall | WC002 | 0.849 | 1.000 | 0.576 | 0.207 | 0.782 |
| | | WC003 | 0.841 | 1.000 | 0.189 | 0.054 | 0.243 |
| | | WC004 | 0.808 | 1.000 | 0.069 | 0.023 | 0.091 |
| 2023 | Winter | WC002 | 0.756 | 1.000 | 0.159 | 0.262 | 0.421 |
| | | WC003 | 0.420 | 1.000 | 0.041 | 0.061 | 0.103 |
| | | WC004 | 0.584 | 1.000 | 0.016 | 0.022 | 0.038 |
| | Spring | WC002 | 0.835 | 1.000 | 0.197 | 0.203 | 0.399 |
| | | WC003 | 0.888 | 0.767 | 0.116 | 0.042 | 0.158 |
| | | WC004 | 1.572 | 1.000 | 0.021 | 0.025 | 0.046 |
| **Zinc** | | | | | | | |
| 2022 | Summer | WC002 | 19.014 | 10.333 | 8.671 | 1.755 | 10.425 |
| | | WC003 | 15.794 | 6.667 | 3.293 | 0.341 | 3.634 |
| | | WC004 | 19.448 | 29.000 | 2.178 | 0.567 | 2.745 |
| | Fall | WC002 | 13.549 | 7.667 | 9.193 | 1.585 | 10.778 |
| | | WC003 | 17.427 | 9.333 | 3.927 | 0.503 | 4.431 |
| | | WC004 | 25.633 | 17.333 | 2.177 | 0.393 | 2.571 |
| 2023 | Winter | WC002 | 14.915 | 10.667 | 3.137 | 2.796 | 5.933 |
| | | WC003 | 18.483 | 9.000 | 1.823 | 0.553 | 2.376 |
| | | WC004 | 31.652 | 19.667 | 0.873 | 0.425 | 1.297 |
| | Spring | WC002 | 25.050 | 7.667 | 5.905 | 1.553 | 7.459 |
| | | WC003 | 27.032 | 11.667 | 3.521 | 0.646 | 4.167 |
| | | WC004 | 40.485 | 25.000 | 0.535 | 0.635 | 1.171 |

"-" = Not Detected

# WHEEL CREEK
# GEOMORPHIC ASSESSMENT
# POST-RESTORATION YEAR 6
# FINAL REPORT

VERSAR

Your Needs. Our Mission.

HARFORD COUNTY MARYLAND

AT THE RISQUE OF OUR LIVES AND FORTUNES

1773

**October 20, 2023**

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# WHEEL CREEK
# GEOMORPHIC ASSESSMENT
# POST-RESTORATION YEAR 6 FINAL REPORT

Prepared for:

Harford County
Department of Public Works
Division of Highways and Water Resources
212 South Bond Street
Bel Air, Maryland 21014

Prepared by

Versar, Inc.
9200 Rumsey Road, Suite 1
Columbia, Maryland 21045

October 20, 2023

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# 1.0 INTRODUCTION

Harford County Department of Public Works (DPW) has completed 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 is the result of previous planning efforts including the Bush River Watershed Restoration Strategy (WRAS), the Bush River Watershed Management Plan in 2003, and the Wheel Creek Watershed Assessment completed in 2008.

Restoration efforts in this watershed began in September 2012 with the retrofit of a stormwater management facility (Pond A) located at the Gardens of Bel Air, and construction was completed in December of 2012. A second project, the Calvert's Walk stream restoration project, began in January of 2013 and was completed that April. In 2015, two more stormwater management facilities were retrofitted, Pond C in August and Pond D in December. The final phase of implementation was completed in March of 2017. These projects included the Lower Wheel Creek stream restoration and the retrofit of the final stormwater management facility (Pond E). After several high intensity rain events since the completion of the Lower Wheel Creek stream restoration, portions of the restoration failed by 2021. The County is currently working on a redesign to repair the structures that failed.

As part of implementing the restoration efforts, the County was awarded funds from a Local Government Implementation Grant through the Chesapeake and Atlantic Coastal Bays 2010 and 2016 Trust Funds. Under the grant proposal, the County implemented a total of four stormwater retrofits and five stream restoration projects to improve water quality, decrease stormwater discharges, and improve instream habitat.

Beginning in 2009, the County initiated monitoring to demonstrate measurable 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 Post-Construction restoration conditions. This report focuses on ten 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 (Up to July 2016)/Versar (July 2016 to present) – 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);
- KCI – Biological and physical habitat data;

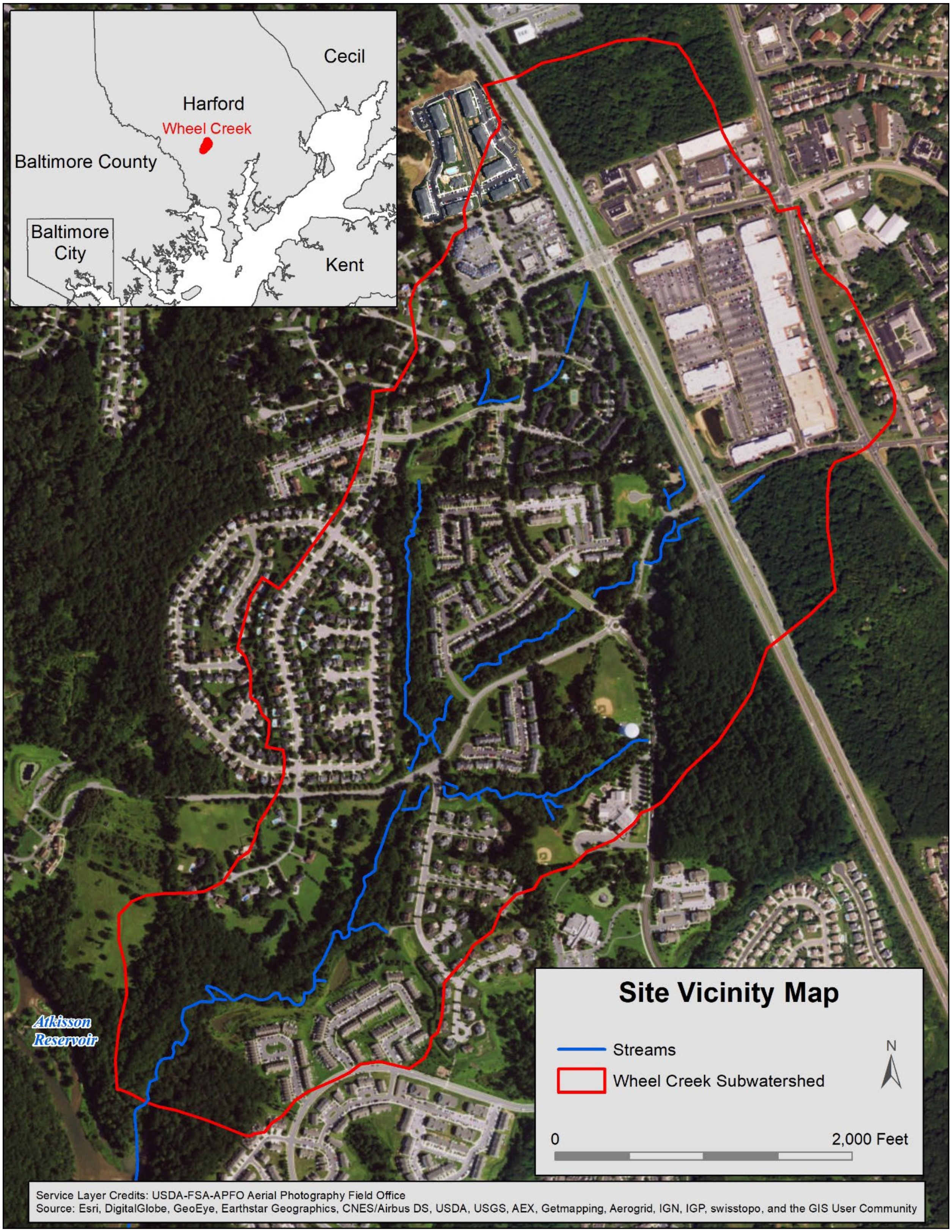


Figure 1-1. Site vicinity map

- Versar – Storm runoff water chemistry and water quality monitoring including 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 for the measured parameters for each sampled event); and
- Harford County DPW (Up to March 2019)/Versar (April 2019 to present) – Baseflow nutrient and total suspended solids data at three stations, one at Wheel Road and two upstream on the eastern tributary at Cinnabar Lane and Wheel Court.

Assessment and monitoring of the physical geomorphologic conditions was initially performed by KCI in 2010 (Pre-Restoration Year 1) to evaluate baseline conditions and was continued by Versar in 2012 (Pre-Restoration Year 2), 2013 (Pre-Restoration Year 3), 2015 (Pre-Restoration Year 4), 2017 (Post-Restoration Year 1), 2018 (Post-Restoration Year 2), 2019 (Post-Restoration Year 3), 2020 (Post-Restoration Year 4), 2022 (Post-Restoration Year 5), and 2023 (Post-Restoration Year 6). 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 (Pre-Restoration Years 1 through 4 and Post-Restoration Years 1 through 6), monitoring bank pins and scour chains (Pre-Restoration Year 1 through 4 only), mapping substrate facies (Pre-Restoration Year 1 only), and evaluating substrate particle size distribution (Pre-Restoration Years 1 through 4 and Post-Restoration Years 1 through 6). 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, Year 3, and Year 4 Studies see *Wheel Creek Geomorphic Assessment Year 2* (Versar, 2013), *Wheel Creek Geomorphic Assessment Year 3* (Versar, 2014) and *Wheel Creek Geomorphic Assessment Year 4* (Versar, 2015). For a complete description of the Post-Restoration Year 1 Study see *Wheel Creek Geomorphic Assessment Post-Restoration Year 1 Final Report* (Versar, 2017), Year 2 Study see *Wheel Creek Geomorphic Assessment Post-Restoration Year 2 Final Report* (Versar, 2018), Year 3 Study see *Wheel Creek Geomorphic Assessment Post-Restoration Year 3 Final Report* (Versar, 2019), Year 4 Study see *Wheel Creek Geomorphic Assessment Post-Restoration Year 4 Final Report* (Versar, 2020), and Year 5 Study see *Wheel Creek Geomorphic Assessment Post-Restoration Year 5 Final Report* (Versar, 2022). This report focuses on continued geomorphic monitoring, including a comparison of data collected during Pre-Restoration Years 1, 2, 3, 4, and Post-Restoration Years 1, 2, 3, 4, 5 and 6.

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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 (Pre-Restoration Year 1 only), and assessment of bank pins and scour chains (Pre-Restoration Years 1 through 4 only). In 2010, four (4) assessment reaches (Figure 2-1) were established by KCI for geomorphic monitoring based on the following treatments:

1. within a stream stabilization reach (WC01);
2. within a stream stabilization reach and downstream of a retrofitted stormwater management facility (WC02);
3. downstream of a retrofitted stormwater management facility (WC03); and
4. a control site with no proposed restoration activities (WC04).

These reaches were re-surveyed by Versar in 2012, 2013, 2015, 2017, 2018, 2019, 2020, 2022, and 2023 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 and to document any changes that have occurred in the restored reaches. Bank and bed pins were monitored to determine rates of potential bank and channel bed erosion or aggradation, while scour chains were used to quantify the extent of bed material scouring. The bank and bed pins along with the scour chains have been discontinued from the monitoring following Pre-Restoration Year 4 (2015). Pebble counts were 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 (2010) 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 at WC03 and WC04 during the Post-Restoration Years 1, 2, 3, 4, 5, and 6 efforts to enable overlays between past surveys.

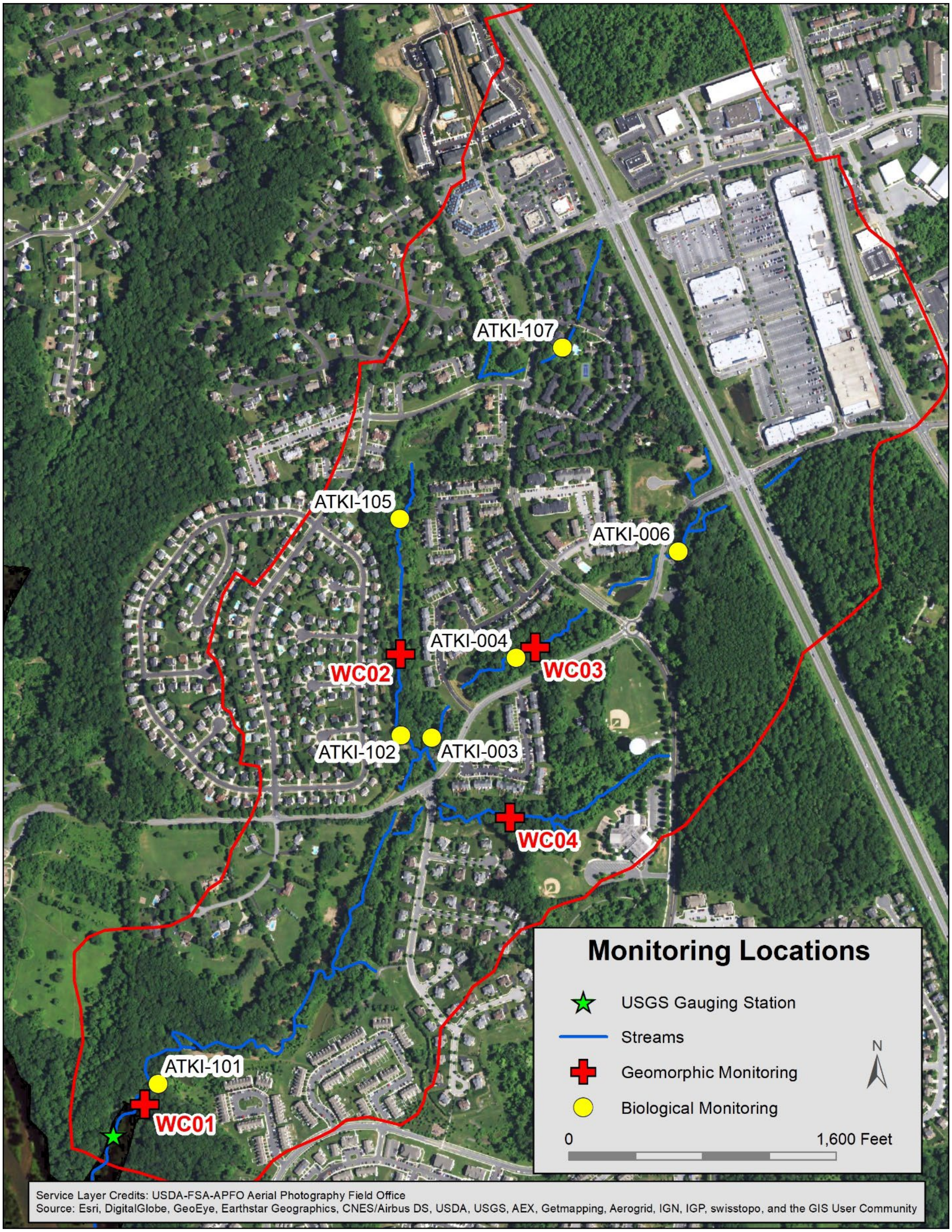


Figure 2-1. Wheel Creek monitoring locations

Versar re-established reaches WC01 and WC02 in 2017 for Post-Restoration Year 1 monitoring. Three (3) benchmark monuments were again installed at both reaches. Two capped iron rebar monuments were installed on each side of the channel to mark the starting point of the new longitudinal profile (i.e., station 0+00). An additional capped iron rebar monument was installed upstream marking the end of the longitudinal profile. These were re-surveyed in 2018, 2019, 2020, 2022, and 2023. During the Post-Restoration Year 5 survey in 2022, the right start pin at the 0+00 station of the WC03 longitudinal profile could not be located by field crews; a new capped pin was set and surveyed against the existing left start pin to allow for elevation adjustments and consistent comparisons of data in future 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 longitudinal profiles were initially established to encompass a minimum reach length of approximately 20 bankfull widths or 300 feet, measured along the centerline of each bankfull channel. Each reach was started at the top of a feature located at the downstream benchmarks, and finished at the top of a feature at or above the upstream benchmark. Each reach included a survey of breakpoints in and between bed features and delineation of riffle, run, pool, and glide features. A survey of the bankfull elevation (where discernible), top of bank, and water surface was also performed. At each site where instream restoration activities did not occur (WC03 and WC04), the plotted Post-Restoration Years 1 through 6 longitudinal profiles were overlaid with the plots from Pre-Restoration Years 1 through 4. These plots enable comparisons between years and are used to track changes that occur in the bed sequences and channel slopes. At the two sites where instream restoration occurred (reaches WC01 and WC02), the plotted profiles from Pre-Restoration Years 1 through 4 were overlaid and the Post-Restoration Years 1 through 6 plotted profiles were compared.

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 Pre-Restoration 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 in 2010 and surveyed during Pre-Restoration Years 1 through 4 and Post-Restoration Years 1 through 6 within each reach at profile stations as shown in Table 2-1. Stationing differed slightly at several stations due to channel migration over time or as a result of re-installing a cross-section when instream restoration has occurred. Cross-sections located in reaches WC01 and WC02 were re-established with new benchmarks in Post-Restoration Year 1 (2017). Due to ongoing restoration construction activities, the WC01 left end pin at Cross-section 2 had to be reinstalled in 2018, as it could not be located during the Post-

Restoration Year 2 survey. Reaches WC03 and WC04 were still monumented to the original benchmarks installed in Pre-Restoration Year 1 (2010) since no instream restoration occurred at those locations. However, the WC03 right end pin at Cross-section 2 had to be reinstalled in 2019, as it had eroded away and fallen into the stream channel during the Post-Restoration Year 3 survey. The same methods were used to establish the new cross-sections in these reaches, although the corresponding station on the longitudinal profile will not be comparable to previous years of Pre-Restoration surveying.

Table 2-1. Cross-sectional survey locations

| **Reach** | WC01* | | WC02* | | WC03 | | WC04 | |
|---|---|---|---|---|---|---|---|---|
| **Profile Station (Pre-Year 1)** | 2+30 | 2+95 | 1+37 | 3+24 | 1+55 | 2+07 | 1+08 | 1+68 |
| **Profile Station (Pre-Year 2)** | 2+30 | 2+95 | 1+38 | 3+24 | 1+57 | 2+08 | 1+08 | 1+68 |
| **Profile Station (Pre-Year 3)** | 2+29 | 2+95 | 1+38 | 3+25 | 1+56 | 2+12 | 1+08 | 1+68 |
| **Profile Station (Pre-Year 4)** | 2+29 | 2+95 | 1+38 | 3+24 | 1+55 | 2+07 | 1+08 | 1+68 |
| **Profile Station (Post-Year 1)** | 2+24 | 2+71 | 0+74.5 | 1+10 | 1+56 | 2+08 | 1+10 | 1+68 |
| **Profile Station (Post-Year 2)** | 2+24 | 2+71 | 0+74.5 | 1+10 | 1+56 | 2+08 | 1+10 | 1+68 |
| **Profile Station (Post-Year 3)** | 2+24 | 2+71 | 0+74.5 | 1+10 | 1+56 | 2+08 | 1+10 | 1+68 |
| **Profile Station (Post-Year 4)** | 2+24 | 2+71 | 0+74.5 | 1+10 | 1+56 | 2+08 | 1+10 | 1+68 |
| **Profile Station (Post-Year 5)** | 2+24 | 2+71 | 0+74.5 | 1+10 | 1+56 | 2+08 | 1+10 | 1+68 |
| **Profile Station (Post-Year 6)** | 2+24 | 2+71 | 0+74.5 | 1+10 | 1+56 | 2+08 | 1+10 | 1+68 |
| **Feature** | Riffle | Meander/ Pool | Riffle | Pool | Riffle | Meander/ Run | Meander/ Pool | Riffle |

*Cross-sections re-established during Post-Restoration Year 1

During Post-Restoration Year 6, 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, 2013, 2015, 2017, 2018, 2019, 2020, 2022, and 2023 provide ten years of data to which subsequent monitoring events will be overlaid and/or compared to assess changes in channel dimension, pattern, and profile.

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 can be utilized for future monitoring events to generate hydraulic geometry values that are more directly comparable between each monitoring effort.

### 2.1.2 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; one (1) feature-specific pebble count was conducted at each cross-section location within the cross-sectional bed feature (two [2] total within each reach), and one (1) 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 Post-Restoration Year 6 evaluations were compared to those found during the previous years of monitoring to evaluate changes in channel substrate composition and stability.

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# 3.0 RESULTS AND DISCUSSION

## 3.1 FLUVIAL GEOMORPHIC ASSESSMENT

### 3.1.1 Longitudinal Profiles and Cross-sectional Surveys

The sixth year of Post-Restoration longitudinal profile and cross-sectional surveys was completed between May 16th and July 5th, 2023. 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 Post-Restoration Year 6 survey. Graphical depictions of each profile are presented in Appendix B. In addition, each surveyed profile was plotted, but only overlain and compared to the Pre-Restoration Years 1, 2, 3, and 4 profiles at WC03 and WC04 (Appendix C) and will be compared to subsequent annual surveyed profiles in order to assess changes occurring in the bed structure. Due to instream restoration activities, WC01 and WC02 Post-Restoration overlays do not share the same monuments as Pre-Restoration. Therefore, separate Post-Restoration overlays were created for these reaches.

Table 3-1. Results of longitudinal profile survey – Post-Restoration Year 6

| Reach | Length (ft) | Slope | Proportion of Features | | | |
|---|---|---|---|---|---|---|
| | | | Riffle | Run | Pool | Glide |
| WC01* | 480 | 2.7% | 53.0% | 9.7% | 25.7% | 11.6% |
| WC02* | 340 | 2.2% | 45.6% | 29.7% | 17.6% | 7.1% |
| WC03 | 308 | 1.7% | 48.4% | 11.1% | 32.8% | 7.7% |
| WC04 | 300 | 3.3% | 48.3% | 32.7% | 7.0% | 12.0% |

*Profiles re-established during Post-Restoration Year 1

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 subjective 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 (where appropriate) and compared to the Pre-Construction year 1, 2, 3, and 4 graphs (Appendix C) and will be compared to subsequent annual cross-section graphs in order to assess changes to channel dimensions post-restoration.

| Table 3-2. Results of cross-sectional survey analysis – Post-Restoration Year 6 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **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+24 | Crossover/Riffle | 23.2 | 0.60 | 41.6 | 1.2 | 13.0 | 128.2 |
| | 2+71 | Meander/Pool | 13.3 | 1.3 | 10.3 | 1.5 | 17.1 | 105.6 |
| WC02* | 0+74.5 | Crossover/Riffle | 15.3 | 0.3 | 54.8 | 1.2 | 4.3 | 31.3 |
| | 1+10 | Pool | 11.5 | 0.5 | 23.5 | 1.2 | 5.6 | 34.9 |
| WC03 | 1+56 | Crossover/Riffle | 9.9 | 0.5 | 20.3 | 1.2 | 4.8 | 45.4 |
| | 2+08 | Meander/Run | 9.4 | 0.6 | 16.3 | 1.6 | 5.5 | 37.3 |
| WC04 | 1+10 | Meander/Pool | 6.9 | 0.7 | 10.6 | 4.4 | 4.6 | 95.1 |
| | 1+68 | Crossover/Riffle | 9.9 | 0.3 | 29.1 | 1.4 | 3.3 | 56.8 |
| *Cross-sections were re-established during Post-Restoration Year 1 | | | | | | | | |

### 3.1.2 Particle Size Analysis

The results of the pebble count data collected during the Post-Restoration Year 6 monitoring are shown in Table 3-3. Reachwide, meander, and riffle surface pebble counts indicate a $D_{50}$ median particle size class ranging from medium gravel to small cobble across all sites. Meander feature surface pebble count $D_{50}$ median particle yield smaller particles due to pool features which is especially evident at the WC01 and WC03 meander/pool cross-sections. Riffle surface and reachwide $D_{84}$ size classes range from very coarse gravel to large cobble at all sites, with the largest particles found at sites WC01 and WC02. Similarly, meander feature surface pebble counts at all sites indicate a $D_{84}$ median particle size class ranging from very coarse gravel to medium cobble. Complete particle size distribution charts are included in Appendix B.

| Table 3-3. Particle size distribution – Post-Restoration Year 6 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ***Riffle Feature Surface*** | | | ***Meander Feature Surface*** | | | ***Reachwide*** | | |
| **Measure** | **Size (mm)** | **Size Class** | **Measure** | **Size (mm)** | **Size Class** | **Measure** | **Size (mm)** | **Size Class** |
| *WC01** | | | | | | | | |
| $D_{50}$ | 48 | very coarse gravel | $D_{50}$ | 44 | very coarse gravel | $D_{50}$ | 57 | very coarse gravel |
| $D_{84}$ | 130 | large cobble | $D_{84}$ | 79 | small cobble | $D_{84}$ | 120 | medium cobble |
| *WC02** | | | | | | | | |
| $D_{50}$ | 35 | very coarse gravel | $D_{50}$ | 32 | coarse gravel | $D_{50}$ | 47 | very coarse gravel |
| $D_{84}$ | 97 | medium cobble | $D_{84}$ | 90 | small cobble | $D_{84}$ | 100 | medium cobble |
| *WC03* | | | | | | | | |
| $D_{50}$ | 39 | very coarse gravel | $D_{50}$ | 47 | very coarse gravel | $D_{50}$ | 33 | very coarse gravel |
| $D_{84}$ | 77 | small cobble | $D_{84}$ | 84 | small cobble | $D_{84}$ | 80 | small cobble |
| *WC04* | | | | | | | | |
| $D_{50}$ | 34 | very coarse gravel | $D_{50}$ | 17 | coarse gravel | $D_{50}$ | 22 | coarse gravel |
| $D_{84}$ | 69 | small cobble | $D_{84}$ | 60 | very coarse gravel | $D_{84}$ | 64 | very coarse gravel |

# 4.0 COMPARISONS BETWEEN YEARS

## 4.1 WC01

This site exhibited the most drastic changes in longitudinal profile over the four years of Pre-Restoration monitoring (2010-2015; Figure C-1). 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 (2012, 2013), the thalweg followed what had been the cutoff channel along the right bank and the previous thalweg channel had only minimal flows. During the fourth year of survey (2015) the thalweg continued to follow the channel along the right bank. Furthermore, a large tree along the left bank fell and was perpendicularly positioned in the stream through this section. The tree caused the stream to widen and flow over most of the mid-channel bar; however, during Years 1 through 3 of Post-Restoration monitoring, the tree migrated onto the left bank, laying parallel, and the outside left bend channel now conveyed the majority of stream flow (Figure C-2). During the Year 4 Post-Restoration survey in 2020, channel conditions at this location were found to have aggraded substantially with the majority of stream flow found mid-channel throughout this portion of the profile. The fifth year of Post-Restoration monitoring found that the mid-channel bar had formed again in this portion of the reach, with equal flow conveyed on either side; conditions during the sixth year of Post-Restoration monitoring were found to be similar, but aggradation was seen in the left channel around the bar, forcing the majority of stream flow to the right of the mid-channel bar. 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 Pre-Restoration monitoring the reach was 420 feet from top to bottom, but during Post-Restoration years the reach was between 480 and 490 feet in length, depending on ending feature. Sinuosity above Cross-section 2 likely increased, adding length to the profile.

Changes in the cross-sections were also observed at WC01 between the four years of Pre-Restoration survey (Figures C-7, C-9). Bed scour was observed at Cross-section 1 (Crossover Riffle at Station 2+29) especially near the right bank between Pre-Restoration Years 1 and 2, while deposition was apparent near the left bank between Pre-Restoration Years 2 and 3. During Pre-Restoration Year 4, continued deposition was observed, and the cross-section once again closely resembled that of Pre-Restoration Year 1. 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 the second and third years of monitoring (2012, 2013). Between Pre-Restoration Years 3 and 4, continued erosion occurred along the left bank increasing the depth of undercutting. Eroded sediment caused slight deposition along the left stream bed. This resulted in increases, from Pre-Restoration Year 1, of bankfull cross-sectional area and top of bank cross-sectional area at this station. Between Pre-Restoration Years 1 and 2, a side-bar formed on the right bank, burying the scour chain at this cross-section. The scour chain was not found during Pre-Restoration Years 3 and 4 of monitoring. In addition, the thalweg pattern changed between Pre-Restoration Years 1 and 2 so that it was no longer perpendicular to the permanently monumented cross-section markers at this location.

The first year of Post-Restoration monitoring was completed in 2017. The WC01 reach underwent an instream restoration and a new longitudinal profile and two cross-sections were selected and monitored for baseline conditions. Cross-section 1 was placed in a crossover riffle at Station 2+24, while Cross-section 2 was placed at a meander bend/pool at Station 2+71. The survey of the longitudinal profile consisted of large riffle and pool features. During 2017, approximately 55.1% of the reach was riffle/run and 44.9% was pool/glide; in 2018, approximately 57.0% of the reach was riffle/run and 43.0% was pool/glide. During 2019, approximately 59.3% of the reach was riffle/run and 40.7% was pool/glide; in 2020, approximately 52.8% of the reach was riffle/run and 47.2% was pool/glide. The longitudinal profile consisted of 65.1% riffle/run and 34.9% pool/glide in 2022, and 63.4% riffle/run and 36.6% pool/glide in 2023. The slope of the reach was high at 2.6% in 2017 and remained high at 2.7% from 2018 through 2023. The cross-sections featured stable banks exhibiting no erosion. Cross-section 1 at Station 2+24 has a defined bench and access to a small floodplain as the banks have been graded back during construction (Figure C-8). Cross-section 2 at Station 2+71 exhibits the same floodplain on the right bank in addition to a point bar, while the left bank is heavily armored by boulders (Figure C-10); between the Post-Restoration years 3 through 6 surveys, this armoring failed, resulting in several of the large boulders eroding out and falling into the stream channel, leaving the bank behind exposed to future erosion. Channel alterations were noted between the 2017 and 2018 Post-Restoration surveys. Minimal scouring (approximately 0.25 feet) of the channel at Cross-section 1 was observed, while significant aggradation of sediment was found along the right bank and channel at Cross-section 2. These changes in streambed were likely the result of an abnormally wet spring, and year overall, which shifted and transported large amounts of sediment throughout the reach. Between the 2018 and 2019 Post-Restoration surveys, channel alteration was again noted. Aggradation of approximately 1.0 feet occurred in the middle of the channel at Cross-section 1, and approximately 1.0 feet of sediment was deposited on the right bank bench was observed; significant aggradation of sediment was found along the right bank and channel at Cross-section 2. Channel alteration was again noted between the 2019 and 2020 Post-Restoration surveys. The channel was noted to have scoured between 0.5 and 0.75 feet across much of the channel at Cross-section 1, and approximately 0.5 feet of scouring of the bench on the right bank was observed; significant scouring of approximately 1.0 feet was found along the left and right banks, with mid-channel conditions remaining the same, at Cross-section 2. The changes in streambed were significant between 2020 and prior year surveys, likely the result of extensive rains which shifted and transported large amounts of sediment throughout the reach. Between 2020 and 2023 surveys, conditions at Cross-section 1 remained stable, with minimal scouring (approximately 0.25 feet) noted mid- to right channel. More significant changes in channel geometry were noted at Cross-section 2 between 2020 and 2023. The armoring on the left bank slumped about 0.5 feet, further demonstrating the ongoing failure of the restoration in this portion of the reach, while significant aggradation (0.5-0.7 feet) of sediment was measured mid- to left-channel between 2020 and 2023 surveys. The right side of the channel and floodplain remained stable between 2020 and 2023, with only minor scouring noted on the right edge of the wetted stream channel. Future surveys will be useful in determining how the stream channel reacts to these changes, how it stabilizes over time, and the success of the planned restoration repair in this reach.

At WC01, $D_{50}$ particle size classes remained the same between all four years of Pre-Restoration study at both cross-sections, and reachwide (Table C-3). $D_{84}$ 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. Although $D_{84}$ classes at Cross-section 2 were unchanged between Years 2 and 3 they transformed during the fourth year of study, increasing from small cobble to medium cobble. Reachwide $D_{84}$ particle size class fluctuated between large cobble during Year 1, to medium cobble during Year 2 and back to large cobble during Years 3 and 4.

In the first year of Post-Restoration (2017), $D_{50}$ particle sizes decreased from very coarse gravel to medium gravel at the meander feature and from very coarse gravel to coarse gravel reachwide. In Post-Restoration Years 2 and 3, reachwide $D_{50}$ particle sizes increased back to very coarse gravel reachwide but fluctuated between medium and very coarse gravel at the meander feature. $D_{50}$ particle sizes categorized as coarse gravel at both the meander feature and reachwide in Post-Restoration Year 4. Median particle size coarsened to small cobble reachwide and at the meander feature in Post-Restoration Year 5. Riffle feature surface $D_{50}$ particle sizes remained as very coarse gravel during the first 4 years of post-restoration monitoring but coarsened to small cobble in Post-Restoration Year 5. In Post Restoration Year 6, $D_{50}$ particle sizes became finer for the riffle, meander/bend, and reachwide surfaces, categorizing as very coarse gravel in all three features. In the first year of Post-Restoration monitoring (2017), reachwide $D_{84}$ decreased to small cobble. The new crossover riffle at Station 2+24 had a $D_{84}$ of small cobble and the new meander bend/pool at Station 2+71 had a $D_{84}$ of very coarse gravel. In 2018, the reachwide $D_{84}$ increased to large cobble. The crossover riffle at Station 2+24 had an increased $D_{84}$ to large cobble and the meander bend/pool at Station 2+71 had an increased $D_{84}$ to medium cobble. In 2019, the reachwide $D_{84}$ decreased to small cobble. The crossover riffle at Station 2+24 had a decreased $D_{84}$ to very coarse sand and the meander bend/pool at Station 2+71 had a decreased $D_{84}$ to medium gravel. This overall decrease in particle size classes at WC01 was likely the result of an increase in smaller particles being transported and deposited into the reach from the above average rainfall received between 2018 and 2019. In 2020, the reachwide $D_{84}$ increased to medium cobble. The crossover riffle at Station 2+24 had an increased $D_{84}$ to medium cobble at the meander bend/pool at Station 2+71 had an increased $D_{84}$ to small cobble. In Post-Restoration Year 5, $D_{84}$ values increased one class at all three locations, coarsening to medium cobble and the meander bend/pool at Station 2+71 and large cobble at both the crossover riffle at Station 2+24 and reachwide. In Post-Restoration Year 6, $D_{84}$ values decreased at all three locations, and decreased one class in the meander/bend and reachwide features, dropping from medium to small cobble in the meander bend/pool at Station 2+71 and large to medium cobble at reachwide; $D_{84}$ values remained as large cobble within the crossover riffle at Station 2+24. This overall increase in particle size classes at WC01 was likely the result of an increase in larger particles being transported and deposited into and within the reach from the above average rainfall intensities between 2019 and 2023, with enough power to redistribute larger substrate, as evidenced by the movement of the large armoring boulders at Station 2+71.

## 4.2 WC02

Significant changes in profile were not observed at WC02 over the four years of Pre-Restoration study. The most noticeable change is a pool feature once approximately at Station

1+00 changed to Station 0+80 (Figures C-3 and C-4). Reach length remained constant and stream slope measurements were fairly consistent overall. Feature proportions within the reach have fluctuated from year to year. While the percentage of glides increased from 0% to 16.7% between Pre-Restoration Years 1 and 2, the percentage of pools declined each year. During the fourth year (2015), 25.5% of the surveyed reach was classified as pools and glides, the lowest percentage since monitoring began. In contrast, riffles and runs made up 74.5% of the surveyed reach which was the greatest percentage of all four years (Table C-1).

Following Pre-Restoration Year 1, bed aggradation occurred at Cross-section 1 (Crossover Riffle at Station 1+38), but banks here remained relatively stable (Figure C-11). There was little change between the third and fourth year of Pre-Restoration study. 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-13). At this station, a bankfull bar exists along the left bank which showed little change between Pre-Restoration Years 2 and 3 of the study. However, during the fourth year of Pre-Restoration monitoring slight degradation can be seen along the left bank and bar.

In the first year of Post-Restoration monitoring, the WC02 reach consisted of 63.6% riffle/run and 36.4% pool/glide (Table C-1). This reach consisted of 60.3% riffle/run and 39.7% pool/glide in the 2018 Post-Restoration monitoring. During 2019 Post-Restoration monitoring, this reach consisted of 61.5% riffle/run and 38.5% pool/glide; the percent riffle/run and percent pool/glide was 59.0% and 41.0% during the 2020 Post-Restoration monitoring, respectively. In the fifth year of Post-Restoration monitoring, WC02 consisted of 73.3% riffle/run and 26.7% pool/glide, a significant change from the gradual decline in riffle/run features seen in the first four years of post-restoration monitoring and similar to the last year of pre-restoration monitoring (2015). This change in stream character was maintain in the sixth year of post restoration monitoring, consisting of 75.6% riffle/run and 24.4% pool/glide features. This reach underwent instream restoration that has straightened the channel causing the meander bend cross-section to be placed in a straight pool. Overall, this reach is still somewhat lacking access to an immediate floodplain, but the banks are stable and well-vegetated despite being steep and high. The entrenchment ratio was low, 1.3, in 2017, and remained low at 1.4 in 2018 and 2019, 1.3 in 2020 and 2022, and 1.2 in 2023, indicating the stream is confined within the banks (Appendix B). The stream is comprised predominately of long riffles and grade control steps into long/wide pools. In 2023, significant aggradation was noted between stations 0+50 and 1+00, raising the streambed nearly one foot in elevation and back to levels seen in 2019 and 2020; scouring was also noted in the two upstream pools within the reach.

Cross-section 1 was newly monumented in a pool at Station 0+74.5 (Figure C-12) and Cross-section 2 was monumented at Station 1+10 in a crossover riffle (Figure C-14). Both cross-sections exhibit little bank erosion and have stable banks. Cross-section 1 aggraded substantially in 2018, with more than 1.5 feet of substrate deposited in the stream channel. Significant aggradation continued in 2019, with an additional 0.5 feet of sediment deposited in the stream channel; conditions at Cross-section 1 were comparable between the 2019 and 2023 surveys, with minimal aggradation noted within the mid-channel bar in 2023, indicating that this portion of the reach may have stabilized post-restoration. Cross-section 2 had minimal scouring (0.25 to 0.5 feet) within the channel in 2018, but experienced aggradation of 0.25 to 1.0 feet of substrate in 2019. Aggradation at this station continued in 2020, with an additional 0.25 feet of sediment being deposited. In the 2022 survey, Cross-section 2 was found to be largely similar to conditions in 2020, with particles being redistributed across the reach; approximately 0.25 feet of sediment was scoured from the right side of the channel while aggradation of approximately 0.25 feet of sediment was noted on the left side of the channel. Conditions at Cross-section 2 were largely the same between 2023 and 2022, with only minor aggradation of sediment noted along the right side of the channel. These changes in streambed could be the result of an abnormally wet years overall between 2018 and 2023, which likely shifted and transported large amounts of sediment throughout the reach. Future surveys will enable evaluation of how the stream channel reacts to these changes, as well as how it stabilizes over time.

$D_{50}$ particle size classes remained the same between all four years of Pre-Restoration study at both cross-sections. The reachwide $D_{50}$ for Pre-Restoration Years 2 and 3 were categorized as coarse gravel which is slightly finer than the very coarse gravel observed in Pre-Restoration Years 1 and 4 (Table C-3). $D_{84}$ particle size classes became slightly finer at both cross-sections, diminishing from medium-sized cobble to small cobble between the first and second years of Pre-Restoration study. Furthermore, both cross-section $D_{84}$ classes coarsened between Pre-Restoration Years 3 and 4 from small cobble to medium cobble. Although reachwide $D_{84}$ particle sizes also reduced between Pre-Restoration Years 1 and 2, particles increased back to medium-sized cobble in Pre-Restoration Year 3 and remained during Pre-Restoration Year 4.

In the first year of Post-Restoration study (2017), $D_{50}$ particle size classes decreased at both cross-sections and reachwide, classifying as coarse gravel at the riffle feature, very fine gravel at the meander feature, and medium gravel reachwide. Riffle feature $D_{50}$ classification rebounded back into the very coarse gravel category in the Post-Restoration Years 2 and 3 surveys, and meander feature $D_{50}$ particle sizes coarsened to small cobble in 2018 and medium gravel in 2019. In the Post-Restoration Year 4 survey, riffle feature $D_{50}$ coarsened to small cobble and meander feature $D_{50}$ coarsened to very coarse gravel. Reachwide $D_{50}$ classifications rated as very coarse gravel in the Post-Restoration Year 4 assessment, and coarse gravel in both Post-Restoration Years 2 and 3 surveys, all coarser than the initial particle class determined by the Post-Restoration Year 1 survey, and recategorized for the first time the same as pre-restoration ratings. From the Post-Restoration Year 5 assessment, riffle feature median particle size significantly decreased, classifying as coarse gravel, while the meander feature and reachwide surveys remained stable in the very coarse gravel classification. In the Year 6 Post-Restoration assessment, $D_{50}$ particle size coarsened to very coarse gravel in the riffle feature, decreased to coarse gravel in the meander feature, and remained as very coarse gravel reachwide; while categorical ratings changed at locations in 2023, actual median particle sizes remained consistent compared to those measured in 2022. Reachwide $D_{84}$ decreased to medium gravel in 2017. The new crossover riffle at Station 1+10 had a $D_{84}$ of very coarse gravel and the new meander bend/pool at Station 0+74.5 had a $D_{84}$ of medium gravel. In the 2018 Post-Restoration study, the reachwide $D_{84}$ increased to coarse gravel. The crossover riffle at Station 1+10 had an increased $D_{84}$ to medium cobble and the meander bend/pool at Station 0+74.5 had an increased $D_{84}$ to large cobble. In the 2019 Post-Restoration study, the reachwide $D_{84}$ increased to small cobble. The $D_{84}$ at the crossover riffle at Station 1+10 remained as medium cobble and the meander bend/pool at Station 0+74.5 had a decreased $D_{84}$ to small cobble. In the 2020 Post-Restoration Year 4 study, the reachwide $D_{84}$ remained as small cobble. The $D_{84}$ at the crossover riffle coarsened to large cobble and the meander bend/pool had an increased $D_{84}$ to medium cobble. In the 2022 Post-Restoration Year 5 study, the reachwide $D_{84}$ remained as small cobble. The $D_{84}$ at the crossover riffle significantly reduced to very coarse gravel and the meander bend/pool slightly declined to small cobble. Overall bed roughness coarsening was noticed in the 2023 Post-Restoration Year 6 assessment. While the $D_{84}$ particle size increased at all three locations, this coarsening was significant enough to increase the categorical rating at the riffle feature from very coarse gravel to medium cobble, and from small cobble to medium cobble reachwide; $D_{84}$ remained as small cobble at the meander feature despite having particle sizes 22mm larger than in the 2022 survey.

### 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 Pre-Restoration Years 1 and 2, respectively. During Pre-Restoration Year 3, however, riffles and runs made up more than half (53.1%) of the reach (Table C-1). Pools and glides were dominant during Pre-Restoration Year 4 (58.5%). Changes in longitudinal profile were noted between the four years' of Pre-Restoration study, most notably the deepening of most pools reachwide between the first two years (Figure C-5). Pool depth has stayed consistent from Pre-Restoration Year 2 through Year 4 except for the pool feature at station 1+00 which has deepened about a foot.

In Post-Restoration Year 1 (2017), WC03 consisted of 66.0% riffle/run and 34% pool/glide which shows a large change from Pre-Restoration Year 4 (2015) when pools and glides were dominant. These percentages were similar in subsequent surveys, with the reach consisting of 62.7% riffle/run and 37.2% pool/glide in 2018 and 62.3% riffle/run and 37.7% pool/glide in 2019. In the Post-Restoration Year 4 survey, riffle/run to pool/glide distributions transitioned closer to Pre-Restoration distributions, consisting of 50.0% riffle/run and 50.0% pool/glide. In the Post-Restoration Year 5 survey, riffle/run to pool/glide distributions transitioned back to Years 1 through 3 Post-Restoration distributions, consisting of 66.1% riffle/run and 33.9% pool/glide. In Post-Restoration Year 6, feature distribution consisted of 59.5% riffle/run and 40.5% pool/glide, maintaining the riffle/run dominance throughout the reach. No instream restoration occurred on this reach and the stream had aggraded over time prior to 2018 (Figure C-5). Many of the pools became shallower due to this aggradation and some transitioned into riffles or runs altogether. Slight scouring was noted in this reach during the 2018 survey when compared to prior monitoring, mostly constrained to the upper 100 feet of the profile. This scouring was maintained from 2019 through 2022 and was evident throughout the reach instead of constrained to the upper 100 feet of the profile, likely due to above average rainfall between 2018 and 2022 which transported substrate out of the reach. This scouring continued in 2023, most evident at the top of pools throughout the reach, with aggradation of sediment noted in the bottom of pools and glides. Elevated stream flows resulting from storm events likely contributed to the instability of stream sediments within the reach.

Cross-section 1 (Station 1+55) had been a crossover riffle when initially established during Pre-Restoration Year 1 of the study and again in Pre-Restoration Years 3 and 4. However, changes in channel profile resulted in the riffle feature migrating downstream, and this cross-section was within a pool feature when surveyed in Pre-Restoration Year 2 (Figure C-5). As a result, Year 2 bankfull cross-sectional dimensions changed significantly at this station, with the deepening of the channel bed (Table C-2). The Pre-Restoration Year 4 streambed most closely resembled that of the Pre-Restoration Year 2 study. The right streambank remained relatively unchanged at Cross-section 1 throughout the four-year Pre-Restoration study while the left bank slightly filled in between 2012 and 2015 (Figure C-15). Significant deepening also occurred at Cross-section 2 (Meander Bend at Station 2+07), and erosion of the outside (left) bank was also observed between Pre-Restoration Years 1 and 2 (Figure C-16). The left bank continued to erode between Pre-Restoration Years 2 and 3 while aggradation occurred in the stream bed near the left bank. Significant erosion continued on the left bank between Pre-Restoration Years 3 and 4 as well as scouring of the left bank streambed. Consequently, bankfull cross-sectional dimensions and entrenchment ratios also differed significantly at this station between all four Pre-Restoration years (Table C-2).

In the first year of Post-Restoration monitoring, Cross-section 1 at Station 1+56 continued eroding slightly on the left bank while the right bank aggraded around the toe of the bank almost 0.5 feet (Figure C-15). In 2018, the left bank stabilized, while scouring occurred around the toe of both the left and right banks. Erosion of the left bank was evident again during the 2019 survey while the toe of the left bank aggraded; measurements across the right bank demonstrated that it has remained stable. Erosion of the left bank was evident during the 2019 and 2020 surveys while the toe of the left bank aggraded in 2019 and remained similar in 2020; measurements across the right bank demonstrated that it has remained stable during Post-Restoration Years 1 through 3 surveys but aggraded approximately 0.33 feet in the Post-Restoration Year 4 survey. The Post-Restoration Year 5 survey of Cross-section 1 showed that both the right and left banks remained relatively stable but minimal scouring of 0.1-0.2 feet of sediment was noted across the entire channel. In the Post-Restoration Year 6 of Cross-section 1, substantial left bank erosion of approximately 0.5 feet was noted, demonstrating the stress that this bank continues to receive; minor scouring was measured on the toe of the right bank, but this continues to remain fairly stable. Cross-section 2 at Station 2+08 has undergone major changes since Pre-Restoration Year 4 (2015). The left bank has eroded an additional 4.0 to 8.5 feet from 2015 to 2023 and has undercut the bank; the left bank at Cross-section 2 eroded away enough between 2018 and 2019 to cause the left end pin of the cross-section to fall into the stream channel, making it necessary for the field crew to install a new end pin further up the bank (Figure C-16). The streambed at this cross-section continues to scour significantly on the left side of the channel and aggrade on the right side of the channel due to the encroaching point bar.

At Cross-section 1 (crossover riffle at Station 1+55), channel substrate became finer, with the $D_{50}$ decreasing from very coarse gravel to coarse gravel between Pre-Restoration Years 1 and 3 (Table C-3). During Pre-Restoration Year 4, $D_{50}$ increased and was once again categorized in the very coarse gravel size class. The $D_{84}$ decreased from small cobble to very coarse gravel and back to small cobble over the four years of Pre-Restoration monitoring. In Post-Restoration Year 1, the $D_{50}$ decreased to coarse gravel and the $D_{84}$ remained very coarse gravel; the Post-Restoration Year 2 $D_{50}$ remained coarse gravel and the $D_{84}$ increased to small cobble. In Post-Restoration Year 3, the $D_{50}$ increased to very coarse gravel and the $D_{84}$ increased to small cobble; the Post-Restoration

Year 4 $D_{50}$ remained very coarse gravel and the $D_{84}$ remained small cobble. In Post-Restoration Year 5, the $D_{50}$ decreased to coarse gravel and the $D_{84}$ decreased to very coarse gravel; the Post-Restoration Year 6 $D_{50}$ coarsened to very coarse gravel and the $D_{84}$ coarsened to small cobble. This fluctuation over time in particle size demonstrates the variability of this portion of the reach due to sediments being transported through the reach from upstream erosion.

The $D_{84}$ decreased at Cross-section 2 (Meander Bend at Station 2+07) from small cobble in Pre-Restoration Year 1 to very coarse gravel in Pre-Restoration Years 2 and 3 to coarse gravel in Pre-Restoration Year 4. At Cross-section 2, $D_{50}$ particle size classes remained the same between the first two years of Pre-Restoration study (medium gravel) and increased during the third (coarse gravel). During the fourth Pre-Restoration year, $D_{50}$ size decreased from coarse gravel to fine gravel. In Post-Restoration Years 1 and 2, the $D_{50}$ increased to medium gravel and the $D_{84}$ increased to very coarse gravel. In Post-Restoration Year 3, the $D_{50}$ increased to coarse gravel and the $D_{84}$ remained small cobble; the Post-Restoration Year 4 $D_{50}$ decreased to medium gravel and the $D_{84}$ decreased to very coarse gravel. In Post-Restoration Year 5, the $D_{50}$ increased to coarse gravel and the $D_{84}$ remained very coarse gravel; the Post-Restoration Year 6 $D_{50}$ coarsened to very coarse gravel and the $D_{84}$ increased to small cobble.

Reachwide, the $D_{50}$ was coarse gravel during three of the four Pre-Restoration study years with a slight increase to very coarse gravel occurring in Year 3. The $D_{84}$ showed the same pattern as the $D_{50,}$ increasing only during Pre-Restoration Year 3 to large cobble and remaining in the same small cobble class Pre-Restoration Years 1, 2, and 4. During the first Post-Restoration year (2017), the reachwide $D_{50}$ was medium gravel and $D_{84}$ was very coarse gravel; reachwide $D_{50}$ increased to coarse gravel in 2018, and $D_{84}$ remained very coarse gravel, continuing the trend to smaller material than in years past. The reachwide $D_{50}$ remained as coarse gravel in 2019, and $D_{84}$ increased to small cobble, discontinuing the trend to smaller materials from years past. The reachwide $D_{50}$ remained as coarse gravel and $D_{84}$ remained small cobble in 2020; reachwide $D_{50}$ remained as coarse gravel and $D_{84}$ decreased to very coarse gravel in 2022. The reachwide $D_{50}$ increased in size to very coarse gravel and $D_{84}$ coarsened to small cobble in 2023. Post-restoration particle sizes continue to increase over time throughout this reach and have reached coarseness values seen in pre-restoration conditions; future monitoring is needed to determine if the particle size distribution is stabilizing in this reach, or if continued erosion will result in shifting particle size distributions throughout this reach.

## 4.4 WC04

No significant changes were observed in the profile of the downstream portion of the reach at site WC04 between the four years of Pre-Restoration study. However, during Pre-Restoration Years 2 through 4 surveys and the Post-Restoration Year 1 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; the streambed was found to be mostly dry from Station 2+50 to the top of the reach in the Post-Restoration Year 2 survey. Around this same station and above, channel aggradation can be seen when comparing the profiles of the initial year and all the following years' surveys (Figure C-6) which may explain the decrease in water depth between these surveys. While no significant channel alterations were noted during the Post-Restoration Years 3 and 4 surveys, this reach was found to have water throughout the entire longitudinal profile both years. In Post-Restoration Year 5, the reach was found to be largely dry above Station 2+50, mirroring conditions seen in the Post-Restoration Year 2 survey. Profile conditions in Post-Restoration Year 6 were largely similar to those in 2022, dry above Station 2+32; however, significant aggradation was noted during the 2023 survey between Station 1+91 and Station 2+71 compared to 2022. Reach length, slope, and proportion of features within the reach remained relatively unchanged (Table C-1).

Similar to the profile, the cross-sections within this reach also remained relatively unchanged between the first three years of Pre-Restoration study, with the exception of some lower bank erosion observed at Cross-section 1 (Meander at Station 1+08) between Pre-Restoration Years 1 through 3 (Figure C-17). During Pre-Restoration Year 4, erosion on the lower left bank continued and was more apparent resulting in higher bankfull and width depth dimensions. This station was identified as a riffle located just above the top of a pool during the initial year of Pre-Restoration monitoring, but was within part of the pool when surveyed in all other subsequent Pre-Restoration years. The channel was actively widening and cutting into the bank at this station during the Pre-Restoration Year 4 survey, resulting in changes in cross-sectional dimensions. This undercutting continued to take place in Post-Restoration Years 1 through 4 (Table C-2). The overall top of bank area slightly decreased again in 2019, remained very similar in 2020, and more significantly decreased again in 2022, due to the growing point bar and bench, while bankfull area slightly increased from the 2018 survey (Figure C-17). Minor aggradation of sediments on the left bank resulted in a decrease in cross-sectional area at this location in 2023, while minor erosion along the point bar to the right of the channel increased top of bank area slightly. Cross-section 1 at Station 1+10 is now in a meander pool feature in Post-Restoration Years 1 through 5, a change from the original riffle feature in Pre-Restoration Year 1 and the pool feature in Pre-Restoration Years 2 through 4 (Table C-2). Cross-section 2 at Station 1+68 remains unchanged and stable through Post-Restoration Year 6, with slight aggradation occurring on the right side of the channel in Post-Restoration Years 1 and 2 (Figure C-18). Changes at Cross-section 2 were noted in 2022, with measured increases in both bankfull width and bankfull cross-sectional area; these increases were attributed to slight erosion of the left bank. Documented conditions during the 2023 Post-Restoration Year 6 survey noted minor aggradation of sediments in the channel which resulted in a decrease in bankfull width and bankfull area, similar to conditions measured in 2018 to 2020; minor erosion on both banks contributed to the slight increase in top of bank area at this location. Future studies will determine if this bank erosion continues and its effect on stream channel form at this cross-section.

Reachwide $D_{84}$ particle size classes remained the same, small cobble, during all four Pre-Restoration years (Table C-3). Reachwide $D_{84}$ decreased in Post-Restoration Years 1 and 2 to very coarse gravel, and increased back to small cobble in Post-Restoration Years 3 and 4. Reachwide $D_{84}$ decreased back to very coarse gravel in Post Restoration Years 5 and 6. $D_{84}$ remained the same at Cross-section 1 during the first three years of Pre-Restoration study (small cobble) and decreased during the fourth year to coarse gravel, where it remained in Post-Restoration Year 1. An increase in $D_{84}$ to very coarse gravel was noted at Cross-section 1 in 2018, and but returned to coarse gravel in 2019. $D_{84}$ at Cross-section 1 in 2020 coarsened again to very coarse gravel and remained in this classification through 2023. At Cross-section 2, $D_{84}$ decreased from small cobble to very coarse gravel between Pre-Restoration Years 2 and 3. It increased back to small cobble between Pre-Restoration Years 3 and 4 and had remained small cobble through Post-Restoration Year 3. $D_{84}$ increased from small cobble to medium cobble between Post-Restoration Years 3 and 4 and decreased in particle size back to very coarse gravel in Post-Restoration Year 5. $D_{84}$ coarsened to small cobble in Post-Restoration Year 6 (Table C-3).

Reachwide $D_{50}$ particle size class increased from coarse gravel to very coarse gravel between Pre-Restoration Years 2 and 3 and decreased back to coarse gravel during Pre-Restoration Year 4 for the reachwide survey. During the Post-Restoration Year 1 survey, the reachwide $D_{50}$ slightly decreased to medium gravel, but increased back to coarse gravel in the 2018 through 2020 studies (Table C-3). In 2022, median particle size decreased to medium gravel reachwide, but $D_{50}$ particle size increased back to coarse gravel in 2023. Cross-section 1 $D_{50}$ has fluctuated by decreasing from medium gravel to very coarse sand and again increasing to medium gravel and Cross-section 2 remained the same (very coarse gravel) between Pre-Restoration Years 2, 3, and 4. In Post-Restoration Year 1, the $D_{50}$ at Cross-section 1 remained medium gravel while the $D_{50}$ at Cross-section 2 decreased to coarse gravel. Post-Restoration Year 2 results showed that the $D_{50}$ at Cross-section 1 decreased again to very coarse sand while the $D_{50}$ at Cross-section 2 increased back to very coarse gravel. Post-Restoration Year 3 results showed that the $D_{50}$ at Cross-section 1 remained as very coarse sand while the $D_{50}$ at Cross-section 2 decreased to coarse gravel. The Post-Restoration Year 4 assessment found the $D_{50}$ at Cross-section 1 decreased to coarse sand, while the $D_{50}$ at Cross-section 2 coarsened to very coarse gravel. The Post-Restoration Year 5 assessment found the $D_{50}$ at Cross-section 1 coarsened substantially to medium gravel, while the $D_{50}$ at Cross-section 2 decreased particle size back to coarse gravel. The Post-Restoration Year 6 assessment found the $D_{50}$ at Cross-section 1 continued coarsening, increasing to medium gravel, while the $D_{50}$ at Cross-section 2 increased particle size back to very coarse gravel (Table C-3).

# 5.0 CONCLUSIONS

The data presented herein provide an assessment of geomorphic conditions within the Wheel Creek watershed prior to and following completion of restoration efforts. During the Pre-Restoration Years 1 and 2 studies, none of the planned restoration projects had been completed within this watershed. During the Pre-Restoration Year 3 study, two planned restoration projects had been constructed while the remaining projects were still in planning stages. Continued planning occurred during Pre-Restoration Year 4 but no new construction activities were initiated. Restoration activities were all completed as of the Post-Restoration Year 1 survey; thus the 2023 survey is the sixth annual assessment following completion of restoration. Results of the geomorphic monitoring show that bank erosion continues to be prevalent in the two reaches (WC03, WC04) that did not receive stream restoration, but has improved in those reaches where instream channel restoration activities took place (WC01, WC02). 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). Efforts have been made to decrease the impact of damaging storm water flow causing erosion among the unstable banks. The two reaches that were restored (WC01, WC02) have stable, vegetated banks in each post-restoration survey and improved floodplain access in some areas but are still somewhat entrenched in others. In both restored reaches, surveyed cross-sections exhibited aggradation in the six years following completion of restoration; the undermining and failure of the bank armoring at station WC01 Cross-section 2 found in 2020 compromised the stability of the bank and effectiveness of the restoration, as portions of the armoring were found to have slumped and fallen into the stream during the 2022 and 2023 surveys; restoration repair efforts are scheduled. These streams may continue to adjust in the coming years, especially during high flow events. Future Post-Restoration monitoring will enable assessment of their stability and the effects of the restoration activities that occurred.

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# 6.0 REFERENCES

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# APPENDIX A

# PHOTOS

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WC01 – Facing downstream at Station 4+50

WC01 - Facing downstream at Station 3+00

WC01 – Facing downstream at Station 2+00

WC01 – Facing downstream at Station 1+00

WC01 – Facing upstream from Station 0+00

WC02 – Facing downstream at Station 3+00

WC02 – Facing downstream at Station 2+00

WC02 – Facing downstream at Station 1+00

WC02 – Facing downstream at Station 0+50

WC02 – Facing upstream at Station 0+00

WC03 – Facing downstream at Station 3+00

WC03 – Facing downstream at Station 2+50


WC03 – Facing downstream at Station 1+50


WC03 – Facing downstream at Station 0+50

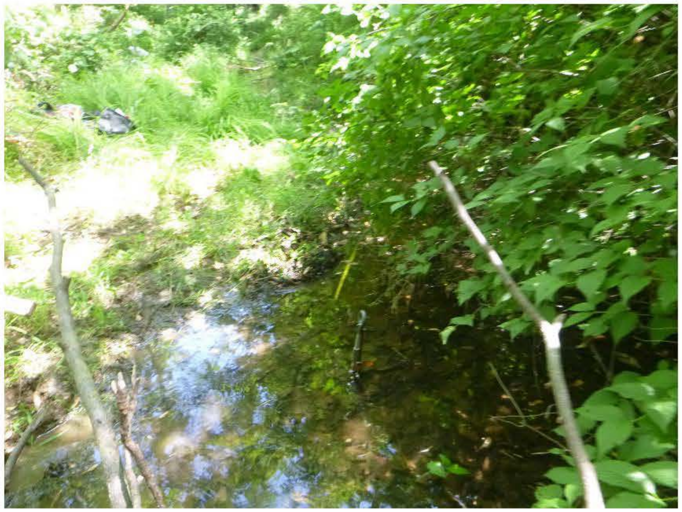

WC03 – Facing upstream at Station 0+00


WC04 – Facing downstream at Station 3+00

WC04 – Facing downstream at Station 2+00

WC04 – Facing downstream at Station 1+00

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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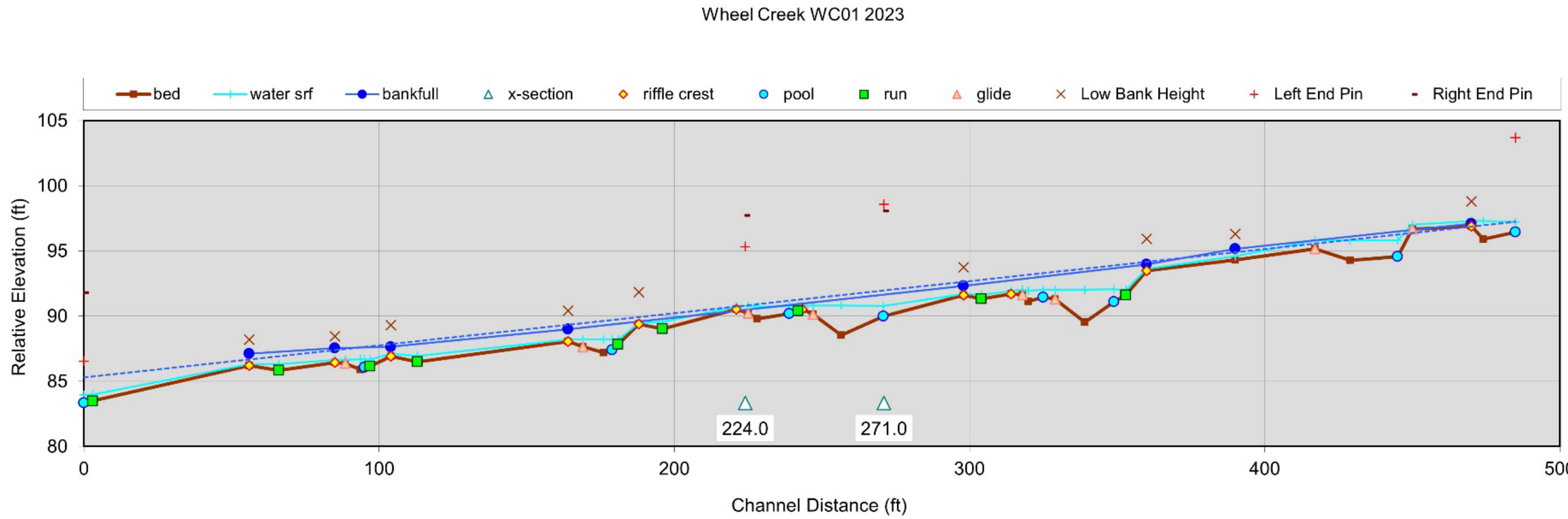
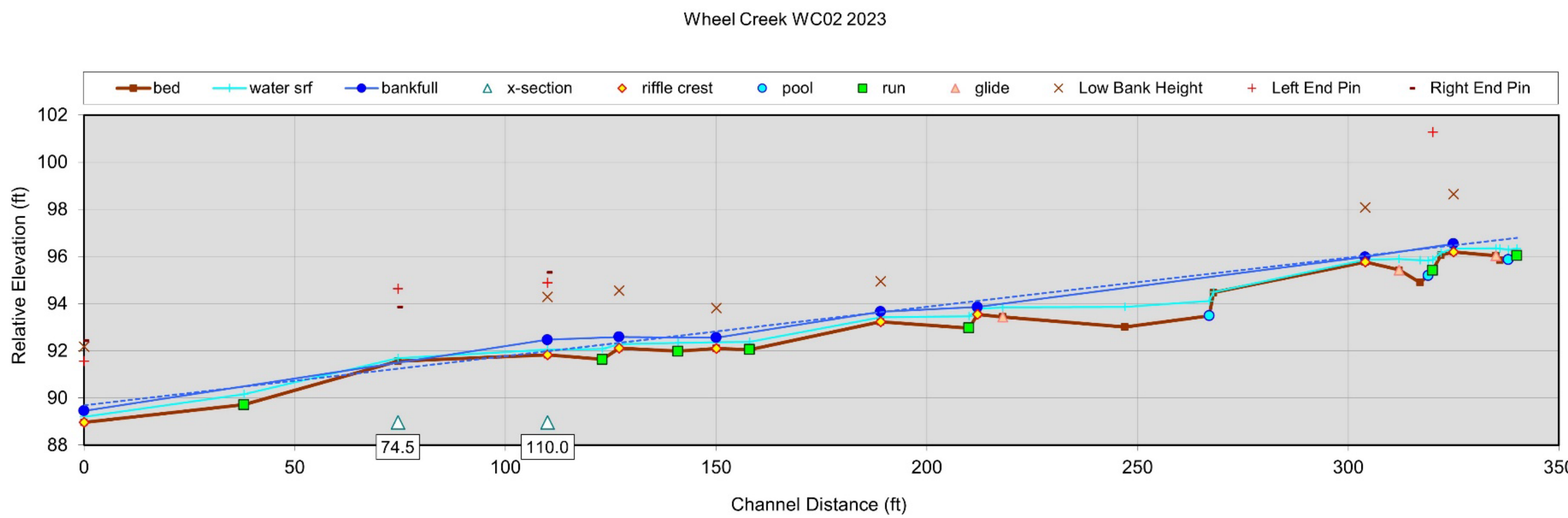
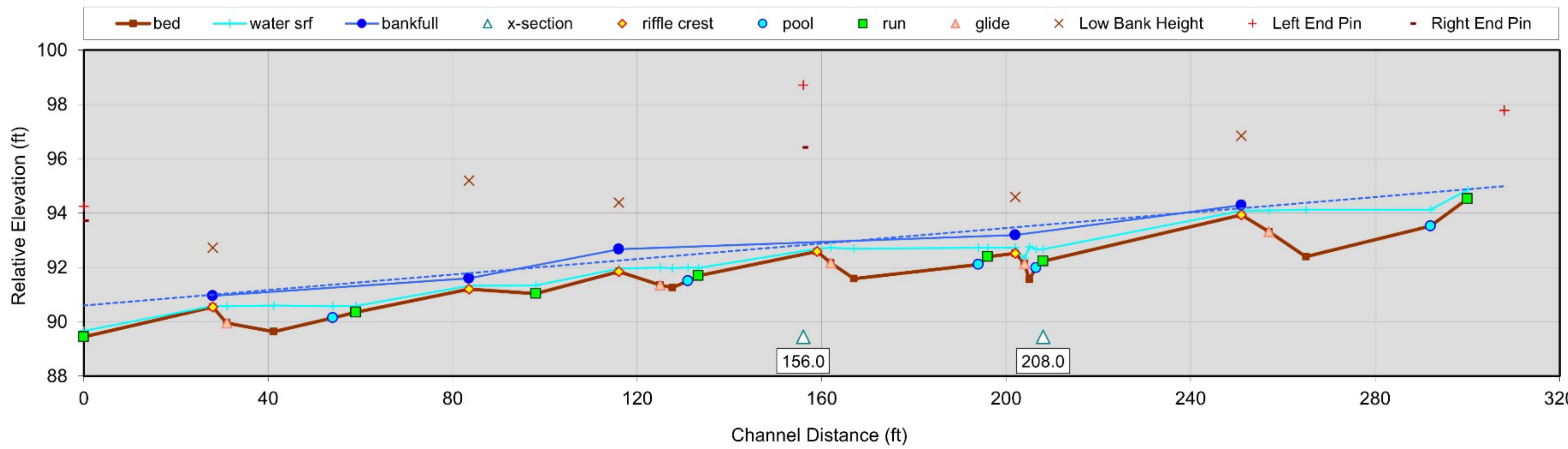
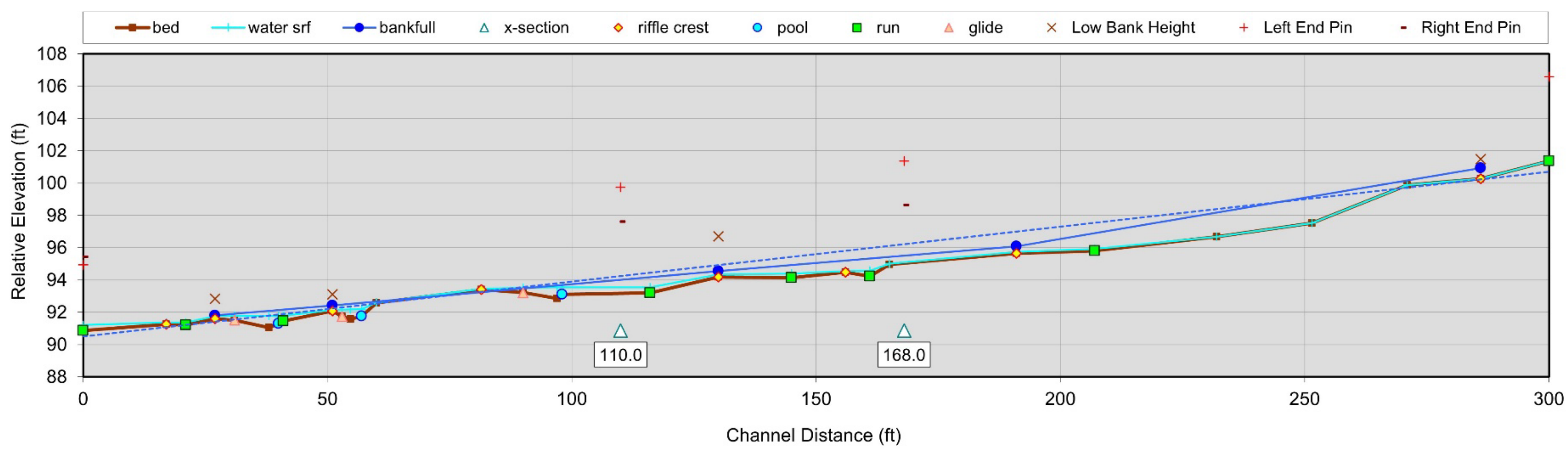

Wheel Creek WC01 2023
bed
water srf
bankfull
x-section
riffle crest
pool
run
glide
Low Bank Height
Left End Pin
Right End Pin
Relative Elevation (ft)
Channel Distance (ft)
224.0
271.0
105
100
95
90
85
80
0
100
200
300
400
500

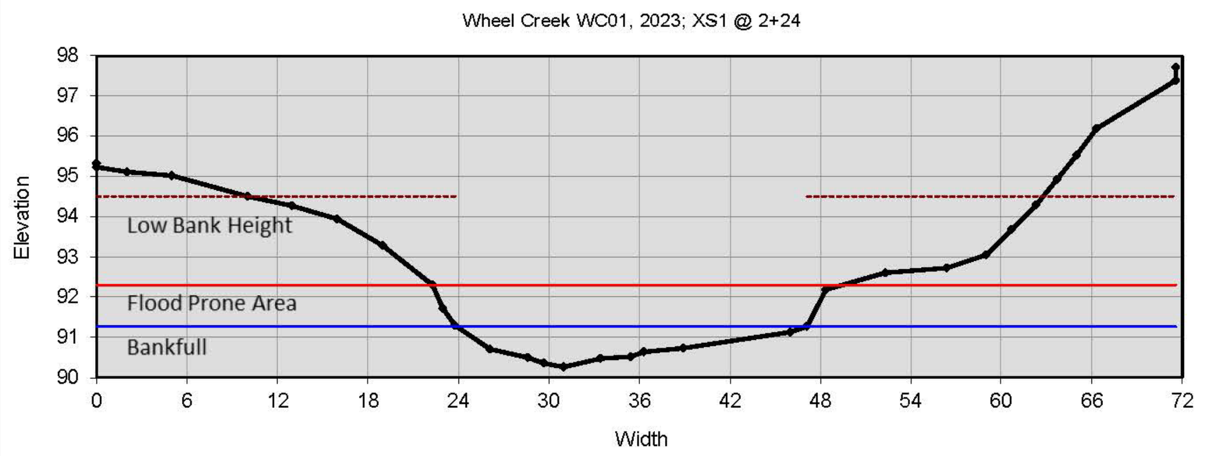

Wheel Creek WC02 2023
bed
water srf
bankfull
x-section
riffle crest
pool
run
glide
Low Bank Height
Left End Pin
Right End Pin
Relative Elevation (ft)
Channel Distance (ft)
74.5
110.0
102
100
98
96
94
92
90
88
0
50
100
150
200
250
300
350

Wheel Creek WC03 2023

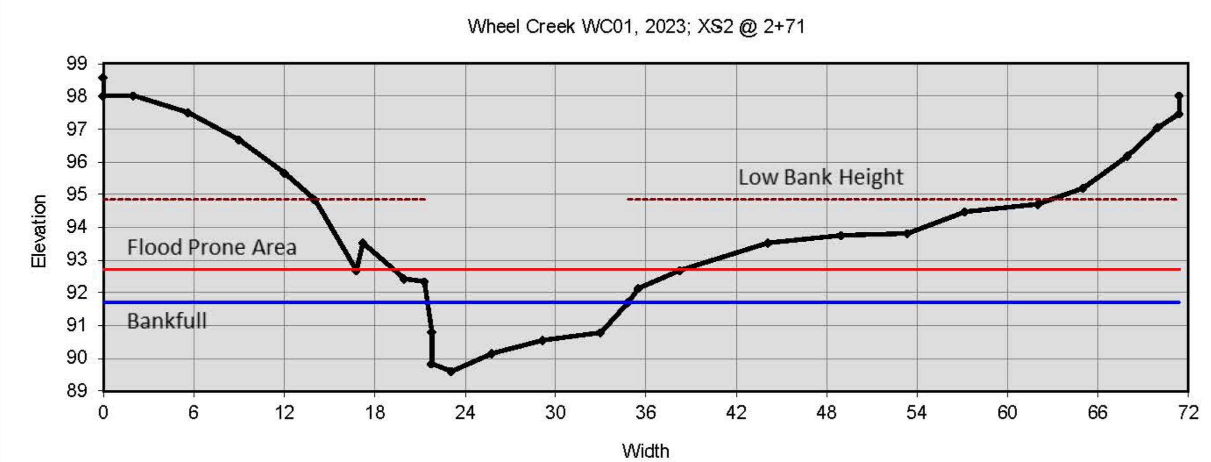



Wheel Creek WC04 2023

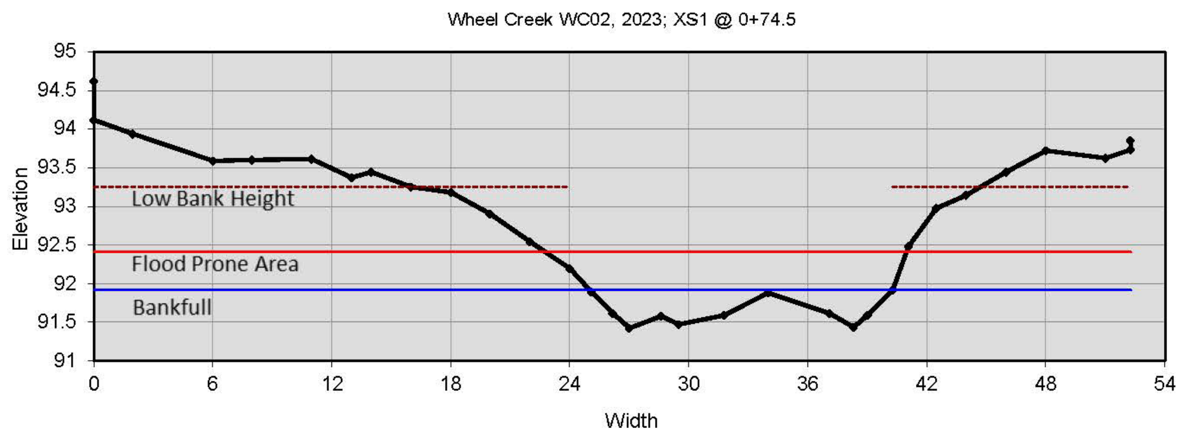




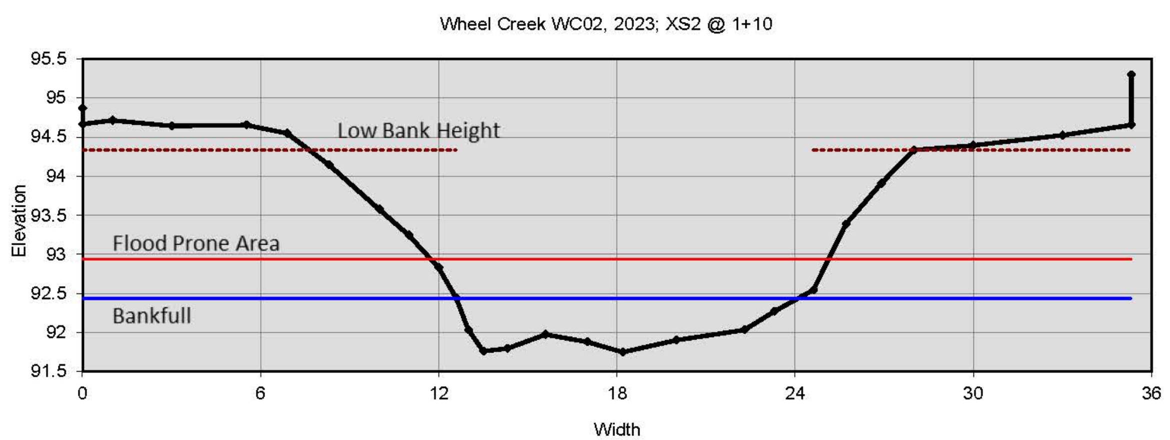

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 13.0 | x-section area (ft.sq.) | 27.2 | W flood prone area (ft) | 48 | D50 Riffle (mm) |
| 23.2 | width (ft) | 1.2 | entrenchment ratio | 130 | D84 Riffle (mm) |
| 0.6 | mean depth (ft) | 3.0 | low bank height (ft) | 34 | threshold grain size (mm): |
| 1.0 | max depth (ft) | 3.0 | low bank height ratio | | |
| 23.4 | wetted parimeter (ft) | | | | |
| 0.6 | hyd radi (ft) | | | | |
| 41.6 | width-depth ratio | | | | |



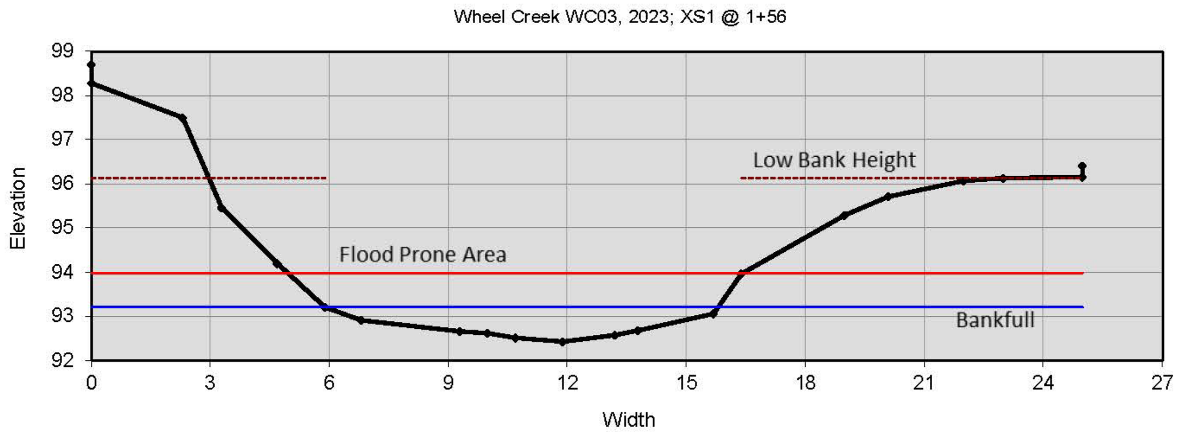

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 17.1 | x-section area (ft.sq.) | 19.3 | W flood prone area (ft) | 48 | D50 Riffle (mm) |
| 13.3 | width (ft) | 1.5 | entrenchment ratio | 130 | D84 Riffle (mm) |
| 1.3 | mean depth (ft) | 4.9 | low bank height (ft) | 45 | threshold grain size (mm): |
| 2.1 | max depth (ft) | 2.3 | low bank height ratio | | |
| 15.3 | wetted parimeter (ft) | | | | |
| 1.1 | hyd radi (ft) | | | | |
| 10.3 | width-depth ratio | | | | |



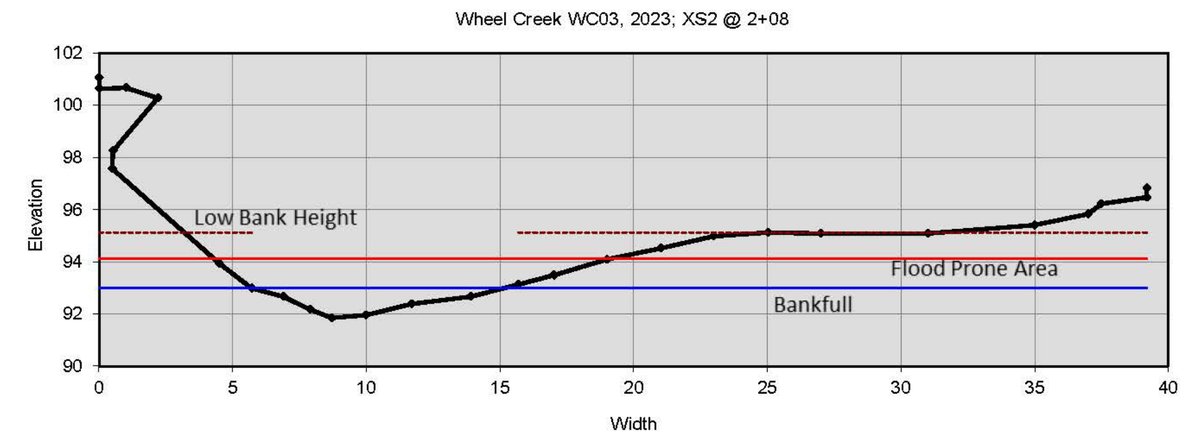

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 4.3 | x-section area (ft.sq.) | 18.3 | W flood prone area (ft) | 35 | D50 Riffle (mm) |
| 15.3 | width (ft) | 1.2 | entrenchment ratio | 97 | D84 Riffle (mm) |
| 0.3 | mean depth (ft) | 1.8 | low bank height (ft) | 22 | threshold grain size (mm): |
| 0.5 | max depth (ft) | 3.7 | low bank height ratio | | |
| 15.5 | wetted parimeter (ft) | | | | |
| 0.3 | hyd radi (ft) | | | | |
| 54.8 | width-depth ratio | | | | |



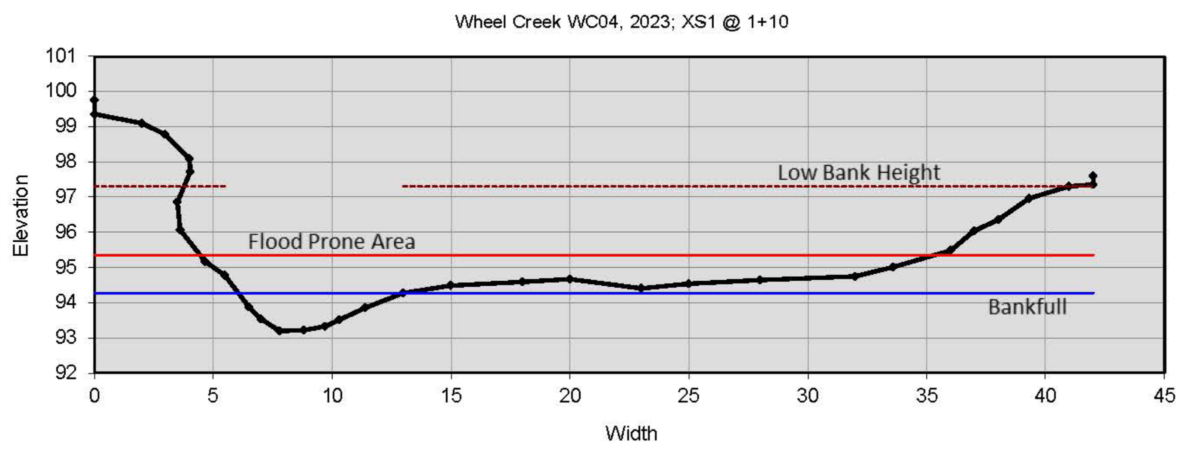

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 5.6 | x-section area (ft.sq.) | 13.3 | W flood prone area (ft) | 35 | D50 Riffle (mm) |
| 11.5 | width (ft) | 1.2 | entrenchment ratio | 97 | D84 Riffle (mm) |
| 0.5 | mean depth (ft) | 2.6 | low bank height (ft) | 25 | threshold grain size (mm): |
| 0.7 | max depth (ft) | 3.7 | low bank height ratio | | |
| 11.8 | wetted parimeter (ft) | | | | |
| 0.5 | hyd radi (ft) | | | | |
| 23.5 | width-depth ratio | | | | |



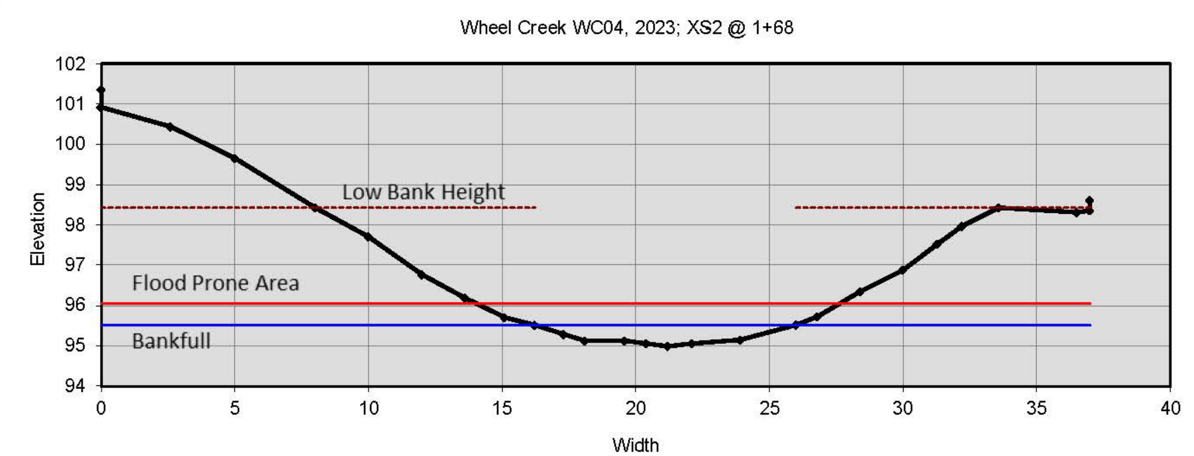

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 4.8 | x-section area (ft.sq.) | 11.5 | W flood prone area (ft) | 39 | D50 Riffle (mm) |
| 9.9 | width (ft) | 1.2 | entrenchment ratio | 77 | D84 Riffle (mm) |
| 0.5 | mean depth (ft) | 3.7 | low bank height (ft) | 25 | threshold grain size (mm): |
| 0.8 | max depth (ft) | 4.8 | low bank height ratio | | |
| 10.1 | wetted parimeter (ft) | | | | |
| 0.5 | hyd radi (ft) | | | | |
| 20.3 | width-depth ratio | | | | |



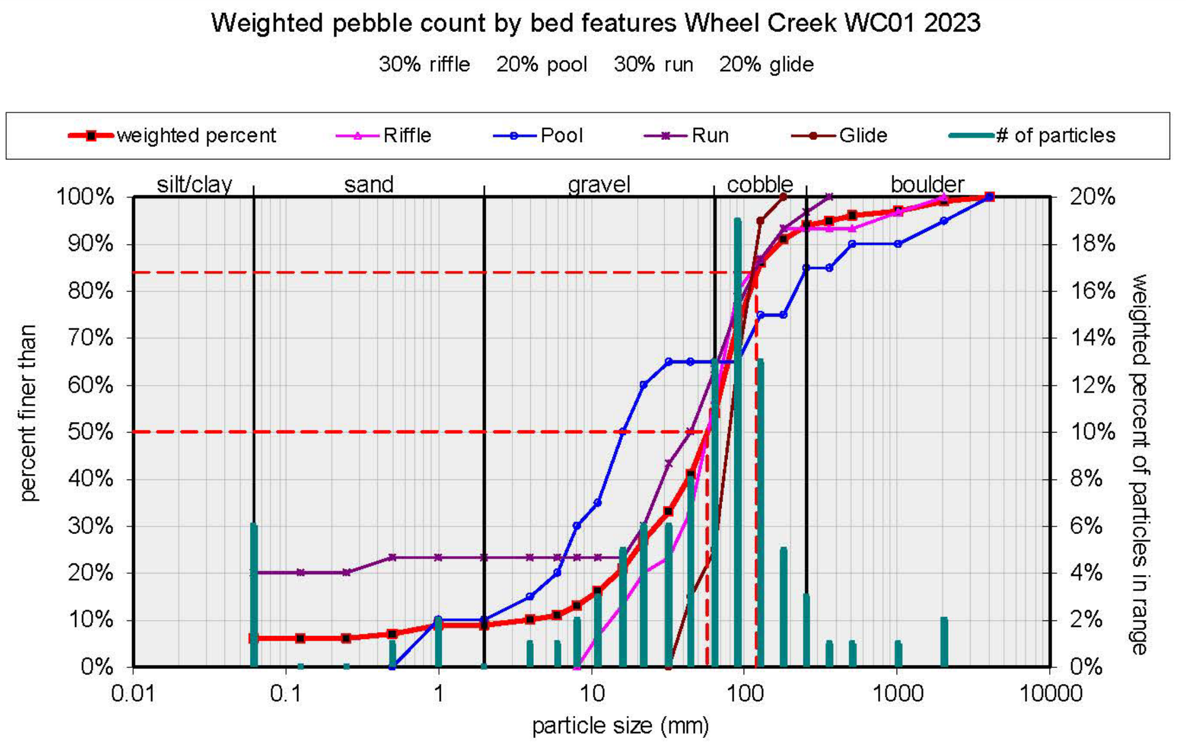

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 5.5 | x-section area (ft.sq.) | 14.8 | W flood prone area (ft) | 39 | D50 Riffle (mm) |
| 9.4 | width (ft) | 1.6 | entrenchment ratio | 77 | D84 Riffle (mm) |
| 0.6 | mean depth (ft) | 4.4 | low bank height (ft) | 26 | threshold grain size (mm): |
| 1.1 | max depth (ft) | 3.9 | low bank height ratio | | |
| 9.8 | wetted parimeter (ft) | | | | |
| 0.6 | hyd radi (ft) | | | | |
| 16.3 | width-depth ratio | | | | |



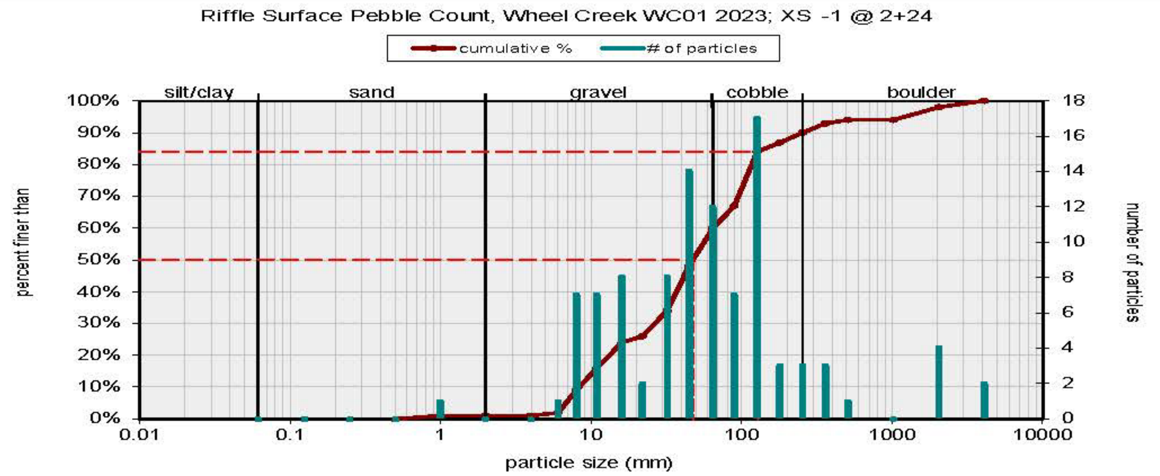

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 4.6 | x-section area (ft.sq.) | 30.8 | W flood prone area (ft) | 17 | D50 Bed (mm) |
| 6.9 | width (ft) | 4.4 | entrenchment ratio | 60 | D84 Bed (mm) |
| 0.7 | mean depth (ft) | 4.1 | low bank height (ft) | 28 | threshold grain size (mm): |
| 1.1 | max depth (ft) | 3.8 | low bank height ratio | | |
| 7.4 | wetted parimeter (ft) | | | | |
| 0.6 | hyd radi (ft) | | | | |
| 10.6 | width-depth ratio | | | | |



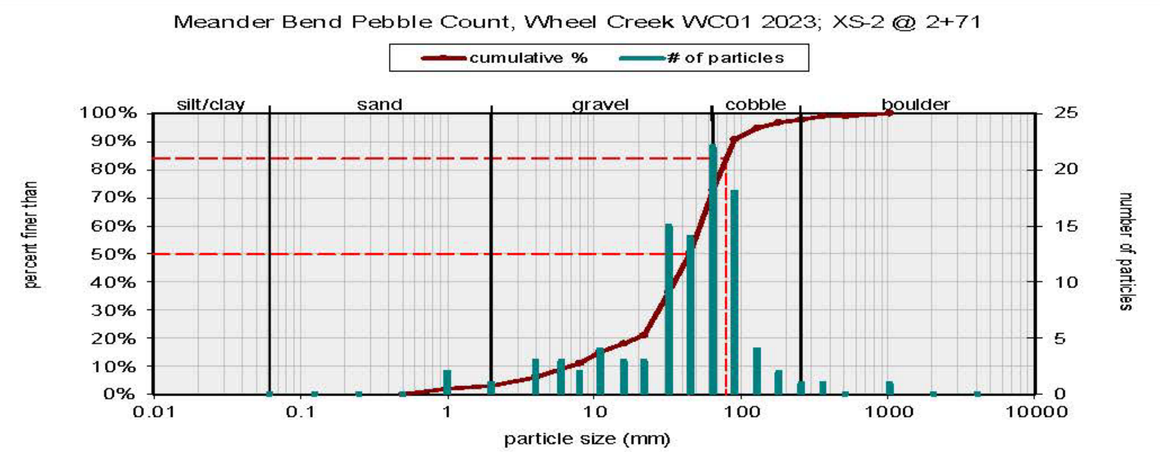

| Bankfull Dimensions | | Flood Dimensions | | Materials | |
|---|---|---|---|---|---|
| 3.3 | x-section area (ft.sq.) | 13.7 | W flood prone area (ft) | 17 | D50 Bed (mm) |
| 9.9 | width (ft) | 1.4 | entrenchment ratio | 60 | D84 Bed (mm) |
| 0.3 | mean depth (ft) | 3.4 | low bank height (ft) | 24 | threshold grain size (mm): |
| 0.5 | max depth (ft) | 6.4 | low bank height ratio | | |
| 9.9 | wetted parimeter (ft) | | | | |
| 0.3 | hyd radi (ft) | | | | |
| 29.1 | width-depth ratio | | | | |



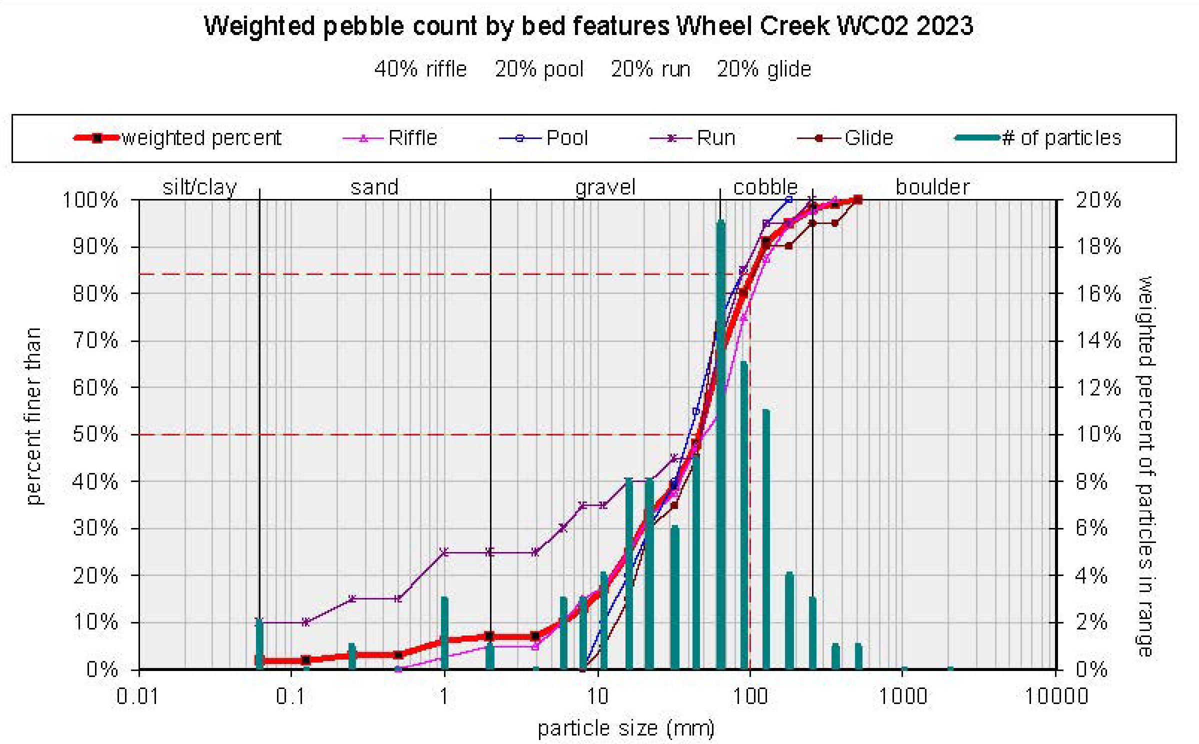

| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 11 | mean | 36.3 | silt/clay | 6% |
| D35 | 35 | dispersion | 3.6 | sand | 3% |
| D50 | 57 | skewness | -0.19 | gravel | 45% |
| D65 | 78 | | | cobble | 40% |
| D84 | 120 | | | boulder | 6% |
| D95 | 360 | | | | |




| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 11 | mean | 37.8 | silt/clay | 0% |
| D35 | 33 | dispersion | 3.5 | sand | 1% |
| D50 | 48 | skewness | -0.10 | gravel | 59% |
| D65 | 82 | | | cobble | 30% |
| D84 | 130 | | | boulder | 10% |
| D95 | 1200 | | | | |



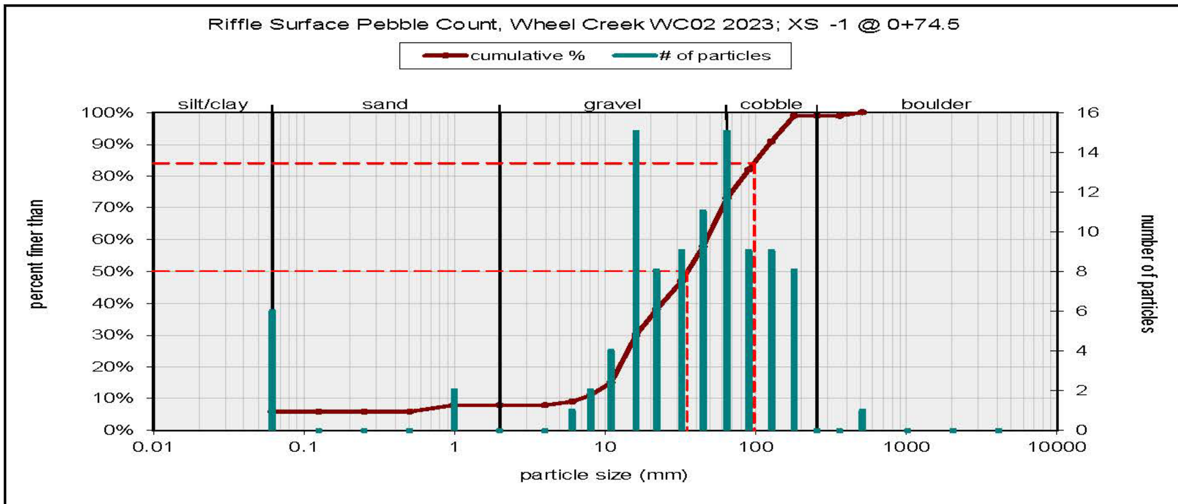

| Size (mm) | | | Size Distribution | | Type | |
|---|---|---|---|---|---|---|
| D16 | 12 | 3.4 | mean | 30.8 | silt/clay | 0% |
| D35 | 31 | 12 | dispersion | 2.7 | sand | 3% |
| D50 | 44 | 17 | skewness | -0.17 | gravel | 69% |
| D65 | 57 | 20 | | | cobble | 25% |
| D84 | 79 | 29 | | | boulder | 2% |
| D95 | 130 | 39 | | | | |



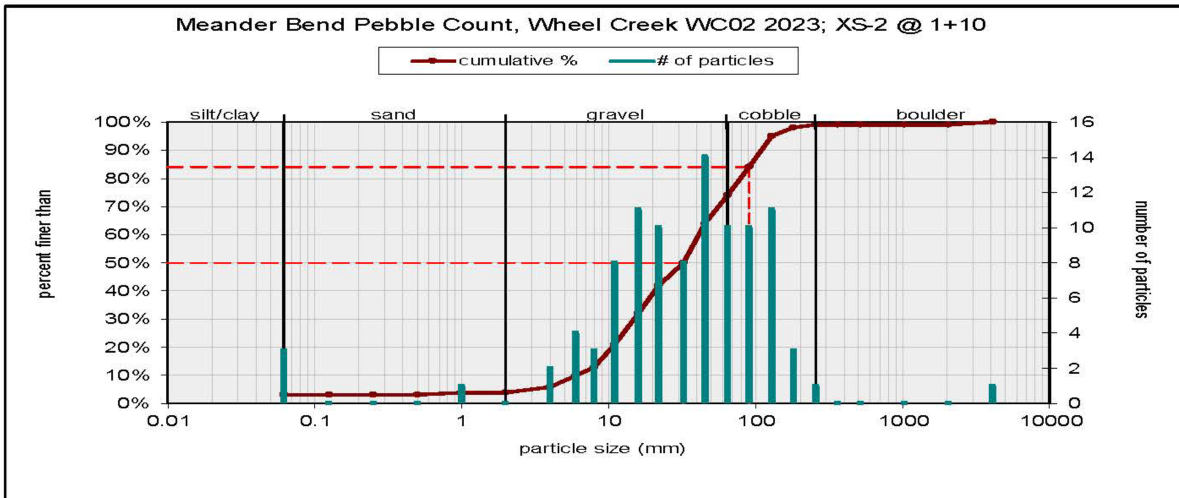

| Size (mm) | |
|---|---|
| D16 | 10 |
| D35 | 25 |
| D50 | 47 |
| D65 | 62 |
| D84 | 100 |
| D95 | 180 |

| Size Distribution | |
|---|---|
| mean | 31.6 |
| dispersion | 3.4 |
| skewness | -0.17 |

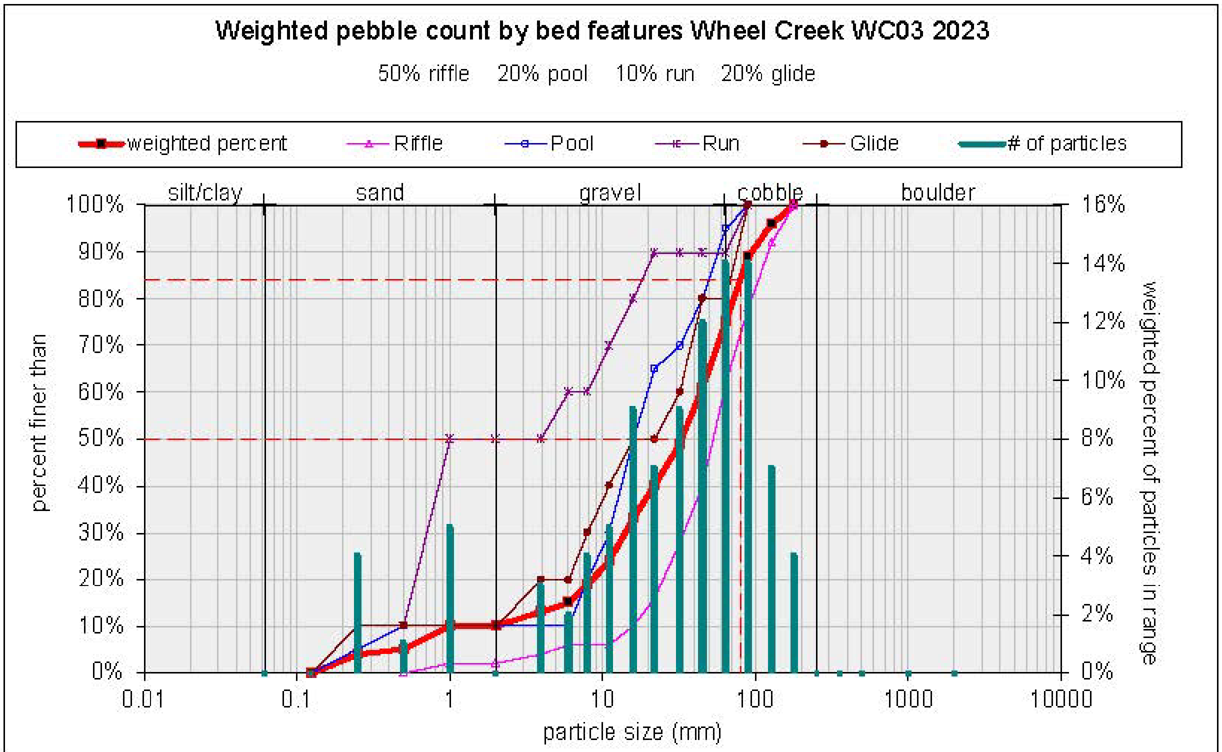
| Type | |
|---|---|
| silt/clay | 2% |
| sand | 5% |
| gravel | 60% |
| cobble | 31% |
| boulder | 2% |




| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 11 | mean | 32.7 | silt/clay | 6% |
| D35 | 20 | dispersion | 3.0 | sand | 2% |
| D50 | 35 | skewness | -0.03 | gravel | 65% |
| D65 | 53 | | | cobble | 26% |
| D84 | 97 | | | boulder | 1% |
| D95 | 150 | | | | |



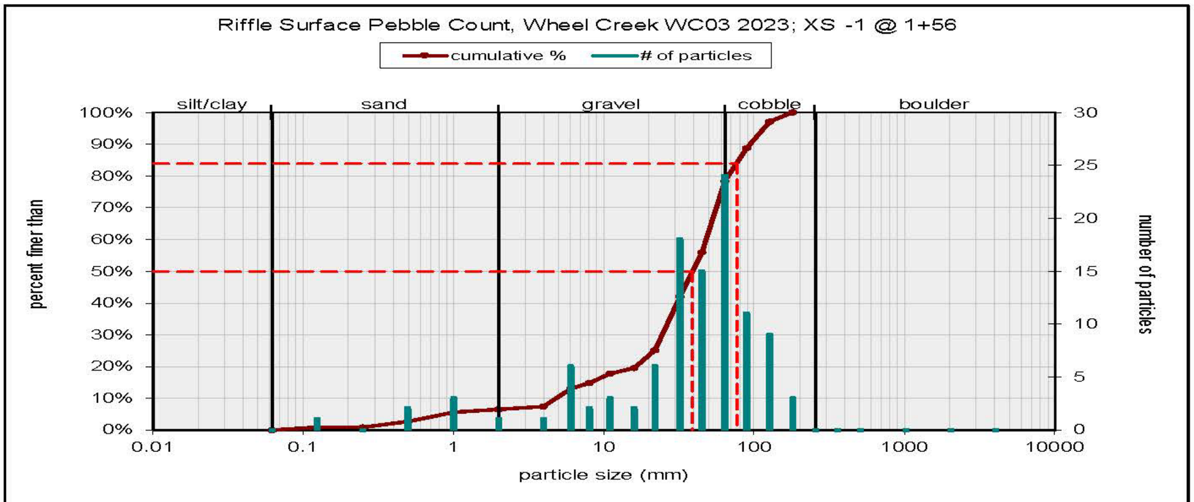

| Size (mm) | | | Size Distribution | | Type | |
|---|---|---|---|---|---|---|
| D16 | 9 | 3.4 | mean | 28.5 | silt/clay | 3% |
| D35 | 18 | 12 | dispersion | 3.2 | sand | 1% |
| D50 | 32 | 17 | skewness | -0.05 | gravel | 70% |
| D65 | 47 | 20 | | | cobble | 25% |
| D84 | 90 | 29 | | | boulder | 1% |
| D95 | 130 | 39 | | | | |



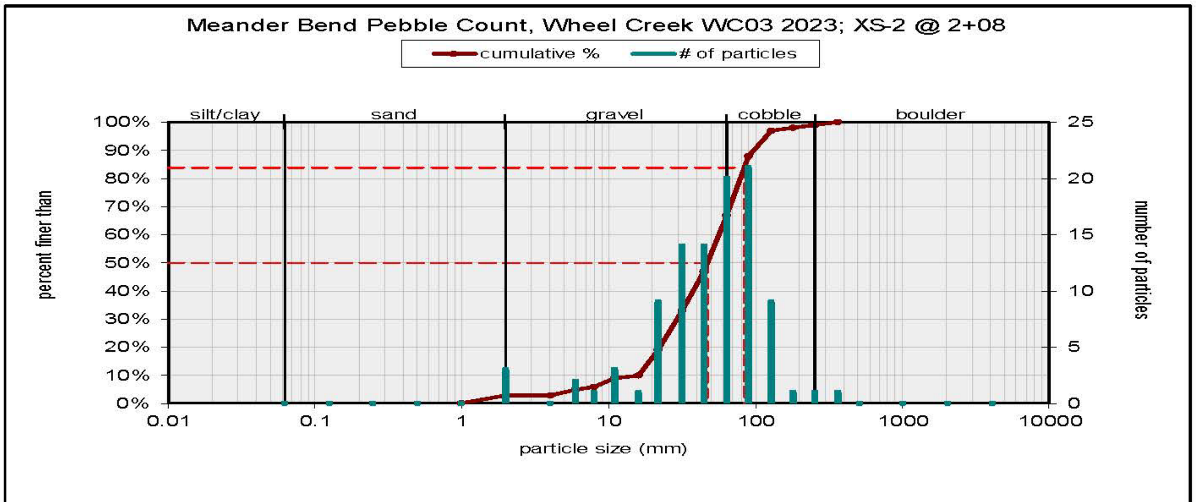

| Size (mm) | |
|---|---|
| D16 | 6.4 |
| D35 | 18 |
| D50 | 33 |
| D65 | 50 |
| D84 | 80 |
| D95 | 120 |

| Size Distribution | |
|---|---|
| mean | 22.6 |
| dispersion | 3.8 |
| skewness | -0.16 |

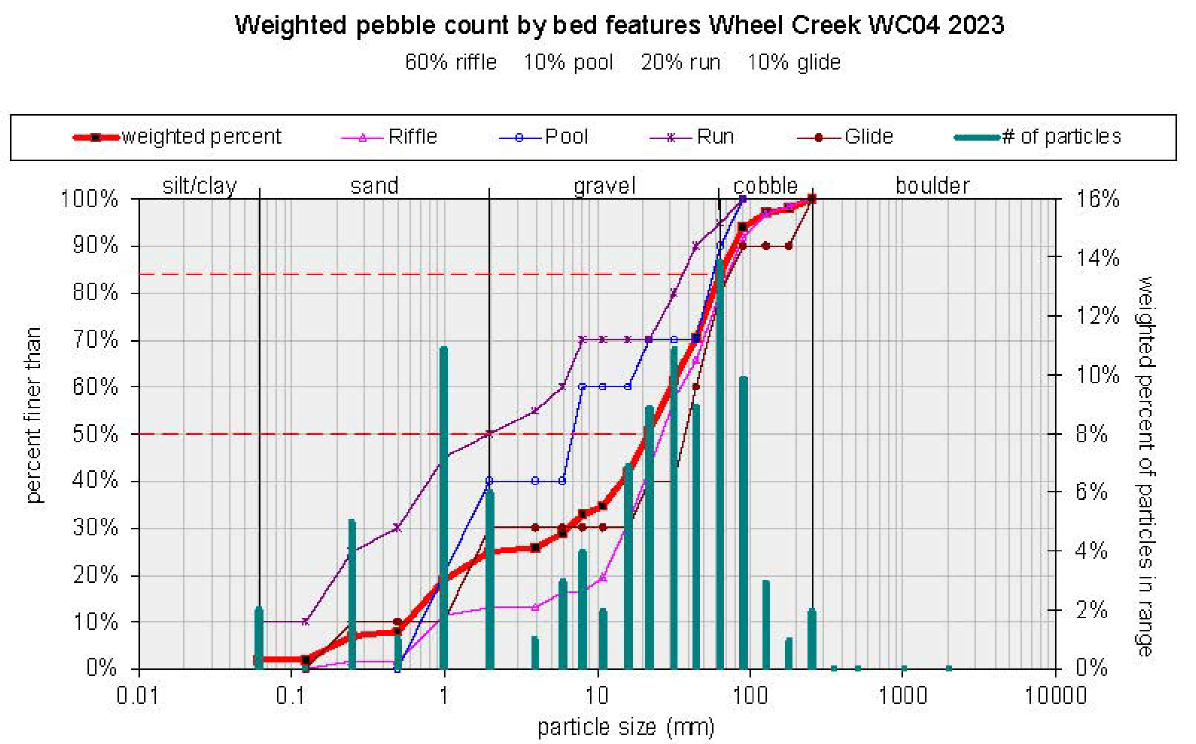
| Type | |
|---|---|
| silt/clay | 0% |
| sand | 10% |
| gravel | 65% |
| cobble | 25% |
| boulder | 0% |




| Size (mm) | | | Size Distribution | | | Type | |
|---|---|---|---|---|---|---|---|
| D16 | 9 | | mean | 26.3 | | silt/clay | 0% |
| D35 | 27 | | dispersion | 3.2 | | sand | 7% |
| D50 | 39 | | skewness | -0.18 | | gravel | 72% |
| D65 | 52 | | | | | cobble | 21% |
| D84 | 77 | | | | | boulder | 0% |
| D95 | 120 | | | | | | |



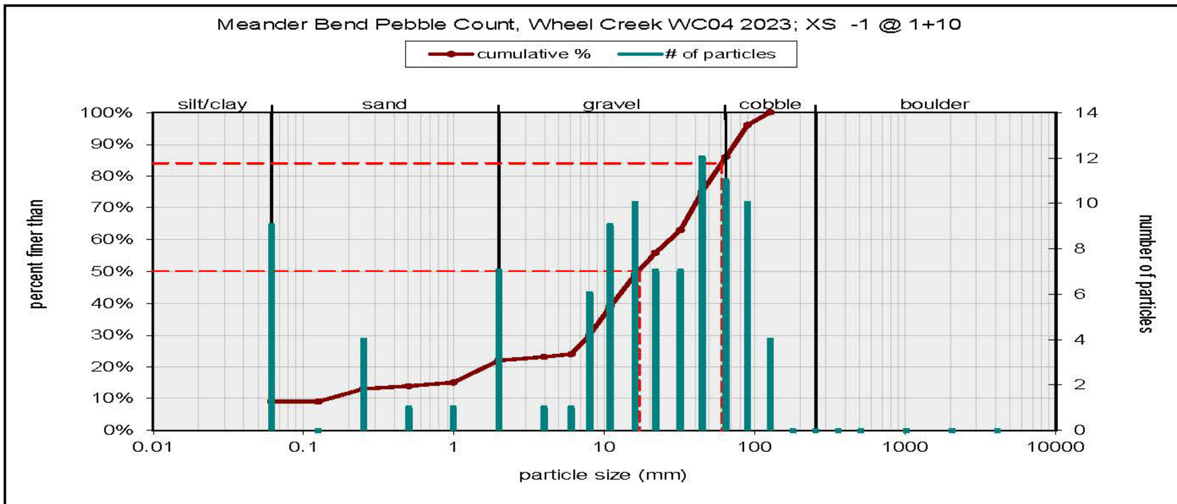

| Size (mm) | | | Size Distribution | | Type | |
|---|---|---|---|---|---|---|
| D16 | 20 | 3.4 | mean | 41.0 | silt/clay | 0% |
| D35 | 34 | 12 | dispersion | 2.1 | sand | 3% |
| D50 | 47 | 17 | skewness | -0.08 | gravel | 64% |
| D65 | 62 | 20 | | | cobble | 32% |
| D84 | 84 | 29 | | | boulder | 1% |
| D95 | 120 | 39 | | | | |



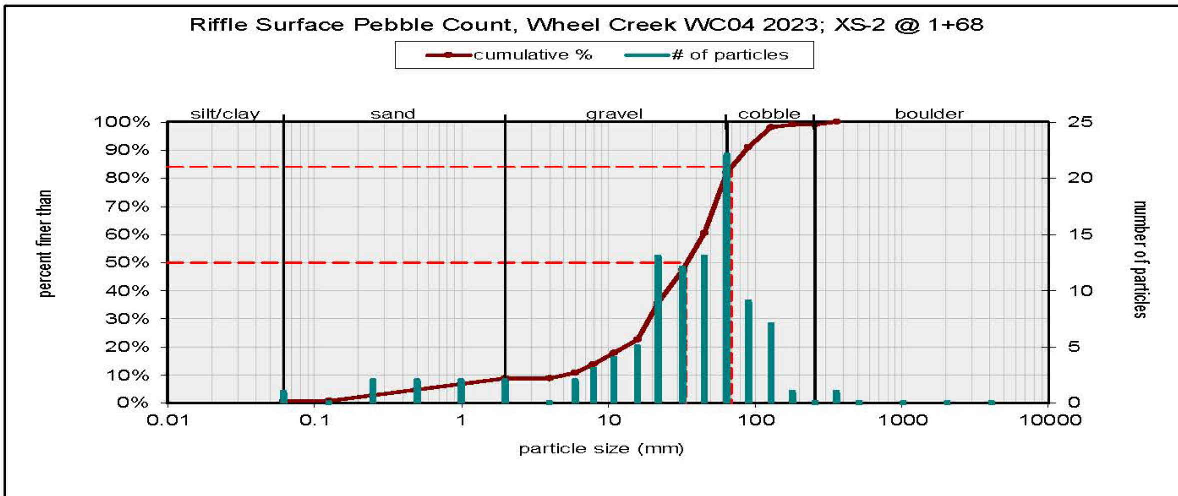

| Size (mm) | |
|---|---|
| D16 | 0.83 |
| D35 | 11 |
| D50 | 22 |
| D65 | 37 |
| D84 | 64 |
| D95 | 100 |

| Size Distribution | |
|---|---|
| mean | 7.3 |
| dispersion | 14.7 |
| skewness | -0.35 |

| Type | |
|---|---|
| silt/clay | 2% |
| sand | 23% |
| gravel | 59% |
| cobble | 16% |
| boulder | 0% |




| Size (mm) | | Size Distribution | | Type | |
|---|---|---|---|---|---|
| D16 | 1.1 | mean | 8.1 | silt/clay | 9% |
| D35 | 9.5 | dispersion | 9.5 | sand | 13% |
| D50 | 17 | skewness | -0.24 | gravel | 64% |
| D65 | 34 | | | cobble | 14% |
| D84 | 60 | | | boulder | 0% |
| D95 | 87 | | | | |




| Size (mm) | | | Size Distribution | | Type | |
|---|---|---|---|---|---|---|
| D16 | 9.5 | 3.4 | mean | 25.6 | silt/clay | 1% |
| D35 | 22 | 12 | dispersion | 2.8 | sand | 8% |
| D50 | 34 | 17 | skewness | -0.13 | gravel | 73% |
| D65 | 48 | 20 | | | cobble | 17% |
| D84 | 69 | 29 | | | boulder | 1% |
| D95 | 110 | 39 | | | | |

# APPENDIX C

# ANNUAL COMPARISONS

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Table C-1. Comparisons of Longitudinal Profile Survey Pre-Restoration Year 1 – Year 4 (2010-2015) and Post-Restoration Years 1 – 6 (2017-2023)

| 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% |
| | 2015 | 420 | 2.2% | 50.9% | 24.8% | 14.1% | 10.2% |
| | *2017* | *490* | *2.6%* | *47.5%* | *7.6%* | *36.6%* | *8.3%* |
| | *2018* | *490* | *2.7%* | *48.5%* | *8.6%* | *28.6%* | *14.4%* |
| | *2019* | *490* | *2.7%* | *46.6%* | *12.7%* | *29.4%* | *11.3%* |
| | *2020* | *490* | *2.7%* | *35.6%* | *17.2%* | *27.8%* | *19.4%* |
| | *2022* | *490* | *2.7%* | *38.4%* | *26.8%* | *18.9%* | *15.9%* |
| | *2023* | *480* | *2.7%* | *53.0%* | *9.7%* | *25.7%* | *11.6%* |
| 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% |
| | 2015 | 350 | 2.2% | 49.4% | 25.1% | 13.4% | 12.1% |
| | *2017* | *321.5* | *2.3%* | *57.3%* | *6.3%* | *28.5%* | *10.5%* |
| | *2018* | *320* | *2.3%* | *45.0%* | *15.3%* | *28.1%* | *11.6%* |
| | *2019* | *320* | *2.2%* | *47.6%* | *13.9%* | *26.4%* | *12.1%* |
| | *2020* | *340* | *2.2%* | *49.7%* | *9.3%* | *23.6%* | *17.4%* |
| | *2022* | *340* | *2.3%* | *45.7%* | *27.6%* | *14.6%* | *12.1%* |
| | *2023* | *340* | *2.2%* | *45.6%* | *29.7%* | *17.6%* | *7.1%* |
| 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% |
| | 2015 | 306 | 1.7% | 32.0% | 9.5% | 34.0% | 24.5% |
| | *2017* | *306* | *1.7%* | *52.4%* | *13.6%* | *23.5%* | *10.5%* |
| | *2018* | *309* | *1.7%* | *48.4%* | *14.3%* | *29.4%* | *7.8%* |
| | *2019* | *308* | *1.8%* | *46.0%* | *16.3%* | *28.1%* | *9.6%* |
| | *2020* | *308* | *1.8%* | *42.6%* | *7.4%* | *35.4%* | *14.6%* |
| | *2022* | *308* | *1.8%* | *49.0%* | *17.1%* | *28.2%* | *5.8%* |
| | *2023* | *308* | *1.7%* | *48.4%* | *11.1%* | *32.8%* | *7.7%* |
| 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% |
| | 2015 | 300 | 3.4% | 50.3% | 21.7% | 19.0% | 9.0% |
| | *2017* | *300* | *3.5%* | *48.2%* | *24.3%* | *14.0%* | *13.5%* |
| | *2018* | *300* | *3.7%* | *67.5%* | *13.0%* | *13.9%* | *5.2%* |
| | *2019* | *300* | *3.3%* | *70.0%* | *8.7%* | *13.3%* | *8.0%* |
| | *2020* | *300* | *3.5%* | *57.2%* | *18.3%* | *16.2%* | *8.3%* |
| | *2022* | *300* | *3.6%* | *67.4%* | *13.5%* | *12.2%* | *7.0%* |
| | *2023* | *300* | *3.3%* | *48.3%* | *32.7%* | *7.0%* | *12.0%* |

*Profiles and cross-sections re-established during Post-Restoration Year 1 (2017)

Table C-2. Comparisons of Cross-sectional Survey Analyses Pre-Restoration Years 1 – 4 (2010 – 2015) and Post-Restoration Years 1 – 6 (2017 – 2023)

| 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 |
| | 2015 | 2+29 | Crossover Riffle | 21.0 | 1.0 | 21.6 | 1.5 | 20.5 | 74.8 |
| | *2017* | *2+24* | *Crossover Riffle* | *20.7* | *0.8* | *26.8* | *1.7* | *16.0* | *164.4* |
| | *2018* | *2+24* | *Crossover Riffle* | *21.7* | *1.0* | *21.9* | *1.8* | *21.6* | *169.6* |
| | *2019* | *2+24* | *Crossover Riffle* | *28.8* | *0.7* | *41.2* | *1.4* | *20.1* | *161.7* |
| | *2020* | *2+24* | *Crossover Riffle* | *24.5* | *0.9* | *27.0* | *1.7* | *22.1* | *148.4* |
| | *2022* | *2+24* | *Crossover Riffle* | *24.1* | *0.9* | *27.1* | *1.6* | *21.4* | *131.1* |
| | *2023* | *2+24* | *Crossover Riffle* | *23.2* | *0.6* | *41.6* | *1.2* | *13.0* | *128.2* |
| | 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 |
| | 2015 | 2+95 | Meander/Riffle | 29.1 | 1.2 | 25.0 | 1.6 | 33.8 | 259.6 |
| | *2017* | *2+71* | *Meander/Pool* | *21.3* | *2.0* | *10.7* | *1.4* | *42.6* | *269.7* |
| | *2018* | *2+71* | *Meander/Pool* | *21.5* | *1.5* | *14.5* | *1.8* | *31.8* | *236.4* |
| | *2019* | *2+71* | *Meander/Pool* | *20.3* | *1.5* | *13.5* | *2.0* | *30.6* | *223.0* |
| | *2020* | *2+71* | *Meander/Pool* | *13.9* | *1.8* | *7.6* | *2.1* | *25.4* | *144.7* |
| | *2022* | *2+71* | *Meander/Pool* | *13.1* | *1.4* | *9.3* | *2.1* | *18.5* | *111.3* |
| | *2023* | *2+71* | *Meander/Pool* | *13.3* | *1.3* | *10.3* | *1.5* | *17.1* | *105.6* |
| 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 |
| | 2015 | 1+38 | Crossover Riffle | 13.9 | 0.8 | 17.9 | 1.2 | 10.8 | 28.4 |
| | *2017* | *1+10* | *Crossover Riffle* | *11.6* | *0.5* | *24.6* | *1.3* | *5.5* | *38.6* |
| | *2018* | *1+10* | *Crossover Riffle* | *13.6* | *0.7* | *20.8* | *1.4* | *8.9* | *56.5* |
| | *2019* | *1+10* | *Pool* | *12.6* | *0.7* | *17.4* | *1.3* | *9.1* | *38.4* |
| | *2020* | *1+10* | *Pool* | *11.9* | *0.6* | *18.6* | *1.2* | *7.6* | *35.3* |
| | *2022* | *1+10* | *Pool* | *12.2* | *0.6* | *22.0* | *1.1* | *6.8* | *35.4* |
| | *2023* | *1+10* | *Pool* | *11.5* | *0.5* | *23.5* | *1.2* | *5.6* | *34.9* |
| | 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 | 9.0 | 71.7 |
| | 2013 | 3+25.5 | Meander/Riffle | 15.6 | 0.7 | 21.8 | 1.5 | 11.1 | 72.0 |
| | 2015 | 3+24 | Meander/Riffle | 16.4 | 0.9 | 19.1 | 1.4 | 14.0 | 74.6 |
| | *2017* | *0+74.5* | *Pool* | *13.6* | *1.3* | *10.2* | *1.3* | *18.2* | *49.0* |
| | *2018* | *0+74.5* | *Pool* | *11.6* | *0.7* | *16.5* | *1.4* | *8.1* | *43.5* |
| | *2019* | *0+74.5* | *Crossover Riffle* | *16.2* | *0.6* | *28.5* | *1.4* | *9.2* | *48.4* |
| | *2020* | *0+74.5* | *Crossover Riffle* | *14.8* | *0.4* | *38.1* | *1.3* | *5.7* | *21.8* |
| | *2022* | *0+74.5* | *Crossover Riffle* | *14.3* | *0.3* | *47.8* | *1.3* | *4.3* | *22.9* |
| | *2022* | *0+74.5* | *Crossover Riffle* | *15.3* | *0.3* | *54.8* | *1.2* | *4.3* | *31.3* |
| 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 |
| | 2015 | 1+55 | Crossover Riffle | 9.3 | 0.7 | 12.7 | 1.2 | 6.8 | 37.9 |
| | *2017* | *1+56* | *Crossover Riffle* | *7.3* | *0.9* | *8.6* | *1.7* | *7.3* | *35.0* |
| | *2018* | *1+56* | *Crossover Riffle* | *10.0* | *1.1* | *9.4* | *1.3* | *10.7* | *41.6* |

| Table C-2. (Continued) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Reach** | **Year** | **Station** | **Feature** | **Bankfull Width (ft)** | **Mean Depth (ft)** | **Width/ Depth Ratio** | **Entrench-ment Ratio** | **Bankfull Area (ft²)** | **Top of Bank Area (ft²)** |
| WC03 | *2019* | *1+56* | *Crossover Riffle* | *10.4* | *0.9* | *11.7* | *1.3* | *9.2* | *42.3* |
| | *2020* | *1+56* | *Crossover Riffle* | *10.7* | *0.7* | *15.2* | *1.6* | *7.6* | *40.5* |
| | *2022* | *1+56* | *Crossover Riffle* | *10.4* | *0.7* | *13.9* | *1.3* | *7.8* | *42.4* |
| | *2023* | *1+56* | *Crossover Riffle* | *9.9* | *0.5* | *20.3* | *1.2* | *4.8* | *45.4* |
| | 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 |
| | 2015 | 2+07 | Meander/Pool | 9.9 | 1.1 | 9.4 | 2.8 | 10.5 | 61.4 |
| | *2017* | *2+08* | *Meander/Run* | *9.8* | *0.9* | *12.2* | *2.7* | *9.8* | *61.5* |
| | *2018* | *2+08* | *Meander/Run* | *11.5* | *0.6* | *18.3* | *2.3* | *7.2* | *61.8* |
| | *2019* | *2+08* | *Meander/Run* | *11.6* | *0.7* | *15.9* | *1.6* | *8.5* | *62.6* |
| | *2020* | *2+08* | *Meander/Run* | *13.0* | *1.3* | *10.4* | *2.7* | *16.2* | *32.1* |
| | *2022* | *2+08* | *Meander/Run* | *14.7* | *1.2* | *12.1* | *2.4* | *17.9* | *34.8* |
| | *2023* | *2+08* | *Meander/Run* | *9.4* | *0.6* | *16.3* | *1.6* | *5.5* | *37.3* |
| 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 | 0.6 | 23.5 | 2.2 | 7.2 | 99.9 |
| | 2015 | 1+08 | Meander/Pool | 13.6 | 0.6 | 24.0 | 2.3 | 7.7 | 102.8 |
| | *2017* | *1+10* | *Meander/Pool* | *20.6* | *0.4* | *51.3* | *1.5* | *8.3* | *99.8* |
| | *2018* | *1+10* | *Meander/Pool* | *6.8* | *0.6* | *13.6* | *3.4* | *4.5* | *93.4* |
| | *2019* | *1+10* | *Meander/Pool* | *11.6* | *0.4* | *28.8* | *2.7* | *4.7* | *90.7* |
| | *2020* | *1+10* | *Meander/Pool* | *7.8* | *0.7* | *10.5* | *4.2* | *5.8* | *90.9* |
| | *2022* | *1+10* | *Meander/Pool* | *7.6* | *0.8* | *9.9* | *4.2* | *5.8* | *80.3* |
| | *2023* | *1+10* | *Meander/Pool* | *6.9* | *0.7* | *10.6* | *4.4* | *4.6* | *95.1* |
| | 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 |
| | 2015 | 1+68 | Crossover Riffle | 11.1 | 0.6 | 17.4 | 1.6 | 7.1 | 55.6 |
| | *2017* | *1+68* | *Crossover Riffle* | *10.4* | *0.5* | *22.3* | *1.4* | *4.8* | *54.8* |
| | *2018* | *1+68* | *Crossover Riffle* | *9.2* | *0.3* | *28.8* | *1.3* | *3.0* | *55.4* |
| | *2019* | *1+68* | *Crossover Riffle* | *9.7* | *0.4* | *24.1* | *1.4* | *3.9* | *56.0* |
| | *2020* | *1+68* | *Crossover Riffle* | *9.4* | *0.3* | *27.4* | *1.4* | *3.3* | *55.7* |
| | *2022* | *1+68* | *Crossover Riffle* | *11.0* | *0.4* | *27.1* | *1.4* | *4.4* | *55.5* |
| | *2023* | *1+68* | *Crossover Riffle* | *9.9* | *0.3* | *29.1* | *1.4* | *3.3* | *56.8* |
| *Profiles and cross-sections re-established during Post-Restoration Year 1 (2017) | | | | | | | | | |

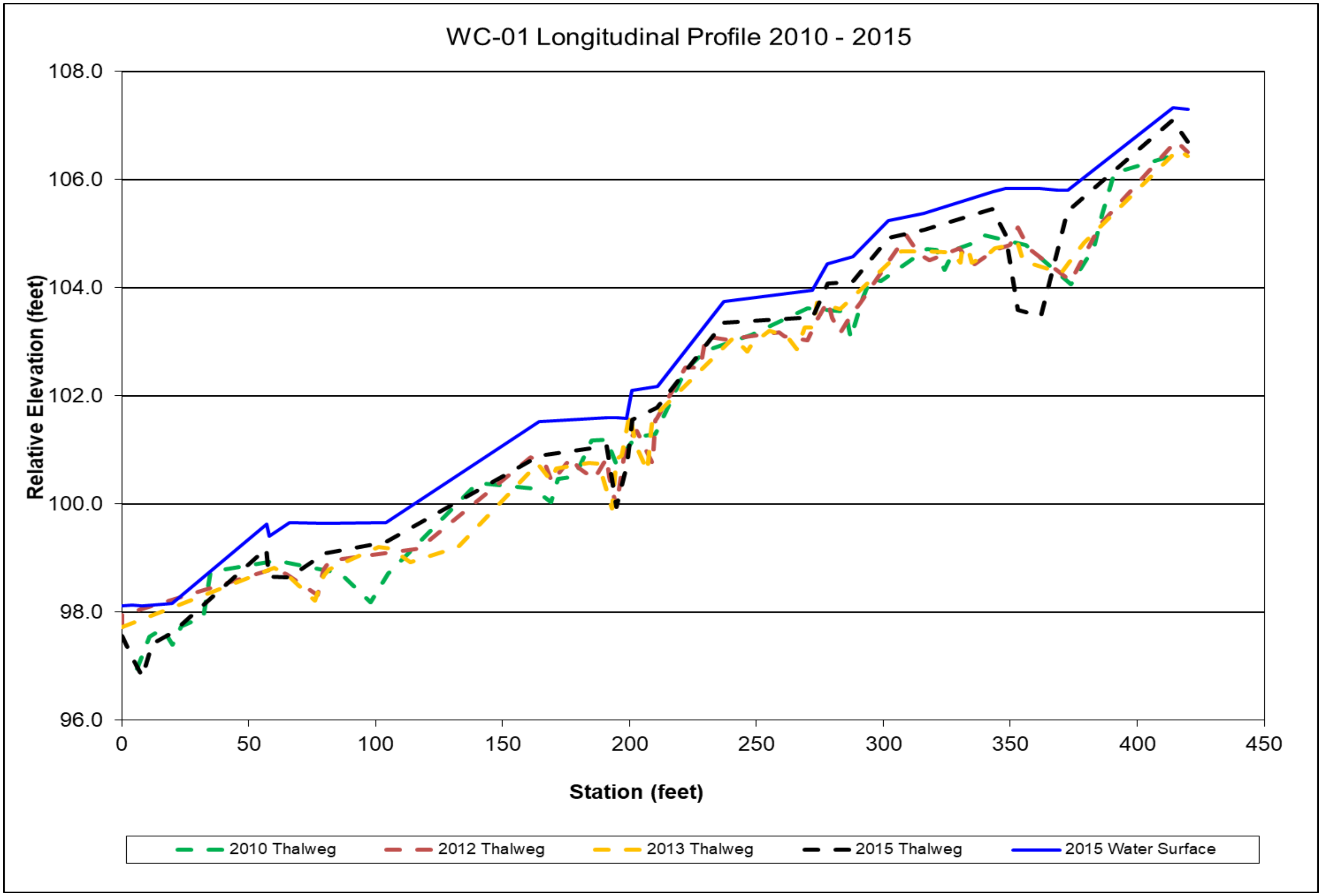


Figure C-1. WC-01 Longitudinal Profile (Pre-Restoration)

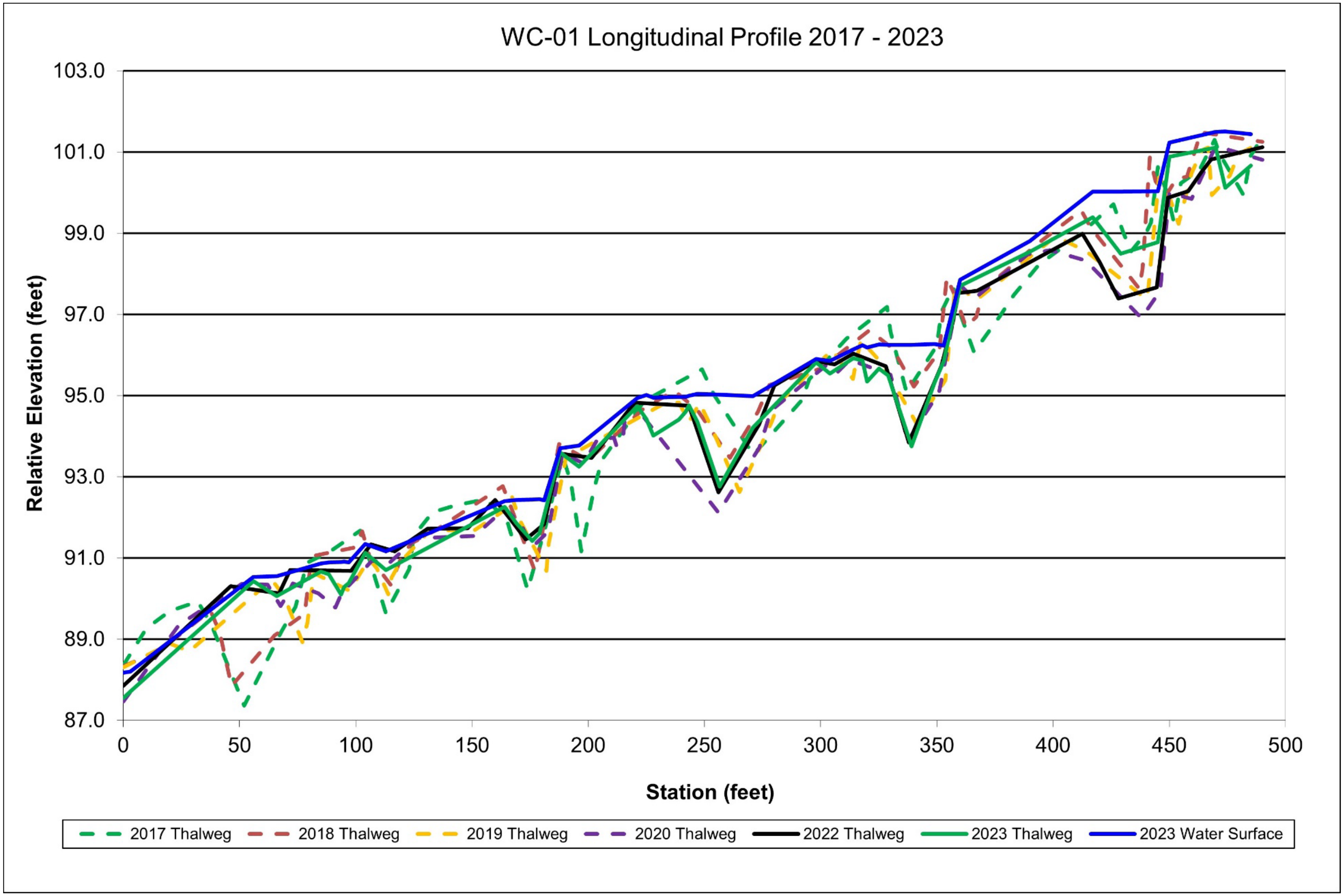


Figure C-2. WC-01 Longitudinal Profile (Post-Restoration)

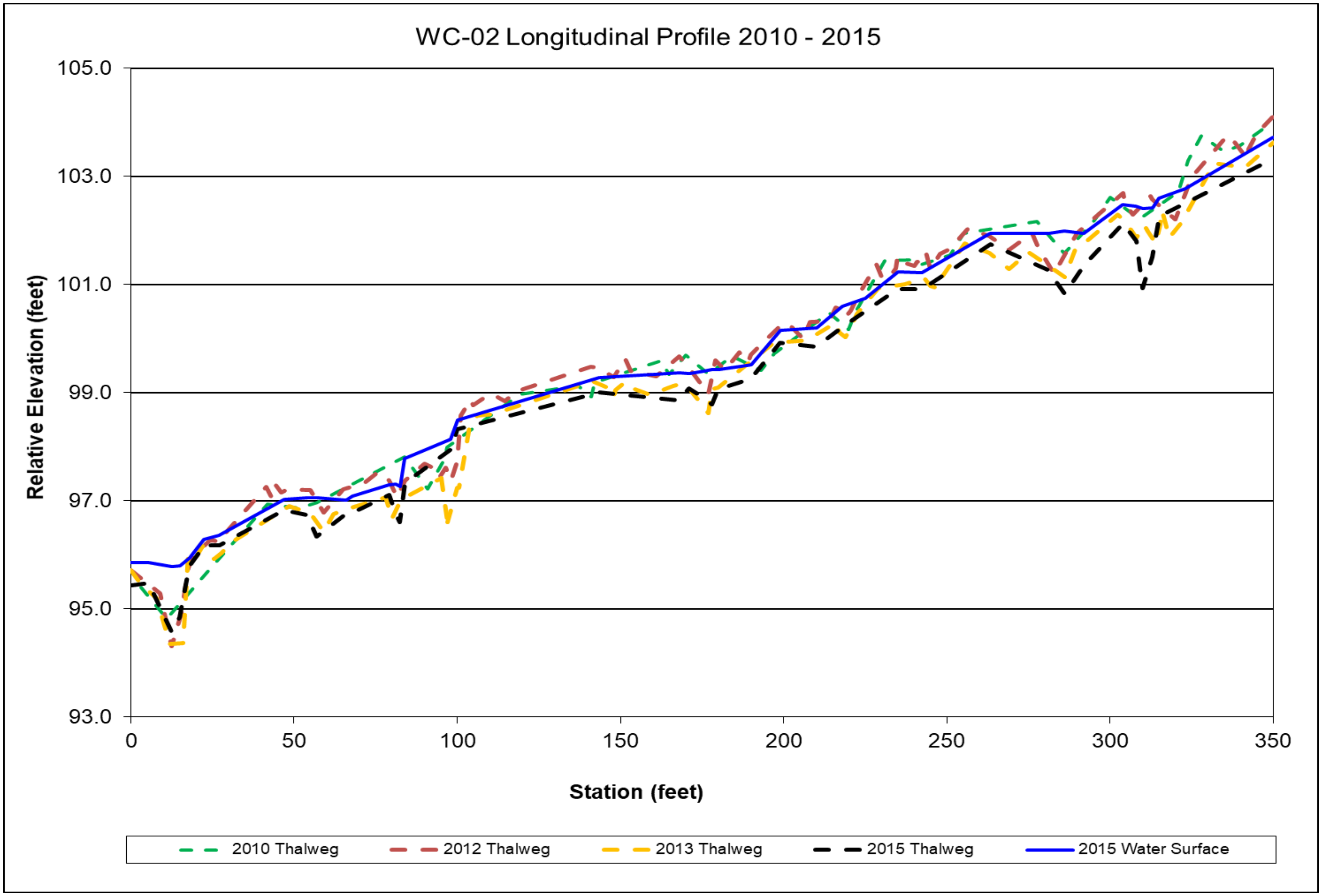


Figure C-3. WC-02 Longitudinal Profile (Pre-Restoration)

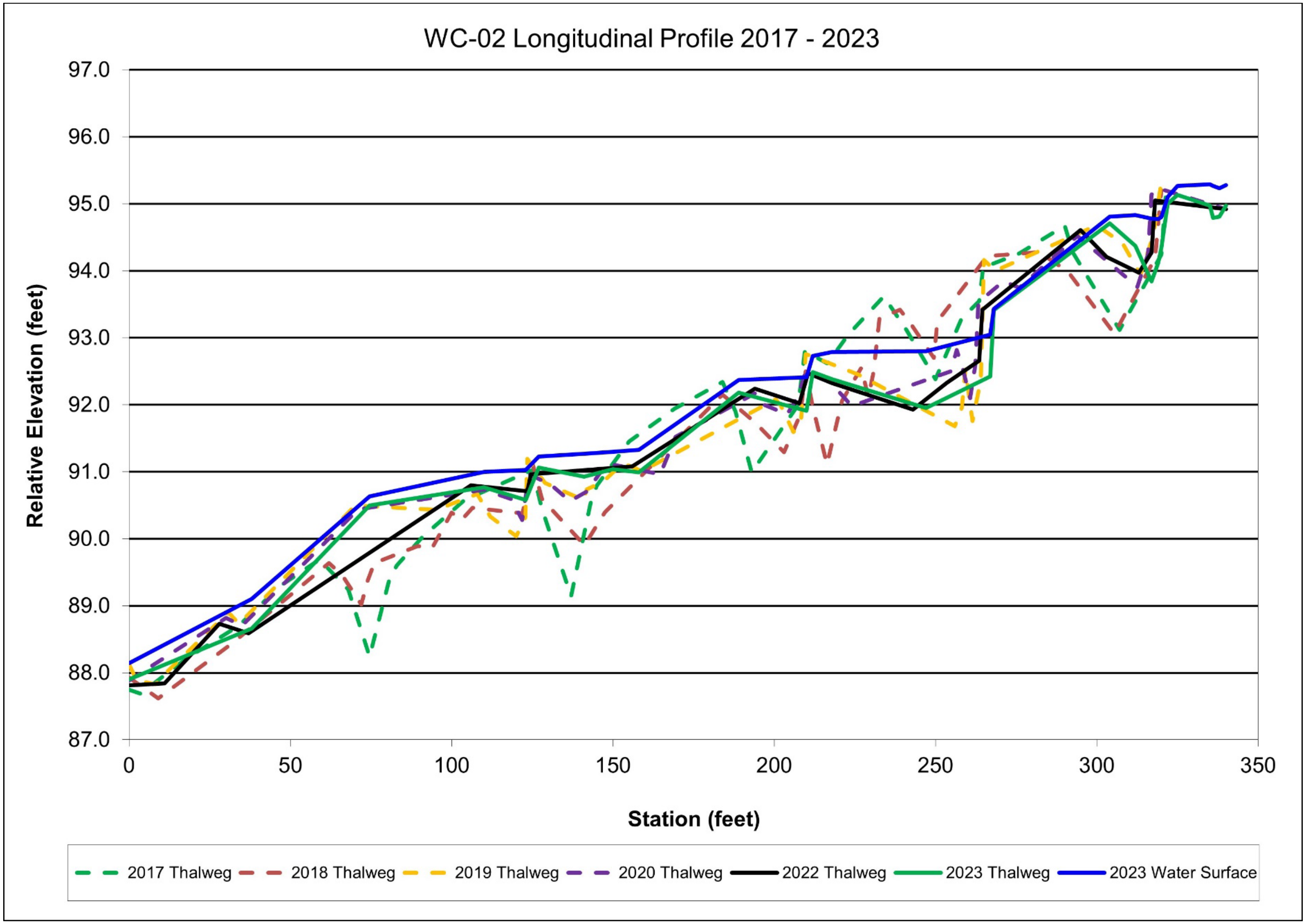


Figure C-4. WC-02 Longitudinal Profile (Post-Restoration)

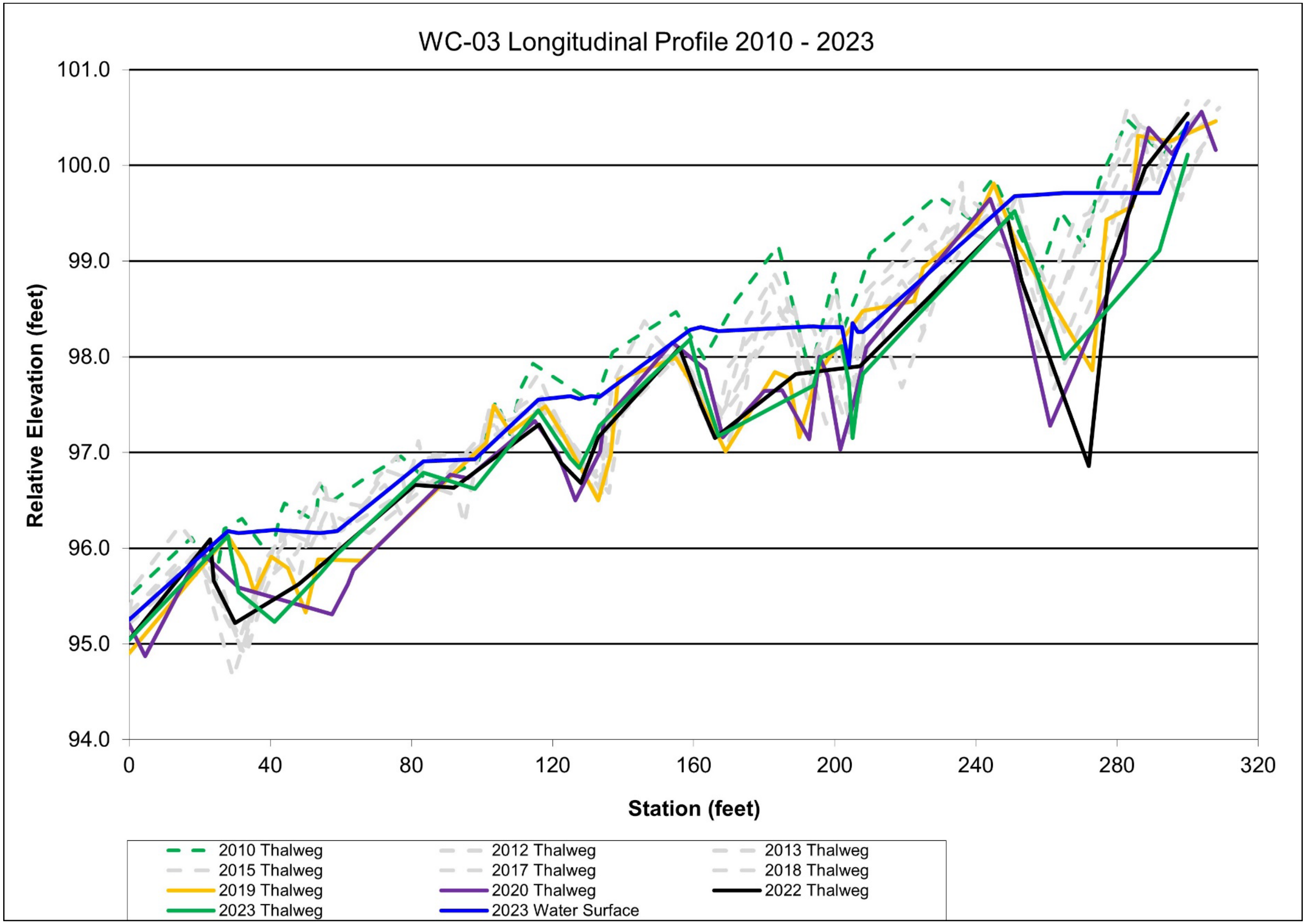


Figure C-5. WC-03 Longitudinal Profile (Pre- and Post-Restoration)

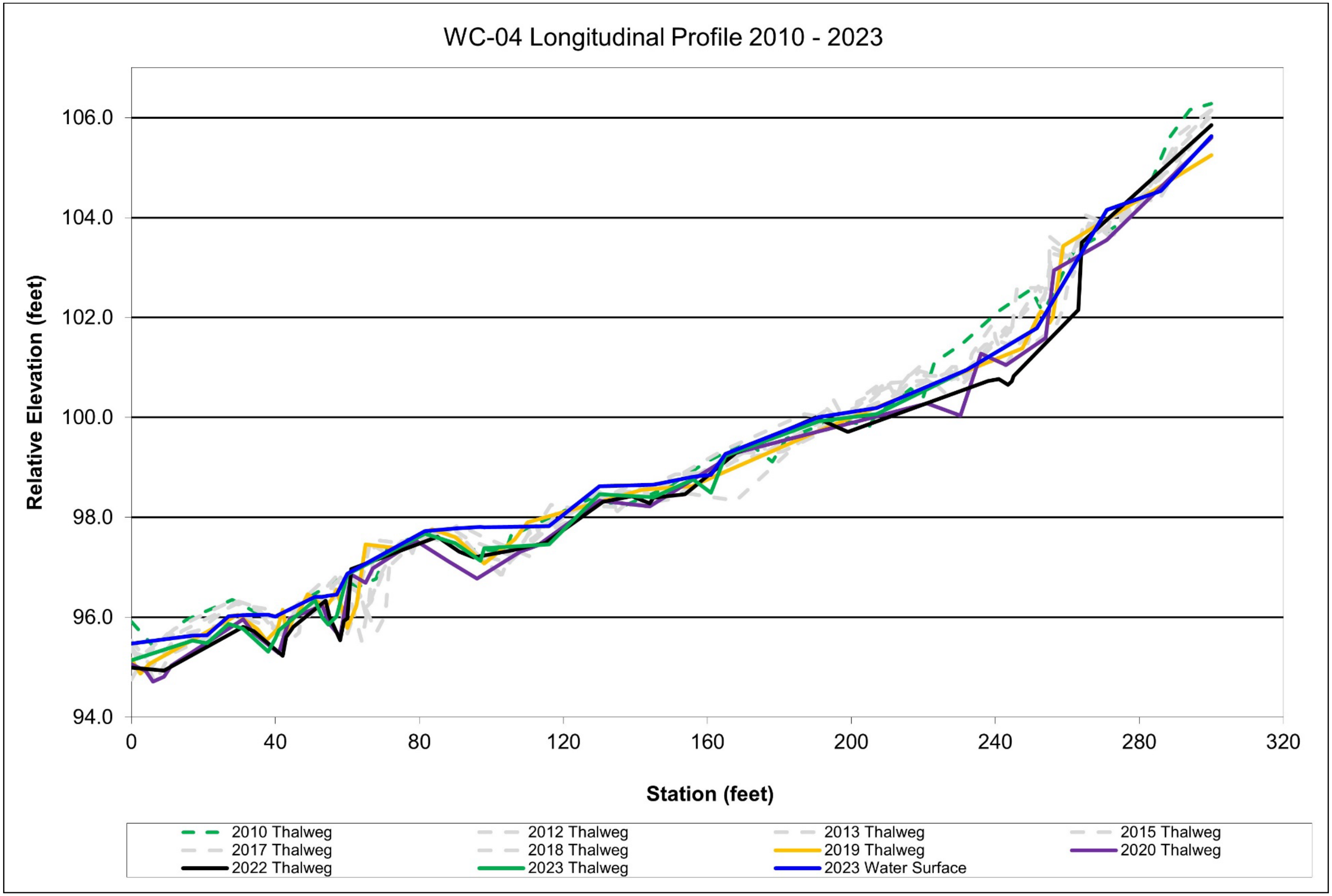


Figure C-6. WC-04 Longitudinal Profile (Pre- and Post-Restoration)

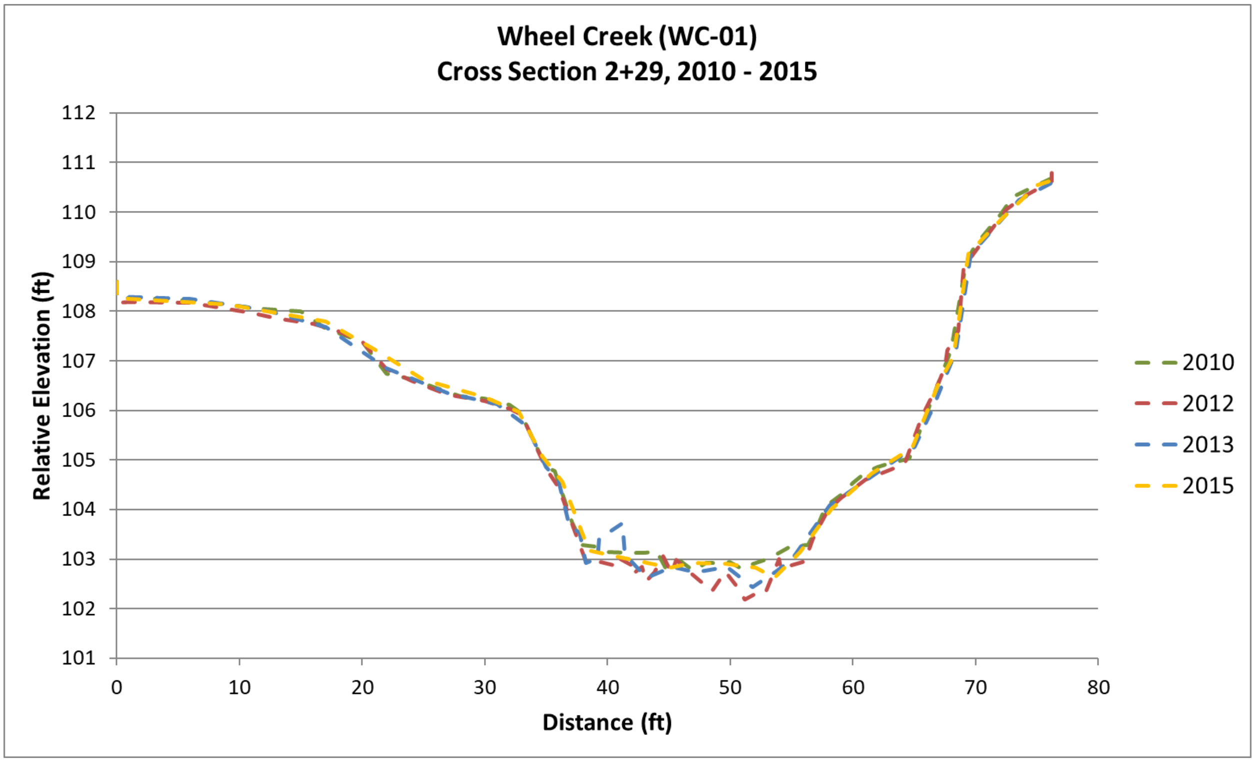


Figure C-7. WC01 Cross-section 1 (Pre-Restoration)

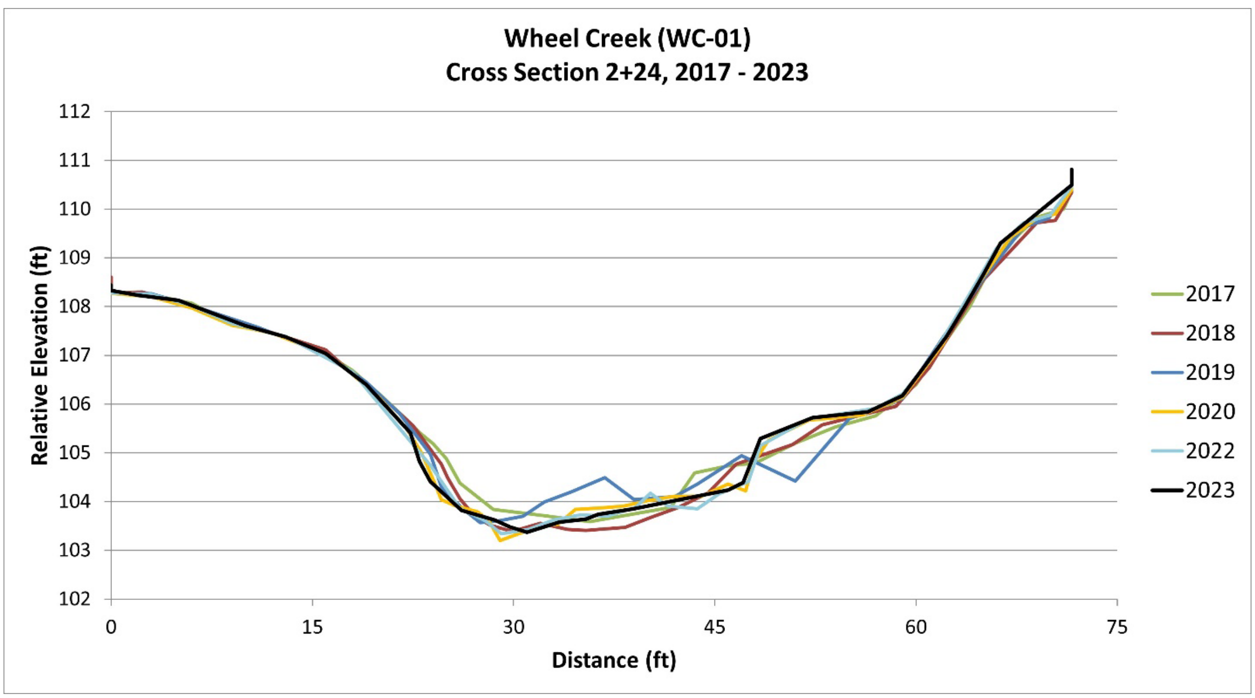


Figure C-8. WC01 Cross-section 1 (Post-Restoration)

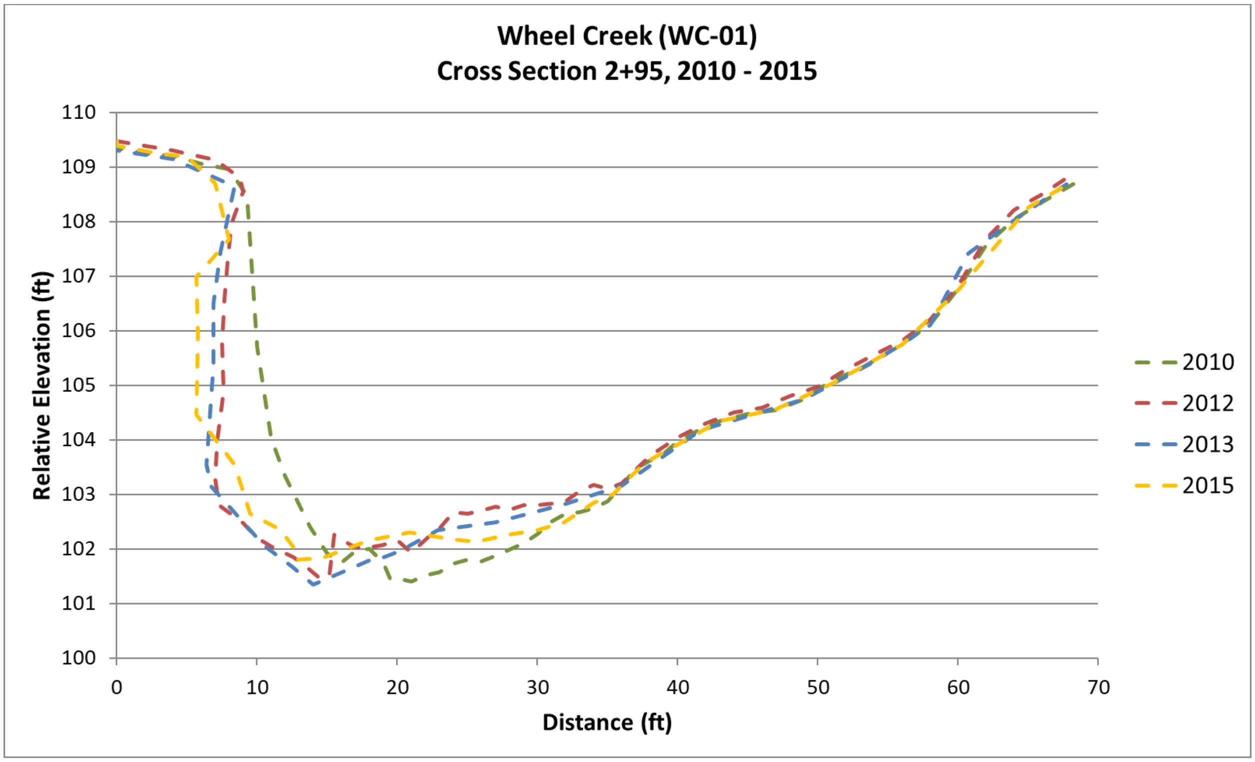


Figure C-9. WC01 Cross-section 2 (Pre-Restoration)

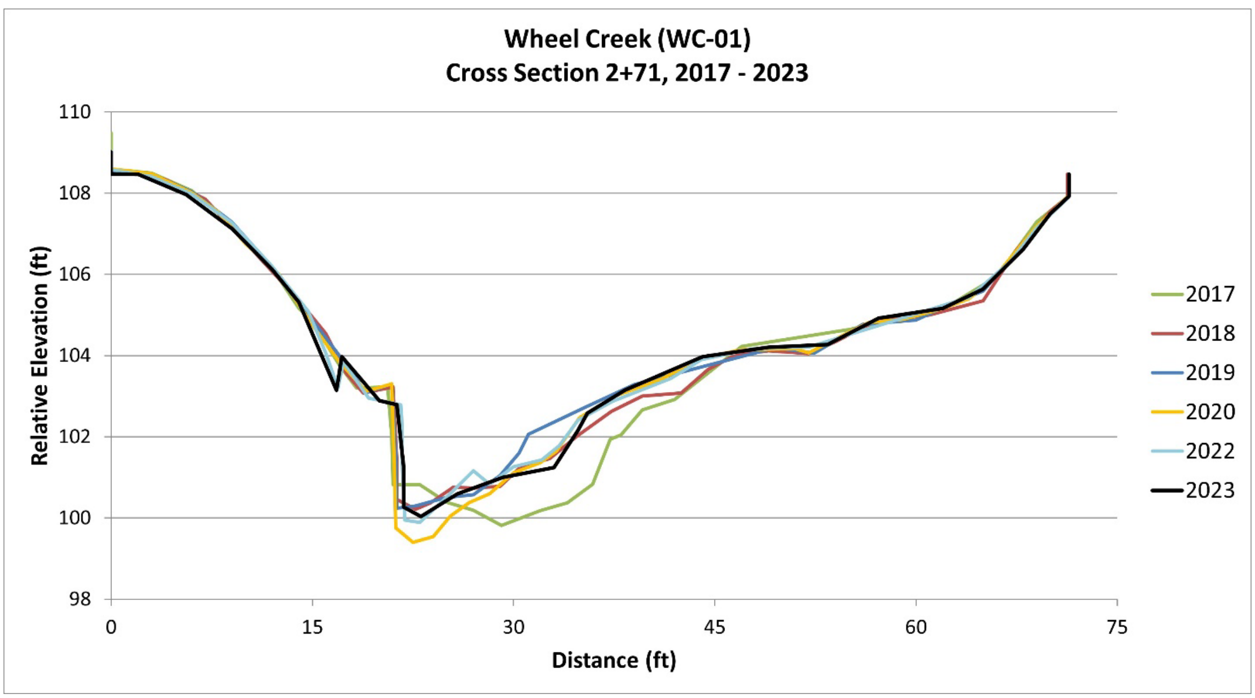


Figure C-10. WC01 Cross-section 2 (Post-Restoration)

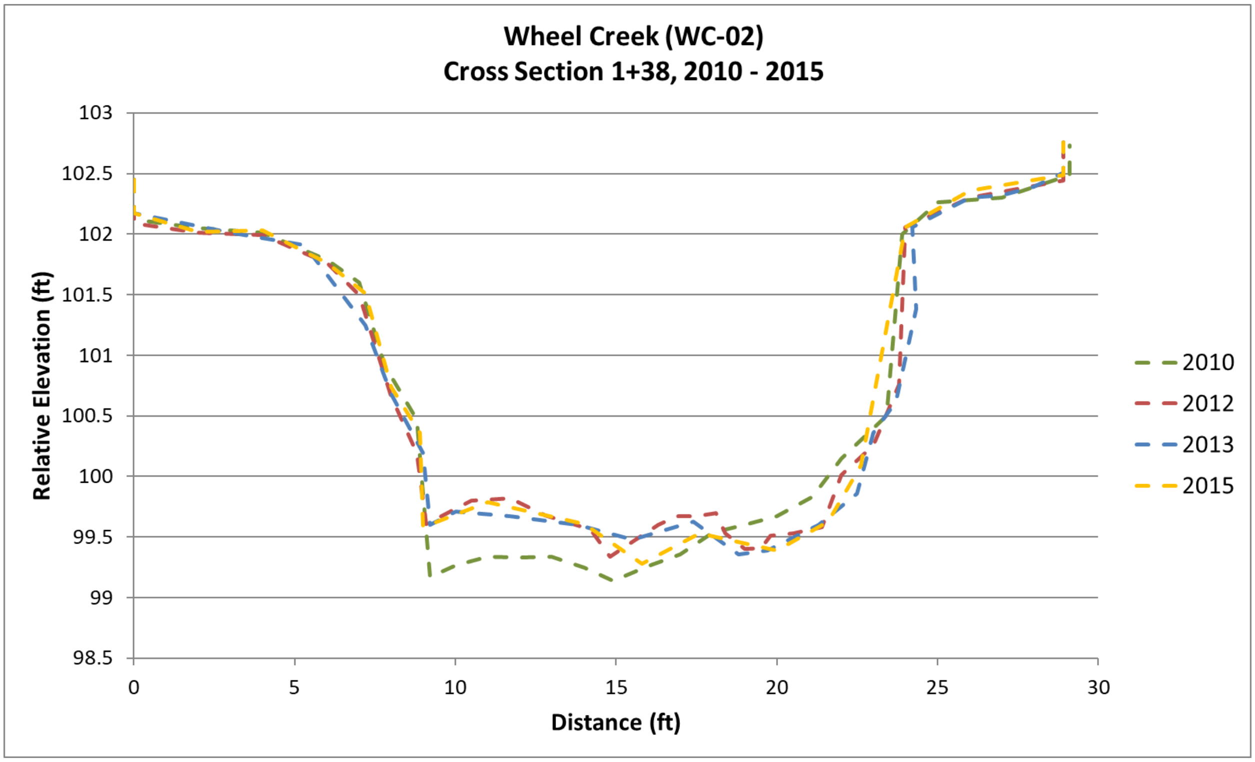


Figure C-11. WC02 Cross-section 1 (Pre-Restoration)

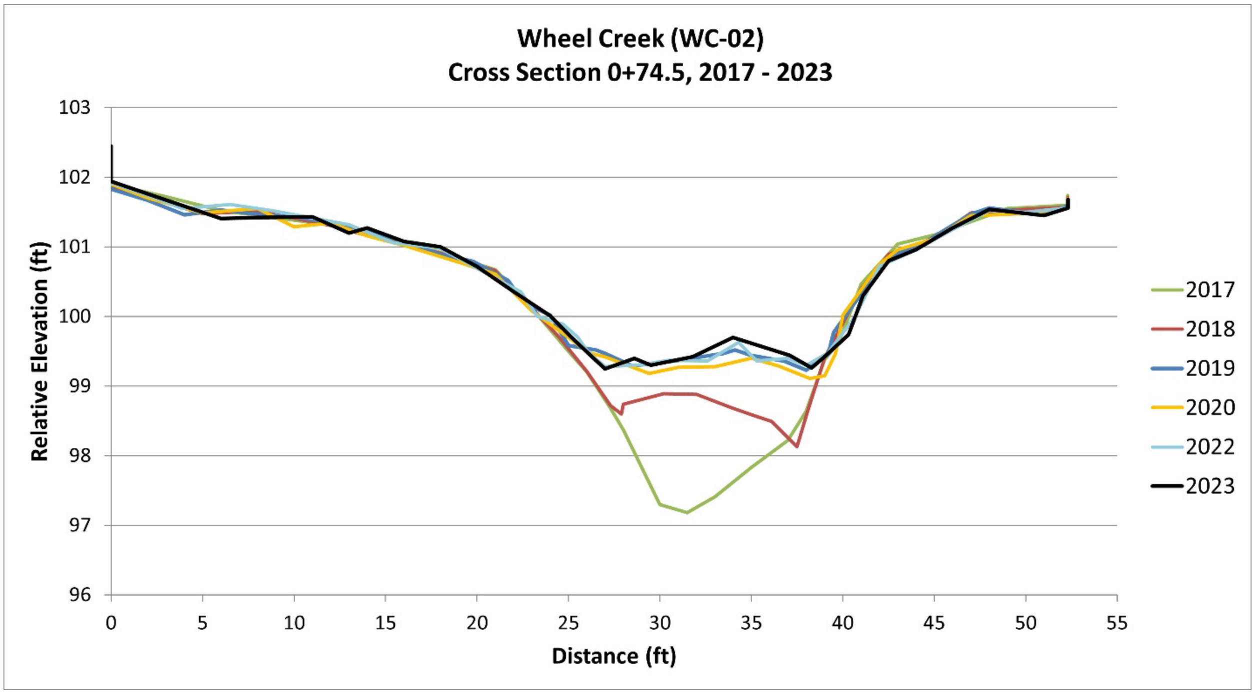


Figure C-12. WC02 Cross-section 1 (Post-Restoration)

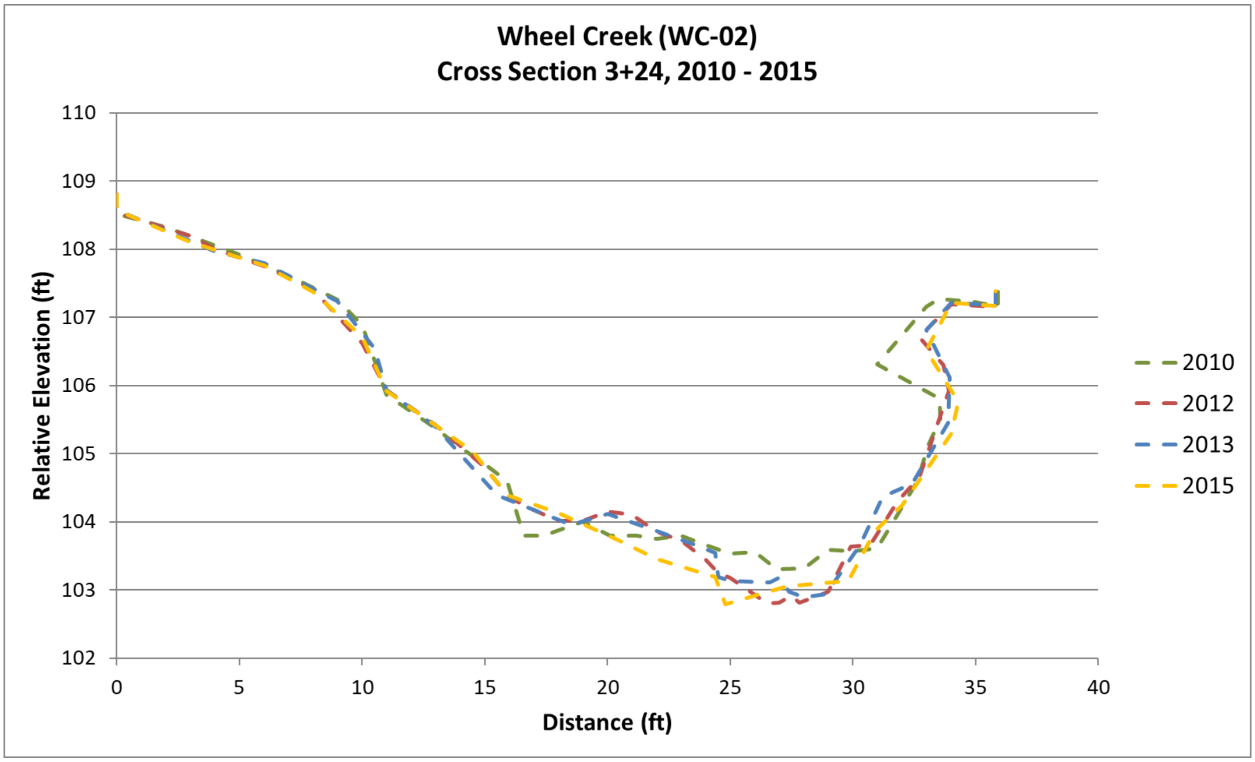


Figure C-13. WC02 Cross-section 2 (Pre-Restoration)

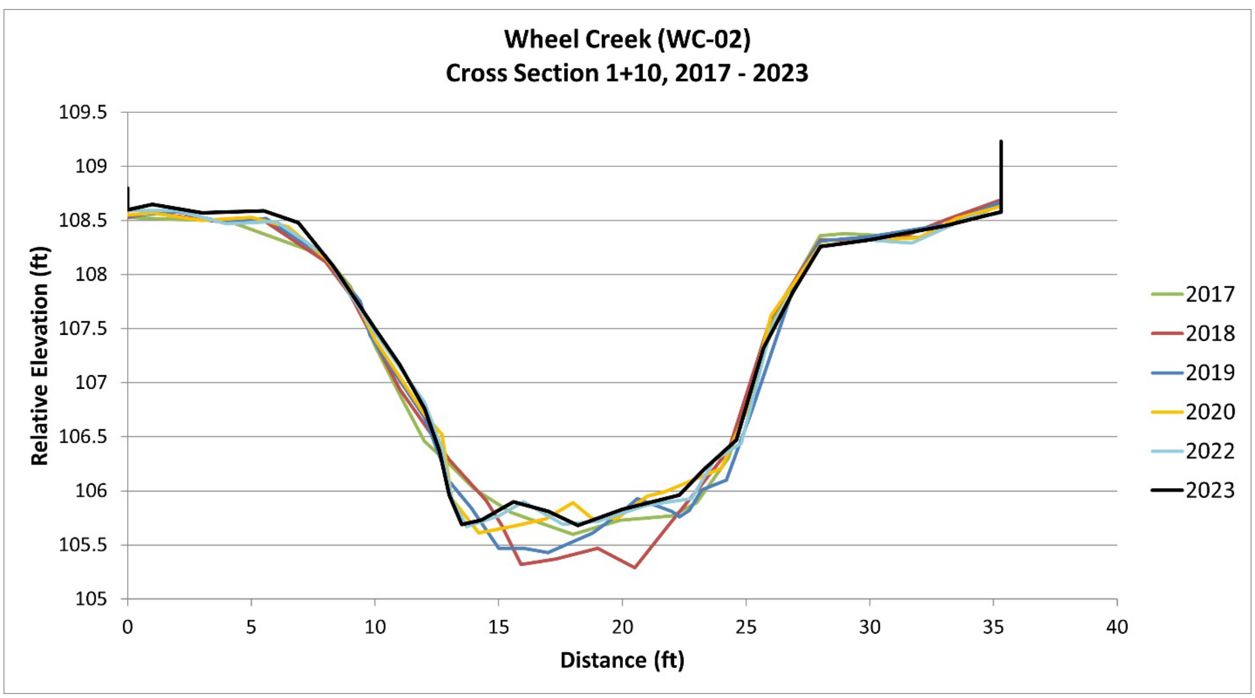


Figure C-14. WC02 Cross-section 2 (Post-Restoration)

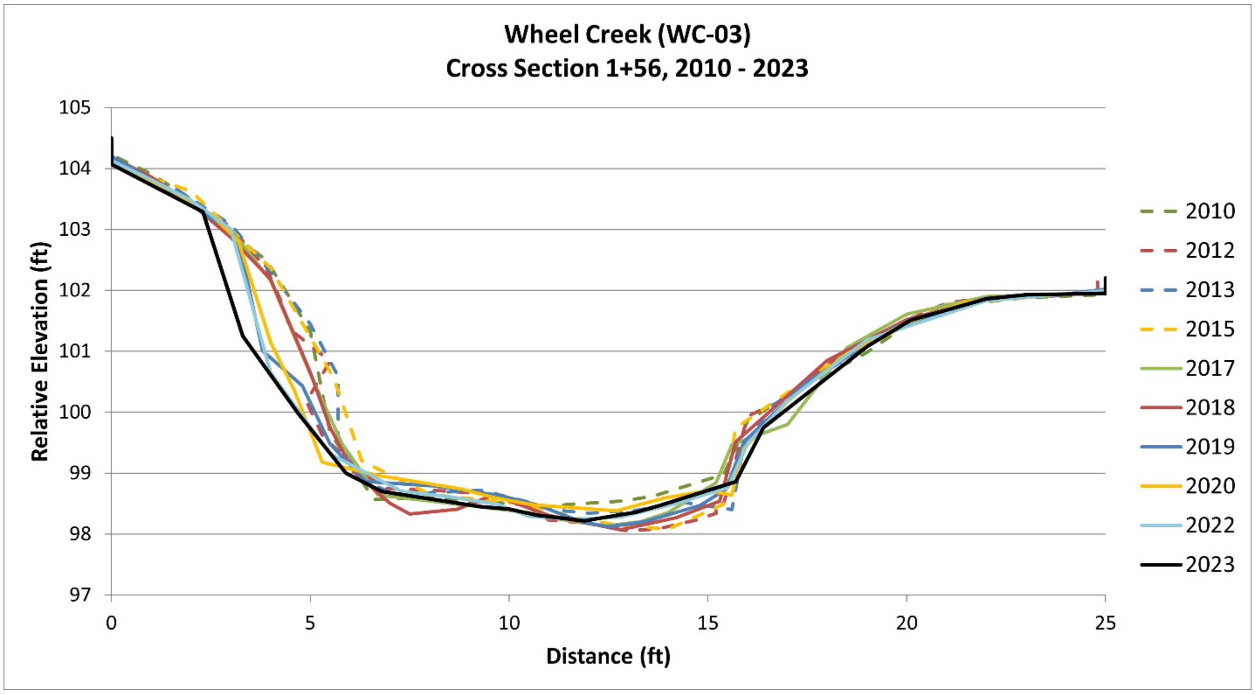


Figure C-15. WC03 Cross-section 1 (Pre- and Post-Restoration)

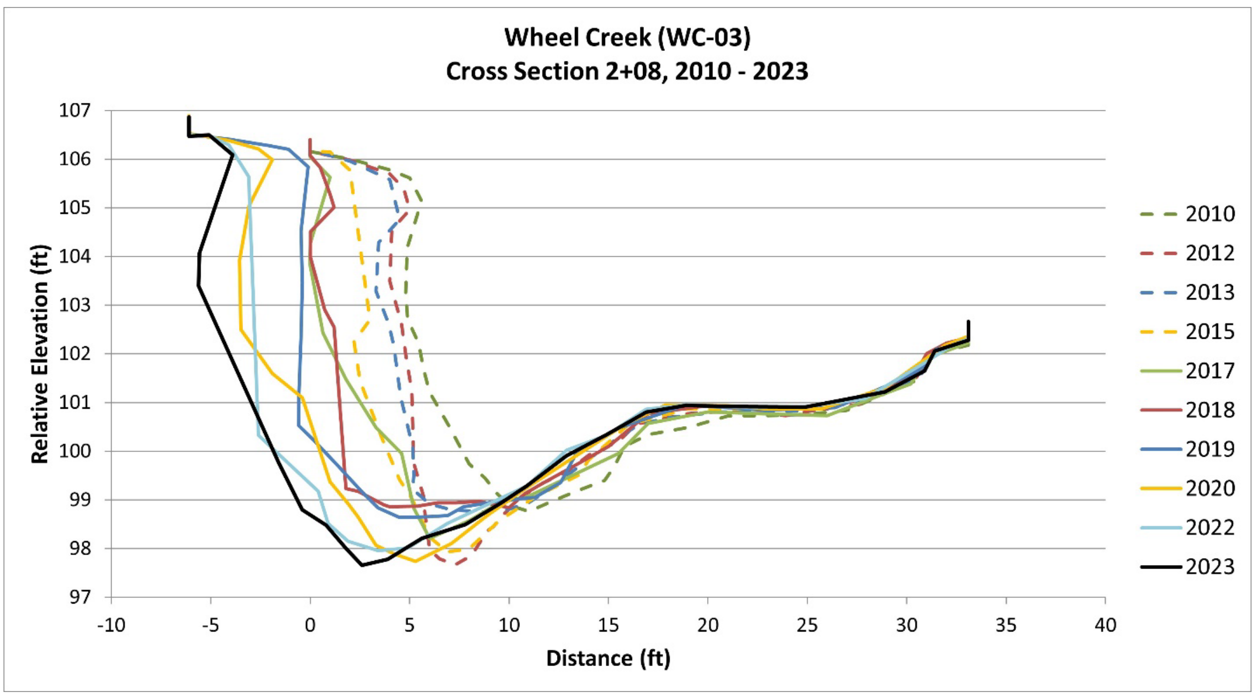


Figure C-16. WC03 Cross-section 2 (Pre- and Post-Restoration)

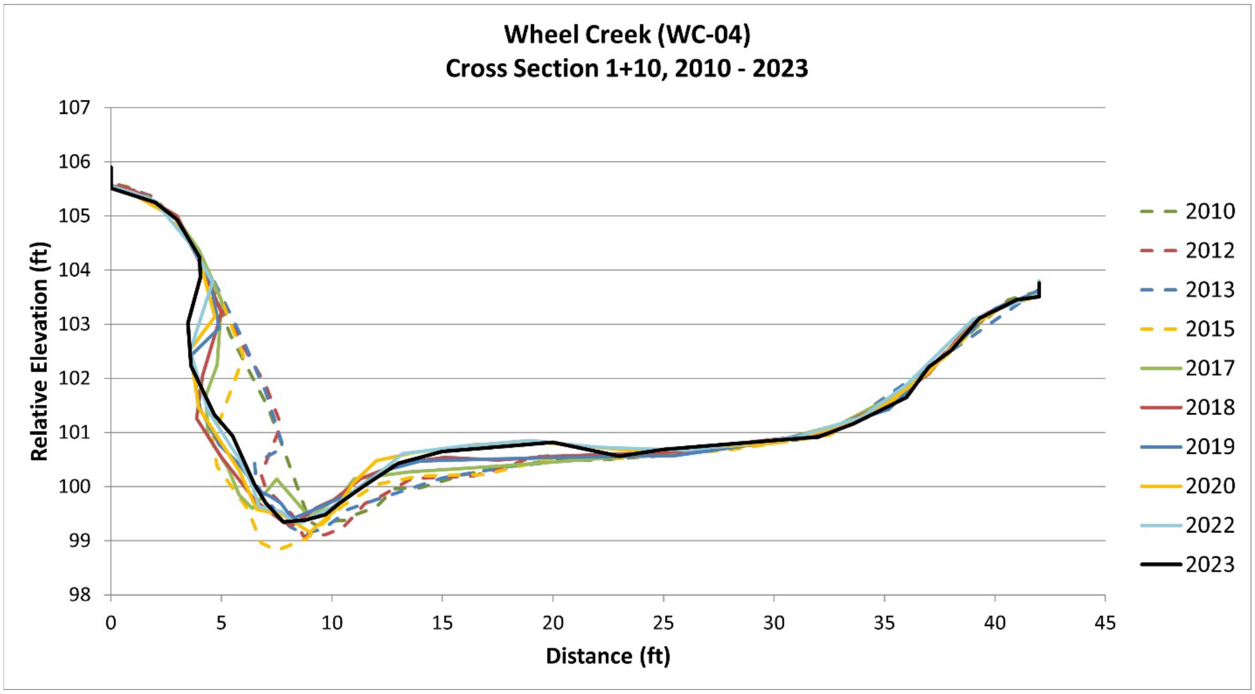


Figure C-17. WC04 Cross-section 1 (Pre- and Post-Restoration)

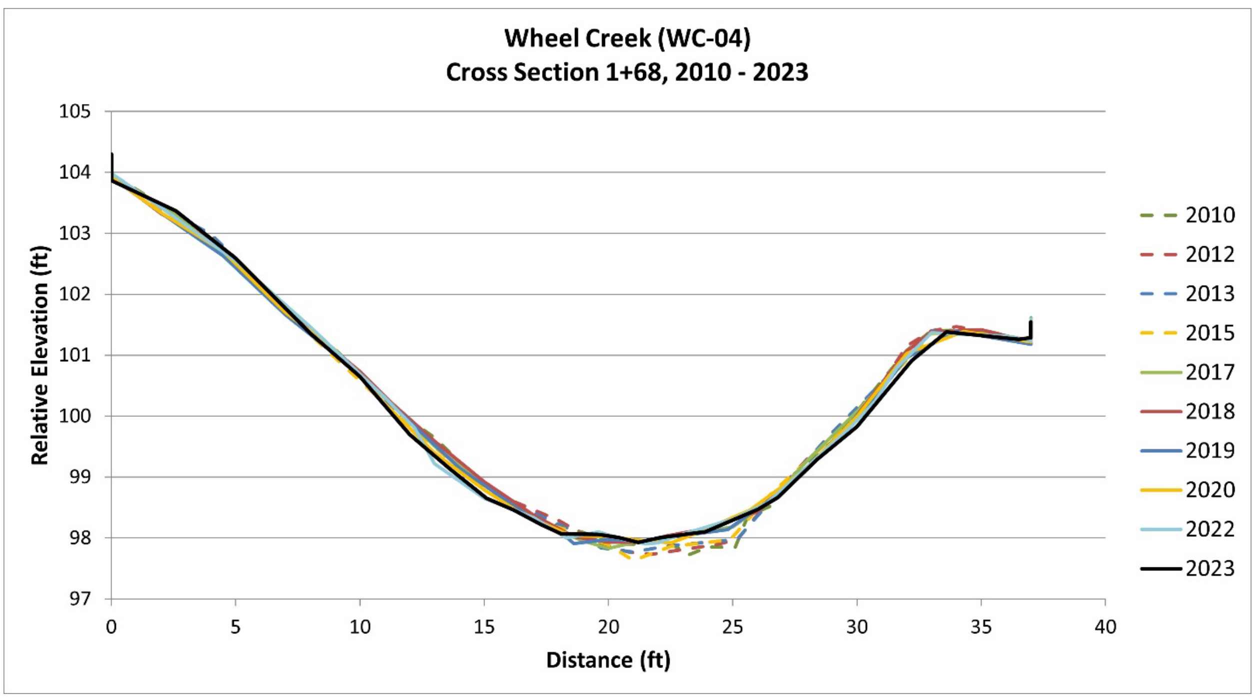


Figure C-18. WC04 Cross-section 2 (Pre- and Post-Restoration)

Table C-3. Particle Size Distribution Pre-Restoration Years 1 – 4, Post-Restoration Years 1 – 6

| Year | *Riffle Feature Surface* | | | *Meander Feature Surface* | | | *Reachwide* | | |
|---|---|---|---|---|---|---|---|---|---|
| | 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 |
| 2015 | D50 | 50 | very coarse gravel | D50 | 55 | very coarse gravel | D50 | 42 | very coarse gravel |
| *2017* | *D50* | *52* | *very coarse gravel* | *D50* | *11* | *medium gravel* | *D50* | *25* | *coarse gravel* |
| *2018* | *D50* | *41* | *very coarse gravel* | *D50* | *32* | *very coarse gravel* | *D50* | *47* | *very coarse gravel* |
| *2019* | *D50* | *47* | *very coarse gravel* | *D50* | *12* | *medium gravel* | *D50* | *37* | *very coarse gravel* |
| *2020* | *D50* | *42* | *very coarse gravel* | *D50* | *25* | *coarse gravel* | *D50* | *32* | *coarse gravel* |
| *2022* | *D50* | *83* | *small cobble* | *D50* | *68* | *small cobble* | *D50* | *82* | *small cobble* |
| *2023* | *D50* | *48* | *very coarse gravel* | *D50* | *44* | *very coarse gravel* | *D50* | *57* | *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 |
| 2015 | D84 | 160 | large cobble | D84 | 110 | medium cobble | D84 | 150 | large cobble |
| *2017* | *D84* | *120* | *small cobble* | *D84* | *57* | *very coarse gravel* | *D84* | *90* | *small cobble* |
| *2018* | *D84* | *150* | *large cobble* | *D84* | *97* | *medium cobble* | *D84* | *160* | *large cobble* |
| *2019* | *D84* | *110* | *medium cobble* | *D84* | *51* | *very coarse gravel* | *D84* | *90* | *small cobble* |
| *2020* | *D84* | *110* | *medium cobble* | *D84* | *84* | *small cobble* | *D84* | *93* | *medium cobble* |
| *2022* | *D84* | *170* | *large cobble* | *D84* | *120* | *medium cobble* | *D84* | *160* | *large cobble* |
| *2023* | *D84* | *130* | *large cobble* | *D84* | *79* | *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 |
| 2013 | D50 | 51 | very coarse gravel | D50 | 47 | very coarse gravel | D50 | 40 | coarse gravel |
| 2015 | D50 | 36 | very coarse gravel | D50 | 26 | very coarse gravel | D50 | 36 | very coarse gravel |
| *2017* | *D50* | *26* | *coarse gravel* | *D50* | *4.3* | *very fine gravel* | *D50* | *16* | *medium gravel* |
| *2018* | *D50* | *41* | *very coarse gravel* | *D50* | *64* | *small cobble* | *D50* | *27* | *coarse gravel* |
| *2019* | *D50* | *51* | *very coarse gravel* | *D50* | *16* | *medium gravel* | *D50* | *22* | *coarse gravel* |
| *2020* | *D50* | *82* | *small cobble* | *D50* | *43* | *very coarse gravel* | *D50* | *37* | *very coarse gravel* |
| *2022* | *D50* | *28* | *coarse gravel* | *D50* | *34* | *very coarse gravel* | *D50* | *43* | *very coarse gravel* |
| *2023* | *D50* | *35* | *very coarse gravel* | *D50* | *32* | *coarse gravel* | *D50* | *47* | *very 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 |
| 2015 | D84 | 100 | medium cobble | D84 | 100 | medium cobble | D84 | 110 | medium cobble |
| *2017* | *D84* | *85* | *very coarse gravel* | *D84* | *19* | *medium gravel* | *D84* | *62* | *very coarse gravel* |
| *2018* | *D84* | *120* | *medium cobble* | *D84* | *130* | *large cobble* | *D84* | *110* | *medium cobble* |
| *2019* | *D84* | *110* | *medium cobble* | *D84* | *64* | *small cobble* | *D84* | *76* | *small cobble* |
| *2020* | *D84* | *150* | *large cobble* | *D84* | *100* | *medium cobble* | *D84* | *80* | *small cobble* |
| *2022* | *D84* | *61* | *very coarse gravel* | *D84* | *68* | *small cobble* | *D84* | *88* | *small cobble* |
| *2023* | *D84* | *97* | *medium cobble* | *D84* | *90* | *small cobble* | *D84* | *100* | *medium 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 |
| 2013 | D50 | 27 | coarse gravel | D50 | 29 | coarse gravel | D50 | 35 | very coarse gravel |
| 2015 | D50 | 36 | very coarse gravel | D50 | 7.2 | fine gravel | D50 | 26 | coarse gravel |
| *2017* | *D50* | *26* | *coarse gravel* | *D50* | *17* | *medium gravel* | *D50* | *16* | *medium gravel* |
| *2018* | *D50* | *26* | *coarse gravel* | *D50* | *14* | *medium gravel* | *D50* | *22* | *coarse gravel* |
| *2019* | *D50* | *45* | *very coarse gravel* | *D50* | *23* | *coarse gravel* | *D50* | *22* | *coarse gravel* |
| *2020* | *D50* | *36* | *very coarse gravel* | *D50* | *12* | *medium gravel* | *D50* | *31* | *coarse gravel* |
| *2022* | *D50* | *28* | *coarse gravel* | *D50* | *20* | *coarse gravel* | *D50* | *21* | *coarse gravel* |
| *2023* | *D50* | *39* | *very coarse gravel* | *D50* | *47* | *very coarse gravel* | *D50* | *33* | *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 |

| Table C-3. (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 | | | | | | | | | |
| 2013 | D84 | 68 | small cobble | D84 | 59 | very coarse gravel | D84 | 130 | large cobble |
| 2015 | D84 | 85 | small cobble | D84 | 30 | coarse gravel | D84 | 69 | small cobble |
| *2017* | *D84* | *59* | *very coarse gravel* | *D84* | *61* | *very coarse gravel* | *D84* | *50* | *very coarse gravel* |
| *2018* | *D84* | *69* | *small cobble* | *D84* | *50* | *very coarse gravel* | *D84* | *51* | *very coarse gravel* |
| *2019* | *D84* | *88* | *small cobble* | *D84* | *70* | *small cobble* | *D84* | *80* | *small cobble* |
| *2020* | *D84* | *77* | *small cobble* | *D84* | *44* | *very coarse gravel* | *D84* | *71* | *small cobble* |
| *2022* | *D84* | *61* | *very coarse gravel* | *D84* | *47* | *very coarse gravel* | *D84* | *56* | *very coarse gravel* |
| *2023* | *D84* | *77* | *small cobble* | *D84* | *84* | *small cobble* | *D84* | *80* | *small 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 |
| 2015 | D50 | 35 | very coarse gravel | D50 | 8.3 | medium gravel | D50 | 28 | coarse gravel |
| *2017* | *D50* | *43* | *coarse gravel* | *D50* | *12* | *medium gravel* | *D50* | *21* | *medium gravel* |
| *2018* | *D50* | *33* | *very coarse gravel* | *D50* | *1.9* | *very coarse sand* | *D50* | *17* | *coarse gravel* |
| *2019* | *D50* | *27* | *coarse gravel* | *D50* | *1.2* | *very coarse sand* | *D50* | *23* | *coarse gravel* |
| *2020* | *D50* | *49* | *very coarse gravel* | *D50* | *20* | *coarse sand* | *D50* | *22* | *coarse gravel* |
| *2022* | *D50* | *19* | *coarse gravel* | *D50* | *15* | *medium gravel* | *D50* | *11* | *medium gravel* |
| *2023* | *D50* | *34* | *very coarse gravel* | *D50* | *17* | *coarse gravel* | *D50* | *22* | *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 |
| 2015 | D84 | 66 | small cobble | D84 | 24 | coarse gravel | D84 | 72 | small cobble |
| *2017* | *D84* | *99* | *small cobble* | *D84* | *26* | *coarse gravel* | *D84* | *68* | *very coarse gravel* |
| *2018* | *D84* | *70* | *small cobble* | *D84* | *32* | *very coarse gravel* | *D84* | *47* | *very coarse gravel* |
| *2019* | *D84* | *80* | *small cobble* | *D84* | *29* | *coarse gravel* | *D84* | *81* | *small cobble* |
| *2020* | *D84* | *92* | *medium cobble* | *D84* | *58* | *very coarse gravel* | *D84* | *75* | *small cobble* |
| *2022* | *D84* | *41* | *very coarse gravel* | *D84* | *58* | *very coarse gravel* | *D84* | *34* | *very coarse gravel* |
| *2023* | *D84* | *69* | *small cobble* | *D84* | *60* | *very coarse gravel* | *D84* | *64* | *very coarse gravel* |

*Profiles and cross-sections re-established during Post-Restoration Year 1 (2017)

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# Wheel Creek

# Year 15 – 2023 Biological and Physical Habitat Monitoring Results

December | 2023

## Prepared For

**Harford County**

**Watershed Protection and Restoration**

**Department of Public Works**

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## APPENDICES

# 1. Background

Harford County commissioned a Small Watershed Action Plan for a small subwatershed in the Bush River watershed. The Wheel Creek Small Watershed Action Plan (BayLand, 2008) was completed in August of 2008. Projects identified in the plan were submitted by the County for funding by the Chesapeake and Atlantic Coastal Bays Trust Fund (Trust Fund). Wheel Creek was one of the first project areas selected for funding for restoration by the Trust Fund. In 2009, the County began intensive monitoring of water quality, geomorphology, and ecological condition in the Wheel Creek watershed as projects were implemented. The first restoration project was completed during 2012, and the last projects were completed in July of 2017.

Wheel Creek is an unnamed tributary to Winters Run at Atkisson Reservoir, south of Bel Air, MD. It is a small subwatershed, approximately 393 acres in size (Becker, 2010). Land use in Wheel Creek watershed is dominated by urban development at 46.1% with forest at 34.7% and agriculture at 19.0%. Impervious surfaces in the watershed cover 21.4% of the watershed area. Harford County Public Schools owns the only parcel of substantial forest, on the Harford Glen property.

Maryland Department of Natural Resources' (MD DNR) Maryland Biological Stream Survey (MBSS) monitored seven sites in Wheel Creek and one additional local urban reference site as part of this effort. The MBSS was responsible for the collection and analysis of the data from 2009 to 2018. All sites were sampled through 2017. The four upstream most sites were discontinued prior to the 2018 sampling year. Sampling at the remaining three downstream Wheel Creek sites and the urban control site was continued by MD DNR through 2019. Sampling and data collection at these four sites has continued through 2023.

KCI Technologies, Inc. completed the fifteenth year of chemical, physical, and biological stream sampling in spring and summer of 2023 at the four remaining stream sites in Wheel Creek. This technical memorandum describes the methods and results of the 2023 sampling effort conducted at those sites.

The primary goal of this effort is to characterize baseline stream conditions (biological, physical habitat, and *in situ* chemical) prior to additional restoration project/BMP implementation. A secondary goal is to conduct monitoring in Wheel Creel that can be used to document ecological uplift and habitat improvement as projects are completed within this watershed.

# 2. Methods

The monitoring effort includes chemical (*in situ* water quality), physical (habitat assessment), and biological (benthic macroinvertebrate, fish, herpetofauna, freshwater mussels, and crayfish) assessments conducted at each of the four active stream sites. The sampling methods used are consistent with MD DNR's MBSS. The methods have been developed locally and are calibrated specifically to Maryland's ecophysiographic regions and stream types.

## 2.1 Sampling Sites

Four sampling sites were selected within the Wheel Creek watershed (Figure 1) to characterize baseline stream conditions and to assess the effect of planned restoration on the ecological health of the watershed. A brief description of sites follows;

### 2.1.1 ATKI-101-X

The lowest downstream site in Wheel Creek is ATKI-101-X and it is located near the USGS gage on Wheel Creek. This site has been monitored continuously since 2009 by MBSS until 2019 and by KCI through 2023. The land use upstream of ATKI-101-X is mostly urban (46.1%) with the remaining portion in forest (34.7%) and agriculture (19.0%).

### 2.1.2 ATKI-102-X

ATKI-102-X is located on the furthest reach downstream, of the west branch of Wheel Creek, a short distance upstream of Wheel Road. The catchment upstream of this site is mostly urban (65.7%) with the remaining land classified as agriculture (18.6%) and forest (15.7%). This site has been monitored continuously through 2023.

### 2.1.3 ATKI-003-X

ATKI-003-X is located on the furthest downstream site, of the east branch. Nearby, ATKI-102-X is a short distance upstream of Wheel Road. The upstream catchment to this site is mostly urban (57.5%) with the remaining land classified as forest (27.8%) and agriculture (14.1%). This site has been monitored continuously through 2023.

### 2.1.4 LWIN-108-X

An urban control site is located nearby on an unnamed tributary to Winters Run, downstream of the Atkinson Reservoir. This site was first sampled in 2009 and was continuously monitored by MBSS until 2019 and by KCI from 2020 through 2023. The land use upstream of this site is mostly urban (50.5%) with the remaining portion in agriculture (26.1%) and forest (23.4%).

## 2.2 Water Quality

Water quality conditions were measured *in situ* during the summer 2023 sampling visits at all Wheel Creek sites. Currently, the MBSS does not measure *in situ* water quality at sites but did so in the past. *In situ* water quality methods used were consistent with those published in DNR, 2010. Field measured parameters include stream water temperature, dissolved oxygen, pH, specific conductance, and turbidity. Measurements at each site were made at the upstream end of the 75-meter sampling reach. *In situ* measurements were made before any sampling activities started to avoid sampling water disturbed by other activities. Most *in situ* parameters (i.e., stream temperature, pH, specific conductivity, and dissolved oxygen) were measured using a multiparameter sonde (YSI Professional Plus), while turbidity was measured with a Hach 2100 Turbidimeter. Water quality meters are regularly inspected and maintained and were calibrated immediately prior to sampling to ensure proper usage and accuracy of the readings.

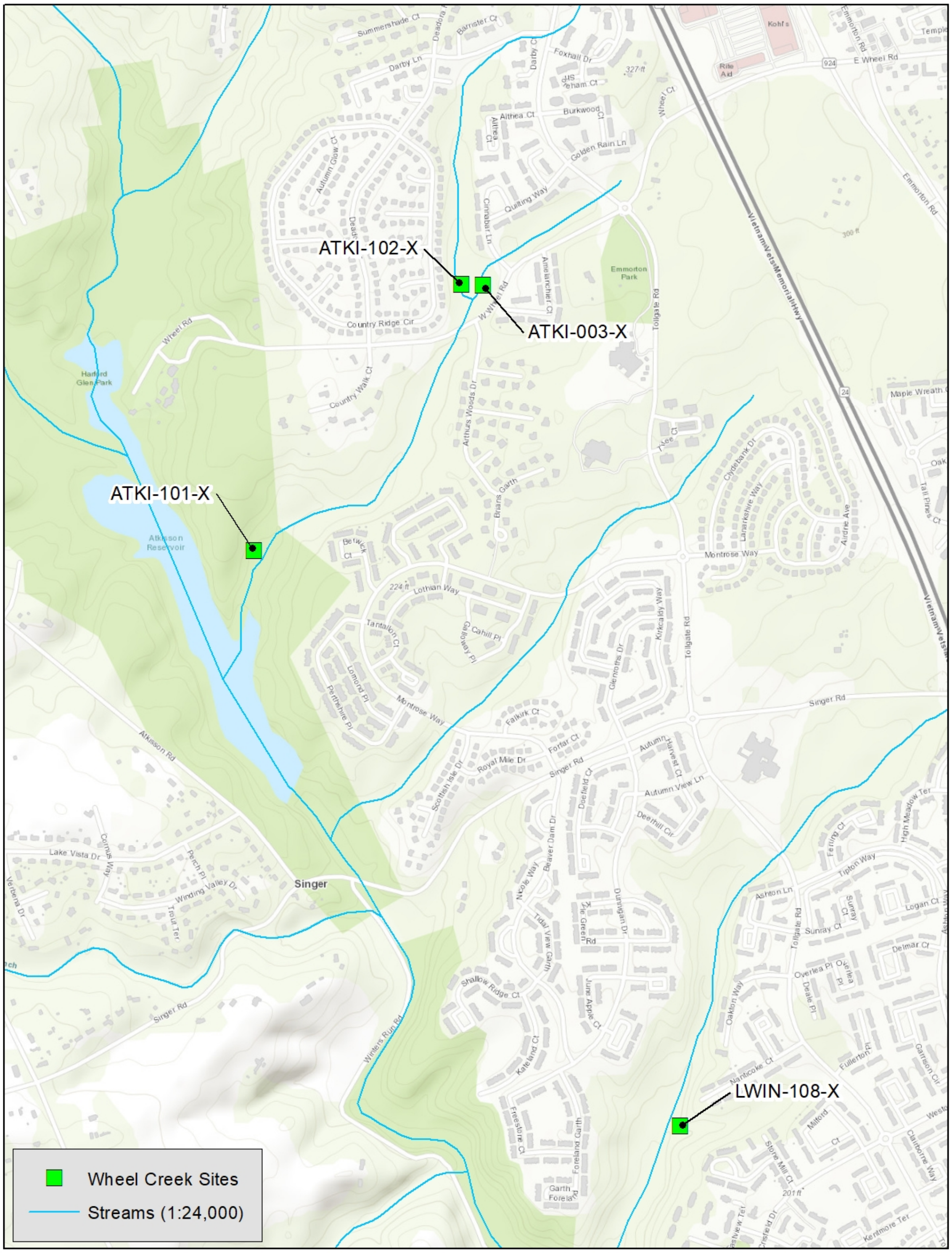


**Figure 1 – Location of Sampling Sites**

## 2.3 Physical Habitat Assessment

Each stream site was characterized based on visual observations of physical characteristics and various habitat parameters. The MBSS Physical Habitat Index (PHI; Paul et al. 2002) was used to assess the physical habitat at the site. Most of the habitat parameters were collected during the summer visits, on June 21, July 7, and August 17, 2023.

To reduce individual sampler bias, assessments were completed as a team with discussion and agreement of the scoring for each parameter among field staff certified in MBSS habitat assessment. In addition to the visual assessments, photographs were taken from three locations within each sampling reach (downstream end, midpoint, and upstream end) facing in the upstream and downstream direction, for a total of six (6) photographs per site.

The PHI incorporates the results of a series of habitat parameters selected for Coastal Plain, Piedmont and Highlands regions. While all parameters are rated during the field assessment, the Piedmont parameters were used to develop the PHI score for these sites because the Wheel Creek watershed is located in Maryland's Piedmont ecophysiographic region. In developing the PHI, MBSS identified eight parameters that have the most discriminatory power for the Piedmont streams. These parameters are used in calculating the PHI (Table 1). Several of the parameters have been found to be drainage area dependent and are scaled accordingly. The drainage area to each site was calculated in GIS by MBSS. The Year 15 analysis will utilize the same catchments for each site to remain consistent with MBSS.

**Table 1 – PHI Piedmont Parameters**

| Piedmont Stream Parameters | |
|---|---|
| Instream Habitat | Epifaunal Substrate |
| Bank Stability | Percent Shading |
| Remoteness | Number Woody Debris/Root wads |
| Embeddedness | Riffle Quality |

Each habitat parameter is given an assessment score ranging from 0-20, with the exception of shading (percentage 0-100%) and woody debris and root wads (total count). A prepared score and scaled score (0-100) are then calculated. The average of these scores yields the final PHI score. The final scores are then ranked according to the ranges shown in Table 2 and assigned corresponding narrative ratings, which allows for a score that can be compared to habitat assessments performed statewide.

**Table 2 – PHI Score and Ratings**

| PHI Score | Narrative Rating |
|---|---|
| 81.0 – 100.0 | Minimally Degraded |
| 66.0 – 80.9 | Partially Degraded |
| 51.0 – 65.9 | Degraded |
| 0.0 – 50.9 | Severely Degraded |

## 2.4 Benthic Macroinvertebrate Community Assessment

Benthic macroinvertebrate collection strictly followed MBSS procedures (Stranko et al. 2019). Sampling occurred during the Spring Index Period (March 1 – April 30), samples were collected from all four Wheel Creek sites on March 1, 2023. The monitoring sites consist of a 75-meter reach and benthic macroinvertebrate sampling is conducted once per year. The sampling methods utilize semi-quantitative field collections of the benthic macroinvertebrate community. The multi-habitat D-frame net approach is used to sample a range of the most productive habitat types present within the reach. Best available habitats include riffles, stable woody debris, root wads, root mats, leaf packs, aquatic macrophytes, and undercut banks. In this sampling approach, a total of twenty kicks or jabs (each approximately one square foot) are distributed proportionally among all best available habitats within the stream site and combined into a single composite sample and preserved in 95 percent ethanol. The composite sample contains material collected from approximately 20 square feet of habitat.

### 2.4.1 Benthic Macroinvertebrate Sample Processing and Laboratory Identification

Benthic macroinvertebrate samples were processed and subsampled according to methods described in the MBSS Laboratory Methods for Benthic Macroinvertebrate Processing and Taxonomy (Boward and Friedman 2019; DNR 2022). Subsampling was conducted to standardize the sample size and reduce variation caused by samples of different size. In this method, the sample was spread evenly across a numbered, gridded tray (100 total grids), and a grid was picked at random and picked clean of organisms. If the organism count was 100 or more, then the subsampling was complete. If the organism count was less than 100, then another grid was selected at random and picked clean of organisms. This repeated until the organism count reached 100 to 120 organisms. The 100 (plus 20 percent) organism target is used to allow for specimens that are missing parts or are not mature enough for proper identification, are terrestrial, or meiofauna. Identification of the subsampled specimens was conducted by Cole Ecological; Inc. Taxa were identified to the genus level for most organisms. Groups including Oligochaeta and Nematomorpha were identified to the family level while Nematoda was left at phylum. Individuals of early instars or those that were damaged were identified to the lowest possible level, which could be phylum or order, but in most cases was family. Chironomidae could be further subsampled depending on the number of individuals in the sample and the numbers in each subfamily or tribe. Most taxa were identified using a stereoscope. Temporary slide mounts viewed with a compound microscope were used to identify Oligochaeta to family and for Chironomid sorting to subfamily and tribe. Permanent slide mounts were then used for Chironomid genus level identification. Results were logged on a bench sheet and entered into a spreadsheet for analysis.

### 2.4.2 Benthic Macroinvertebrate Data Analysis

Benthic macroinvertebrate data were analyzed by KCI using methods developed by MBSS as outlined in the *New Biological Indicators to Better Assess the Condition of Maryland Streams* (Southerland et al. 2005). The Benthic Index of Biotic Integrity (BIBI) approach involves statistical analysis using metrics that have a predictable response to water quality and/or habitat impairment. The metrics selected fall into five major groups including taxa richness, composition measures, tolerance to perturbation, trophic classification, and habit measures. Raw values from each metric were given a score of 1, 3 or 5 based on ranges of values developed for each metric. The results were combined into a scaled IBI score from 1.00 to 5.00, and a corresponding narrative biological condition rating was applied.

Three sets of metric calculations have been developed for Maryland streams based on broad eco-physiographic regions. These include the Coastal Plain, Piedmont and combined Highlands. The study area is located in the Piedmont region; therefore, the following metrics (Table 3) and BIBI scoring (Table 4) were used for the analysis.

**Table 3 – Benthic Macroinvertebrate Metric Scoring for the Piedmont BIBI**

| Metric | Score | | |
|---|---|---|---|
| | 5 | 3 | 1 |
| Total Number of Taxa | ≥ 25 | 24 – 15 | < 15 |
| Number of EPT Taxa | ≥ 11 | 5 – 10 | < 5 |
| Number of Ephemeroptera Taxa | ≥ 4 | 3 – 2 | < 2 |
| % Intolerant to Urban | ≥ 51 | <51 – 12 | < 12 |
| % Chironomidae | ≤ 24 | >24 – 63 | > 63 |
| % Clingers | ≥ 74 | <74 – 31 | < 31 |

**Table 4 – BIBI Condition Ratings**

| IBI Score | Narrative Rating |
|---|---|
| 4.00 – 5.00 | Good |
| 3.00 – 3.99 | Fair |
| 2.00 – 2.99 | Poor |
| 1.00 – 1.99 | Very Poor |

## 2.5 Fish Community Assessment

The fish community at each of the four Wheel Creek sites was sampled during the Summer Index Period, June 1 through September 30, according to methods described in *Maryland Biological Stream Survey: Round Four Field Sampling Manual* (Stranko et al. 2019). These data were collected at the four Wheel Creek sites on June 21, July 7, and August 17, 2023. In general, the approach uses two-pass electrofishing of the entire 75-meter study reach. Block nets were placed at the upstream and downstream ends of the reach, as well as at tributaries or outfall channels, to obstruct fish movement into or out of the study reach. Two passes were completed along the reach to ensure the segment was adequately sampled. The time in seconds for each pass was recorded and the level of effort for each pass was similar. Captured fish were identified to species and enumerated following MBSS protocols (Stranko et al. 2019). A total fish biomass for each electrofishing pass was measured. Unusual anomalies such as fin erosion, tumors, etc. were recorded. Photographic vouchers were taken in lieu of physical voucher specimens.

### 2.5.1 Fish Data Analysis

Fish data for Wheel Creek sites were analyzed using methods developed by MBSS as outlined in the *New Biological Indicators to Better Assess the Condition of Maryland Streams* (Southerland et al. 2005). The IBI approach involves statistical analysis using metrics that have a predictable response to water quality and/or habitat impairment. Raw values from each metric were assigned a score of 1, 3 or 5 based on ranges of values developed for each metric. The results were combined into a scaled FIBI score, ranging from 1.00 to 5.00, and a corresponding narrative rating of 'Good', 'Fair', 'Poor' or 'Very Poor' was applied, again in accordance with standard practice.

Four sets of FIBI metric calculations have been developed for Maryland streams. These include the Coastal Plain, Eastern Piedmont, and warmwater and coldwater Highlands. Wheel Creek is located in the Eastern Piedmont region, therefore, the following metrics listed in Table 5 were used for the FIBI scoring (Table 6) and analysis.

**Table 5 – Fish Metric Scoring for the Piedmont FIBI**

| Metric | Score | | |
|---|---|---|---|
| | 5 | 3 | 1 |
| Abundance per Square Meter | ≥ 1.25 | <1.25 – 0.25 | < 0.25 |
| Number of Benthic species * | ≥ 0.26 | <0.26 – 0.09 | < 0.09 |
| % Tolerant | ≤ 45 | >45 – 68 | > 68 |
| % Generalist, Omnivores, Invertivores | ≤ 80 | >80 – 99.9 | >99.9 |
| Biomass per Square Meter | ≥ 8.6 | <8.6 – 4 | < 4 |
| % Lithophilic Spawners | ≥ 61 | <61 – 32 | < 32 |

*Adjusted for catchment size

**Table 6 – FIBI Condition Ratings**

| IBI Score | Narrative Rating |
|---|---|
| 4.00 – 5.00 | Good |
| 3.00 – 3.99 | Fair |
| 2.00 – 2.99 | Poor |
| 1.00 – 1.99 | Very Poor |

## 2.6 Herpetofauna Survey

Herpetofauna (i.e., reptiles and amphibians) were surveyed at each of the four Wheel Creek sites using methods following MBSS protocols (Stranko et al. 2019). All collected individuals were identified to species level and released. Photographic vouchers were collected if a specimen could not be positively identified in the field.

Herpetofauna data collection occurs primarily to assist MBSS with supplementing their inventory of biodiversity in Maryland's streams. Currently, MBSS has not developed an index of biotic integrity for herpetofauna, and therefore, they were not used to evaluate the biological integrity of sampling sites throughout this study. Rather, the data are provided to help document existing conditions.

## 2.7 Freshwater Mussel Survey

A survey of freshwater mussels was conducted at each site using MBSS protocols (Stranko et al. 2019). A search for freshwater mussels was conducted at each site. Any live individuals encountered were identified, photographed, and then returned back to the stream as closely as possible to where they were collected. Any dead shells were retained as voucher specimens.

## 2.8 Crayfish Survey

Crayfish were surveyed for at each site using MBSS protocols (Stranko et al. 2019). All crayfish observed while electrofishing were captured and retained until the end of each electrofishing pass. Captured crayfish were identified to species and counted before release back into the stream, outside of the 75-meter sampling reach. Crayfish encountered outside of the electrofishing effort were identified and noted on the datasheet as an incidental observation. Any crayfish burrows observed in and around the sampling site were excavated and an attempt made to capture the burrowing crayfish.

## 2.9 Invasive Plant Survey

A survey of invasive plants was performed at each site during the Summer Index Period, following MBSS protocols (Stranko et al. 2019). The common name and relative abundance of invasive plants (i.e., present or extensive) within view of the study reach and within the 5-meter riparian vegetative zone parallel the stream channel were recorded.

Invasive plant data collection occurs to assist MBSS with supplementing their inventory of biodiversity. The data are provided to help document existing conditions at each site.

## 2.10 Quality Assurance and Quality Control

All work was conducted with strict adherence to established quality assurance and quality control procedures. Biological assessment methods have been designed to be consistent and comparable with the methods used by MBSS (Stranko et al. 2019). Field crews receive yearly training in MBSS protocols and certification by DNR to perform habitat assessment, benthic macroinvertebrate sampling, fish sampling, and fish identification procedures. All field forms are checked and signed by the Crew Leader before leaving the site. Digital data entry is also checked for accuracy. Field equipment are checked regularly and calibrated as necessary prior to use. Calculation of metric scores and IBIs are completed using KCI's controlled and verified spreadsheet and each site undergoes a documented quality control check.

# 3. Results

Biological monitoring and water quality sampling were conducted to assess the conditions in the Wheel Creek watershed. Presented below are the summary results for each monitoring component.

## 3.1 Water Quality

Water quality measurements were collected during the Summer Index Period sampling visit at each of the four Wheel Creek sites. Table 7 presents the results of spring *in situ* water quality measurements and Table 8 presents the results of the summer measurements.

**Table 7 - Spring In-Situ Water Quality Measurement Results 2020-2023**

| Site | Season | Temperature (°C) | Dissolved Oxygen (mg/L) | pH (Units) | Specific Conductance (µS/cm) | Turbidity (NTU) |
|---|---|---|---|---|---|---|
| ATKI-101-X | Spring 2020 | 19.3 | 10.01 | 7.88 | 452.2 | 1.82 |
| ATKI-101-X | Spring 2021 | 16.6 | 7.87 | 7.42 | 468.3 | 2.55 |
| ATKI-101-X | Spring 2022 | 2.8 | 14.22 | 7.56 | 561.9 | 1.58 |
| ATKI-101-X | Spring 2023 | 5.7 | 13.13 | 8.20 | 284.6 | 2.5 |
| ATKI-102-X | Spring 2020 | 19.0 | 7.88 | 7.65 | 480.9 | 2.38 |
| ATKI-102-X | Spring 2021 | 16.0 | 8.68 | 6.88 | 525.4 | 2.77 |
| ATKI-102-X | Spring 2022 | 3.1 | 15.33 | 7.05 | 594.0 | 1.95 |
| ATKI-102-X | Spring 2023 | 7.50 | 12.99 | 7.96 | 473.1 | 2.5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| ATKI-003-X | Spring 2020 | 23.5 | 8.31 | 8.11 | 502.1 | 4.35 |
| ATKI-003-X | Spring 2021 | 18.9 | 8.93 | 7.41 | 525.9 | 4.10 |
| ATKI-003-X | Spring 2022 | 2.4 | 14.35 | 7.35 | 822.4 | 3.30 |
| ATKI-003-X | Spring 2023 | 7.6 | 11.73 | 7.77 | 627.3 | 2.4 |
| LWIN-108-X | Spring 2020 | 19.1 | 10.51 | 7.51 | 394.0 | 2.58 |
| LWIN-108-X | Spring 2021 | 17.0 | 8.46 | 7.79 | 419.9 | 3.52 |
| LWIN-108-X | Spring 2022 | 3.0 | 16.02 | 8.13 | 429.2 | 1.5 |
| LWIN-108-X | Spring 2023 | 8.18 | 7.97 | 13.14 | 339.1 | 2.2 |

Shaded cells indicate values exceeding either water quality criteria or published values

**Table 8 – Summer In Situ Water Quality Measurement Results 2020-2023**

| Site | Season | Temperature (°C) | Dissolved Oxygen (mg/L) | pH (Units) | Specific Conductance (µS/cm) | Turbidity (NTU) |
|---|---|---|---|---|---|---|
| ATKI-101-X | Summer 2020 | 19.3 | 10.01 | 7.88 | 452.2 | 1.82 |
| ATKI-101-X | Summer 2021 | 16.6 | 7.87 | 7.42 | 468.3 | 2.55 |
| ATKI-101-X | Summer 2022 | 22.2 | 8.61 | 7.23 | 269.5 | 3.97 |
| ATKI-101-X | Summer 2023 | 21.3 | 7.03 | 7.56 | 417.6 | 3.18 |
| ATKI-102-X | Summer 2020 | 19.0 | 7.88 | 7.65 | 480.9 | 2.38 |
| ATKI-102-X | Summer 2021 | 16.0 | 8.68 | 6.88 | 525.4 | 2.77 |
| ATKI-102-X | Summer 2022 | 20.8 | 8.07 | 6.82 | 445.9 | 4.32 |
| ATKI-102-X | Summer 2023 | 17.5 | 9.60 | 7.06 | 474.5 | 4.21 |
| ATKI-003-X | Summer 2020 | 23.5 | 8.31 | 8.11 | 502.1 | 4.35 |
| ATKI-003-X | Summer 2021 | 18.9 | 8.93 | 7.41 | 525.9 | 4.10 |
| ATKI-003-X | Summer 2022 | 21.5 | 7.16 | 7.27 | 498.4 | 4.41 |
| ATKI-003-X | Summer 2023 | 24.3 | 7.63 | 7.46 | 478.9 | 6.69 |
| LWIN-108-X | Summer 2020 | 19.1 | 10.51 | 7.51 | 394.0 | 2.58 |
| LWIN-108-X | Summer 2021 | 17.0 | 8.46 | 7.79 | 419.9 | 3.52 |
| LWIN-108-X | Summer 2022 | 22.8 | 5.23 | 7.38 | 310.8 | 6.19 |
| LWIN-108-X | Summer 2023 | 21.3 | 7.80 | 7.80 | 393.8 | 4.15 |

Shaded cells indicate values exceeding either water quality criteria or published values

MDE has established acceptable water quality standards for each designated Stream Use Classification, which are listed in the *Code of Maryland Regulations (COMAR) 26.08.02.03-.03 - Water Quality*. Wheel Creek is covered in *COMAR* in Sub-Basin 02-13-07: Bush River Area as Use I-P waters. Specific designated uses for Use I-P streams include public water supply, growth and propagation of fish and aquatic life, water supply for industrial and agricultural use, water contact sports, fishing, and leisure activities involving direct water contact.

The acceptable criteria for Use I-P waters are as follows:

- pH - 6.5 to 8.5
- DO - may not be less than 5 mg/l at any time
- Turbidity - maximum of 150 Nephelometric Turbidity Units (NTU's) and maximum monthly average of 50 NTU
- Temperature - maximum of 90°F (32°C) or ambient temperature of the surface water, whichever is greater

*In situ* water quality measurements for temperature, dissolved oxygen, pH, and turbidity were within COMAR standards for Use I-P streams. Although MDE does not have a water quality standard for specific conductivity, Morgan and others (Morgan et al, 2007; Morgan et al, 2012) have reported critical values for specific conductance in Maryland streams, above which there is a potential for detrimental effects on the stream biological communities. For the benthic macroinvertebrate community that critical value is 247 µS/cm, and for the fish community it is 171 µS/cm. Each of the four Wheel Creek stream sites had specific conductivity values far exceeding the threshold for both benthic macroinvertebrate and fish community impairments for all water quality sampling events during 2023. Specific conductivity measurements from summer of 2022 were generally the lowest of the three years of sampling completed since MBSS discontinued sampling but rebounded back to higher measurements in the summer of 2023. Conductivity levels in this watershed are likely influenced by runoff from impervious surfaces (i.e., roads, sidewalks, parking lots, roof tops). Increased stream inorganic ion concentrations (i.e., conductivity) in urban systems typically results from paved surface de-icing, accumulations in storm-water management facilities (Casey et al. 2013), runoff over impervious surfaces, passage through pipes, and exposure to other infrastructure (Cushman 2006). While elevated conductivity may not directly affect stream biota, its constituents (e.g., chloride, metals, and nutrients) may be present at levels that can cause biological impairment.

## 3.2 Physical Habitat Assessment

The summary results of the PHI habitat assessments for 2020 through 2023 are presented in Table 9. All Wheel Creek sites are exhibiting compromised physical habitat, with PHI ratings ranging from 'Degraded' to 'Partially Degraded' categories. All sites remained in the lowest categories of 'Degraded' or 'Partially Degraded' over the last three years. Both ATKI-003-X and LWIN-108-X improved from 'Degraded' to 'Partially Degraded' between 2020 and 2023. Overall, the relatively low habitat scores observed throughout the watershed are likely due to urbanization effects on the stream channels. Complete physical habitat data for each site are included in Appendix A.

**Table 9 – PHI Habitat Assessment Results for 2020-2023**

| Site | Season/Year | PHI Score | PHI Narrative Rating |
|---|---|---|---|
| ATKI-101-X | Summer 2020 | 68.5 | Partially Degraded |
| ATKI-101-X | Summer 2021 | 68.9 | Partially Degraded |
| ATKI-101-X | Summer 2022 | 72.7 | Partially Degraded |
| ATKI-101-X | Summer 2023 | 69.3 | Partially Degraded |
| ATKI-102-X | Summer 2020 | 64.1 | Degraded |
| ATKI-102-X | Summer 2021 | 63.8 | Degraded |
| ATKI-102-X | Summer 2022 | 60.4 | Degraded |
| ATKI-102-X | Summer 2023 | 68.8 | Partially Degraded |
| ATKI-003-X | Summer 2020 | 53.1 | Degraded |
| ATKI-003-X | Summer 2021 | 73.0 | Partially Degraded |
| ATKI-003-X | Summer 2022 | 66.4 | Partially Degraded |
| ATKI-003-X | Summer 2023 | 66.0 | Partially Degraded |
| LWIN-108-X | Summer 2020 | 61.9 | Degraded |
| LWIN-108-X | Summer 2021 | 73.6 | Partially Degraded |
| LWIN-108-X | Summer 2022 | 73.6 | Partially Degraded |
| LWIN-108-X | Summer 2023 | 66.2 | Partially Degraded |

## 3.3 Benthic Macroinvertebrate Community

The results of 2023 benthic macroinvertebrate community assessments are presented in Table 10. For 2023 benthic macroinvertebrate sampling, all Wheel Creek sites had biological condition ratings in the ‘Poor’ or ‘Very Poor’ categories, with ATKI-102-X-2022 and LWIN-108-X receiving the lowest scores of 2.00 and 1.33. BIBI scores ranged from 1.33 to 2.33. Individual metrics were low across all sites, apart from one individual metric in the category of Total Number of Taxa, which site ATKI-101-X and ATKI-003-X had a score of ‘5’ and ATKI-102-X, and LWIN-108-X had a score of ‘3’. Scores for the metrics Number of EPT, Number of Ephemeroptera Taxa, Percent Intolerant, Percent Chironomidae, and Percent Clingers all either scored a ‘1’ or a ‘3’ across sites. The only category with consistently low scores was Percent Intolerant Urban with a score of ‘1’ received at each of the four sites. These low BIBI scores are likely due to a combination of degraded instream habitat and poor water quality. All sites had measured specific conductivity values greater than the published impairment threshold of 247 µS/cm for benthic macroinvertebrates (Morgan et al., 2007). Complete benthic macroinvertebrate data for 2023 at each site are included in Appendix B.

**Table 10 – Benthic Index of Biotic Integrity (BIBI) Summary Data – 2023**

| Metric | ATKI-101-X | ATKI-102-X | ATKI-003-X | LWIN-108-X |
|---|---|---|---|---|
| ***Metric Values*** | | | | |
| Total Number of Taxa | 27 | 24 | 25 | 23 |
| Number of EPT Taxa | 5 | 3 | 3 | 4 |
| Number of Ephemeroptera Taxa | 0 | 0 | 0 | 0 |
| % Intolerant to Urban | 2.92 | 2.17 | 0.00 | 9.92 |
| % Chironomidae | 54.74 | 52.90 | 54.33 | 67.18 |
| % Clingers | 28.47 | 40.58 | 55.91 | 20.61 |
| ***Metric Scores*** | | | | |
| Total Number of Taxa | 5 | 3 | 5 | 3 |
| Number of EPT Taxa | 3 | 1 | 1 | 1 |
| Number of Ephemeroptera Taxa | 1 | 1 | 1 | 1 |
| % Intolerant to Urban | 1 | 1 | 1 | 1 |
| % Chironomidae | 3 | 3 | 3 | 1 |
| % Clingers | 1 | 3 | 3 | 1 |
| **BIBI Score** | 2.33 | 2.00 | 2.33 | 1.33 |
| **Narrative Rating** | Poor | Poor | Poor | Very Poor |

A comparison of BIBI scores from 2009 to 2023 is presented in Table 11 and Figure 2. In 2023 only ATKI-003-X experienced an increase in its BIBI score. ATKI-101-X and ATKI-102-X maintained the same BIBI score from 2022 to 2023. LWIN-108-X had its BIBI score decrease from 1.67 to 1.33 between 2022 and 2023.

**Table 11 – BIBI Scores and Narrative Ratings from 2009 through 2023.**

| Site | Year | BIBI Score | Narrative Rating |
|---|---|---|---|
| ATKI-101-X | Spring 2009 | 2.67 | Poor |
| ATKI-101-X | Spring 2010 | 3.00 | Fair |
| ATKI-101-X | Spring 2011 | 2.33 | Poor |
| ATKI-101-X | Spring 2012 | 1.33 | Very Poor |
| ATKI-101-X | Spring 2013 | 2.00 | Poor |
| ATKI-101-X | Spring 2014 | 1.00 | Very Poor |
| ATKI-101-X | Spring 2015 | 2.67 | Poor |
| ATKI-101-X | Spring 2016 | 2.67 | Poor |
| ATKI-101-X | Spring 2017 | 1.33 | Very Poor |
| ATKI-101-X | Spring 2018 | 1.67 | Very Poor |
| ATKI-101-X | Spring 2019 | 1.67 | Very Poor |
| ATKI-101-X | Spring 2020 | 2.00 | Poor |
| ATKI-101-X | Spring 2021 | 1.67 | Very Poor |
| ATKI-101-X | Spring 2022 | 2.33 | Poor |
| ATKI-101-X | Spring 2023 | 2.33 | Poor |
| ATKI-102-X | Spring 2009 | 2.00 | Poor |
| ATKI-102-X | Spring 2010 | 1.67 | Very Poor |
| ATKI-102-X | Spring 2011 | 1.33 | Very Poor |
| ATKI-102-X | Spring 2012 | 1.67 | Very Poor |
| ATKI-102-X | Spring 2013 | 1.67 | Very Poor |
| ATKI-102-X | Spring 2014 | 2.00 | Poor |
| ATKI-102-X | Spring 2015 | 2.00 | Poor |
| ATKI-102-X | Spring 2016 | 2.67 | Poor |
| ATKI-102-X | Spring 2017 | 1.67 | Very Poor |
| ATKI-102-X | Spring 2018 | 1.67 | Very Poor |
| ATKI-102-X | Spring 2019 | 1.00 | Very Poor |
| ATKI-102-X | Spring 2020 | 2.00 | Poor |
| ATKI-102-X | Spring 2021 | 1.67 | Very Poor |
| ATKI-102-X | Spring 2022 | 1.67 | Very Poor |
| ATKI-102-X | Spring 2023 | 2.00 | Very Poor |
| ATKI-003-X | Spring 2009 | 2.00 | Poor |
| ATKI-003-X | Spring 2010 | 1.67 | Very Poor |
| ATKI-003-X | Spring 2011 | 1.33 | Very Poor |
| ATKI-003-X | Spring 2012 | 2.67 | Poor |
| ATKI-003-X | Spring 2013 | 2.00 | Poor |
| ATKI-003-X | Spring 2014 | 1.33 | Very Poor |
| ATKI-003-X | Spring 2015 | 2.33 | Poor |
| ATKI-003-X | Spring 2016 | 1.33 | Very Poor |
| ATKI-003-X | Spring 2017 | 1.33 | Very Poor |
| ATKI-003-X | Spring 2018 | 1.67 | Very Poor |
| ATKI-003-X | Spring 2019 | 1.33 | Very Poor |
| ATKI-003-X | Spring 2020 | 1.67 | Very Poor |
| ATKI-003-X | Spring 2021 | 2.00 | Poor |
| ATKI-003-X | Spring 2022 | 2.00 | Poor |
| ATKI-003-X | Spring 2023 | 2.33 | Poor |
| LWIN-108-X | Spring 2009 | 2.67 | Poor |
| LWIN-108-X | Spring 2010 | 3.00 | Fair |
| LWIN-108-X | Spring 2011 | 1.33 | Very Poor |
| LWIN-108-X | Spring 2012 | 3.00 | Fair |
| LWIN-108-X | Spring 2013 | 2.67 | Poor |
| LWIN-108-X | Spring 2014 | 1.67 | Very Poor |
| LWIN-108-X | Spring 2015 | 2.33 | Poor |
| LWIN-108-X | Spring 2016 | 3.00 | Fair |
| LWIN-108-X | Spring 2017 | 2.00 | Poor |
| LWIN-108-X | Spring 2018 | 1.33 | Very Poor |
| LWIN-108-X | Spring 2019 | 1.33 | Very Poor |
| LWIN-108-X | Spring 2020 | 1.67 | Very Poor |
| LWIN-108-X | Spring 2021 | 1.33 | Very Poor |
| LWIN-108-X | Spring 2022 | 1.67 | Very Poor |
| LWIN-108-X | Spring 2023 | 1.33 | Very Poor |

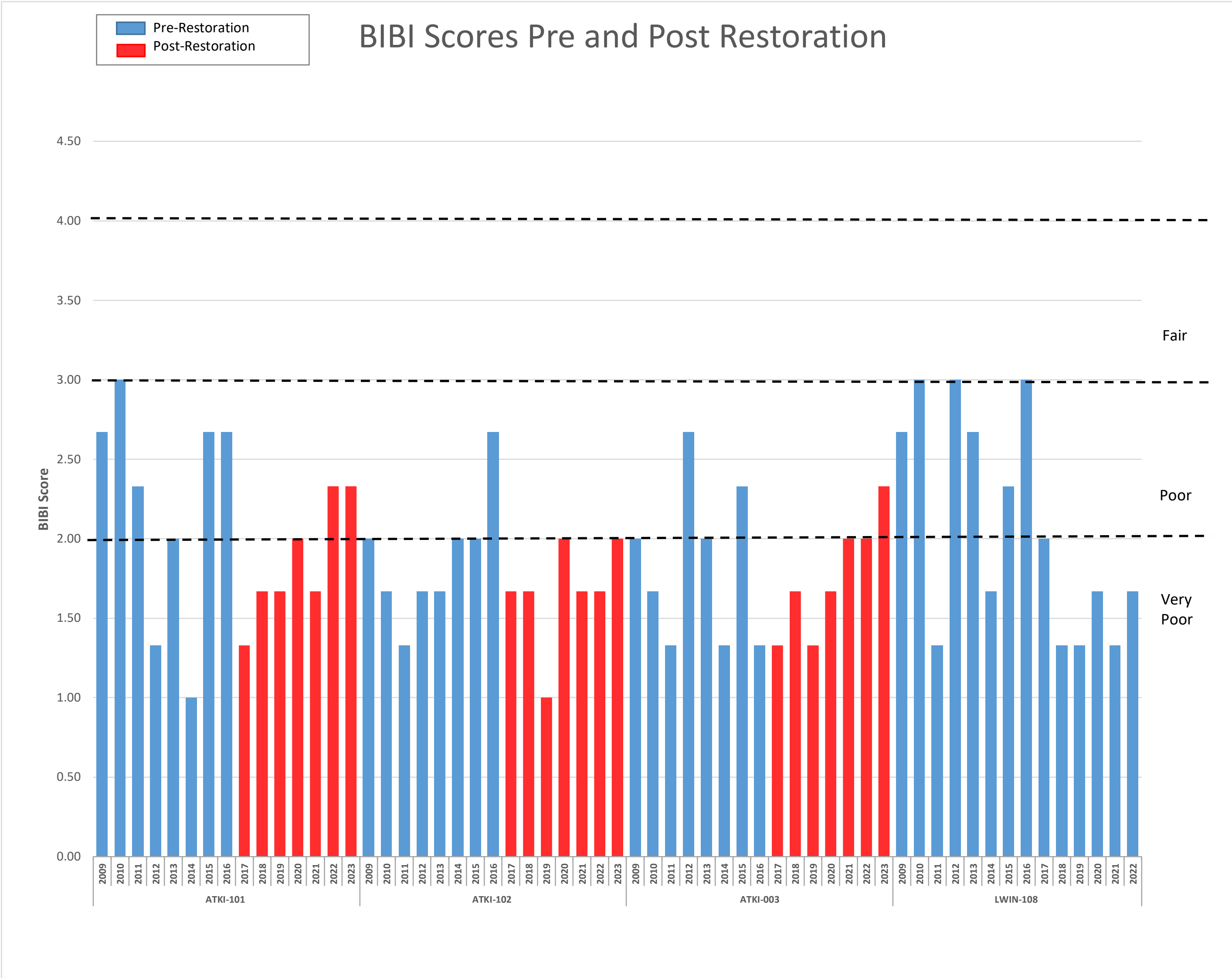


**Figure 2 – Wheel Creek BIBI Scores by Year**

## 3.4 Fish Community

The results of the 2023 fish community assessments are presented in Table 12 and a cumulative list of species collected at each site (2020 – 2023) can be found in Table 13. Complete fish community data from 2023 for each site are included in Appendix C.

**Table 12 – Fish Index of Biotic Integrity (FIBI) Summary Data – 2023**

| Metric | ATKI-101-X | ATKI-102-X | ATKI-003-X | LWIN-108-X |
|---|---|---|---|---|
| ***Metric Values*** | | | | |
| Abundance per Square Meter | 3.18 | 4.30 | 3.27 | 1.42 |
| Adjusted Number of Benthic Species | 2.26 | 2.89 | 6.00 | 2.20 |
| % Tolerant | 49.14 | 96.28 | 88.49 | 41.89 |
| % Generalist, Omnivores, Invertivores | 80.75 | 96.49 | 88.49 | 60.27 |
| Biomass per Square Meter | 9.48 | 12.60 | 10.71 | 7.20 |
| % Lithophilic Spawners | 43.66 | 33.88 | 68.73 | 62.16 |
| ***Metric Scores*** | | | | |
| Abundance per Square Meter | 5 | 5 | 5 | 5 |
| Adjusted Number of Benthic Species | 5 | 5 | 5 | 5 |
| % Tolerant | 3 | 1 | 1 | 5 |
| % Generalist, Omnivores, Invertivores | 3 | 3 | 3 | 5 |
| Biomass per Square Meter | 5 | 5 | 5 | 3 |
| % Lithophilic Spawners | 3 | 3 | 5 | 5 |
| **FIBI Score** | 4.00 | 3.67 | 4.00 | 4.67 |
| **Narrative Rating** | Fair | Fair | Good | Good |

**Table 13 – Cumulative List of Fish Species Collected at Wheel Creek Sites – 2020-2023**

| Common Name | Scientific Name | ATKI-101-X | ATKI-102-X | ATKI-003-X | LWIN-108-X |
|---|---|---|---|---|---|
| American Eel | *Anguilla rostrata* | | | | X |
| Margined Madtom | *Noturus insignis* | | | | X |
| Creek Chubsucker | *Erimyzon oblongus* | X | | | |
| Northern Hogsucker | *Hypentelium nigricans* | | | | X |
| White Sucker | *Catostomus commersonii* | X | X | X | X |
| Goldfish | *Carassius auratus* | | | X | |
| Golden Shiner | *Notemigonus crysoleucas* | X | | | |
| Cutlip Minnow | *Exoglossum maxillingua* | X | | | X |
| Bluntnose Minnow | *Pimephales notatus* | X | | | X |
| Fathead Minnow | *Pimephales promelas* | X | | | |
| Satinfin Shiner | *Cyprinella analostana* | X | | | |
| Common Shiner | *Luxilus cornutus* | X | | | X |
| Swallowtail Shiner | *Notropis procne* | X | | | |
| Rosyside Dace | *Clinostomus funduloides* | X | | | X |
| River Chub | *Nocomis micropogon* | | | | X |
| Fallfish | *Semotilus corporalis* | X | | | X |

| Common Name | Scientific Name | ATKI-101-X | ATKI-102-X | ATKI-003-X | LWIN-108-X |
|---|---|---|---|---|---|
| Creek Chub | *Semotilus atromaculatus* | X | X | X | X |
| Blacknose Dace | *Rhinichthys atratulus* | X | X | X | X |
| Longnose Dace | *Rhinichthys cataractae* | X | | | X |
| Eastern Mosquitofish | *Gambusia holbrooki* | X | | | |
| Banded Killifish | *Fundulus diaphanus* | X | | | |
| Mummichog | *Fundulus heteroclitus* | | X | | |
| Blue Ridge Sculpin | *Cottus caeruleomentum* | X | X | X | X |
| Tessellated Darter | *Etheostoma olmstedi* | X | | | |
| Smallmouth Bass | *Micropterus dolomieu* | X | | | X |
| Largemouth Bass | *Micropterus salmoides* | X | | | |
| Green Sunfish | *Lepomis cyanellus* | X | | | |
| Redbreast Sunfish | *Lepomis auritus* | X | | | X |
| Bluegill | *Lepomis macrochirus* | X | | | |
| Pumpkinseed | *Lepomis gibbosus* | X | | | |

The Wheel Creek sites had FIBI ratings ranging from 'Fair' to 'Good' in all monitoring years. LWIN-108-X had the highest FIBI score in 2023, was 4.67 and had a narrative rating as 'Good'. ATKI-101-X and ATKI-003-X were rated as 'Good' both with scores of 4.00. The lowest scoring site was ATKI-102-X with a score of 3.67 and a narrative rating of 'Fair'. ATKI-101-X had the highest diversity of the four sites, with seventeen species of fish, followed by LWIN-108-X, with fifteen species of fish. ATKI-102-X and ATKI-003-X had four species captured in 2023. Percent tolerant varied the most between the sites, with LWIN-108-X scoring a '5', ATKI-101-X scoring a '3', and ATKI-102-X and ATKI-003-X scoring a '1'. Minor differences in the other three metrics between sites accounted for the minor variability in FIBI scores between sites.

A comparison of FIBI scores from 2009 to 2019 during the MBSS years of monitoring as well as 2020, 2021 2022, and 2023 is presented in Table 14 – FIBI Scores and Narrative Ratings from 2009 through 2023.and Figure 3. Out of the four sites, only LWIN-108-X increased in its FIBI score, going from 4.33 in 2022 to 4.67 in 2023. This was the second time in the past six years that LWIN-108-X has reached this rating. ATKI-003-X maintained its FIBI score (4.00) from 2021 to 2023 with a narrative rating of 'Good'. ATKI-101-X and ATKI-102-X both experienced a decrease in their FIBI score and narrative rating. ATKI-101-X maintained a narrative rating of 'Good' where as ATKI-102-X went from a narrative rating of 'Good' in 2022 to 'Fair' in 2023. ATKI-102-X FIBI score went from 4.00 to 3.67 when Percent Tolerant was reduced to a '1'.

**Table 14 – FIBI Scores and Narrative Ratings from 2009 through 2023.**

| Site | Year | FIBI Score | Narrative Rating |
|---|---|---|---|
| ATKI-101-X | Summer 2009 | 4.67 | Good |
| ATKI-101-X | Summer 2010 | 4.33 | Good |
| ATKI-101-X | Summer 2011 | 4.33 | Good |
| ATKI-101-X | Summer 2012 | 4.00 | Good |
| ATKI-101-X | Summer 2013 | 4.67 | Good |
| ATKI-101-X | Summer 2014 | 4.00 | Good |
| ATKI-101-X | Summer 2015 | 3.33 | Fair |
| ATKI-101-X | Summer 2016 | 4.33 | Good |
| ATKI-101-X | Summer 2017 | 3.67 | Fair |
| ATKI-101-X | Summer 2018 | 3.00 | Fair |
| ATKI-101-X | Summer 2019 | 3.67 | Fair |
| ATKI-101-X | Summer 2020 | 4.00 | Good |
| ATKI-101-X | Summer 2021 | 4.67 | Good |
| ATKI-101-X | Summer 2022 | 4.33 | Good |
| ATKI-101-X | Summer 2023 | 4.00 | Fair |
| ATKI-102-X | Summer 2009 | 5.00 | Good |
| ATKI-102-X | Summer 2010 | 4.67 | Good |
| ATKI-102-X | Summer 2011 | 4.33 | Good |
| ATKI-102-X | Summer 2012 | 4.67 | Good |
| ATKI-102-X | Summer 2013 | 4.67 | Good |
| ATKI-102-X | Summer 2014 | 4.00 | Good |
| ATKI-102-X | Summer 2015 | 3.67 | Fair |
| ATKI-102-X | Summer 2016 | 3.33 | Fair |
| ATKI-102-X | Summer 2017 | 3.67 | Fair |
| ATKI-102-X | Summer 2018 | 3.67 | Fair |
| ATKI-102-X | Summer 2019 | 3.67 | Fair |
| ATKI-102-X | Summer 2020 | 3.67 | Fair |
| ATKI-102-X | Summer 2021 | 3.67 | Fair |
| ATKI-102-X | Summer 2022 | 4.00 | Good |
| ATKI-102-X | Summer 2023 | 3.67 | Fair |
| ATKI-003-X | Summer 2009 | 4.00 | Good |
| ATKI-003-X | Summer 2010 | 3.67 | Fair |
| ATKI-003-X | Summer 2011 | 3.67 | Fair |
| ATKI-003-X | Summer 2012 | 3.00 | Fair |
| ATKI-003-X | Summer 2013 | 3.67 | Fair |
| ATKI-003-X | Summer 2014 | 3.00 | Fair |
| ATKI-003-X | Summer 2015 | 2.67 | Poor |
| ATKI-003-X | Summer 2016 | 3.67 | Fair |
| ATKI-003-X | Summer 2017 | 2.33 | Poor |
| ATKI-003-X | Summer 2018 | 3.33 | Fair |
| ATKI-003-X | Summer 2019 | 3.33 | Fair |
| ATKI-003-X | Summer 2020 | 3.67 | Fair |
| ATKI-003-X | Summer 2021 | 4.00 | Good |
| ATKI-003-X | Summer 2022 | 4.00 | Good |
| ATKI-003-X | Summer 2023 | 4.00 | Good |
| LWIN-108-X | Summer 2009 | 4.67 | Good |
| LWIN-108-X | Summer 2010 | 4.33 | Good |
| LWIN-108-X | Summer 2011 | 4.33 | Good |
| LWIN-108-X | Summer 2012 | 4.33 | Good |
| LWIN-108-X | Summer 2013 | 4.67 | Good |
| LWIN-108-X | Summer 2014 | 4.33 | Good |
| LWIN-108-X | Summer 2015 | 4.33 | Good |
| LWIN-108-X | Summer 2016 | 4.33 | Good |
| LWIN-108-X | Summer 2017 | 4.67 | Good |
| LWIN-108-X | Summer 2018 | 4.00 | Good |
| LWIN-108-X | Summer 2019 | 4.33 | Good |
| LWIN-108-X | Summer 2020 | 4.33 | Good |
| LWIN-108-X | Summer 2021 | 4.67 | Good |
| LWIN-108-X | Summer 2022 | 4.33 | Good |
| LWIN-108-X | Summer 2023 | 4.67 | Good |

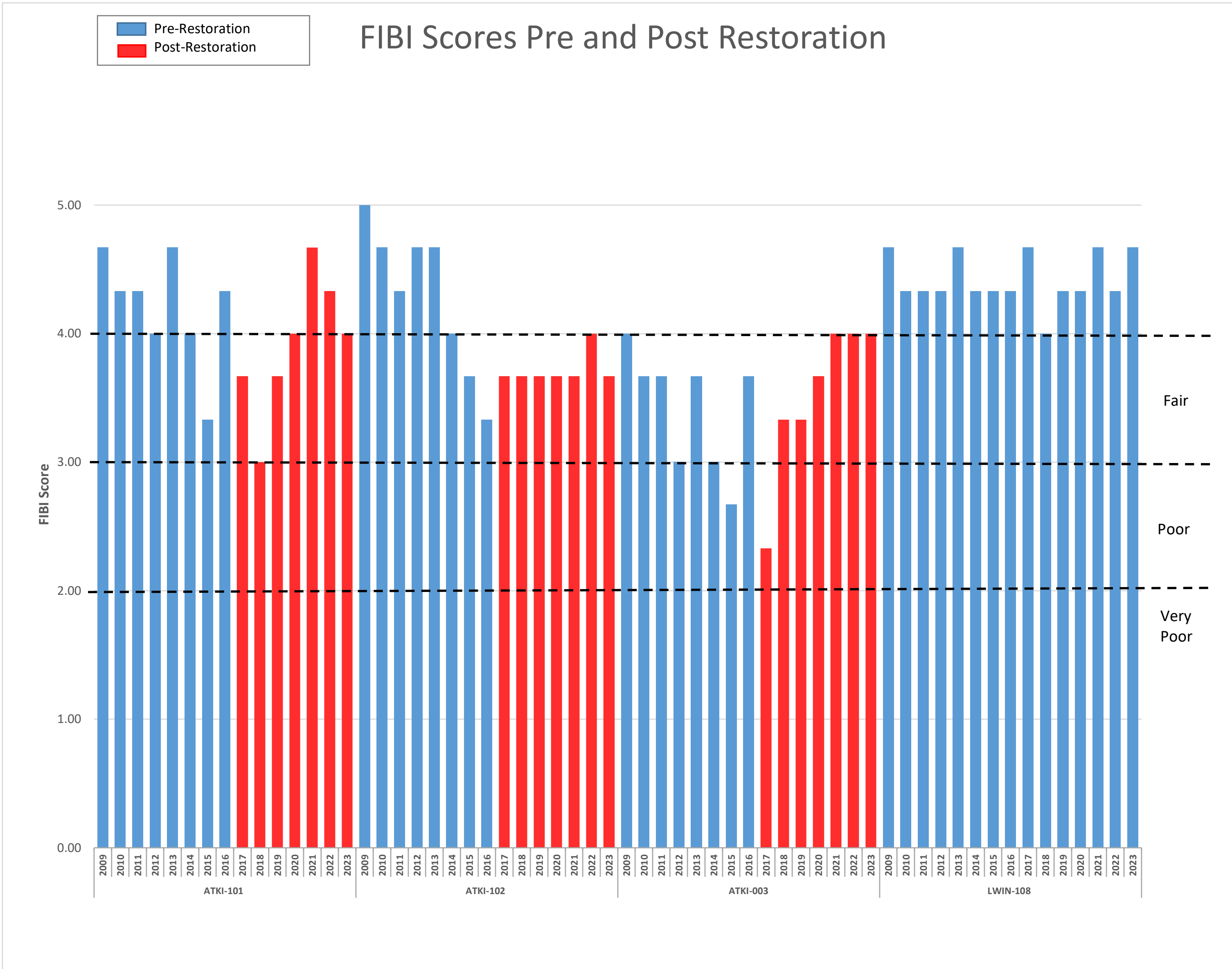


**Figure 3 – Wheel Creek FIBI Scores by Year**

## 3.5 Herpetofauna

At least four reptile or amphibian species were observed at each of the sites, as presented in Table 15, which presents a cumulative list of all species found at each monitoring site across all sampling visits. ATKI-003-X had the highest diversity with seven species found at the site. The most widely distributed species were the Northern Green Frog and Northern Two-lined Salamander, which were both present at all four Wheel Creek sites. The number of stream salamanders were low at all sites where they were observed, and consisted entirely of the most pollution-tolerant species the Northern Two-lined Salamander.

**Table 15 – Cumulative Herpetofauna Presence at Wheel Creek Sites**

| Common Name | Scientific Name | ATKI-101-X | ATKI-102-X | ATKI-003-X | LWIN-108-X |
|---|---|---|---|---|---|
| American Toad | *Anaxyrus americanus* | X | | | |
| Northern Green Frog | *Lithobates clamitans melanota* | X | X | X | X |
| American Bullfrog | *Lithobates catesbeianus* | | | X | |
| Pickerel Frog | *Lithobates palustris* | X | | X | X |
| Cope's Gray Tree Frog | *Hyla chrysoscelis* | | X | X | |
| Green Tree Frog | *Hyla cinerea* | | | X | |
| Northern Watersnake | *Nerodia sipedon* | X | X | | |
| Eastern Milksnake | *Lampropeltis triangulum* | | | X | |
| Queen Snake | *Regina septemvittata* | X | | | X |
| Snapping Turtle | *Chelydra serpentina* | | X | | |
| **Stream Salamanders** | | | | | |
| Northern Two-lined Salamander | *Eurycea bislineata* | X | X | X | X |

The low density and diversity of stream salamanders at all sites is likely due to a combination of habitat degradation and water quality impairment. There was very little suitable stream salamander habitat present at ATKI-102-X and ATKI-003-X during the first visit for the field crew to search. Stream salamanders generally prefer large cover objects over loose cobble and gravel, creating a moist microclimate and many interstices for shelter and foraging. Water quality may be influencing the distribution of stream salamanders in the Wheel Creek watershed. Measured specific conductivity was high at all four sites, ranging from 393.8 and 478.9 µS/cm in 2023. Stream salamanders breathe through their skins, and because of their highly permeable skin, are particularly sensitive to water quality impairments. The high conductivity values suggest that salamanders would experience osmotic difficulties in these conditions.

## 3.6 Freshwater Mussels

No freshwater mussels were observed at any Wheel Creek site during 2020 through 2023 field visits. The lack of freshwater mussels at these sites is likely due to a combination of habitat degradation and water quality impairment. Freshwater mussels are relatively sessile organisms which live partially embedded within the stream substrates. The flashy hydrology characteristic of urban streams like Wheel Creek creates habitat conditions unsuitable for freshwater mussels. Also, it is likely that water quality conditions in urban streams are outside the range of tolerance of these sensitive organisms.

### 3.7 Crayfish

Crayfish were observed at all the Wheel Creek sites for 2023. *Faxonius virilis*, a non-native species, was the only crayfish species observed. Crayfish burrows were not observed at any of the Wheel Creek sites. The lack of native crayfish is most likely due to competition with non-native crayfish. In the Patapsco River watershed, *Faxonius virilis* has displaced the native *Faxonius limosus* from the entire watershed (Kilian et al. 2010). It is likely that similar species displacement has occurred in the Winters Run watershed. Water quality conditions may also be impacting crayfish, but currently, the water quality requirements for crayfish in Maryland are poorly understood.

### 3.8 Invasive Plant Species

Invasive plant species were present at each of the four Wheel Creek sites. Table 16 presents all invasive species found at each monitoring site across all sampling visits. ATKI-003-X has nine invasive plant species, while ATKI-102-X has seven species, ATKI-101-X has six species, and LWIN-108-X only has two species. Multiflora rose and Japanese stiltgrass were the most widely distributed invasive plant species, found at each of the four sites.

**Table 16 – Cumulative Invasive Plant Species Presence at Wheel Creek Sites**

| Common Name | Scientific Name | ATKI-101-X | ATKI-102-X | ATKI-003-X | LWIN-108-X |
|---|---|---|---|---|---|
| Japanese barberry | *Berberis thunbergii* | X | | X | |
| Garlic mustard | *Alliaria petiolata* | X | | X | |
| Oriental bittersweet | *Celastrus orbiculatus* | X | X | X | |
| Japanese stiltgrass | *Microstegium vimineum* | X | X | X | X |
| Multiflora rose | *Rosa multiflora* | X | X | X | X |
| Wineberry | *Rubus phoenicolasius* | X | | X | |
| Mile-a-minute | *Persicaria perfoilata* | | X | X | |
| Privet | *Ligustrum sp.* | X | | X | |
| Japanese honeysuckle | *Lonicera japonica* | X | X | X | |

## 4. Conclusions

Ecological conditions at the three treatment sites in Wheel Creek, as well as the urban control site, vary over time throughout the 15 years of monitoring, with some exhibiting trends towards further degradation. BIBI scores at all four sites have remained in the 'Very Poor' or 'Poor' categories, varying slightly from year to year. While two sites appear to show trends toward lower BIBI scores over time (Figure 4), FIBI scores at the three Wheel Creek treatment sites also vary over time, but generally declined or remained in the 'Good' category. Comparing data between the pre- and post-restoration periods, there is no discernable ecological lift in the IBI scores. The ecological condition of Wheel Creek, especially the benthic macroinvertebrate community, continues in a degraded condition similar to other post-restoration urban streams in central Maryland (Hilderbrand et al 2019; Southerland et al 2018). However, the urban control site is showing a trend towards further degradation of the benthic macroinvertebrate community in recent years, suggesting that recent restoration efforts may be ameliorating effects of urbanization within the treatment watershed. Although, it should be noted that fish communities at the urban control site have consistently been rated as 'Good' throughout the entire monitoring period.

Though there has been little additional development around Wheel Creek the stream itself could be facing urban stream syndrome. Urban stream syndrome can be defined as framework of common responses seen in streams that are in or near urban settings (Booth et al 2016). Frequent stream responses can include increased nutrient loads and increases dominance of tolerant species (Walsh et al 2005). Despite restoration efforts some pollutants and nutrients can have legacy effects on a stream causing the stream to remain impaired, ultimately preventing the stream from supporting benthic communities. Lastly, the proximity of Wheel Creek to healthy and biologically diverse communities may not be conducive to dispersal or migration of benthic taxa causing the re-establishment of more sensitive populations to be delayed or non-existent (Southerland et al 2018).

A more comprehensive analysis of data collected at Wheel Creek project sites will occur at the end of 2024. This larger analysis will integrate all ecological, habitat, and water quality data to try to identify correlations in the data set that would help understand what is affecting ecological condition in the Wheel Creek watershed. Analysis will focus not only on the IBI scores, but on individual metrics and species-level response over time to try and highlight changes, if any exist, in the post-restoration data.

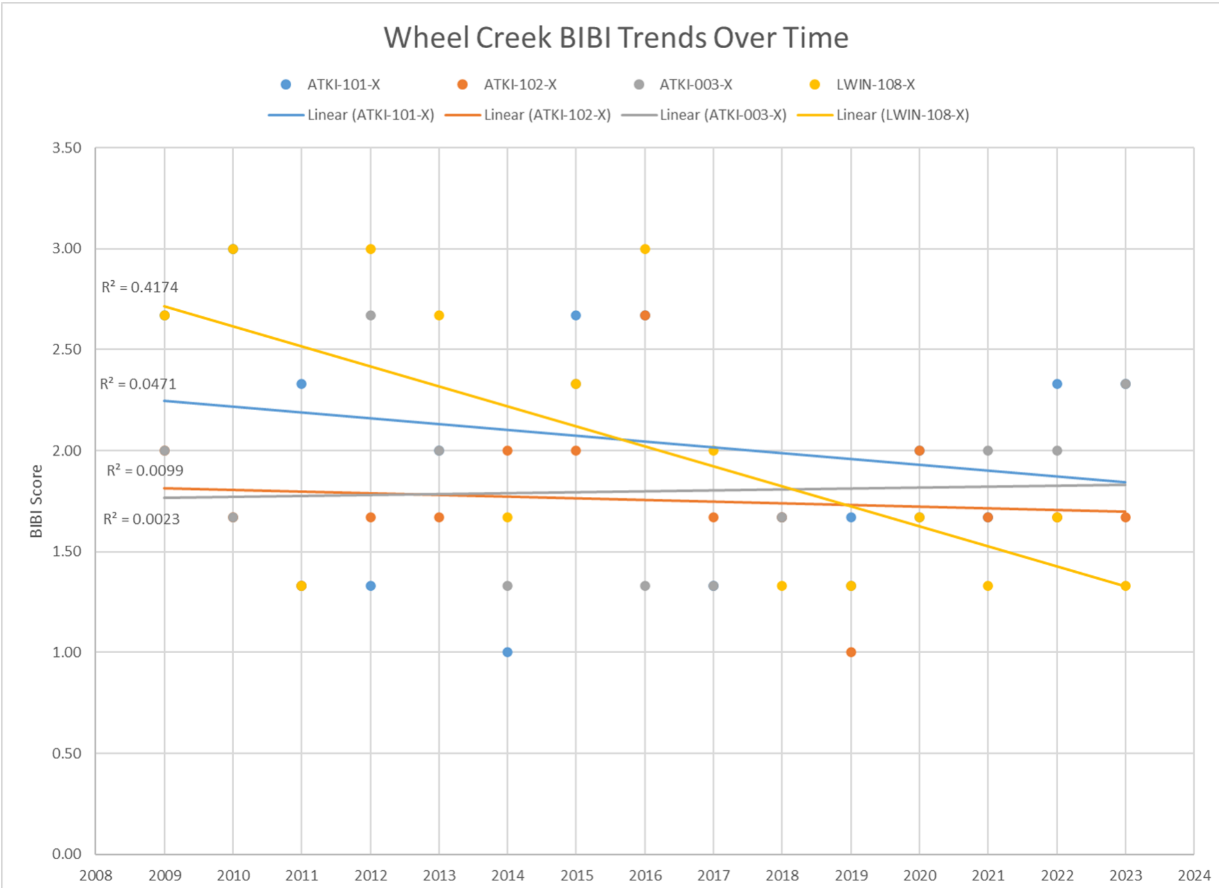


**Figure 4 - BIBI Trends over time (2009 - 2023)**

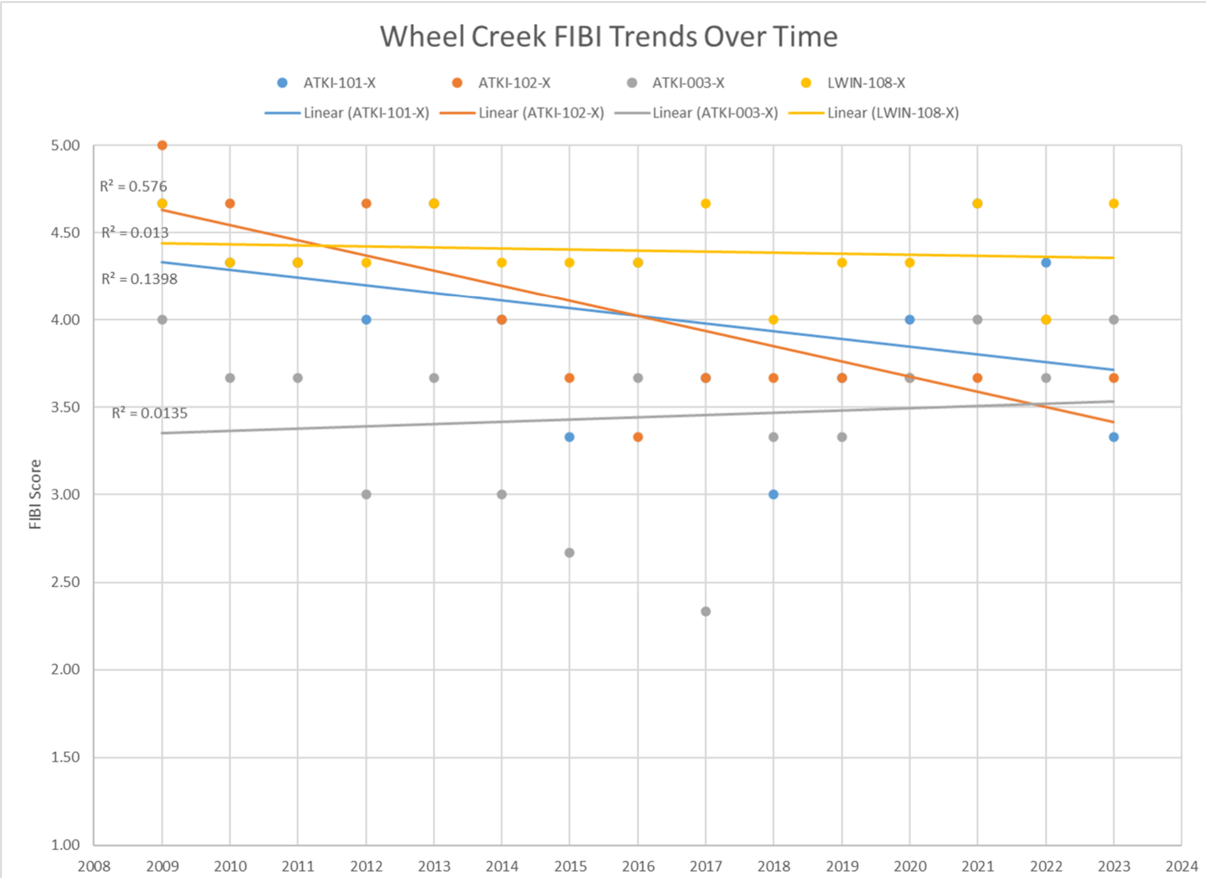


**Figure 5 - FIBI Trends over time (2009 - 2023)**

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